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ENFORCEMENTS INFRASTRUCTURE RESILIENCE INDEX OF THE WATER AND SANITATION SECTORS TO CLIMATE CHANGE IN COASTAL CITIES

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Abstract

Climate change (CC) is a significant global environmental issue that poses severe consequences, particularly on agricultural productivity, lifestyle, infrastructure, and overall population well-being. These impacts are projected to vary among different countries. The primary concern of this research is that infrastructure networks, which both contribute to the causes of climate change and are essential for its resilience, would be more susceptible to its physical impacts, notably in the water and drainage sector. The research aims to develop a model for measuring the climate change resilience index for the water and drainage sector in coastal cities. Through an inductive approach to study climate change and its risks and the resilient infrastructure to climate change and its principles, then analysing structural and administrative adaptation measures, extracting structural, administrative, and emergency plans, then assessing the extent of adopting the principles of planning and confronting climate change, developing a measurement index, then applying it to New York, Melbourne, and Thessaloniki, and finally extracting the conclusions.

Keywords: assess resilience; emergency plans; facing climate change; water; drainage; resilience index; urban resilience.

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INTRODUCTION

Climate change (CC) is an alteration in the typical climatic conditions, including temperatures, wind patterns, and precipitations, that are characteristic of each region on Earth. The long-term effects of extensive climate change will significantly influence natural biological systems. Rising temperatures will result in alterations in weather patterns, including wind directions, precipitation levels, and various extreme climate occurrences. The situation results in extensive and unforeseeable environmental, social, and economic impacts (Environmental Affairs Agency of the Ministry of Environment in Egypt, 2022).

Climate change affects mortality and morbidity by increasing the occurrence of extreme weather phenomena like heat waves, storms, and floods. It also disrupts food systems and leads to a rise in zoonotic diseases, food and waterborne-illnesses, vector-borne diseases, and mental health problems (WHO, 2022). The World Health Organization forecasts that climate change will lead to the deaths of 250,000 individuals from 2030 to 2050 as a result of starvation, malaria, and heat stress. The United Nations FAO has found that climate change leads to severe weather phenomena, droughts, floods, and other calamities that impact the livelihoods of millions of people worldwide. Approximately 78% of the global impoverished population, estimated over 800 million individuals, is significantly impacted by such an issue (FAO, 2019).

LITERATURE REVIEW

Infrastructure

Infrastructure is the set of physical components of interconnected systems that provide necessary goods and services to enable, sustain, or improve community living conditions. Water and sanitation networks include:

- Water purification, treatment, and storage operations.
- Water facilities and structures.
- Water installations: water lines, pumping, electrical and mechanical equipment.
- Wastewater and rainwater collection operations.
- Wastewater treatment operations.
- Reuse of treated wastewater.

The Impact of the Water and Sanitation Sector on Climate Change

Sanitation pollution is an increasingly significant danger to both humans and marine life, and it is the primary cause of coastal contamination on a global scale. Globally, we discharge approximately 80% of wastewater into the environment without any treatment, (UNESCO, 2017), releasing numerous detrimental contaminants into the ocean, causing direct harm to both individuals and coral reefs. resulting in:

- Physical and biological degradation of coral reefs, seagrasses, and salt marshes;
- a loss of coastal ecological services like erosion control, storm buffering, and fish spawning grounds;
- Detrimental algal blooms that result in the mortality of marine organisms, the closure of coastal areas, and the emergence of diseases in humans; and
- Pathogens, metals, and toxic substances can cause diseases.

Impacts of Climate Change on Water and Sanitation Sector

Climate change has an impact on the water and sanitation sectors. Figure 1 shows how the water and drainage industries are affected by climate change.

Temperature changes	**Sea level rise**	**Changing rainfall patterns**	**Changing storm patterns**
- Increased need for water due to heat. - Increased need for treatment. - Increased evaporation from tanks. - Increased evaporation of irrigation water. - Deterioration of the quality of drinking water due to high temperatures and the spread of pests. - deteriorating water quality.	- Inundation of coastal infrastructure. - Salinization of groundwater sources - Low level of protection provided by coastal defenses - Overburden of sewage systems.	- Increased need for water storage capacity. - Increased risk of dam overflow. - Increased risk of overflowing drains and sewage problems. - Deterioration of water quality, decrease in drinking water and increased treatment costs.	- Structural damage - Low level of protection provided by flood defences.

