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## INTEGRATED WATER RESOURCES MANAGEMENT IN AN URBAN CONCEPT: RESULTS FROM WATER SMART CITIES AND WATER MANAGEMENT INSTITUTIONS IN SLOVAKIA\*

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**Abstract.** Climate change, urbanisation and population growth are creating the necessity in urban systems to integrate the management of water resources which volume been significantly declined. Several cities are already feeling water stress. The solution is to conceptualise Smart Cities that are considering aspects of effective water resources management. Countries like Slovakia have not been adequately considering these issues as much as they should. Responding to the opportunity to fill a research gap, primary research has been conducted that seeks i) to update data from the Arcadis Sustainable Cities Water Index in selected cities and for Slovakia; ii) to identify the current situation in integrated water resources management both globally and in Slovakia; and iii) to propose a process for integrated management of limited water resources based on our own research findings. Research data were collected through sociological interrogation that was processed and subsequently evaluated. The findings point to the need to build resilience, efficiency and quality in water resources both in urban environments and in water management institutions. The main output from this paper is a proposed process for managing water resources within the Smart Cities concept. It can be utilised for strategic city management, water management institutions, fellow researchers and residents of any city implementing it in their own practices. Part of planned future research is to verify the process in practice.

**Keywords:** integrated water management; sustainable development; water management institutions; strategic management practices for sustainability

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## 1. Introduction

Water is the driving force behind the emergence and development of human civilisation, which climate change is significantly affecting (Kopáček et al., 2021; Stelian, & Juhasz, 2022).

According to a 2019 study by Nature Climate Change, it has had a rapid impact on both groundwater and drinking water supplies (Szalai, 2019). Most countries in the world have reached the final phase, which means that more than 10,000 years will be required for water resources to regenerate from the state of their current ecosystems (Szalai, 2019). Scientists foresee up to 4.5 billion of Earth's population by 2025 experiencing water scarcity due to stress on water supplies (Mann, 2021).

Climate change affects both social and ecological systems with positive and negative interlinkages between them. To conserve limited water resources in future, Smart Cities need to incorporate integrated water management into their urban concepts (Kleinová, 2018; Nzimakwe, 2020; Alexopoulos et al., 2021; Elgamal & Khafif, 2021; Todorova & Parzhanova, 2020).

## 2. Research background

Several authors have taken different approaches to conceptualising integrated water management. Taji et al. (2021) define it as urban development to capture water, construct water ecosystems for cities and create a community for conservation and low consumption of water resources. They argue for the incorporation of modern technology, adaptation and transparency in water management (Taji et al., 2021).

Vacca (2021) defines integrated water management as citizen-centred (social) management that responds flexibly to a growing urban population through sustainable, safe water resource solutions. Jindal et al. (2022) define the term as the monitoring of consumed water in order to ensure its sufficiency, quality and availability within the entire urban area.

This paper views the concept of integrated water management as a comprehensive and flexible approach to managing limited water resources in response to climate change. It operates on the basis of elements and the relationships between them.

The issue of integrated water management in global Smart Cities has been discussed in several scientific publications. The most recent studies conducted this year have concentrated on flood management, applications and the economic framework (Yereseme et al., 2022; Oberascher et al., 2022; Grigg, 2022).

Best water practices in Smart Cities can be analysed by using the Arcadis Sustainable Cities Water Index. This index was selected based on our previous research (Šulyová et al., 2021; Šulyová & Kubina, 2021b). The ranking in Arcadis Sustainable Cities Water Index was last updated in 2016. The articles that used the given ranking in their analyzes used data from 2012 and 2016. However, updating the data with analyzes conducted from other studies only reflects the situation in 2020 and uses mostly secondary data (Maiolo et al., 2018; Batten, 2018; Hoekstra et al., 2018; Alkhalidi et al., 2018; Sáez et al., 2020; van Ginkel et al., 2018).

In Slovakia, water resources are likewise in an unfavourable situation, with scientists predicting 30-50% less water in Slovakia by 2075. Local resources have felt the impact of climate change since the 1980s (Szalai, 2019). Even though Slovakia has no Smart Cities itself, as part of our own research activity, we deal with building this

concept in the given area (Šulyová & Vodák, 2020; Kubina et al., 2021a; Kubina et al., 2021b; Vodák et al., 2021; Šulyová et al., 2021; Šulyová & Kubina, 2022a; Šulyová & Kubina, 2022b).

The most water-stressed parts of Slovakia can be found in the west and south of the country, while eastern Slovakia's water stress is moderate and the north of Slovakia is the least stressed.

Climatologists believe Slovakia's climate to be moving closer to what countries like Croatia and Bulgaria are now experiencing. According to the Slovak Hydrometeorological Institute (SHI), the amount of precipitation in Slovakia has changed dramatically since 2000 (Pekárová, 2018). The European Union Water Framework Directive (2000/60/EC) seeks to regulate the situation legislatively with the objective of good water status achievable by 2027 and for updates every six years. The last update took place in 2021 (Strelková, 2021).

All locations in Slovakia are currently experiencing a shortage of water resources. Slovakia's population consumes 630 cubic metres of water each year, of which 58% of the total comes from groundwater and 52% from surface freshwater resources. According to Pekárová (2018), industry consumes the most water resources (52%), followed by households (43%) and agriculture (5%). It has become crucial to learn from mistakes of past civilisations and droughts Slovakia experienced between 1861 and 1870 (Pekárová, 2018). A timely response is essential when contending with the alarming situation in water resources.

In the face of the critical situation described above, there were relevant articles published that discussed integrated water management in Slovakia, appearing in 1994, 2016 and 2017. They focused on trends in water use, reservoir water and wastewater treatment (Zeľňáková et al., 2017; Fidlerová & Hlúbiková, 2016; Námer & Hyánek, 1994).

Nevertheless, an opportunity to fill the emerging research gap has been presented by the severity of the crisis in water resources, the relative lack of research into the issue, outdated Arcadis rankings and the lack of primary sources.

The aim of this article is i) to update data from the Arcadis Sustainable Cities Water Index in selected cities and for Slovakia; ii) to identify the current situation in integrated water resources management both globally and in Slovakia; and iii) to propose a process for integrated management of limited water resources based on our own research findings.

The basis of the research activity is represented by the research questions set out in section 3 and the hypotheses that serve to verify, describe and better understand the issue in the territory of Slovakia, as follows:

**Hypothesis 1:** *If climate change is directly related to population size, then water scarcity will be reflected in Slovakia's large cities (with populations greater than 100,000).*

**Hypothesis 2:** *If a city's readiness to implement the Smart City concept is related to the factors of water resources management/troubleshooting water issues, then the greatest potential for Slovakia successfully implementing the Smart City concept in the area of water resources management have cities with populations greater than 100,000.*

### 3. Methodology

**Study area** – the research was focused on the world's best practice Smart Cities according to a selected ranking and on cities in Slovakia. Among member states of the European Union, Slovakia ranks 31st by population. Its area is 49,035 square kilometres and the population is 5,449,270 (Slovensko – regionální geografie, 2022; Slovensko, 2022; Slovenská republika – sumárne štatistiky, 2022). Slovakia has no Smart Cities itself at this time

although initial conceptualisation initiatives started in 2017. They remain only theoretical and the concepts have yet to be put into practice (Bakonyi, 2020). None of the plans presented have ever been implemented (Ministerstvo hospodárstva Slovenskej republiky, 2017). However, climate change, migration and population growth, evident in the scarcity of resources, are creating the conditions for conceptualising Smart Cities and pressure is being put on Slovakia to follow through on its first Smart Cities and to embrace principles of integrated water management. Research involved the contact of 71 sufficiently populated district cities, covering an adequate enough area to be feasible, out of the 141 cities registered in Slovakia's eight regions (Zoznam miest na Slovensku, 2022).

