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Effective Management of Scarce Water Resources: From Antiquity to Today and into the Future

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Abstract: Water is a critically important element of human life. The best practice of effective water management comes from ancient civilizations that, despite their technologies and practices, were unable to prevent collapse from water scarcity. In the 21st century, in an era of climate change, pollution or population explosion, cities are looking for innovative ways to effectively manage scarce resources for future generations. Which elements should cities of the future follow to avoid water collapse? The following article aims to identify the key elements of effective management and to represent them graphically in the form of a recommended model, which will be verified in the future in Slovakia. The article uses case analysis of best past and current practices, comparison and summarization to identify the elements, creativity, and logic in the development of the model, including induction and deduction. The article serves as a basis for fellow researchers (analyses carried out) and strategic urban management (effective urban water management). The main finding of the article is that ecological change puts pressure on social elements and therefore it is necessary to focus on the area of strategic management. Cities should not only know how to manage resource abundance or short-term scarcity, but also long-term scarcity. They should use elements of trust, awareness and continuous improvement through modern monitoring technologies (UAVs, sensors) and prediction (machine learning). This is the only way to generate water sustainability in the urban concept of the future.

Keywords: water scarcity; efficient management; water management; old age; Smart Cities; best practice; technology

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1. Introduction

Climate change has a huge impact not only on the efficient management and availability of water resources, but also on the quality of human life and the existence of ecosystems. All natural, human, and technological phenomena form a single system interconnected by interrelationships. The system is complex, with each faction having its own irreplaceable part. Activities that cannot be carried out continuously by the population due to the limitation of scarce resources are not sustainable. By continuing to deplete these resources, the system is heading towards collapse [1].

On a global scale, the so-called 'shifting starting point phenomenon' is widespread. Different generations judge the normal state of limited water resources according to their own life experience, i.e., based on the current state without comparison with the past [1]. According to Maxton, the ecological limits to growth were already exceeded in 1980 [2]. Maxton believes that the consequences of the systemic problem of ineffective management of limited resources must be addressed within the next 20 years at the latest [2]. However, new solutions require preparation, implementation into practice and adaptation of citizens to the changes, which takes time.

According to experts from the "International Panel on Climate Change" (IPCC) greenhouse gases, will contribute to a warming of 1.5 to 2 °C in 2035. According to the World

Bank, if the temperature increases to a 3 to 4 °C increment, the population is expected to decrease by up to 90%, the limit of possible adaptation will be rapidly reduced by water scarcity and the system will collapse (Maxton, 2020). The fundamental problems are [2]:

- Lack of action to reduce greenhouse gases—Electric cars are not the solution, according to Maxton, as their production drains precious metals, increases the carbon footprint and pollutes waterways.;
- Rainfall—changes in the frequency and intensity of rainfalls, coastal cities like Singapore will be affected by drought, heat and high humidity, other cities will be affected by floods and rise in sea levels (Amsterdam);
- Increase in migration—due to resource scarcity, social inequalities, which have been a global trend for 200 years, this will widen;
- Population growth—the number of scarce resources cannot meet the needs of the growing number of people.

Maxton believes that "the 21st century represents a phase of life where nature is unable to regenerate, the fundamental credo of the future should be the efficient management of limited resources" [2].

Climate change is causing the melting of glaciers and the greenhouse effect. Pollution of rivers, construction of dams, and draining of wetlands has reduced water supplies by 50% in 2020 compared to the 20th century [1].

In the 2030s, scientists predict the dieback of the Amazon rainforest, which will result in reduced rainfall and water scarcity in major urban areas. The Arctic is predicted to lose its ability to cool the Earth [1].

A decade later, permafrost is set to begin melting, drying up lakes and a huge loss of freshwater resources. Ocean acidification will cause the ocean to rapidly deteriorate in the 2050s. Then, 30 years later, global warming and pesticides will contribute to the collapse of agriculture [1].

At the beginning of the 22nd century, Attenborough predicts in his publication that there will be a mass migration of populations from countries affected by flooding, global warming, and scarce resources. These activities may generate war conflict or pandemics of viral diseases [1].

Currently, humanity is in the fifth innovation wave. After hydropower, steam, electricity, automation and the digital revolution, the sixth wave, i.e., the sustainable development revolution, is about to take place [1].

As a first wave, the sustainable development revolution will prioritize the ecological aspect and the needs of people over technological innovation, which will only form the basis for a higher goal, i.e., the protection of limited water resources and the stabilization of the current ecosystem. Linked to the trend towards urbanization and mobility to cities is the need for ecological planning of urban infrastructure. According to Attenborough, high population density generates the potential for sustainability and the development of advanced technologies in the Smart City concept [1,3–5]. The same view is shared by Glaeser, who argues that "densely populated cities represent a centre of progress and a nucleus for the emergence of innovative ideas" [6].

Jared Diamond is of the opinion that most ancient cities and civilizations disappeared due to the depletion of limited resources or through devastation. Diamond predicts that the current globalized world is reaching a similar state [6,7].

Jared Diamond's view, at its core, compares ancient civilizations to the present. The population of ancient Rome, Mexico or Egypt was nowhere near the current number of people in the world, which is steadily increasing in size due to the trend of population growth [6,7]. The argument alludes to a highly consumerist way of life, which also heralds the decline of today's society, i.e., the essence of humanity remains unchanged. History and the life of the ancestors provide invaluable insights and life experiences that humanity should learn from rather than ignore. The most appropriate solution would be to draw information from the past, analyze the present well and prepare predictively for various future scenarios. For if this is not done, the system will radically change or collapse, regardless of geographical location or time period.

Based on insights from the analysis of best water practices of ancient and contemporary cities, the aim of this paper is to identify the key elements of effective water resource management for future smart cities and to represent them graphically in the form of a custom model.

2. Research Background

The content of this section is a selection of best practices of urban water management in the ancient period, including comparison, identification of differences and common elements, analysis of the causes of the collapse of ancient civilizations due to water scarcity, to the summarization of the knowledge gained.

2.1. Best Urban Water Management Practice in History

Best practice of urban water management in the concept of water management in the urban environment is a multi-disciplinary approach, i.e., it uses knowledge not only from ecology, biology, but also sociology, political science, history, and archaeology.

The first hypothesis in the field of water management was developed in the 1950s by Karl Wittfogel, who argued that "the use of water for irrigation purposes raises the need for a regulation (institution) that shapes the cultural and social dimensions" [8].

Based on Wittfogel's assertion, knowledge in the field of water management has contributed to the transformation of human society from the hunter–gatherer phase to the farmer phase. The resulting effect was the generation of cities and the emergence of social stratification [8].

However, invaluable sources of knowledge on how to control, monitor and manage water do not date back to the period of the first hypothesis, but originate from the ancient past of ancient sites and cities. Two types of sites or cities can be considered as best practice [9]:

- Cities with the natural advantage of abundant water resources from major rivers such as the Nile (Egypt), Euphrates and Tigris (Mesopotamia);
- Cities with scarce water resources that have been able to find efficient ways of using it (Humayma, Greece).

The aim of this section is primarily to focus on the second group of cities, as contemporary cities are facing a population growth trend with the associated negative effect of diminishing water resources. Subsequently, to carry out a comparison of water resource management approaches in best practice cities with sufficient water resources, Egypt, and those with scarce water resources, i.e., Greece.

Humayma

The ancient site of Hawara, now known as Humayma, is one of the areas of Petra that belonged to the Nabataean people in the historical period of the 1st century BC. A local analysis of the water management system was carried out by experts in 2010. The Nabataean water system in the desert region has been in operation for approximately 800 years [8].

Hawara possessed regional anomalies, which had an impact on effective water management. The northern part of the country benefited from ample rainfall, a rich tradition of water management, and quality agriculture. In contrast, the south of the country, Petra, receives only 40 mm of rainfall per year. The Nabataeans, however, were able to eliminate these shortcomings with technologies dating back to the Bronze and Iron Ages. The water system consisted of 57 cisterns, five reservoirs, three protective dykes, terraced fields, and a 27 km long aqueduct [8].

The water system in Hawara is called "qanat". It consists of a water shaft and tunnels that distribute a directed flow of water to a central open reservoir. A shaft in the shaft trapped debris and openings in the side served as easy access for after-need maintenance of the water tunnels. The Nabataeans acquired this practice from Persia [8].