Figure 1: the impact of climate change on the water and sanitation sector.
Source: OCED, (2018)

The Concept of Climate Change Resilient Infrastructure

It is the infrastructure that is planned, designed, constructed, and operated in a way that anticipates, prepares for, and adapts to changing climatic conditions. It can also withstand, respond to, and recover quickly from disturbances caused by these climatic conditions. Ensuring climate resilience is an ongoing process throughout the life of infrastructure. Efforts to achieve climate resilience can be mutually reinforced through efforts to increase resilience to natural hazards (OCED, 2018). It is known as a network of equipment and components used to confront civilizational climate challenges by relying on nature as much as possible (UNDRR, 2022). the principles of infrastructure resilience are shown Figure (2).

Principles of Climate Change Resilient Infrastructure Planning

Infrastructure can play an essential role in strategies to manage risks and reduce the negative impacts of climate change. The physical effects of climate change, such as rising temperatures, shifting precipitation patterns, increased intensity or frequency of extreme weather phenomena, and rising sea levels, will affect all types of infrastructure. Principles for planning climate-resilient infrastructure include (Cinta Lomba-Fernández, and others, 2019):

- Ensuring infrastructure is resilient to climate change;
- Guaranteeing financial flows;
- Increasing the lifespan of infrastructure;
- Using an approach based on smart infrastructure;
- Using an ecosystem-based approach;
- Taking into account social changes; and
- Taking into account economic changes.

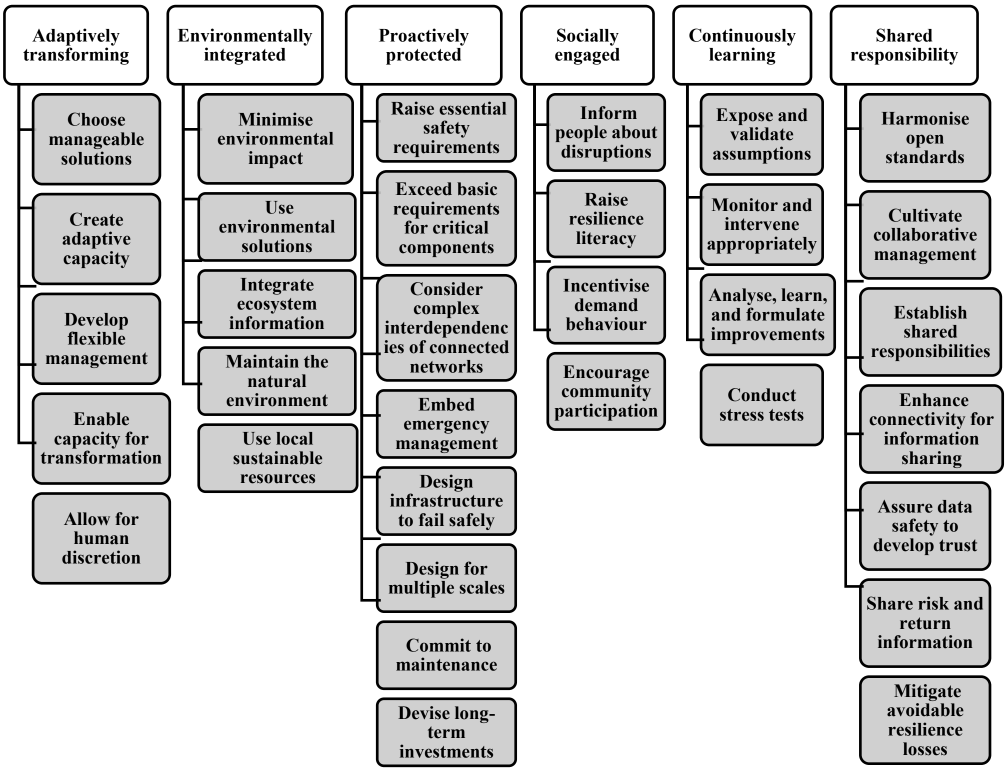

Figure 2: principles of infrastructure resilience.
Source: UNDRR, (2022)

Climate resilient infrastructure plans (water and sanitation sectors)
Plans for resilience to climate change in the water and sanitation sectors can be developed based on achieving the previously mentioned resilience principles. The extent to which these plans achieve the previously described principles will be tested, as shown in Tables (1) and (2).