**The aim of article is** i) to update data from the Arcadis Sustainable Cities Water Index in selected cities and for Slovakia; ii) to identify the current situation in integrated water resources management both globally and in Slovakia; and iii) to propose a process for integrated management of limited water resources based on our own research findings.

Intensive research needed to be carried out because Smart Cities are a topic that has not been sufficiently covered in Slovakia and no research with this type of focus had been previously done in Slovakia. The results bring new findings and fill a research gap that exists according to section 2. Obtained results from this paper can serve as a basis for identifying best practice and adopting best practices in another Smart Cities, water management institutions, fellow researches or strategic city management. Obtained results can have positive impact also on resident's motivation for protection of limited water resources.

**Subjects of research** – Smart City respondents consisting of the following:

- The world's best practice cities according to the rankings in the 2016 Arcadis Sustainable Cities Water Index (Batten, 2016);
- Slovakia's 71 district cities (see Appendix 1);
- Representatives from water management institutions in Slovakia responsible for managing water resources: Department of Strategic Water Planning at the Ministry of the Environment, Slovak Hydrometeorological Institute, Slovak Water Management Company, Water Management Research Institute and Slovak Environmental Inspectorate.

Cities in Slovakia were categorised by their size into five groups:

1. Less than 6,000 (two cities)
2. 6,000 – 10,999 (5 cities)
3. 11,000 – 19,999 (22 cities)
4. 20,000 – 99,999 (40 cities)
5. 100,000 or more (two cities)

For research purposes, contact was made with cities which water management practices had been ranked best by the 2016 Arcadis Sustainable Cities Water Index. The intention behind selection of the cities to approach was to include twelve best practice cities, chosen according to their position in the rankings. In addition for the sake of interest, a city from among those ranked in the middle of the index ranking and a city from the bottom of the ranking were randomly selected. All of the subjects of research (respondents) were approached and given a questionnaire survey over a 14-month time interval (June 2021 to August 2022).

**Arcadis Sustainable Cities Water Index** – Arcadis was selected due to its previous use in our research and our ambition was to follow up on this research. Because the ranking of the cities had not been updated since 2016, an opportunity was created to fill a gap with our own research. Arcadis is a consultancy that has identified 50 cities in 31 countries across the globe as samples for its Sustainable Cities Water Index. The cities were selected on the

basis of their extensive geographical coverage and took into account their economies and environmental aspects in their sustainable consumption of water resources. Table 1 displays the three elements examined in compiling the Sustainable Cities Water Index. Each element consists of a group of indicators assessed on a scale from a minimum of 0 to a maximum of 100 (Batten, 2016).

**Table 1.** List of indicators characterizing the elements of sustainable Water Smart Cities

Elements	Resilience	Efficiency	Quality
	Water stress level	Fees	
	Lots of green	Consumption measurement	Pollution of streams
	Flood risk	Sanitation	Sanitation
	Risk associated with natural disasters	State of drinking water	Drinking water level
	Water balance	Water recycling	
	Water reserves	Flow	

*Source:* own processing according to Batten, 2016

**Methods** – primary research was comprised of sociological interrogation with an online questionnaire created in Google Forms, which contained the research questions below. They were developed from previous research and the results therefrom, with the aim of follow-up research and to prepare this article.

- To what degree do the indicators cover urban resilience in specific cities?
- To what degree do the indicators cover efficiency of water resources in specific cities?
- To what degree do the indicators cover quality of water resources in specific cities?
- What specific cities are experiencing water scarcity?
- What is the level of the city's strategic management's readiness to put the Smart City concept into practice?
- Does integrated water resources management stimulate principles of sustainable urban development?
- What are the implications of climate change for water resource management?
- What drove integrated water resources management to be implemented?
- What economic measures for water resources management are exploited by stakeholders?
- Which water resources management activities are being implemented?
- What elements are used to manage limited water resources in urban environments?
- What processes have been implemented within the social aspect of water resources management?

Data obtained from responses to the resilience, efficiency and quality research questions were then used to update the Arcadis rankings. The data obtained from the questionnaires were then statistically processed in IBM SPSS Statistics 26 software, where the variables were correlated according to their type for ordinal numbers with Spearman's rank correlation coefficient ( $\rho$ ) to compare two variables. In addition to the statistical tests, a hypothesis verification method and a Pareto distribution diagram were also used. Comparative methods were applied through benchmarking for the results from Smart Cities and water management institutions in Slovakia, while problem-solving methods such as modelling, creativity, logic, synthesis, induction and deduction contributed toward the development of a process for integrated water resources management.

## 4. Results

### 4.1. Profile of respondents

#### 4.1.1. Sampled cities

After contacting mayors in selected cities several times with an online questionnaire, responses were obtained from 10 Smart Cities around the world (71.4% success rate) and all 71 district cities in Slovakia (100% success rate). The Table 2 shows in boldface the cities that participated in the research. Institutions in Slovakia responsible for water resources management were including because there is no Smart City or Water Smart City in Slovakia to represent it.

**Table 2.** Selection of addressed places, area of integrated water resources management

Arcadis Sustainable Cities Water Index	Water Smart Cities	Ranking	Selection argument
Top	<b>Rotterdam</b>	1.	Best practice
	<b>Copenhagen</b>	2.	
	<b>Amsterdam</b>	3.	
	<b>Berlin</b>	4.	
	Brussel	5.	
	Toronto	6.	
	Frankfurt	7.	
	<b>Sydney</b>	8.	
	<b>Birmingham</b>	9.	
	Manchester	10.	
	<b>Melbourne</b>	11.	
	<b>Paris</b>	12.	
Middle	<b>Seoul</b>	23.	Random choice
End	<b>Rio de Janeiro</b>	44.	

Source: own processing according to Batten, 2016

#### 4.1.2. Slovakian water management institutions sampled

Questionnaires were completed by five representatives from institutions in Slovakia that are responsible for water resources management: Department of Strategic Water Planning at the Ministry of the Environment, Slovak Hydrometeorological Institute, Slovak Water Management Company, Water Management Research Institute and Slovak Environmental Inspectorate.

### 4.2. Verification of hypotheses

Water-related issues caused by climate change (rated on a scale of 1-3 where 1 equals minor, 2 equals moderate and 5 equals significant) and city size (five specified categories – see the research background section 3) are ordinal variables of Hypothesis 1 (Table 4). Because it was an element in the particular research question, information needed to be obtained on water scarcity indicators.