"Qanat" is continuously used as a best practice for water resources management in Iran until the present day of the 21st century. It does not only constitute a management approach but also a way to use historical technologies in modern practice in an improved form on a traditional basis [7].

For the needs of continuous irrigation, not only natural waterfalls but also artificially created ones were present in the area of the capital city of Petra. The city's original inhabitants and outsiders considered effective water management a critical success factor for local leaders, i.e., an ancient form of strategic management. The protection of water resources was grounded in its psychological conception, as an asset of status and power [10].

The planning procedures, funding sources, and the way of organizing or administering have not been preserved in written form, and therefore cannot be used as a source of inspiration for contemporary Smart Cities [11].

Greece

The technological development of the Minoan civilization has set three objectives in the field of integrated water management, i.e., efficient water capture, distribution and use. Ancient engineers in Crete were able to manage water based on hydraulic principles, using pipelines, more than 50 aqueducts, boreholes, fountains and storing rainwater [6].

They transported water resources through technology over long distances, even in inaccessible mountainous terrain, where they were able to adjust the slope to ensure a regular supply of water [9,12].

On the island of Thera, also known as Santorini, the city leadership encouraged the construction of a pipeline or sewerage system. Rainwater was stored through cisterns, which had both above- and below-ground forms [9,12].

The water retention reservoir in Alysia is still in use today, i.e., the old-age building infrastructure is still functioning after more than 2500 years. In Athens, which has always suffered from water scarcity, wells, cisterns and especially an aqueduct dating back to the time of Emperor Hadrian were key elements of success [9,12].

2.2. Comparison of Best Practices in Ancient Water Management (Egypt and Greece)

Ancient Egyptian and Greek civilizations maintained integrated cooperative relationships with each other in the sharing of hydro-technologies, such as [13–15]:

- Aqueducts;
- Cisterns;
- Filters;
- Sedimentation basins;
- Ceramic pipes;
- Sewage system;
- Hydrogeology;
- Water and waste management;
- Irrigation process;
- Rainwater harvesting and control;
- Water reuse.

Due to the gradual impact of climate change and the initial water scarcity problems, Egyptians and Greeks started to focus on the development in the field of water engineering, with a preference for the irrigation process [13].

According to Ahmedi et al. Egyptian technologies were simple and highly efficient, Greek technologies did not require a living process of complex control. While the managerial and technological aspects of water resource management from the Egyptian territory are still used today, the Greek ones meet the conditions of sustainability also for the cities of the future [13].

A popular tool for lifting water was the so-called elevator, the shadouf, which had an arm with a bucket that moved based on the strength of the human operator. The device was able to lift water up to 1.5 m and irrigate 0.12 hectares of agricultural land in 12 h [13,14].

Advanced devices based on a similar principle included water wheels, water mills, Archimedes screw or force pump [13].

The palace of King Scorpio had the first water management system for the needs of water regulation and irrigation of gardens or fields, including the distribution of water for the construction of a new canal. Historically, the first irrigation process design was developed by King Menes. Dams were used to retain water. The water level monitoring system consisted of indicators in the form of steps with markers. The quality and purity of the water were ensured by sedimentation. Advanced civilizations have always associated water resources with the level of health, quality of life and survival [13].

Differences and Common Elements of Water Management in Egypt and Greece

The biggest difference comparing best water practices in Egypt and Greece is the size of the projects being prepared and implemented. While the Egyptians preferred large projects in larger areas, the Greeks preferred smaller projects [13–17].

An important site for the application of technological innovations for water resources for the Egyptians was the Nile basin, where they implemented, for example, shadouf or water paddles. The Greeks concentrated in cities, cultivated small plots of land and used the Archimedes screw principle and the Ktesibius pump [13–17].

The two ancient civilizations share the following common elements of water management [13–17]:

- A very early and innovative focus on water resource management in the areas of canalization, water treatment, drinking water supply, monitoring;
- Development of new hydro-technologies that are still in use today in an improved form.

In examining the elements of water management, the innovative and efficient approach of cities to limited water resources has been confirmed, which also forms a model for today's civilization. What impact did water scarcity have on ancient cities, and why were they unable to stave off collapse with such advanced technologies and systems?

2.3. Lack of Water, One of the Contributing Factors Leading to the Collapse of Ancient Civilizations

The decline of important ancient civilizations was probably related to the lack of water resources. The drought leads to scarcity of water, which negatively affected the amount of food produced from lack of irrigation and thirst. The ecological problem subsequently resulted in social forms of conflict, the overthrow of the ruling class, and even the collapse of the entire civilization. Experts on the historical droughts that afflicted ancient civilizations, Sheffield and Wood, have identified 10 civilizations that were destroyed by water scarcity. The civilizations and the causes of their decline are arranged chronologically (in ascending order) [18–20].

2.3.1. The Akkadian Empire, Syria

The empire that dominated Mesopotamia was one of the global leaders between 2334 BC and 2193 BC. However, 4200 years ago, the proportion of rainfall dropped by 30% due to a volcanic eruption. A 100-year drought period devastated not only the Akkadian but also the Egyptian empire, as confirmed by archaeological finds and marine sediment investigations [18,19,21–23].

2.3.2. Egypt

A volcanic eruption caused a negative situation 4200 years ago when the Nile stopped flowing out of its bed, thus fertilizing the surrounding land. Poor harvests caused lower taxes, insufficient funds for the pharaoh, famine, drought and thirst. In the long term, the main consequence was collapse [14,16–19].

2.3.3. Mycenae

Ancient Greek civilization, located in the Mycenaean region, reached its peak at the turn of the 14th and 15th centuries BC. Around 1200 BC, however, it disappeared due to the prevailing drought. The dehydrated population launched rebel attacks that further contributed to the disruption of the empire. Historical records thematically focusing on the Mycenaean period show huge regional variations in rainfall. Results from fossilized pollen grains point to a 300-year drought in Mycenaean territory (Sheffield and Wood, 2011; Masters, 2016). According to expert Michel Wood, climate change, which manifested itself in ancient times through drought due to low rainfall, caused the collapse of civilizations dating back to the historic Bronze Age period, such as the Minoans. Moreover, ecological collapse spurred the social disintegration of an unstable Greek society [18,19,24].

2.3.4. Garamentes of Central Sahara

The northern region of Africa is characterized by climate change and a variable ecosystem. In Paleolithic times, the Sahara was not a desert but a subtropical savannah with plenty of rainfall. In the historical period of approximately 2000 BP to 500 AD, arguments and findings of archaeologists point to the presence of a civilization of warriors and nomads Garamentes. Living conditions in the Sahara depended primarily on oases and a distribution system of groundwater supply from the mountain slopes via so-called foggaras, or qanats. However, after the rapid decline of water and its scarcity in the form of rainfall, the distribution system dried up and the Garmentes civilization disappeared [18,25,26].

2.3.5. Mayan Empire

The subtropical territory of North America was home to a flourishing urban civilization of the Maya between 50 BC and 900 AD. For this ancient civilization, water harvesting and storage technologies were critical to the success of its survival. Precipitation was at its peak mainly in the months of June and September, with droughts prevailing in the other months. Effective water management was implemented, for example, by the ancient city of Tikol, which was able to store water resources for more than 10,000 inhabitants for 18 months. Around 750 AD, however, the population began to migrate from the overcrowded Maya cities to rural areas. Growing population, disease, scarcity of water resources, excessive depletion of land due to urbanization, or its contamination by saltwater due to sea level rise, all contributed to a cascading internal collapse of the great empire as part of climate change [18–20,25,27].

2.3.6. Tang Dynasty

The rulers of the Tang Dynasty, who led the country from 700 to 907 AD, created the so-called Golden Age of literature and art in China. However, climate change, drought and water shortages generated rebellions at the same time as the Mayan Empire began to decline (c. 750 AD). The rapid decline of monsoon rainfall by 70% is confirmed by expert analysis of sediments in Lake Huguang Maar. The same fate befell the Ming dynasty [18,19,28,29].

2.3.7. Tiwanaku Empire

In South America, the Tiwanaku empire was located on Lake Titicaca between 300 and 1000 AD. Sedimentation of the lake revealed that around 1000 AD, ice accumulation took place in Peru, resulting in regional droughts and a 10m drop in the level of Lake Titicaca. The effect was manifested by the migration of inhabitants and the demise of the empire [18,19,30].