Table 1: Evaluation of climate change resilient infrastructure water sector plans in terms of achieving the principles

	Climate resilient infrastructure plans		resilient to climate change and facing				smart infrast	ecosy	econo mic	social chang	Increa se	financia l flow
			High tempe rature	Sea level rise	Change rainfall pattern	Chang storm pattern						
Structural plans	1	Equitable access to safe drinking water for all	•								•	high
	2	Provide a good water network								•	•	high
	3	Maintenance of water transmission and distribution networks							•	•	•	low
	4	Ensure that the materials from which water networks are made conform to specifications.	•		•				•	•	•	low
	5	Improve water quality and providing high-quality water.							•	•	•	med ium
	6	Reducing greenhouse gas emissions associated with the operation of water systems	•	•	•	•		•	•	•	•	low
	7	Use various sources to charge environmental water.			•			•	•		•	low
	8	Address increased evaporation in water sources	•		•			•	•		•	med ium
	9	Use various water sources.			•			•	•		•	med ium
	10	Achieve gray water reuse			•			•	•		•	low
	11	Achieve black water reuse.			•			•	•		•	low
	12	Sustainability of irrigation methods			•			•	•		•	low
	13	Use modern technology to conserve water.			•		•		•		•	low
	14	Establish watersheds			•			•	•		•	high
	15	Reduce water pollution and stopping the dumping of waste and hazardous chemicals			•			•	•	•	•	low
	16	Work on natural and human defenses against floods.		•	•	•	•	•	•		•	high
	17	Use of land to provide green spaces and water paths for shading and cooling	•					•	•	•		low
Administrative plans	18	Form a water protection administration	•	•	•	•	•		•	•	•	low
	19	Establish departments and responsibilities for watershed management.	•	•	•	•	•		•	•	•	low
	20	Review water forecasts to ensure they meet community needs.	•		•		•			•	•	low
	21	Protect water resources and associated ecosystems	•					•			•	low

		Climate resilient infrastructure plans	resilient to climate change and facing				smart infrast	ecosy	econo mic	social chang	Increa se	financia l flow
			High tempe rature	Sea level rise	Change rainfall pattern	Chang storm pattern						
	22	Provide research on future water efficiency							•		•	low
	23	Monitor the flow of water streams, groundwater, & climate information	•	•	•	•	•		•	•	•	low
	24	Water prices are appropriate in relation to the income of individuals in those areas.			•				•	•	•	low
	25	Enhance the scope of cooperation and supporting capacity building in water-related programs	•	•	•	•			•	•	•	low
	26	Create an automatic leak notification program.			•		•		•	•	•	medium
	27	Raise population awareness of the need to conserve water.			•				•	•	•	low
	28	Consider the correction of behaviors associated with the actions of community members.			•				•	•	•	low
Emergen-cy plans	29	Water-related risk management	•	•	•	•			•	•	•	Must be available at whatever cost.
	30	Develop emergency designs for water systems.	•	•	•	•			•	•	•	
	31	Periodically review drought preparedness plans.			•				•	•	•	

Source: Author's Calculation

Table 2: Evaluation of climate change resilient infrastructure sanitation sector plans in terms of achieving the principles

		Climate resilient infrastructure plans	resilient to climate change and facing				smart infrastructu	ecosystem	economic changes	social changes	Increase lifespan	Financial FLOW
			High tempe rature	Sea level rise	Change rainfall pattern	Chang storm pattern						
Structural plans	1	Achieve the goal of universal access to sanitation and hygiene services								•		high
	2	Providing a sewage network								•	•	high
	3	Maintenance of sewage transportation and treatment networks.								•	•	low
	4	Separate sewage networks from rainwater networks.		•	•	•			•		•	high
	5	The potential benefits of generating energy from waste are significant.	•	•	•	•		•	•			low
	6	The potential to use waste as organic fertilizer	•	•	•	•		•	•			low
	7	Reduce greenhouse gas emissions associated with the operation of wastewater systems	•	•	•	•		•		•	•	low
	8	prevent individuals from directly dealing with waste.								•	•	high
	9	Drainage treatment			•			•	•	•	•	High/medium
	10	Completely dispose of sewage in a safe manner.		•	•	•		•			•	medium