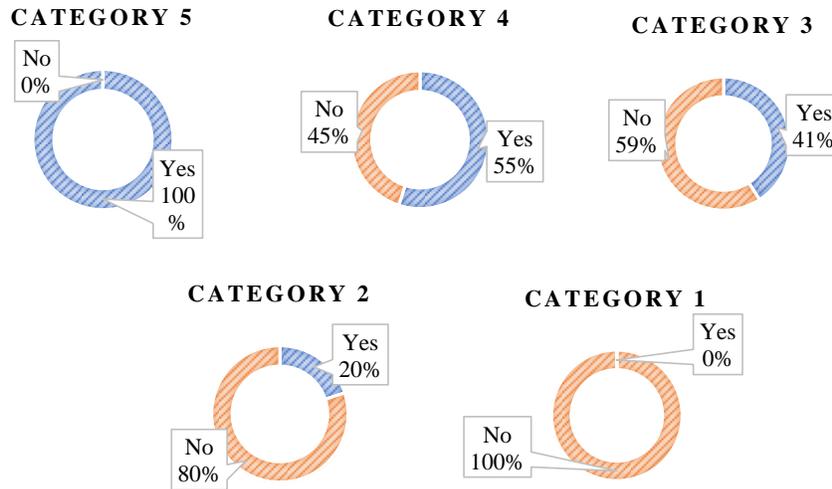


Figure 1. Problems with lack of water resources in five categories of cities in Slovakia

Source: own processing according to research data

*What specific cities are experiencing water scarcity?*

The collected data covers five categories of cities dependent on their size (see Figure 1, in order of relevance from the largest to the smallest cities). The following findings can be reasoned from the results:

- Category 5 – water scarcity was confirmed in both cities with populations greater than 100,000
- Category 4 (population 20,000 – 99,999) – of the 40 cities, 55% indicated that water scarcity existed
- Category 3 (population 11,000 – 19,999), Category 2 (6,000 – 10,999) and Category 1 (less than 6,000) – a decreasing number of these cities indicated that water scarcity existed.

The results show a correlation between water scarcity and population, but it needs to be confirmed through statistical verification (Table 4).

*What is the level of the city's strategic management's readiness to put the Smart City concept into practice?*

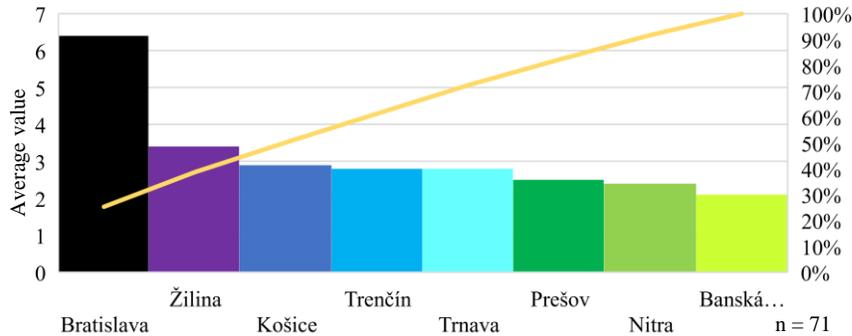
The nature of the research questions required information to be obtained about the level of readiness to implement Smart City concepts in practice and on the water scarcity indicator (Figures 1 and 2). Figure 2 and Table 3 show the processed results and how they were interpreted. They show that the cities in Bratislava Region are the most prepared to adopt the Smart City concept into practice.

Table 3. Average value of city readiness for the Smart City concept by region

Region	Readiness (average value)
Bratislavský	6.4
Banskobystrický	2.1
Košický	2.9
Nitrianský	2.4
Prešovský	2.5
Trenčiansky	2.8
Trnavský	2.8
Žilinský	3.4

Source: own processing according to research data

Cities in Žilina and Košice Regions were the second and third most prepared, respectively. But compared to Bratislava Region, they were on average about two times less prepared.



**Figure 2.** Readiness of Slovak cities according to regions for the building of the Smart Cities concept  
*Source:* own processing according to research data

*Statistical verification of the hypothesis*

The correlation between the variables was statistically verified by Spearman’s rho, as displayed in Table 4.

**Table 4.** Statistical verification of hypotheses

<b>Hypothesis 1</b>			
Spearman’s rho		Problem_water	Size
Problem_water	Correlation coefficient	1,000	,447**
	Sig.	-	,000
	Number/Amount (N)	71	71
Size	Correlation coefficient	,447**	1,000
	Sig.	,000	-
	Number/Amount (N)	71	71
<b>Hypothesis 2</b>			
Spearman’s rho		Problem_water	Readiness
Problem_water	Correlation coefficient	1,000	,548**
	Sig.	-	,000
	Number/Amount (N)	71	71
Readiness	Correlation coefficient	,548**	1,000
	Sig.	,000	-
	Number/Amount (N)	71	71

\*\* the correlation is significant at level 0.05

*Source:* own processing according to primary research data

The information argues for a direct link between population size and climate change. Data processing highlighted water scarcity issues in large cities with a population of over 100,000, while Spearman’s rho confirms a significant correlation, therefore Hypothesis 1 is accepted. The results in Table 4 confirmed a significant level of correlation between the variables of water scarcity and readiness, So Hypothesis 2 is accepted.

4.3. Assessment of data for updated rankings in the Arcadis Sustainable Cities Water Index

4.3.1. Resilience

To what degree do the indicators cover urban resilience in specific cities? (1 = minimum, 10 = maximum)

The optimal number of points for evaluating urban resilience should be 15. In water resources management, such issues as lack of water resources, green areas, risk associated with water disasters, flood threat and unbalanced water consumption should score 1 point (total of 5 points).

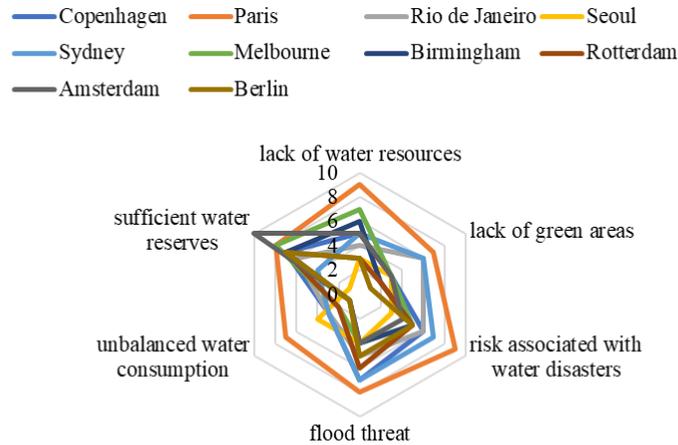


Figure 3. Benchmarking in the area of the resilience element of the world's best water practices  
Source: own processing according to research data

If a city has sufficient water reserves, it should optimally score 10 points for it. Amsterdam has the most water reserves, Seoul the least. Paris scores the lowest in urban resilience according to the benchmarking in Figure 3. The Slovak Hydrometeorological Institute gave the most positive assessment of water resources (Figure 4).