2.3.8. Anasazi (Pueblo), Mesa Verde

During the same time period, the Pueblo Indian civilization collapsed in the USA due to lack of water resources. The inhabitants lived in the area of the so-called green plateaus, i.e., in the Mesa Verde area in the canyons. This location helped keep the area hidden until the 1870s when cowboys discovered it. Archaeology suggests that approximately

19,000 people lived in caves at Mesa Verde. Around 1300 AD, however, the Pueblo Indian civilization died out. Conflicts began to emerge due to water shortages, which resulted in the migration of the inhabitants to a better water-supplied area called the Rio Grande [25].

2.3.9. Khmer Empire

The seat of the Khmer Empire between 802 and 1431 AD, it formed Angkor in Cambodia (Southeast Asia). Tree rings in Vietnam confirmed a drought of more than 600 years due to climate change, which alternated with the flooding activities of monsoon rains, making the area uninhabitable. These factors caused the collapse of the empire [18,19,31,32].

2.4. Summary of Knowledge from Antiquity

Ancient cities of best water practices bring critical elements of success for effective management of limited water resources to the present day in the form of the following lessons learned [13,33–35]:

- Water quality and purity through the process of sedimentation, sanitation and water supply is a fundamental element of water sustainability;
- Hydro-technologies have been characterized by a simple process of implementation and maintenance without a complex control system;
- Small water capture projects preferred cisterns, large ones used aqueducts;
- Water systems from Egypt and Greece serve as a model for current and future smart cities in the field of integrated water management;
- Retrospective problem solving based on ancient best practices is an effective management approach;
- Based on the negative trend of decreasing water quantity, current and future cities need to develop sustainable systems for managing these limited resources.

An important finding of the study and comparative analysis is that ancient civilizations were able to manage water resources excellently in case of abundance or short-term scarcity through the process of water storage. However, during prolonged droughts, a phase of decline occurred in the form of the collapse of the most important ones. Ancient water management was based on simple technologies and resource management with the absence of a credible strategic management (government layer) to provide relevant information to the population, predict future conditions and manage problems effectively. The ecological aspect has fuelled social decline, and this has resulted in the collapse of the whole society. In addition to ancient best practices, it is necessary to analyze the strategic approach of water resource management in contemporary cities in Section 4.

3. Materials and Methods

3.1. Model Creation Procedure

The first step in the process of processing (Figure 1) own model was the analysis of the world's best water practice in history. Summarizing the findings from this section provided important data that formed the input for the next steps of the process, including the creation of your own model. The search for the best current water practice was carried out through the Arcadis Water Index for Sustainable Cities [36].

Mapping of effective approaches to water resources management is currently very limited. The only relevant available ranking that links urban and water management issues is the Arcadis Water Index for Sustainable Cities [36]. The common elements formed the basis for the creation of its own general model of effective management of water resources in the urban environment. The main criterion of the model is its orientation for the geographical area of Europe. Testing of the model in real conditions will be implemented in the phase of future research activities of the dissertation in Slovakia. Promoting sustainability, effective integrated water management, trust, awareness, and transparency are the basic parameters and values of model development.

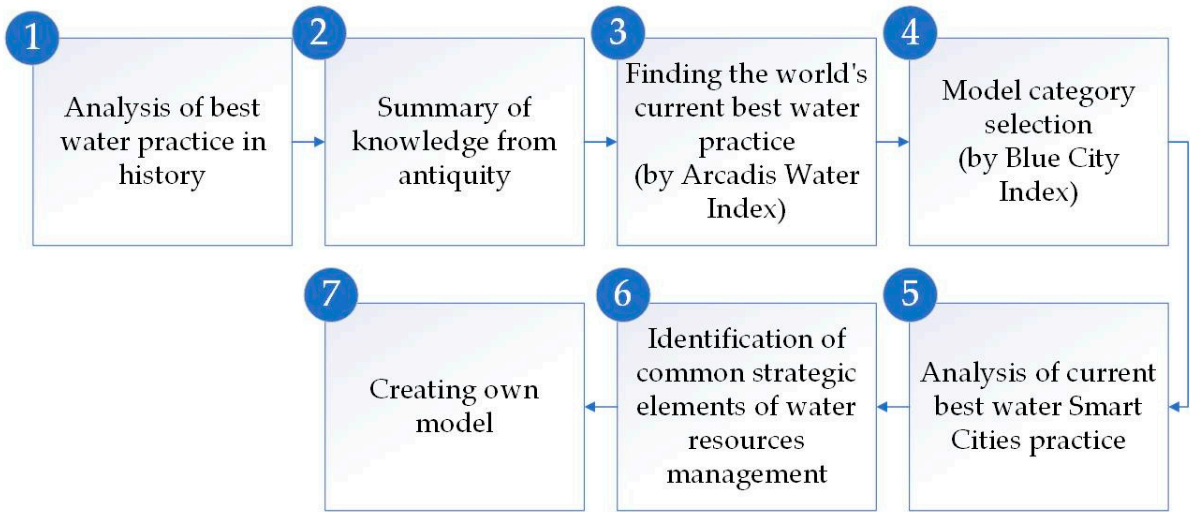

Figure 1. The process of elaborating one's own general model of efficient management of water resources in the urban environment (own processing by authors).

From the data obtained from the analysis, the own model of efficient water resources management will be proposed and tested in the future in Slovakia as part of the dissertation research activities.

3.2. *Procedure for Secondary Analysis*

In Section 4, a secondary analysis of Smart Cities strategic documents was performed, which were selected based on the results of the Arcadis Sustainable Cities Water Index and structured according to the Blue City Index categories [36,37].

3.2.1. Arcadis Sustainable Water Index

Arcadis has identified 50 cities from 31 countries as a sample for the Sustainable Cities Water Index. Cities have been selected on the basis of coverage of a large geographical area, taking into account their economic and environmental aspects in terms of the sustainability of water consumption [36].

The Sustainable Cities Water Index examines three elements, namely the resilience, efficiency and quality of limited water resources in an urban environment. Each element consists of a group of indicators, the fulfillment of which has been rated on a scale from 0 (minimum) to 100% (maximum) [36]. An overview of indicators for a specific element can be found in the Table 1.

Table 1. Overview of indicators for the three elements of the Arcadis Sustainable Cities Water Index.

Resiliency	Efficiency	Quality
water stress	water charges	water pollution
green space	metered water	sanitation
disaster risk	sanitation	drinking water
flood risk	drinking water	water-related disease
water balance	reused water	
reserve water	leakage	

Source: own elaboration according to [36].

Data from Arcadis' Sustainable Cities Water Index are from 2016 and have not yet been updated by the company. The effort to update the data was initiated by Koop and van Leeuwen, who created a new Blue City Index in 2020 according to its Chinese version.

3.2.2. Blue City Index

The basic structure of the model is represented by the identified common strategic elements of the three categories according to the Blue City Index (Trends and Pressure Framework, City Blueprint Performance Framework and Governance Capacity Analysis) [37]. Strategic elements were obtained by analyzing world best practice in Section 4.

Trends and Pressure Framework includes trends in urbanization, limited water resources or population pressures [37].

City Blueprint Performance Framework has indicators in seven areas, basic water services, water quality, water infrastructure, plans, wastewater treatment, solid waste, and climate change [37].

Governance Capacity Analysis has areas of knowing, wanting, and enabling. Knowing consists of indicators of the level of awareness, adaptation to change, and continuous learning and evaluation. Wanting includes indicators of stakeholder participation, realistic strategic management and change management. Enabling examines role allocation, implementation capacity, and project funding in the area of Water Smart Cities [37].

3.2.3. Relationship between Previous Work and Model Development

The main limitation of the data from the Arcadis Water Index are the data from 2016, the negative of the Blue City Index is that it currently only includes pilot results from cities such as Melbourne or Amsterdam [36,37].

The relationship between previous work (Water Index and Blue City Index) and this study, the main aim of which is to develop the model, is reflected in the selection of Arcadis best practice sites and the identification of key categories of the Blue City Index's own general model.

From the Sustainable Cities Water Index 2016, the first five cities were selected for analytical purposes, taking into account the following criteria:

- Each city selected should be located in a different country to eliminate duplication in strategies and elements;
- American cities and Asian cities were excluded from the selection due to the different culture and distance for the territory of Europe, where the country of further research focus and subsequent testing of the proposed general model, i.e., Slovakia, is also ranked.

The top five highest ranked cities, in the Sustainable Cities Water Index 2016 by Arcadis, are [36]:

1. Rotterdam;
2. Copenhagen;
3. Amsterdam;
4. Berlin;
5. Brussels.

Secondary analysis focused on answering the research question: What strategic elements are used by the world's best practice Smart Cities for integrated water management in a global perspective?