	Climate resilient infrastructure plans		resilient to climate change and facing: High temperature	Sea level rise	Change rainfall pattern	Chang storm pattern	smart infrastructure	ecosystem	economic changes	social changes	Increase lifespan	Financial FLOW
	11	Preserve water and natural resources from pollution resulting from sewage						•	•	•	•	low
	12	Support natural systems that absorb, delay, and treat rainwater.	•	•	•	•		•	•	•	•	low
Administrative plans	13	Raise public awareness to increase the acceptance of wastewater treatment products.			•	•		•	•	•		low
Administrative plans	14	Motivate stakeholders to invest in research and technology to improve the use of wastewater treatment outputs.			•	•	•		•		•	low
Administrative plans	15	Enhance the scope of cooperation and supporting capacity building in sanitation-related programs	•	•	•	•	•		•		•	low
Administrative plans	16	Create an automatic leak notification program					•		•		•	medium
Administrative plans	17	Availability of public and personal hygiene with various drainage systems								•	•	low
Administrative plans	18	Involve the community in developing appropriate drainage programs.								•	•	low
Emergency plans	19	Sanitation risk management	•	•	•	•			•	•	•	Must be available at whatever cost.
Emergency plans	20	Develop emergency designs for sanitation systems.	•	•	•	•			•	•	•	
Emergency plans	21	Periodically, review storm preparedness plans.			•	•			•	•	•	

Source: Author's Calculation

Develop the Climate Change Resilient Infrastructure Index

Through a survey that 34 experts have conducted, experts assigned the values and weights based on their relative importance. The weights and degrees of the values were verified and the results of the questionnaire as shown in Table 3. The specific weight factor was calculated for each of the principles of resilient infrastructure to climate change using the following equation.1:

$$i = \frac{\sum(x*y)}{340} \qquad (1)$$

Table 3: Matrix of questionnaire results and calculation of the specific weight factor for the principles

Principals		Rating -y- where (10 is the most influential, and 1 is the least influential): 1	2	3	4	5	6	7	8	9	10	(i)
Facing high temperatures	number of experts (x)	0	3	2	7	5	1	3	3	5	5	0.70
Facing sea level rise		1	1	2	3	2	5	1	2	8	9	0.82
Facing the risks of drought		4	0	6	4	6	4	5	3	2	0	0.56
Facing storms and floods		1	1	2	5	3	2	7	2	5	6	0.75
Use Smart infrastructure approach		0	2	0	4	4	4	0	7	6	7	0.81

Principals		Rating -y- where (10 is the most influential, and 1 is the least influential)										(i)
		1	2	3	4	5	6	7	8	9	10	
Use Ecosystem-based infrastructure approach		3	1	1	5	4	1	3	2	6	8	0.75
Take into account economic changes		0	2	7	5	5	1	2	5	4	3	0.65
Take into account social changes		5	5	6	4	2	1	1	4	5	1	0.53
Increase the lifespan of the infrastructure system		1	2	2	4	5	3	2	2	6	7	0.75
Guarantee financial flow		4	4	1	4	3	1	2	3	3	9	0.69

Source: Author's Calculation

The specific weight of the evaluation element (wi), where the value of (i) ranges between [1:10]: The element was evaluated based on achieving the principals, as previously done in Table (1), through 10 points represented in.

The value of the element itself (Rj), where the value of (j) ranges between [0:5]: The element was evaluated based on the extent to which the plans for each city were achieved through 5 grades (very good=5, good=4, average=3, bad=2, very bad=1) or not available, so it takes the value zero.

Resilience indicators for the infrastructure sectors under study are calculated through the following equations:

The value of the resiliency of the water sector (RW) calculated using equation (2).

$$RW = \sum(wi * Rj)/31 \qquad (2)$$

$$IRW = \frac{RW}{50}\% \qquad (3)$$

Where IRW is the resiliency index for the evaluating element of the water sector, w is the specific weight of the evaluation element, R is the value of the element, 31 is the number of resilience plans for the water sector, and 50 is the maximum resiliency value for the element.