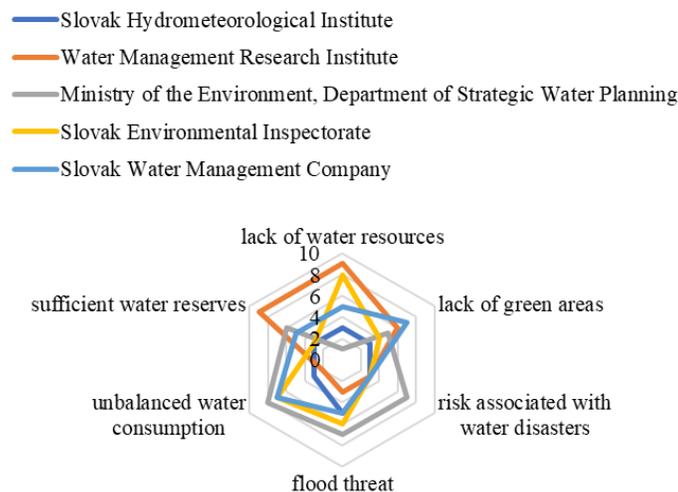


Figure 4. Benchmarking in the field of resistance element in Slovakia  
Source: own processing according to research data

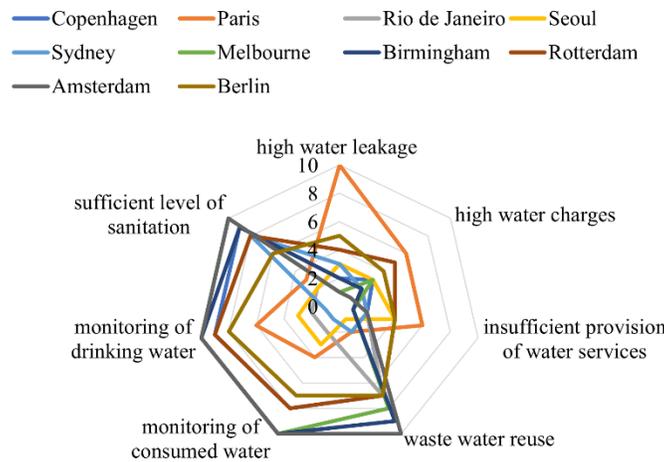
The opinion of the five Slovakian institutions was that the values coming out of the benchmarking were hardly uniform and large differences between them could be seen. For example, the Water Management Research

Institute evaluated water reserves at nine points, the Ministry of the Environment gave six points, the reserves scored only five points with the Slovakian Water Management Company and both Slovak Hydrometeorological Institute and the Slovak Environmental Inspectorate assessed them at only three points. Awareness of the current state of the examined indicators in Slovakia can be described as ambiguous and chaotic.

*4.3.2. Efficiency*

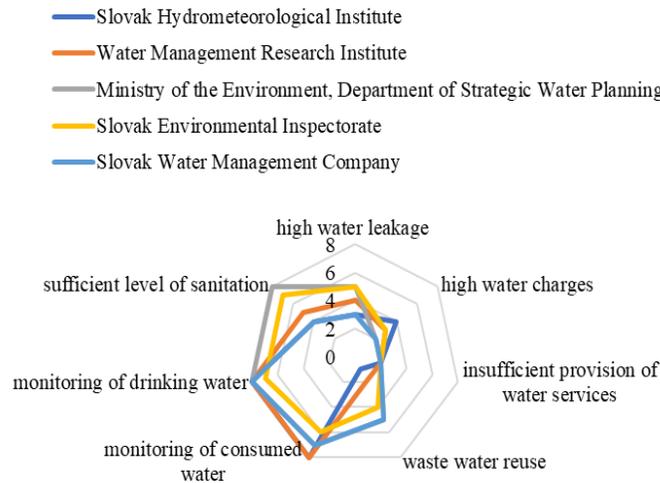
*To what degree do the indicators cover efficiency of water resources in specific cities? (1 = minimum, 10 = maximum)*

In the optimal case of integrated water resources management, high water leakage, water charges and insufficient provision of water services should score only one point (for a total of three points). Conversely, elements such as waste water reuse, monitoring of consumed water and drinking water levels, including sufficient level of sanitation, should receive the full ten points each (for a total of 40 points). Therefore, the optimal number of points for a best practice city should be 43 points.



**Figure 5.** Benchmarking in the area of efficiency of world cities of best water practice  
*Source: own processing according to research data*

Birmingham and Melbourne received the best scores for water resources efficiency according to the benchmarking on Figure 5. The least efficient city from the outcome of primary research was Seoul. The five institutions in Slovakia rated efficiency quite homogeneously (Figure 6).



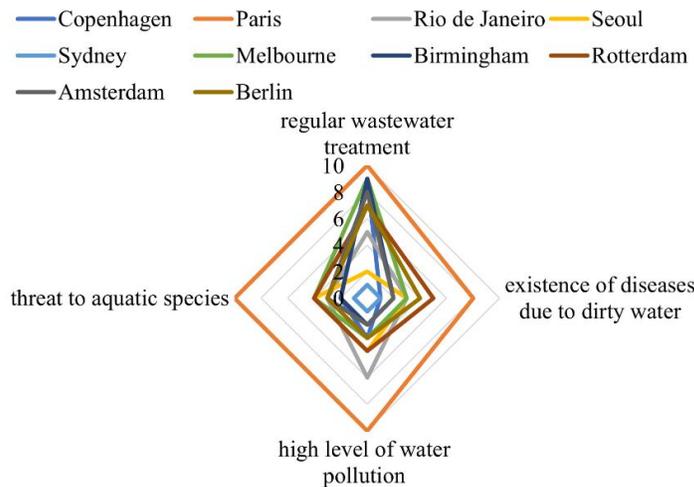
**Figure 6.** Benchmarking in the field of efficiency element in Slovakia  
*Source:* own processing according to research data

Slovakia’s monitoring is optimal according to the results from the assessment, although the country in general does not make adequate use of wastewater.

### 3.3.3. Quality of water resources

*To what degree do the indicators cover quality of water resources in specific cities? (1 = minimum, 10 = maximum)*

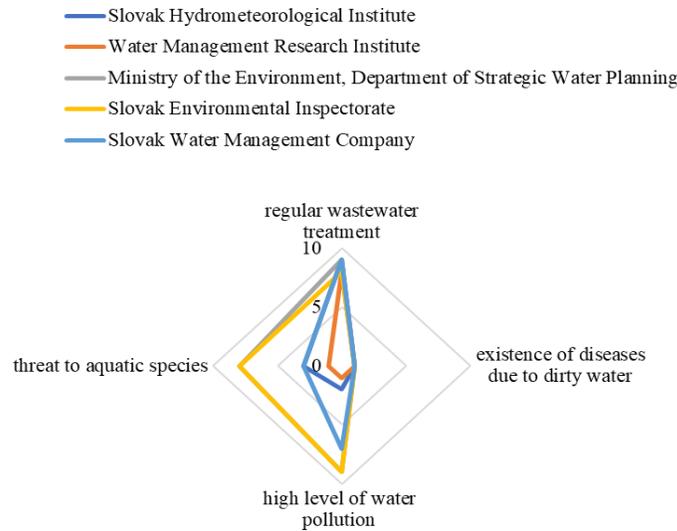
Optimally, regular wastewater treatment should be assessed at ten points in water quality, while the other benchmarks in Figure 7 would be awarded one point each (for a total of three points).