Cities' strategic documentations on sustainability, climate change adaptation, and integrated water management were used as the evidence base. The following Table 2 summarizes the documents analyzed for each city.

Table 2. Strategy documents of the selected cities that were analyzed.

City	Document
Rotterdam	Rotterdam Network Exchange
	Rotterdam Water City 2035
	Water Plan 2
Copenhagen	The City of Copenhagen
	Digital Water City
	International Water Association
Amsterdam	Blue City Index
	International Water Association
	Amsterdam Rainproof
	City of Amsterdam
	Amsterdam Rainproof Magazine
Berlin	Berliner Wasserbetriebe
	International Water Association
Brussels	EurEau

Source: own elaboration.

In addition to analysis, summarization of findings and comparison, the methods of creativity, logic, deduction (model building) and induction have been used in the paper. The discussion consists of the authors' views on the findings of the article, including the model and recommendations for strategic management of the city's water resources management in the future.

4. Results

The section consists of a secondary analysis of five Smart Cities best practices in 21st century water management, selected based on the results of the Water Index 2016. The structure of the layout reflects the three categories of the Blue City Index, Trends and Pressure Framework, City Blueprint Performance Framework, and Governance Capacity Analysis [36,37]. The analysis of each category is followed by a comparison of common and different strategic elements of water resources management in the urban environment. A summary of the key findings and strategic elements can be found in Section 4.4.

4.1. Trends and Pressure Framework

The Water City 2035 strategy formulates interventions in connection with urban development and population growth trends and environmental aspects [38–41].

The Copenhagen City Council has set targets for a water "smart" strategy by 2030. The main motive is to achieve efficient use of water in a sustainable way and to significantly reduce the number of people who might experience water scarcity in the area in the future [42]. The vision is to achieve resilience in the Smart City concept from current and future climate change [42–44].

The approach in Amsterdam is based on three frameworks. In the first one, the main challenges and trends that have an impact from the external environment on the Smart City system are considered. The performance area deals with the adequacy of the current state of water management. The third framework assesses the strategic capacity of management to effectively manage limited water resources [45,46].

Trends of the 21st century (urbanization, population growth, climate change) have a significant impact on Berlin's water supply, creating problems that must be addressed by research activities, through projects that receive funding from the German Ministry of Education and Research [47]. In addition to trends, Berlin also responds to past historical events. In 1948 and 1949, Berlin was isolated from the rest of Germany, accelerating innovative development and independence in the supply and management of water resources necessary for survival [48].

Belgian water management is guided by European Union regulations and regional standards for Flanders, Wallonia, and the capital Brussels. Water resources are not a scarce resource in Belgium, as the city management effectively manages the ratio of water consumption per inhabitant (monitoring via sensors). However, ecological changes and threatened diversity create a risk of water resource scarcity for future Belgian generations (prediction via machine learning) [49].

A comparison of the elements of the Trends and Pressure Framework category is given in Table 3.

Table 3. Comparison of elements of the Trends and Pressure Framework category.

Element	Rotterdam	Copenhagen	Amsterdam	Berlin	Brussels
Trends and challenges	x	x	x	x	x
Historical events				x	

Source: own elaboration according to Section 4.1.

4.2. City Blueprint Performance Framework

The promotion of resilience, sustainability, and threat elimination is provided through three elements, i.e., water storage, communities, and management. Water storage is implemented through green roofs, facades, infiltration zones [38,39]. The city's second water plan, "Water Plan 2", is based on the argument that "the management of limited water resources depends largely on the strategic management of the city" [40]. To exploit the natural advantage of the Netherlands (rivers, lakes, groundwater reserves, etc.), smart systems for water harvesting, storage, monitoring and conservation through the use of drones (UAV devices) have been developed as part of technological developments [38]. Although Smart City Rotterdam is one of the leaders in integrated water management according to the Arcadis Water Index 2016, strategic management must take preventive and corrective action by using machine learning [38].

To ensure the sustainability of water resources, Copenhagen's strategic management continuously measures and monitors water quality through sensors (IoT, drones). Protection of the biosystem and diversity is implemented by purposely fishing harmful fish, such as carp, which prey on smaller fish that clean Copenhagen's lakes. For water management, so-called water ambassadors are responsible for creating campaigns and training on the efficient use and protection of the limited water resource. The regulation of wastewater depends on not exceeding the maximum limits set by the city and regularly monitors its status. The benefits of this predictive initiative will be especially evident for future generations. Regular cleaning and decontamination of water bodies contribute to the sustainability of the city as a whole [42].

The "Water Wise City" strategy in Copenhagen primarily focuses on the provision of water services based on the "Cloudburst" management plan. The aim is to reduce water consumption to 100 L per citizen per day by 2025. Other activities include rainwater reuse through infiltration, local storage, and reduced water wastage in cooperation with HOFOR [44,50]. In the design phase part of the water-sensitive city, the basis is again the Cloudburst plan, which is followed by the Climate Change Adaptation Strategy. Knowledge and best practices are shared in cooperation with Smart Cities such as New York, Washington DC, Beijing, etc. [44].

The capital of the Netherlands, Amsterdam, achieves a high level of quality in integrated urban water management. The attractiveness of the city is achieved on the basis of a robust water infrastructure (sensors, IoT, drones) and the quality of limited water resources [45]. The greatest challenge to effective water management in Amsterdam is not management that achieves a stable level, but nature that creates limiting factors in terms of climate change, water scarcity and sea level rise [45].

Amsterdam's strategic framework is based on a vision that is firmly anchored in three essential development plans, namely "Amsterdam Rainproof" (rainwater capture program), the Amsterdam Sustainable Agenda and the Structural Vision 2040. Management creates water management strategies based on coherent, comprehensive and integrated planning of water resources and city development using intelligent modern information and communication technologies (UAV, machine learning, etc.) [45]. Integrated water management in Amsterdam is managed by the public regional authority in cooperation with the water company Waternet [45]. Collaborative learning among global Smart Cities, accelerating the learning process and gaining useful knowledge for strategic city management [45,46].

The management of sustainable water resources for future generations is achieved on the basis of the objectives set by the Berlin Senate. The aim is to plant green spaces and build a citywide street network based on the sponge principle. Traditional water conservation in the form of the "Berliner Wasserbetriebe" can maintain surface water supplies in sufficient quantity and quality through bank filtration and infiltration ponds [47]. For the development of water management, Berlin uses the Federal Water Supply Strategy, and for environmental protection, the Climate Protection Plan. Both of these strategic documents have tented goals, programs, plans, and activities up to the time period 2030 [47]. Government and strategic city management are investing funds in the protection of scarce resources, the modernization of water management through monitoring processes (UAVs, IoT, sensors) and predictive machine learning-based solutions in the Smart City concept [47].

A major risk for the city of Brussels is the low water quality of its rivers, whose nitrate concentration reaches values twice as high as in other cities in the European Union. However, up to 95% of the water is treated and reused. Population growth in Brussels and the increased cost of water are making it difficult for people in the lower social strata to access drinking water. The city management has therefore created a Federal Plan to fight poverty between 2016 and 2019 [49].

Smart City Brussels takes into account the local specificities of urban development in its integrated water management. The primary focus is on the rational management of water resources and the protection of catchment quality [49]. Belgium also offers its solutions to other countries such as Vietnam, Madagascar or Africa [49]. Monitoring is provided by sensors and prediction uses machine learning.

A comparison of the elements of the City Blueprint Performance Framework category is given in Table 4.

Table 4. Comparison of elements of the City Blueprint Performance Framework category.

Element	Rotterdam	Copenhagen	Amsterdam	Berlin	Brussels
Sponge effect	x		x	x	
Monitoring (UAV, IoT, sensors)	x	x	x	x	x
Prediction (machine learning)	x	x	x	x	**x**
Biodiversity conservation		x			
Water ambassadors		x			
Cooperation with other Smart Cities		x	x		x

Source: own elaboration according to Section 4.2.

4.3. Governance Capacity Analysis

The management of the water cycle in Smart City Rotterdam is provided by the Ministry of Infrastructure and Water Management. Positive factors influencing the sustainability of the system, according to the strategic management in Rotterdam, include efficient ways of storing water resources, awareness, and participation of stakeholders, including continuous improvement of water strategy and management [38]. Stakeholder participation is an essential element of the water cycle, which includes, for example, the strategic management of the City of Rotterdam, the Water Council of the Netherlands, the Environmental Protection Agency, or the local port [38].