The value of the resiliency of the sanitation sector (RS) calculated using equation (4).

$$RS = \sum(wi * Rj)/21 \qquad (4)$$

$$IRS = \frac{RD}{50}\% \qquad (5)$$

Where IRS is the resiliency index for the evaluating element of the sanitation sector, w is the specific weight of the evaluation element, R is the value of the element, 21 is the number of resilience plans for the sanitation sector, and 50 is the maximum resiliency value for the element.

Case Studies Climate Resilient (Water & Sanitation Sector)
The research will study three case studies (New York, Melbourne, and Thessaloniki), Case studies were selected based on the following criteria:

- Spatial criteria: (The cities should be coastal, and the difference in geographical location and the coastline that the city overlooks).
- Socio-economic criteria: diversity in the general culture of the city’s population, and diversity is the main activity on which the city depends.
- Administrative standards: diversity in flexibility strategy.

New York City (USA)
New York City (NYC) is one of the major cities in the United States and the most populous city with 8,335,897 residents. (U.S. and World Population Clock, 2023). In October 2012, New York experienced Hurricane Sandy. Which caused severe of damage on different levels. The city lost $19 billion in damages, and many neighbourhoods suffered from flooding. According to new projections, the sea level will rise 0.53 meters by 2050. Since 2012 Sandy, New York has adopted key goals for dealing with climate change risks: preparing for future risks, reducing the time and costs of post-shock recovery, it also suffers from climate change represented by rising sea levels, rising temperatures, and increasing rainfall rates, (NPCC, 2015).

New York City is the largest water supplier in the United States. Approximately 125 miles north of New York City, the Catskill/Delaware watersheds provide over 94% of the city's water supply; the remaining 6% is sourced from the Croton watershed. The reservoir capacity is 550 billion gallons, and the watersheds of the three systems (Figure 3) encompass an area of approximately 2,000 square miles (nyc.gov., 2018). Canals deliver water into New York City; by gravity, 97% of the water reaches residences and businesses; only 3% must be pumped to its final destination. To eliminate bacteria, New York City adds chlorine to its water supply, (nyc.gov., 2023a). The goals of the city of New York are to diminish neighbourhood inundation and deliver water services of superior quality. Water treatment systems are essential to the state's provision of high-quality water services. Despite experiencing a population increase of 1.6 million individuals since 1980, New York has witnessed a reduction in water demand of approximately 35%. The rationalization of municipal potable water usage yields advantageous outcomes for the municipality.

It has contributed to the annual reduction of 68 metric tons of greenhouse gas emissions associated with water and sewer system operation, the limitation of rainfall-induced drainage flow increases into local waterways, and the development of an automated leak notification system that notifies property owners of any abnormal increase in water consumption, (nyc.gov.,2023b). The city's sewer system is approximately 60% combined and 40% separated, with more than 7,400 miles of sewer mains, 135,000 collection basins, and 95 pumping stations. The Department of Environmental Protection (DEP) works on building and improving sewers in underserved areas, (nyc.gov.,2023b). The city has committed to rebuilding and expanding the stormwater drainage network to mitigate flooding and improve the quality of life for residents. When planning future drainage infrastructure, the (DEP) considers future sea level rising and rainfall intensity with environmental justice in mind.

Figure 3: New York's main water connections through tunnels neighborhood
Source: nyc.gov., 2023a

The city aims to eliminate biosolid waste by 2030. Which means developing a program to reuse it beneficially. Additional processing techniques to qualify for reuse include composting, drying, gasification, and pyrolysis. The city has made citywide investments in stormwater management to improve water quality and prepare for a future climate. It built more natural systems that absorb, delay, and treat rainwater (green infrastructure) in addition to traditional systems for transporting storm water to central treatment (grey infrastructure), (NYC environmental protection, 2023).

Melbourne city (Australia)

The city of Melbourne is a vibrant Centre with 4.3 million residents from different cultures and diverse backgrounds. Melbourne is exposed to many risks from climate change, including high temperatures, droughts, heavy rainfalls, and rising sea levels (Feisal Zeinab and Haron Ahmed Osama, 2020). The city prepares to confront climate change and makes efforts to ensure the resilience, adaptation, and flexibility of its infrastructure, (the water and sanitation sector).