**Figure 7.** Benchmarking in the area of water quality element of best water practice  
*Source:* own processing according to research data

The overall optimal score should therefore be 13 points. Figure 7 show cities such as Seoul, Birmingham, Melbourne, Amsterdam and Berlin to come closest to the optimal state in benchmarking results, while Paris received the least optimal score. In Slovakia, both the Ministry of the Environment and the Slovakian Environmental Inspectorate have taken a critical view of quality (Figure 8). Although wastewater is regularly

treated in Slovakia according to the assessment of quality, efficiency data indicates that these water resources are not reused.



**Figure 8.** Benchmarking in the field of water resources quality in Slovakia  
 Source: own processing according to research data

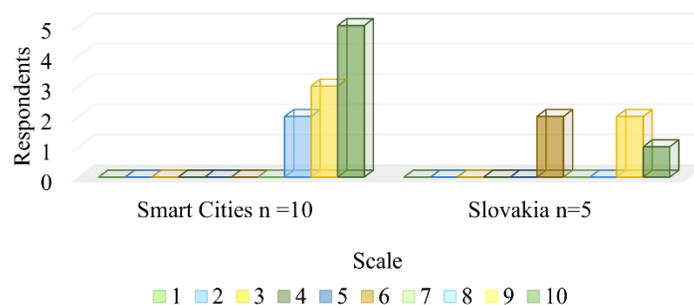
In pollution of water resources, none of the institutions have taken the same view regarding the existence of diseases due to poor water quality and the threat they pose to aquatic species. However, the most relevant opinion here is expressed by the Ministry of the Environment and Slovak Environmental Inspectorate, both of which monitor water quality.

#### 4.4. Integrated water resources management

Part of this paper concentrates on the responses to research questions and findings from them have identified the current state of water resources management in both the world’s best water practice cities and in water institutions operating in Slovakia (because of the absence of Smart Cities in the country).

##### *Does integrated water resources management stimulate principles of sustainable urban development?*

An overwhelming majority of global respondents believe that integrated water resources management significantly stimulates principles of sustainable urban development. On a scale of 1 (minimum) to 10 (maximum), Figure 9 assesses water resources management institutions in Slovakia for their level of stimulation at 6, 9 and 10 points.

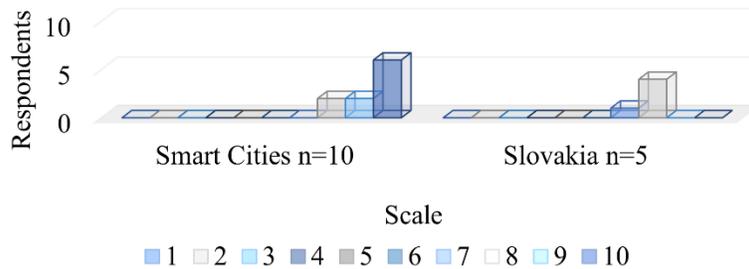


**Figure 9.** Evaluation of the impact of stimulating water management on sustainable urban development  
 Source: own processing according to research data

The result suggests that the world’s Smart Cities consider integrated water resources to be more related to sustainable urban development.

*What are the implications of climate change for water resource management?*

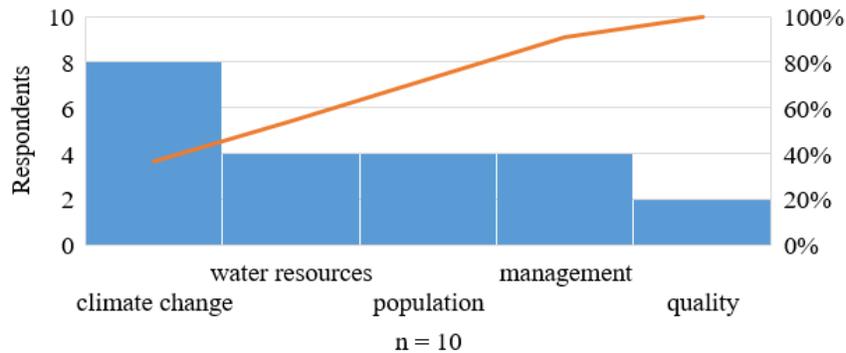
Using a scale of 1 (minimum) to 10 (maximum), the answers given by both global and local respondents suggest that climate change has a significant impact on effective water resources management. The respondents from foreign Smart Cities rated the implications at 8-10 and the institutions in Slovakia put them at 7-8 out of a possible 10 points (Figure 10).



**Figure 10.** Impact of climate change on water resources management  
 Source: own processing according to research data

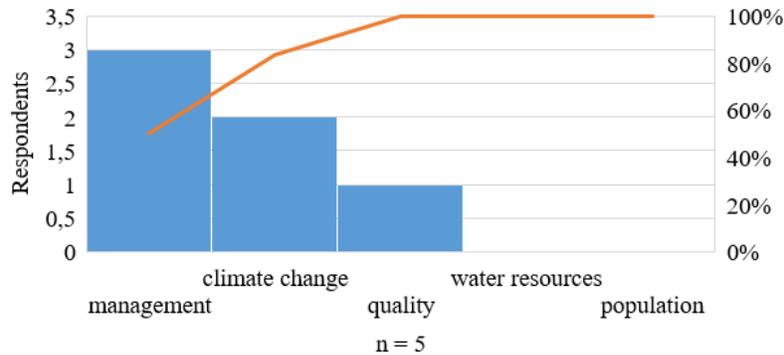
*What drove integrated water resources management to be implemented?*

Respondents consider climate change, out of the five options shown in Figure 11 in the global Smart Cities’ best water practices, as the main driver for implementing integrated water resources management.



**Figure 11.** Reasons for the implementation of integrated water management - world cities  
 Source: own processing according to research data

Second place was occupied by water scarcity, linked to the growing urban population. According to the answers the selected sample of respondents provided, neither management nor quality of water resources were seen to be the key causes behind the emergence of the necessity to implement integrated water resources management in practice based on Smart City approaches. Figure 12 shows the key reasons for water resources management, according to the five water institutions in Slovakia, to have been current ineffective management of scarce resources, climate change and poor water quality.

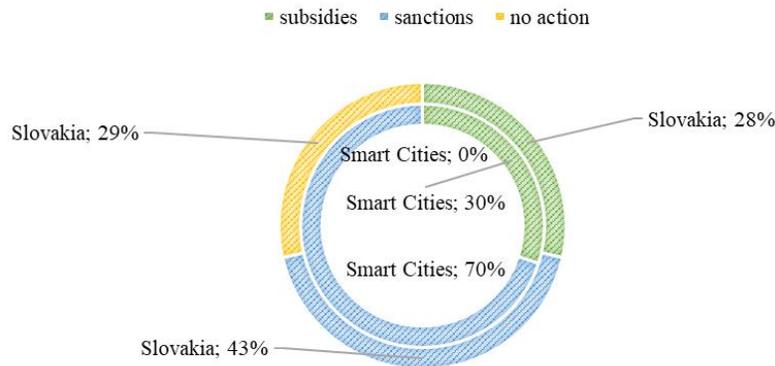


**Figure 12.** Reasons for the implementation of integrated water management - water institutions in Slovakia  
 Source: own processing according to research data

None of the respondents associated climate change with the gradual reduction in the limited number of water resources, which rapid decline they put down to population growth. While representatives of Smart Cities are aware of the links, water institutions in Slovakia are not. In discussing ineffective management of scarce water resources, the Department of Strategic Water Planning at the Ministry of the Environment attributed the low level of effective management mainly due to its fragmented nature.