The purpose of the city management is not only to cooperate with the Water Board, to perform the managerial function of planning, to implement cooperation, build communities and to achieve the set goals, but also to present the vision, to build knowledge through awareness, its transfer, and subsequent implementation. With the new strategy, Rotterdam wants to achieve attractiveness, environmental friendliness, a holistic stakeholder-centric approach, and climate resilience [40,41].

A strength of the project is the segmentation of the city into locations according to their specific natural advantages. Thus, the management of each area can prepare a "customized" proposal that reflects the specific conditions given by the ecological system.

In this sense, management's approach acts as a model for other stakeholders, thus creating an imitation or emulation effect. When public administrations and the city finance projects, they motivate the primary sector, which in turn motivates citizens to participate. If the mayor not only encourages citizens to reduce water consumption, but also implements the recommendations in his/her personal life, he/she again has a positive impact on individual aspects (his/her reputation), but also on collective awareness and level of participation [38–41].

Management in Rotterdam incentivizes the primary sector and citizens to finance projects through 'leveraging', i.e., by creating a relationship between the public and private sector, e.g., through lower taxes for citizens who invest in integrated water projects [38–41].

At the local level, citizens, city stakeholders, experts are involved in the plans and strategies. The strategic level of water resource management is the responsibility of the Mayor's office, which focuses primarily on trust-oriented leadership and providing transparent information to raise awareness, adaptation and participation among Copenhagen's citizens [42–44]. The management wants to achieve water balance by 2027 based on a holistic water management approach in the context of Smart City development. To meet the set goal, integrated water management uses action plans at local, national, and European level [42]. The implementation phase is provided through funding from water consumption fees and investments from HOFOR, a Danish company dedicated to promoting sustainable cities. Their motto is to preserve resources and cities for future generations. The object of the activity is the creation of so-called blue-green infrastructure based on lakes and green spaces for the needs of a simple process of water seepage and its capture in the lower layers, which reduces the risk of flooding and water scarcity. The timeframe for implementation is set to 2035 [44,50]. Feedback is provided by communities, supporting a process of continuous improvement.

Amsterdam's strategic framework is based on a vision that is firmly anchored in three essential development plans, namely "Amsterdam Rainproof" (rainwater capture programme), the Amsterdam Sustainable Agenda and the Structural Vision 2040 [46]. Participation with other Smart Cities on water resources is implemented through the National Delta Programme. Cooperation is promoted through annual meetings at the International Water Week in Amsterdam, where city representatives, citizens and businesses come together. Primary sources of funding are revenues from saved water cycle costs, i.e., water reuse [46]. Management develops water-based management strategies [45]:

- Citizen-orientation—Quality of life in the Smart City concept;
- Education and preparation for change from early childhood (awareness, adaptation);
- Participation of all stakeholders;
- Win-win strategy—benefits for all stakeholders;
- Cost-effective solutions;
- Creating communities;
- Feedback-based improvements;
- Risk, change and project management.

The vision of the management is to build Berlin into a city that is sustainable, ensures the renaturation of the watersheds and the protection of the rivers. Investment primarily came from the federal government and the European Union, the confidence of citizens in management is underpinned by the fact that the actual costs were never passed on to the people of Berlin. Government subsidies after 2006 form the core of the success of current water management technologies and projects [47,51,52].

The city's measures to achieve the vision and goals are governed by the standards of the European Water Framework Directive [47,51,52].

Communication with citizens is carried out through the so-called "Town Talks", where the positive effects of integrated water management for the population are discussed and presented (water quality, water sufficiency, elimination of droughts, floods, weather impacts, climate change, etc.) [47,51,52].

To promote the sustainability of Berlin, brainstorming meetings such as the "CoWorking Space" or "InfraLab Berlin" are organized. These conferences and seminars help to generate innovative thoughts and ideas on the subject of Smart City and water management [47,51,52].

The main stakeholders of effective water resource management, such as the Senate and the Department of Urban Development, include non-profit research organizations such as the Kompetenzzentrum Wasser Berlin, the Technical University of Berlin and activist groups such as the Green League [47,51,52]. Key success factors for strategic water management in Berlin are [47,48,51,52]:

- Managed water demand on the basis of higher tariffs for large water consumers - in this way reducing water consumption by 50% over 20 years;
- Risk management and Change management;
- Organizational structure—the division into national, regional, and local levels contributes to close connectivity, information transparency, management efficiency, trust, and implementation of plans in a shorter period of time, as the water sector has the authority to act as a flexible independent body;
- Senate—plays the role of executive regulator of environmental protection, comprising leaders who are environmentally conscious, charismatic, and blend science and policy (several of whom teach at universities);
- High awareness of the importance of protecting water resources—environmental issues are presented as a local problem, environmental protection and activism around water resources has been a trending and well-known issue since the 1980s. Awareness campaigns use marketing tools in the form of advertisements or effective public relations.

By working together on joint projects, an atmosphere of trust is created between the parties involved. At the same time, Belgium cooperates with the UN on human rights such as drinking water and safe sanitation. The Hydrology Programme is working together to share knowledge on water systems in times of climate change. Funding is seen as crucial by all parties, so they voluntarily support it [49].

The water management model in Brussels is public administration-oriented, except for the wastewater treatment process, which is handled by the private sector. Residents have the possibility to communicate water quality problems directly with the Ministry of the Environment. Water monitoring in Brussels is carried out by the Regional Authority of the Department of the Environment, which also sets and regulates standards for the quality of water resources [52].

Smart City Brussels takes into account the local specificities of urban development in its integrated water management. The primary focus is on the rational management of water resources and the protection of catchment quality [49].

Development plans have proposals for flood control measures. When plans and strategies are re-implemented, all stakeholders are involved in the implementation process [49]:

- Political;
- Scientific;
- Administrative;
- Socio-economic;
- Non-profit.

A comparison of the elements of the Governance Capacity Analysis category is given in Table 5.

Table 5. Comparison of elements of the Governance Capacity Analysis category.

Element	Rotterdam	Copenhagen	Amsterdam	Berlin	Brussels
Awareness	x	x	x	x	x
Participation	x	x	x	x	x
Adaptation	x	x	x	x	x
Communities	x	x	x	x	x
Funding:					
city			x	x	
public sector			x	x	
private sector	x	x	x		
citizens	x	x	x		
voluntary					x
Subsidy	x				
Restriction				x	
Vision	x	x	x	x	
Transparency	x	x	x	x	
Trust	x	x	x	x	x
Segmentation	x			x	x
Imitation effect	x				
Holistic approach	x	x			
Feedback		x	x		
Risk management		x	x	x	x
Change management			x	x	x
Project management		x	x		

Source: own elaboration according to Section 4.3.

4.4. Summary of Key Findings

A secondary analysis of global best practice identified 25 strategic elements used by management for water resource management in the concept of the five Smart Cities Rotterdam, Copenhagen, Amsterdam, Berlin, Brussels.

The analyzed cities have applied the 'sponge effect' to their concepts, which helps Smart Cities to achieve sensitivity and resilience. All cities have implemented elements of awareness, stakeholder participation, climate change adaptation, and building environmentally conscious communities in their integrated water management strategies.

In three cases, municipal and public funding of projects predominates (Amsterdam, Berlin). Other cities prefer to raise funds in partnership with private sector water companies and citizen contributions. In Brussels the water strategy is funded only by residents on a voluntary basis.

Significant common elements where there was consistency across the four or more cities are:

- Creating a practical and inspiring long-term vision;
- Providing transparent information through technology-based monitoring, sensors, UAVs and IoT devices;
- Building trust;
- Predicting the future state through the use of machine learning technology;

- Segmentation of the city into smaller localities and their specific management;
- Risk and change management;
- Mutual support, assistance and cooperation with other global Smart Cities.

The other elements identified from the analysis were represented by only a minority (characteristic of three cities or less). The positive form of motivation and stimulation of inhabitants through subsidies is used only by Rotterdam, its negative form in the form of restrictions is typical for Smart City Berlin.

Rotterdam's strategic management is based on the desire to provide quality drinking water for all and thus reduce or even eliminate social inequalities.

A direct effect of emulating strategic management behaviour is built into the strategy of Rotterdam, which, along with Copenhagen, favours a holistic approach of viewing the ecosystem as a unified whole.