*What economic measures for water resources management are exploited by stakeholders?*

Cities and institutions, irrespective of geography, currently favour negative form of motivation such as higher sanctions for inefficient water consumption over subsidies for efficient water management (Figure 13).

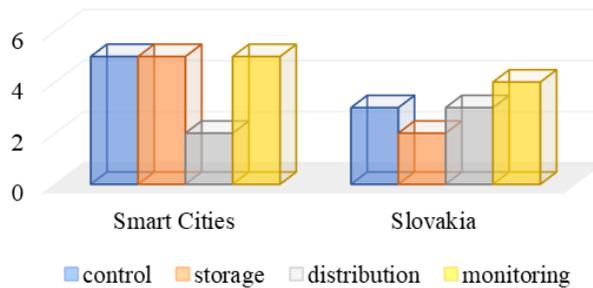


**Figure 13.** Evaluation of measures in the field of water resources management  
 Source: own processing according to research data

The Department of Strategic Water Planning stated that sanctions are imposed on national water administration authorities and district authorities and on cities when either violate general binding regulations governing them. Slovak Hydrometeorological Institute believes economic tools such as sanctions and financial assistance to be only supportive. Slovakia therefore emphasises regulatory instruments and planning more, while not imposing any action.

*Which water resources management activities are being implemented?*

The best water practice cities globally primarily act to control, storage and monitoring of water resources (Figure 14).

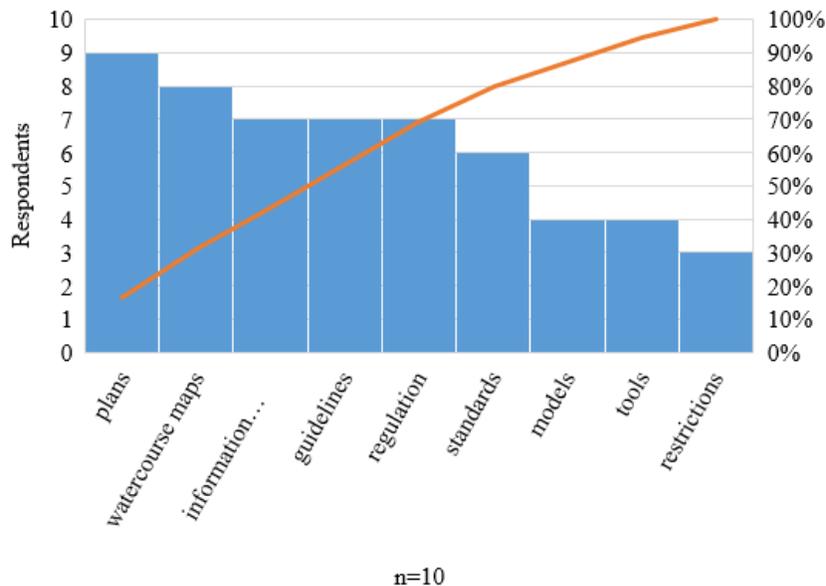


**Figure 14.** Evaluation of the implemented activities of the city in the field of water resources  
*Source:* own processing according to research data

In Slovakia, a city manages its water resources primarily through control and monitoring.

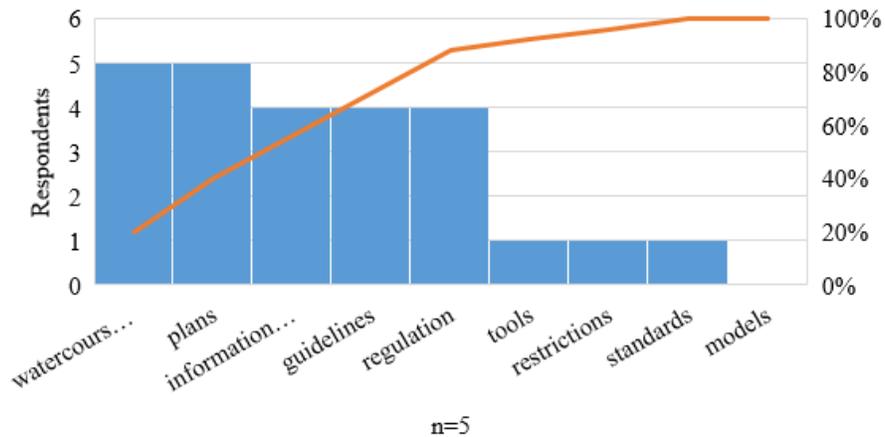
*What elements are used to manage limited water resources in urban environments?*

Figure 15 shows 90% of the Smart Cities selected from the 2016 Arcadis ranking consider plans, watercourse maps, information systems, guidelines and regulation on water consumption to be the key elements in water resources management.



**Figure 15.** Elements of water management in the urban environment - the world's best water practice  
*Source:* own processing according to research data

The least preferred option is restrictions. The outcome of research, displayed in Figure 16, list Slovakia's key elements as watercourse maps, plans and information systems.



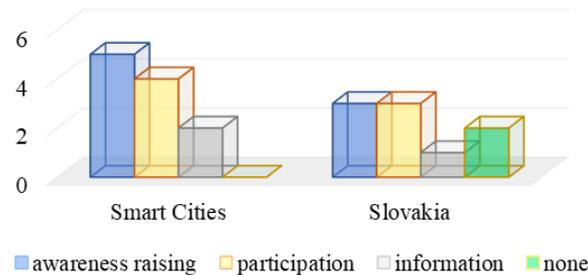
**Figure 16.** Elements of water management in the urban environment - Slovakia

Source: own processing according to research data

Models are absent, while management and decision support tools, restrictions and standards are poorly covered.

*What processes have been implemented within the social aspect of water resources management?*

All of the respondents mention raising awareness, encouraging participation and providing information as part of the social aspect of water resources management (Figure 17). Smart Cities are also socially raising awareness about climate change and its impact on limited water resources.



**Figure 17.** Implemented processes within the social side of water resources management

Source: own processing according to research data

Compared to the global cities, some of the water institutions, such as the Slovak Environmental Inspectorate and the Slovakian Water Management Company have not implemented any processes yet within the social aspect of water resources management.

#### 4.5. Summarising the main findings

In urban resilience, Seoul has the best practice with a score (18 points) oscillating toward the optimal value of 15. In terms of water resources efficiency, the best practice cities include Birmingham and Melbourne, each having the optimal score of 43. Regarding water quality, the last of the three elements examined, best practices were once again observed in Seoul, which scored the optimal number of points (13). Paris was the least effective city for integrated water resources management among the selected cities.

Cities such as Berlin, Amsterdam, Rotterdam, Melbourne and Birmingham, can likewise be perceived as examples of "best practice" according to the results displayed in Table 5.

Averaging the scores given to Slovakia's five water institutions on the three elements made it possible to express the resilience, efficiency and quality of water resources management in the country Table 5. Here, Slovakia ranks third worst in resilience, reflects the average ranking in terms of efficiency and has the second lowest ranking in water quality. Compared to the world's best water practices, Slovakia's level of water resources management is quite low (Table 5). Based on our own research, it was possible to update some amount of data from the 2016 Arcadis Sustainable Cities Water Index and this is also shown in Table 5.