Specific elements of the cities studied also include strategic elements of biodiversity conservation, project management, water ambassadors, trend analysis, or lessons and knowledge from historical events.

The insights gained are used to identify common key elements of a successful water strategy in best global practice for the effective management of scarce water resources in the concept of future Smart Cities.

5. Discussion

An analysis of water management best practices dating back to the historical period of antiquity shows that previous civilizations were able to develop and implement effective hydro-technologies and manage water resources.

Egypt is one of the countries that had a large amount of water at the time of the Nile watershed. Greece, on the other hand, does not naturally possess large amounts of freshwater flows or rainfall. Nevertheless, both of these civilizations are according to Ahmed et al., Berking and Koutsoyiannis et al., among the best water management practices since antiquity [8,9,13].

The collapse of civilizations that were able to cope with short-term water scarcity or water management challenges depended primarily on climate change, natural disasters such as volcanic eruption, or social unrest due to hunger and thirst.

The authors argue that the main cause of the decline of ancient civilizations was not the scarcity of water resources, but the ineffective response of strategic management to ecological change. Government layers failed to predict future drought conditions, thus failing to prepare for the necessary change management and risk reduction through transparent information sharing. If the ancient inhabitants had known that natural conditions were changing and a drought was gradually setting in, they would naturally have consumed less water. However, it was also necessary for the highest levels of society to implement water conservation, thus building an atmosphere of trust, cohesion, and efficiency. Environmental problems affect all social classes indiscriminately.

If management were to implement elements of prediction, trust, awareness raising, or the imitation effect, it is possible that rebellions and conflicts would not arise, the degree of migration would be eliminated, and civilizations might not cease to exist.

This assumption of the authors is based on the fact that ancient civilizations, especially Egypt and Greece, excelled in the technological and managerial aspects of water engineering and economics, but achieved a low focus on the so-called soft skills of the ruling class. The view is supported by the fact from Section 2.4. that entire dynasties such as the Ming and Tang came to an end as a result of the failure of strategic management to cope with rebellion due to the scarcity of water resources.

Current best practice cities (Section 4) have only partially learned from the mistakes of the past. They have innovative technologies based on the principle of digitalization, creating awareness, sharing knowledge and information, encouraging participation and visioning.

However, they minimally reflect the demands of citizens and their values. After analysis and main findings, including a comparison, the authors identify the problem as the theoretical focus of cities on defining a vision without orientation towards its fulfilment, as this will be a problem for the next generations.

It is essential that the cities of the future respect the past and the present, but also prepare for the alternative of water scarcity, which may not be a critical issue for today's cities, but will certainly be a global problem in 2030 or 2040. It is therefore essential that effective solutions start to be generated today, as they require finance, time, a change in people's mindsets and, above all, effective management.

A General Model for the Effective Management of Water Resources in Urban Environments

The output of this paper is a recommended general model for effective water resource management in urban environments that reflects the trends of population growth and water scarcity.

Part of the technological, information system and integrated water management functions in Figure 2 fall under the City Blueprint Performance Framework category (Section 4.2).

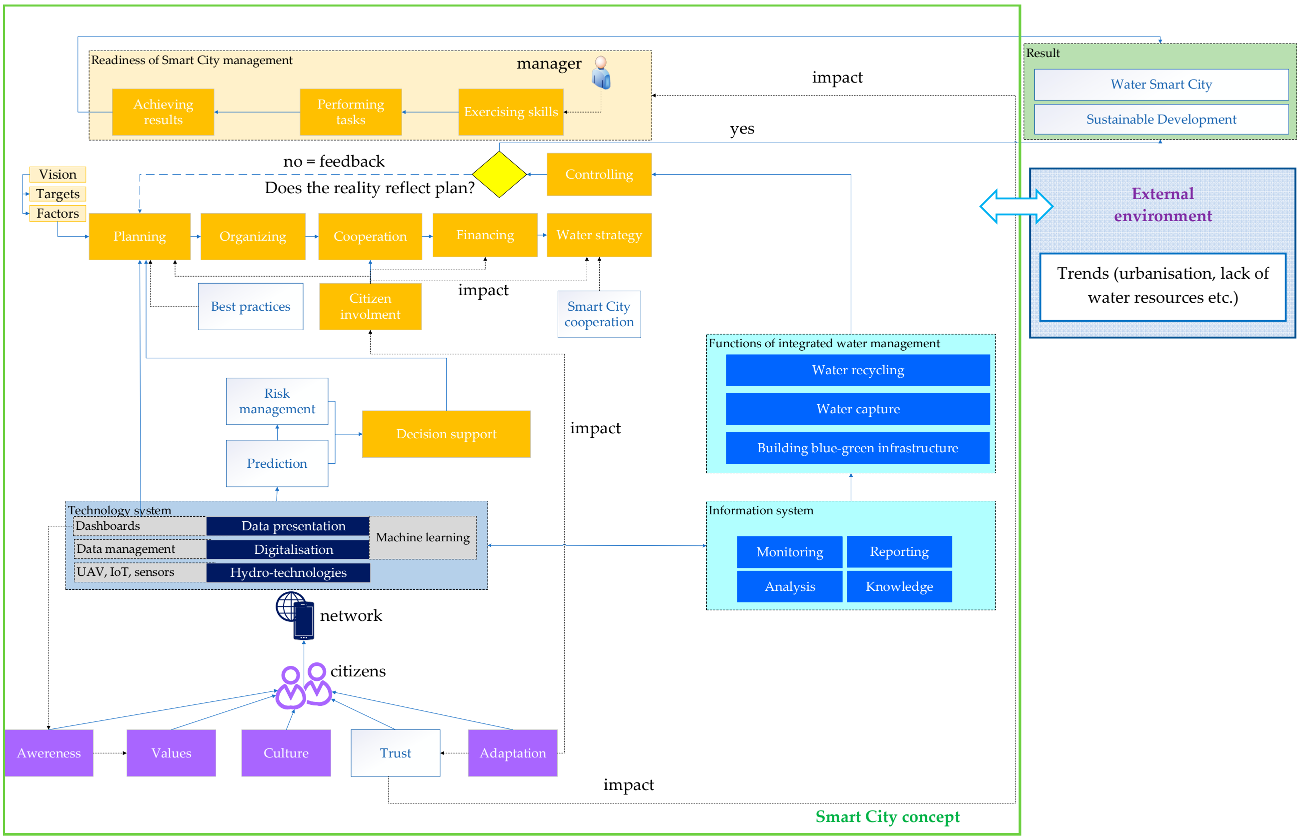

Figure 2. A general model for the effective management of water resources in urban environments (own processing by authors according to the results of Sections 2.4 and 4.1–4.4).

The external trend environment reflects the Trends and Pressure Framework category according to the 2020 Blue City Index (Section 4.1).

The purple and yellow (Figure 2) areas concerning citizens and the level of strategic management represent the Governance Capacity Analysis category (Section 4.3).

In the future, cities should implement simple hydro-technologies as a basic base, which will be adopted from past best practices and enhanced by digitalization to cover current conditions and needs. Data collection should be implemented through UAV, Internet of Things (IoT) and sensor technologies, according to the authors and the best practice results in Section 4.3. Data processing will be provided by a data management-based digitization layer. The presentation of the data is implemented through city dashboards, which contribute to a higher awareness of the issue among the citizens. In the context of data processing and its presentation in the form of information, it is appropriate to use machine learning technology, which can make the prediction and decision-making process more efficient.

According to Ahmed et al. the best technical practice is to use the Internet of Things for monitoring and measurement, for trend analysis and prediction to focus on machine learning, which can generate decisions based on facts taking into account the future state [53].

The model (Figure 2) is a centrist, bottom-up approach to reflect the values of the citizens, their culture, level of awareness, adaptation, and to create an atmosphere of trust that directly influences the level of citizen involvement in the projects.

There is a mutual influence and correlation between the Smart City concept and integrated water management, which is supported by the argument of Clover Moore, who states that "Smart Cities clusters have an indispensable role in eliminating climate change and protecting scarce resources, as they can manage change, risks, influence and predict the future state, or mediate communities oriented towards a common vision and ecological goals" [54]. A key level of the model is the area of strategic management, which should focus on:

- Setting a practical and inspiring vision;
- Forecasting and planning;
- Assigning responsibilities based on expertise;
- Controlling;
- Feedback and continuous improvement;
- Raising awareness through the publication of information on the city's notice boards.

The water management strategy consists of an information system that has a direct link to the technology system (using technologies such as UAVs, sensors, and IoT for process monitoring and machine learning for process prediction according to results in Section 4.4.). The importance of machine learning for prediction in the field of integrated water management is confirmed not only by the results of best practice, but also by Rahim et al., who emphasize its meaning in digital water measurement, prediction, and early warning systems. Machine learning technology can simplify decision-making, predict future conditions, detect errors in time and thus reduce or even eliminate risk [55].

The information system can monitor data, perform analysis, reporting and process the data into information. Another part is to perform integrated water management functions by building blue–green infrastructure based on the sponge effect, i.e., capturing water and recycling it for reuse. The implementation of these functions is subject to control. If the reality does not reflect the plan, there will be a feedback loop and thus continuous improvement of the system. If the reality reflects the plan and meets the stated objectives, the results of the model (sustainability and efficient management of limited water resources) are achieved.

Thus, a separate part of the model that influences the phase of performing managerial functions is the characteristic of the leader, which, in the authors' opinion, should meet Covey's assumptions of trustworthiness, i.e., [56,57]:

- Integrity;
- Intent;
- Competence;
- Results.

On the basis of credibility, the manager should apply his/her skills, perform tasks and achieve results in the form of sustainable development and building a Water Smart City. From the external environment, it is necessary to constantly analyze and timely respond to global trends such as migration, urbanization, technology development, etc.

Testing (verification) of this general model and its specification will take place in the future as part of the dissertation, which focuses on the effective management of water resources in Slovakia based on the use of Smart City principles.

The contribution of the model is for the fellow researchers who can use the knowledge from the analyses in their work and for the strategic management of cities in the field of effective water management in urban environments, which will be verified in practice in the near future.

6. Conclusions

The threat of climate change affects society as a whole globally and has a major impact on the supply of limited water resources.

The knowledge from the analysis of historical and current places of best water practice represents an opportunity for change and effective integrated water management.

If current and future Smart Cities want to focus on the area of water sustainability, they need to learn from the mistakes of the past.

According to several world authors (for example, Ahmed et al., Berking and Koutsoyiannis), cities in Egypt and Greece are among the best historical practices of water management.

Data from the analysis of historical books, relevant articles and documents contributed to the assumption that ancient civilizations were able to excellently manage water resources in case of their sufficient, rather than short-term scarcity through the process of water storage. During long-term droughts, however, there was a phase of their decline in the form of the collapse of the most important of them.

Ancient water management was based on simple technologies and resource management in the absence of credible strategic management (government layer), which would provide the population with relevant information, predict the future state and effectively manage problems. The ecological aspect has stimulated social decline, and this has resulted in the collapse of society as a whole.

The world's best water practice Smart Cities of the 21st century uses technology as a basic layer to promote sustainability, but does not forget the importance of social, managerial and environmental aspects. A key level of the model is the area of strategic management, which should focus on:

- Setting a practical and inspiring vision;
- Forecasting and planning;
- Assigning responsibilities based on expertise;
- Controlling;
- Feedback and continuous improvement;
- Raising awareness through the publication of information on the city's notice boards.

The main output of the article is a general model of efficient management of water resources in the urban environment, which is adapted to the concept of European cities. Its testing and verification will take place in the future on the territory of the Slovak Republic. The elaborated study in the article provides an overview of findings from the analyzes, the connection of integrated water management in the Smart Cities concept, the updating of rankings from Arcadis and the Blue City Index, including a model for strategic city management in effective water management in the urban environment.

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References

1. Attenborough, D. *A Life on Our Planet*; Ebury Press: London, UK, 2020; p. 286. ISBN 9781529108279.
2. Maxton, G. *CHANGE!: Warum wir eine Radikale Wende Brauchen*, 1st ed.; Komplett-Media GmbH: München, Germany, 2018; p. 160. ISBN 9783831204748.
3. Kubina, M.; Šulyová, D.; Vodák, J. Comparison of Smart City Standards, Implementation and Cluster Models of Cities in North America and Europe. *Sustainability* **2021**, *13*, 3120. [CrossRef]
4. Šulyová, D.; Vodák, J. The Impact of Cultural Aspects on Building the Smart City Approach: Managing Diversity in Europe (London), North America (New York) and Asia (Singapore). *Sustainability* **2020**, *12*, 9463. [CrossRef]
5. Kubina, M.; Šulyová, D.; Vodák, J. Managing Global Smart Cities in an Era of 21st Century Challenges. *Sustainability* **2021**, *13*, 2610. [CrossRef]
6. Glaeser, E. *Triumph of the City. How Our Greatest Intention Makes Us Richer, Smarter, Greener, Healthier, and Happier*; Penguin Press: New York, NY, USA, 2011; p. 394. ISBN 978-1-59420-277-3.
7. Diamond, J. *Collapse. How Societies Choose to Fail or Survive*; Penguin Books: London, UK, 2011; ISBN 0241958687.
8. Berking, J. *Water Management in Ancient Civilizations*; Pro Business: Berlin, Germany, 2018; ISBN 9783981836967.
9. Koutsoyiannis, D. Rethinking Climate, Climate Change, and Their Relationship with Water. *Water* **2021**, *13*, 849. [CrossRef]
10. Bensi, N.S. The Qanat System: A Reflection on the Heritage of the Extraction of Hidden Waters. In *Adaptive Strategies for Water Heritage*; Hein, C., Ed.; Springer: Cham, Switzerland, 2019; ISBN 9783030002688. [CrossRef]
11. Shqiarat, M.A. Water Management in Petra: Nabataean Hydraulic Overview. *Manag. Sci. Eng.* **2018**, *12*, 12–22.
12. Koutsoyiannis, D.; Zarkadoulas, N.; Angelakis, A.N.; Tchobanoglous, G. Urban Water Management in Ancient Greece: Legacies and Lessons. *J. Water Resour. Plan. Manag.* **2008**, *134*, 45–54. [CrossRef]
13. Ahmed, A.T.; El Gohary, F.; Tzanakakis, V.A.; Angelakis, A.N. Egyptian and Greek Water Cultures and Hydro-Technologies in Ancient Times. *Sustainability* **2020**, *12*, 9760. [CrossRef]
14. Mehana, M.; Abdelrahman, M.; Emadeldin, Y.; Rohila, J.S.; Karthikeyan, R. Impact of Genetic Improvements of Rice on Its Water Use and Effects of Climate Variability in Egypt. *Agriculture* **2021**, *11*, 865. [CrossRef]
15. Angelakis, A.N.; Christodoulakos, Y.; Tzanakakis, V.A. Roman Aqueducts in Crete, Greece: Learning from the Past. *Water* **2021**, *13*, 1069. [CrossRef]
16. Lazaridis, N. "Like Wringing Water from a Stone!" Information Extraction from Two Rock Graffiti in North Kharga, Egypt. *Heritage* **2021**, *4*, 2253–2260. [CrossRef]
17. Abd El Baki, H.M.; Fujimaki, H. An Evaluation of a New Scheme for Determination of Irrigation Depths in the Egyptian Nile Delta. *Water* **2021**, *13*, 2181. [CrossRef]
18. Sheffield, J.; Wood, E.F. *Drought: Past Problems and Future Scenarios*, 1st ed.; Routledge: London, UK, 2011; ISBN 9781849710824.
19. Masters, J. Ten Civilizations or Nations That Collapsed from Drought. Available online: https://www.wunderground.com/blog/JeffMasters/ten-civilizations-or-nations-that-collapsed-from-drought.html (accessed on 11 July 2021).
20. Richardson, B.G.; Mayewski, P.A.; Nyberg, J.; Haug, G.H.; Peterson, L.C. Drought and the Maya Collapse. *Anc. Mesoam.* **2007**, *18*, 283–302. [CrossRef]
21. Cullen, H.M.; de Menocal, P.B. North Atlantic Influence on Tigris-Euphrates Streamflow. *Int. J. Climatol.* **2000**, *20*, 853–863. [CrossRef]
22. Cullen, H.M.; de Menocal, P.B.; Hemming, S.; Hemming, G.; Brown, F.H.; Guilderson, T.; Sirocko, F. Climate change and the collapse of the Akkadian empire: Evidence from the deep sea. *Geology* **2000**, *28*, 379–382. [CrossRef]
23. Hoerling, M.; Eischeid, J.; Judith, P.; Xiaowei, Q.; Zhang, T.; Pegion, P. On the Increased Frequency of Mediterranean Drought. *J. Clim.* **2012**, *25*, 2146–2161. [CrossRef]
24. Cook, B.I.; Anchukaitis,, K.J.; Touchan, R.; Meko, D.M.; Cook, E.R. Spatiotemporal drought variability in the Mediterranean over the last 900 years. *JGR Atmos.* **2016**, *121*, 2060–2074. [CrossRef] [PubMed]
25. Heathcote, R.L. *Drought and the Human Story: Braving the Bull of Heaven*; Routledge: London, UK; New York, NY, USA, 2016; ISBN 9781409405016.
26. de Menocal, P.B. Cultural responses to climate change during the late Holocene. *Science* **2001**, *292*, 667–673. [CrossRef]
27. Haug, G.H.; Günther, D.; Peterson, L.C.; Sigman, D.M.; Hughen, K.A.; Aeschlimann, B. Climate and the collapse of Maya civilization. *Science* **2003**, *299*, 1731–1735. [CrossRef]
28. Wendel, J. Chinese Cave Inscriptions Tell Woeful Tale of Drought. *EOS* **2015**, *96*, 4. [CrossRef]
29. Yancheva, G.; Nowaczyk, N.R.; Mingram, J.; Dulski, P.; Schettler, G.; Negendank, J.F.W.; Liu, J.; Sigman, D.M.; Peterson, L.C.; Haug, G.H. Influence of the intertropical convergence zone on the East Asian monsoon. *Nature* **2007**, *445*, 74–77. [CrossRef]
30. Ortloff, C.R.; Kolata, A.L. Climate and Collapse: Agro-Ecological Perspectives on the Decline of the Tiwanaku State. *J. Archaeol. Sci.* **1992**, *20*, 195–221. [CrossRef]