**Table 5.** Summary evaluation of elements of integrated water city management

City	Element					
	Resilience	Optimum	Efficiency	Optimum	Quality	Optimum
Copenhagen	31	15	40	43	15	13
Paris	48		37		38	
Rio de Janeiro	30		20		17	
Seoul	18		19		13	
Sydney	32		19		4	
Melbourne	29		43		19	
Birmingham	25		43		15	
Rotterdam	25		45		20	
Amsterdam	27		44		15	
Berlin	22		41		17	
Slovakia	30		33		20	

Source: own processing according to research results in section 4.3.

According to own research results authors conclude that integrated water resources management stimulates sustainable urban development. Simultaneously, climate change affects every city and it has an impact on the management of limited resources.

Management is primarily carried out through control and monitoring of water resources. The tools used in practice are maps, plans and information systems. An interesting finding from primary research is that both the global cities and Slovakian water institutions currently prefer negative motivation to motivate behaviour in the form of sanctions for inefficient management of limited water resources.

While the social side of management builds and raises awareness, encourages participation and shares relevant information, some of the institutions in Slovakia responsible for managing water resources have never implemented any processes involving the social aspect of management (Figure 17).

A summary of the main findings can be found in Table 6.

**Table 6.** Summary of main findings

Hypothesis		Result
1	If climate change is directly related to population size, then water scarcity will be reflected in Slovakia's large cities (with populations greater than 100,000).	Confirmed
2	If a city's readiness to implement the Smart City concept is related to the factors of water resources management/troubleshooting water issues, then the greatest potential for Slovakia successfully implementing the Smart City concept in the area of water resources management have cities with populations greater than 100,000.	Confirmed
Research questions		Answers
To what degree do the indicators cover urban resilience in specific cities?		Best practice = Amsterdam Worst practice = Paris Slovakia (average points) = 30
To what degree do the indicators cover efficiency of water resources in specific cities?		Best practice = Amsterdam, Birmingham Worst practice = Seoul, Sydney

	Slovakia (average points) = 33
To what degree do the indicators cover quality of water resources in specific cities?	Best practice = Birmingham, Melbourne, Amsterdam, Berlin Worst practice = Paris Slovakia (average points) = 20
Does integrated water resources management stimulate principles of sustainable urban development?	yes
What are the implications of climate change for water resource management?	significant
What drove integrated water resources management to be implemented?	Water Smart Cities = climate change, water scarcity, population Slovakia = inefficient management, climate change, low quality of water resources
What economic measures for water resources management are exploited by stakeholders?	Water Smart Cities = sanctions (70 %) Slovakia = sanctions (60 %)
Which water resources management activities are being implemented?	Water Smart Cities = control, storage, monitoring Slovakia = control, monitoring
What elements are used to manage limited water resources in urban environments?	Water Smart Cities, Slovakia = plans, water resource maps, information systems
What processes have been implemented within the social aspect of water resources management?	Water Smart Cities = awareness, information, participation Slovakia = awareness, information, participation, no processes

*Source:* own processing according to section 4 Results

The benefit to be gained is information for the creation of an integrated water resources management process and the subsequent verification thereof in practice at cities within Slovakia that have the greatest potential to become Smart Cities, namely those with populations greater than 100,000 (as implied in the verification of Hypothesis 1 and Hypothesis 2 and as displayed in Table 6).

## 5. Discussion

The actual design for managing limited water resources in the Smart City concept consists of the existing and new activities marked in yellow on Figure 18.

In managing water resources, the watercourses (and the data collected from these sources) have to be primarily mapped. Segmenting them into smaller units would simplify monitoring and delegation, but it should not fragment the system excessively. Several authors share this view (Batten, 2016; Šulyová et al., 2021; Koutsoyiannis, 2021; Bell, 2020; Köster, 2019; Nieuwenhuis et al., 2022).

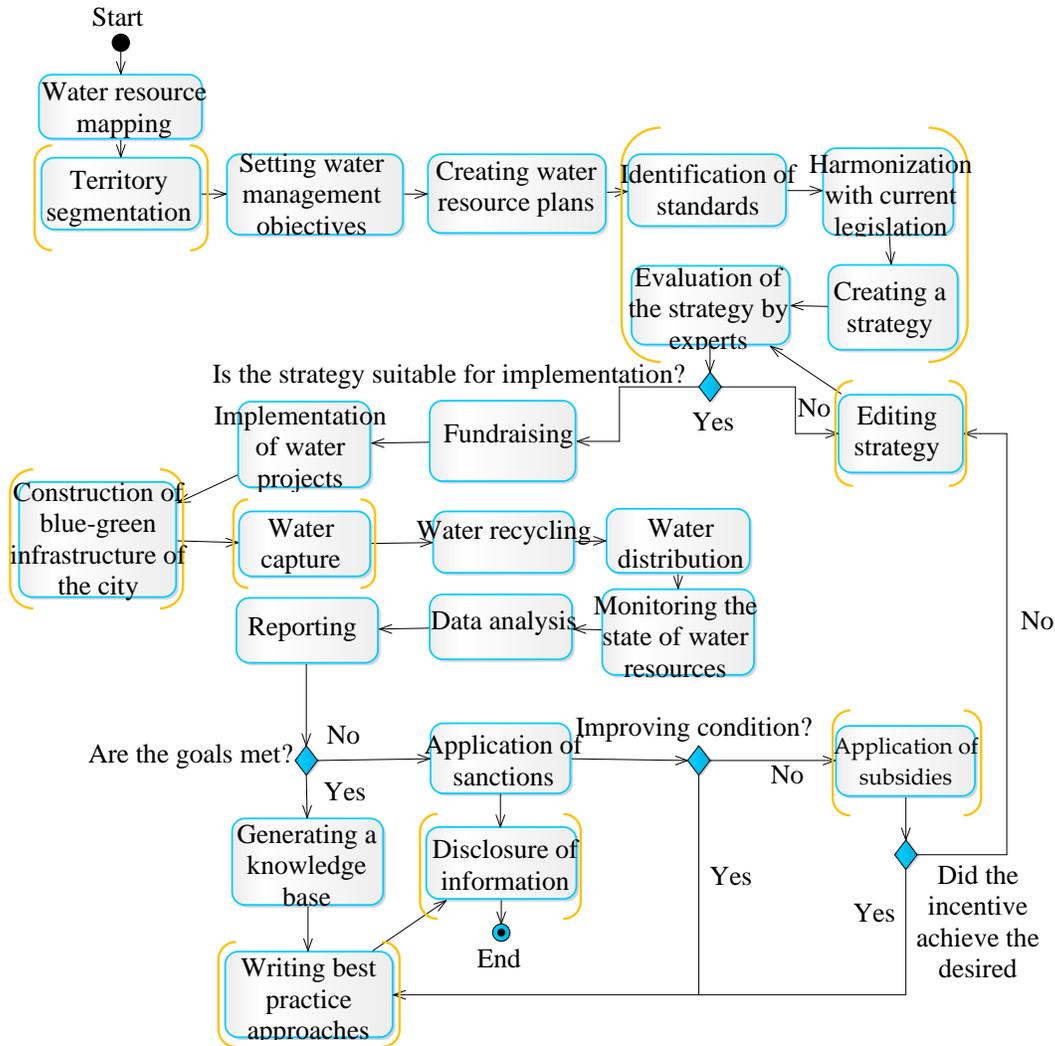
When creating strategic documents, it is essential for goals to be set that reflect the Smart City vision and to develop plans. Iftekhar & Islam (2022) share the same opinion, emphasising the creation of master plans and strategies for integrated urban water management. Standards such as setting minimum and maximum consumption thresholds would be subsequently identified and then used to assess whether targets have been met. These standards should be harmonised both with existing legislation governing water resources management and for conceptualising Smart Cities. Hydrological issues may arise unless political and administrative aspects are harmonised (Nicollier et al., 2022).