31. Buckley, B.M.; Anchukaitis, K.; Penny, D.; Fletcher, R.; Cook, E.R.; Sano, M.; Nam, L.C.; Wichienkeeo, A.; Minh, T.T.; Hong, T.M. Climate as a contributing factor in the demise of Angkor, Cambodia. *Proc. Natl. Acad. Sci. USA* **2010**, *107*, 6748–6752. [CrossRef]
32. Kaniewski, D.; Van Campo, E.; Guiot, J.; Le Burel, S.; Otto, T.; Baeteman, C. Environmental Roots of the Late Bronze Age Crisis. *PLoS ONE* **2013**, *8*, e71004. [CrossRef] [PubMed]
33. Ramos, H.M.; McNabola, A.; López-Jiménez, P.A.; Pérez-Sánchez, M. Smart Water Management towards Future Water Sustainable Networks. *Water* **2020**, *12*, 58. [CrossRef]
34. Bell, S. *Urban Water Sustainability*, 1st ed.; Routledge: London, UK, 2020; p. 200. ISBN 9780367593483.
35. Köster, S. *Urban Water Management for Future Cities*; Springer: Vienna, Austria, 2019; ISBN 9783030014889.
36. Batten, J. Sustainable Cities Water Index. Available online: https://www.slideshare.net/GilesBooth1/arcadis-sustainable-cities-water-index-62105827 (accessed on 11 July 2021).
37. Koop, S.; van Leeuwen, K. Application of The City Blueprint Framework. Available online: https://www.ipr.northwestern.edu/documents/docs/worldwaterweek-city-blueprint-approach24-07-2020.pdf (accessed on 11 July 2021).
38. Fletcher, M. The City Water Resilience Approach. City Characterisation Report Rotterdam. Available online: https://www.resilienceshift.org/wp-content/uploads/2019/04/CWRA_CCR_Rotterdam.pdf (accessed on 11 July 2021).
39. Rotterdam Network Exchange. Water Management & Multi-Benefit Solutions. Available online: https://climate-adapt.eea.europa.eu/metadata/guidances/rotterdam-exchange-water-management-and-multi-benefit-solutions/100resilientcities_rotterdam_2015_exchangehandbook.pdf (accessed on 11 July 2021).
40. van der Brugge, R.; de Graaf, R. Linking water policy innovation and urban renewal: The case of Rotterdam, The Netherlands. *Water Policy* **2010**, *12*, 381–400. [CrossRef]
41. Molenaar, A. Rotterdam Climate Proof. Available online: https://www.oecd.org/env/cc/50426794.pdf (accessed on 11 July 2021).
42. The City of Copenhagen. The Capital of Sustainable Development. The City of Copenhagen's Action Plan for the Substainable Development Goals. Available online: https://international.kk.dk/sites/international.kk.dk/files/the_capital_of_sustainable_development_sustainable_development_goals_2018.pdf (accessed on 11 July 2021).
43. Digital Water City. Policy Matrix. *Screening of Digital, Data and Water Policies.* Available online: https://www.ecologic.eu/sites/default/files/publication/2020/DWC_D3-2_2020-07_Policy-matrix_S.pdf (accessed on 11 July 2021).
44. International Water Association. City Water Stories: Copenhagen. Available online: https://iwa-network.org/wp-content/uploads/2016/12/IWA_City_Stories_Copenhagen.pdf (accessed on 11 July 2021).
45. Peters, S.; Ouboter, M.; van der Lugt, K.; Koop, S.; van Leeuwen, K. Retrospective Analysis of Water Management in Amsterdam, The Netherlands. *Water* **2021**, *13*, 1099. [CrossRef]
46. International Water Association. City Water Stories: Amsterdam. Available online: https://iwa-network.org/wp-content/uploads/2016/12/IWA_City_Stories_Amsterdam.pdf (accessed on 11 July 2021).
47. International Water Association. City Water Stories: Berlin. Available online: https://iwa-network.org/wp-content/uploads/2015/12/IWA_City_Stories_Berlin_screen.pdf (accessed on 11 July 2021).
48. Salian, P.; Anton, B. Making Urban Water Management more Sustainable: Achievements in Berlin. Available online: http://www.switchurbanwater.eu/outputs/pdfs/w6-1_gen_dem_d6.1.6_case_study_-_berlin.pdf (accessed on 11 July 2021).
49. Michel, C.H. Pathways To Sustainable Development. First Belgian National Voluntary Review on the Implementation of the 2030 Agenda. Available online: https://sustainabledevelopment.un.org/content/documents/15721Belgium_Rev.pdf (accessed on 11 July 2021).
50. Hofor. About HOFOR. Available online: https://www.hofor.dk/english/about-hofor/ (accessed on 11 July 2021).
51. Schwarzmüller, H.; Grützmacher, G.; Gnirss, R. Integrated Urban Water Management in Berlin with Focus on natural Water Treatment in a Partially Closed Water Cycle. Available online: https://www.yumpu.com/en/document/read/7576163/integrated-urban-water-management-in-berlin-with- (accessed on 11 July 2021).
52. EurEau. The Governance of Water Services in Europe. Available online: https://www.eureau.org/resources/publications/150-report-on-the-governance-of-water-services-in-europe/file (accessed on 11 July 2021).
53. Ahmed, U.; Mumtaz, R.; Anwar, H.; Mumtaz, S.; Qamar, A.M. Water quality monitoring: From conventional to emerging technologies. *Water Supply* **2020**, *20*, 1580. [CrossRef]
54. Kingspan & Urban Water Cycle Solutions. Alternative Water Strategy For Sydney. Available online: file:///C:/Users/KMNTNB1/Downloads/143171_Alternative%20Water%20Strategy%20for%20Sydney%20-%20Kingspan%20&%20Urban%20Water%20Cycle%20Solutions.pdf (accessed on 11 July 2021).
55. Rahim, M.S.; Nguyen, K.A.; Stewart, R.A.; Giurco, D.; Blumenstein, M. Machine Learning and Data Analytic Techniques in Digital Water Metering: A Review. *Water* **2020**, *12*, 294. [CrossRef]
56. Covey, M.R.; Merrill, R. *The Speed of Trust. The One Thing That Changes Everything*, 1st ed.; Free Press: New York, NY, USA, 2006.
57. Koman, G.; Kundrikova, J. Application of Big Data Technology in Knowledge Transfer Process between Business and Academia. In *Procedia Economics and Finance, Proceedings of the 3rd Global Conference on Business, Economics, Management and Tourism 2016, Rome, Italy, 26–28 November 2015*; Elsevier: Amsterdam, The Netherlands, 2016; Volume 39, pp. 605–611.