The outcome of primary main research showed cities preferring projects to strategies, which in most cases were absent. Therefore, an element of strategy development and expert evaluation (e.g. by water research institutions) was incorporated into designing the process.

Afterward, decisions would be made on whether the strategy is appropriate for implementation. If not, it would need to be adapted and re-evaluated. If the strategy were to meet conditions for implementation, funds would then

be obtained to implement the water projects. According to Iftekhar & Pannell (2022), decision-making in integrated water management plays an essential role in the building of water-sensitive urban designs.

City councils should seek to build a blue-green infrastructure to capture water resources whose depletion is causing climate change on a global scale. This is driving construction of the so-called “sponge city”. Water management also includes recycling and distributing water, a view is supported by opinion of several authors (Lara-Valencia et al., 2022; Yang et al., 2022; Wang et al., 2022; Pokhrel et al., 2022).



**Figure 18.** The process of managing limited water resources in the Smart Cities concept  
 Source: own processing according to own research

Assessment of the current situation would be mediated through monitoring, analysis of the collected data and the drafting of reports (Rentachintala et al., 2022). If the objectives are met, a knowledge database will be generated, best practice cases written up as a model for other cities and, in the end, relevant information will be published.

These activities will contribute toward raising awareness and building trust (Vacca, 2021; Ahmed et al., 2022; Garciadiego, 2022). The need to develop a process for managing scarce water resources based on integrating the process into the urban environment, both in the wake of climate change and because of the currently low efficiency in how water resources are managed now, has been recognised by several authors (Wang et al., 2022; Kitessa et al., 2022; Ksibi et al., 2022).

Unless the objectives are met, the usual economic measures, namely sanctions, will be imposed. Even negative information has to be published in order to build trust. If the situation fails to improve, a positive incentive will be employed, such as grants appropriated for reduced water consumption.

The success of these incentives will be written into best practice cases and subsequently published. Unless financial assistance guarantees the desired effect (specifically to reach the outlined objectives), a strategy will need to be adapted which objectives are likely to be very ambitious, but which would have to be achieved through evolutionary development (Batten, 2016; Šulyová & Kubina, 2022b).

### 5.1. Benefits and a utilisation of process for managing scarce water resources in the smart cities concept

The proposed process shown in Figure 18 contributes theoretically to the management of scarce resources in an urban environment as it fills a research gap in this area with data derived from the results of our own research. Once it has been implemented in practice, it will convey practical benefits from lower consumption of water resources, efficient management based on blue-green infrastructure, continuous improvement of the system and a positive impact socially on residents, winning their trust, awareness and involvement. The findings in this paper constitute a model for implementation for fellow researchers, urban strategic management and water management institutions can utilise for conceptualising and developing sustainable water Smart Cities which results will be perceivable by residents.

### 5.2. Limitations of the model

Limitations of the process include the following:

- Research was confined to best water practice cities and to Slovakia;
- Dependence on a city's size as the process would be best implemented in a city which population is greater than 100,000;
- Taking an innovative approach primarily for cities just planning to conceptualise a Smart City or for a Smart City in the development phase;
- Conditions set out for putting Smart City concepts in practice, such as achieving an adequate level of government support and a level of trust and willingness by residents to commit themselves to a Smart City;
- Need for verification of it in practice.

### 5.3. Future research

Part of future research includes verifying the model in practice.

## Conclusions

Water resources are in grave condition. Water Smart Cities need today to develop preventive measures. The outcome from our own research points toward the importance of integrated management of water resources that are being greatly affected by climate change. The global water Smart Cities ranked in the Arcadis Sustainable Cities Water Index provide a major reference for the elements of water resources resilience, efficiency and quality. However, the social aspect should not be neglected, namely residents and their level of awareness, trust and participation. In most cities, negative motivation prevail in the form of sanctions. The world's best practice cities are implementing integrated water resources management as a consequence of climate change and Slovakia, a country that does not even have one Smart City within its borders, is seeking to take this approach due either to a currently ineffective water strategy or a complete lack of one. Cities with populations over 100,000 are particularly vulnerable to water stress. Yet our own research confirms that conceptualising a Smart City and developing the concepts can reduce or even eliminate water shortages.

The main output from this paper is a process for managing limited water resources within the Smart Cities concept that comprises both current and new activities. It was developed from findings in our own research and the model created from previous research, which it complements. Innovative elements are, in particular, the application of grants and financial assistance, raising awareness, the building of blue-green infrastructure, and harmonisation with legislation that stresses integration. Inspiration from best water practice, including an updated ranking from Arcadis through its own research, is essential.

The proposed process outlines an implementation pattern especially for strategic urban management, water management institutions and research findings utilisable by fellow researchers. Positive impacts from the process will have an effect even on residents. When implementing the process, it is also necessary to take its limitations into account such as its origin from research, conditions for implementation and its link to the size of the city in the Smart City concept (in the conceptualisation and development phases, among other things). Part of future research includes planning to verify the model in practice.

## Appendix 1.

List of 71 district towns involved in the research

**Bratislavský kraj:** Bratislava, Malacky, Pezinok, Senec

**Trnavský kraj:** Dunajská Streda, Galanta, Hlohovec, Piešťany, Senica, Skalica, Trnava

**Nitriansky kraj:** Komárno, Levice, Nitra, Nové Zámky, Šaľa, Topoľčany, Zlaté Moravce

**Trenčiansky kraj:** Bánovce nad Bebravou, Ilava, Myjava, Nové mesto nad Váhom, Partizánske, Považská Bystrica, Prievidza, Púchov, Trenčín

**Banskobystrický kraj:** Banská Bystrica, Banská Štiavnica, Brezno, Detva, Krupina, Lučenec, Poltár, Revúca, Rimavská Sobota, Veľký Krtíš, Zvolen, Žarnovica, Žiar nad Hronom

**Žilinský kraj:** Bytča, Čadca, Dolný Kubín, Kysucké Nové Mesto, Liptovský Mikuláš, Martin, Námestovo, Ružomberok, Turčianske Teplice, Tvrdošín, Žilina

**Prešovský kraj:** Bardejov, Humenné, Kežmarok, Levoča, Medzilaborce, Poprad, Prešov, Sabinov, Snina, Stará Ľubovňa, Stropkov, Svidník, Vranov nad Topľou

**Košický kraj:** Gelnica, Košice, Michalovce, Rožňava, Sobrance, Spišská Nová Ves, Trebišov

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