Melbourne's water storage capacity has been 98.2% over the past three years, utilizing rainfall catchment and flows to reservoirs. About 62% of the stored water is available for Melbourne's water supply system. The remainder is water held by other water entitlement holders, such as the Regional Water Corporations, the owner of Victorian Environmental Water (VEWH), irrigation, or water that is not readily accessible under normal operating conditions (due to infrastructure limitations and risks to water quality), (Melbourne Water, 2022a).

Melbourne Water supplies water to the southern countryside and other regional water corporations, including Barwon Water, Gippsland Water, South Gippsland Water, and Westernport Water. While each regional water corporation has its own annual water forecast, Melbourne gets its water from catchments, desalinated water, and rivers and is managed by water corporations, Figure 4.

Residential water uses accounts for 69% of Melbourne's total water use in 2021–2022. Despite above-average rainfall, a summer that has been cooler than average, and changes in water use patterns from continues work from home due to coronavirus, water consumption per capita has increased. Based on updated census data, Melbourne's per capita water use in 2021–2022 was 164 litters per person per day, compared to 2020–2021's per capita rate of 160 litters per person per day, (Melbourne Water, 2022a).

The Melbourne Water Resilience Plan aims to work in partnership with local owner groups to manage the natural resources on which water services depend and build community relationships. The plan fosters a commitment to reconciliation by, (Melbourne Water, 2018):

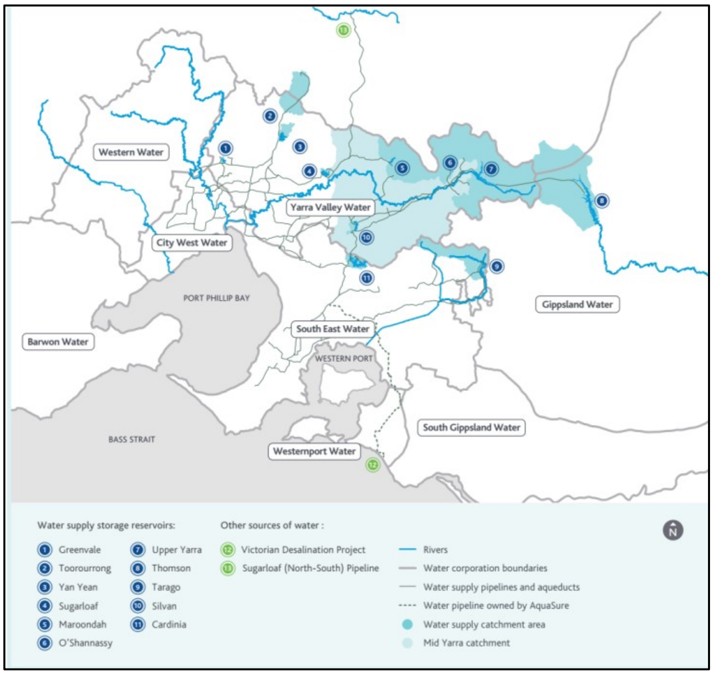

Figure 4: Melbourne Water Supply System
Source: Melbourne water strategy, (2018)

- Understand community needs and expectations, foreseeing their implications, ensuring all core service strategies are linked and improve demand forecasts;
- Fostering sustainable green spaces and water paths for shading and cooling;
- Reducing greenhouse gas emissions from treatment plants;
- confronting the changing climate, investing in climate research, activating the results, and identifying climate risks to the environmental values of waterways;
- Making the most of the water supply system, updating annual operational planning, establishing departments and responsibilities for watersheds management, developing asset management and maintenance;
- Using water efficiently, supporting effective water use across the community, providing research on future water efficiency, periodically reviewing drought preparedness plans, and reviewing water projections;
- Improving the water network, and developing a plan to manage water resource; and
- Using diverse sources of water, investigating the use of it for environmental water charging, and monitoring applications of rainwater and recycled water.

The sanitation system faces major challenges. Melbourne will become a hotter and drier city with the possibility of heavy rain, But severe storms are likely to be more frequent. High wastewater temperatures may lead to increased rates of unpleasant odors and corrosion of pipes. Rainwater may enter the sewage system through cracks in the pipes, which may lead to sewer spills. Climate change affects the services provided to society. Figure (5) presents the sewage system, which includes, (Melbourne Water, 2022b):

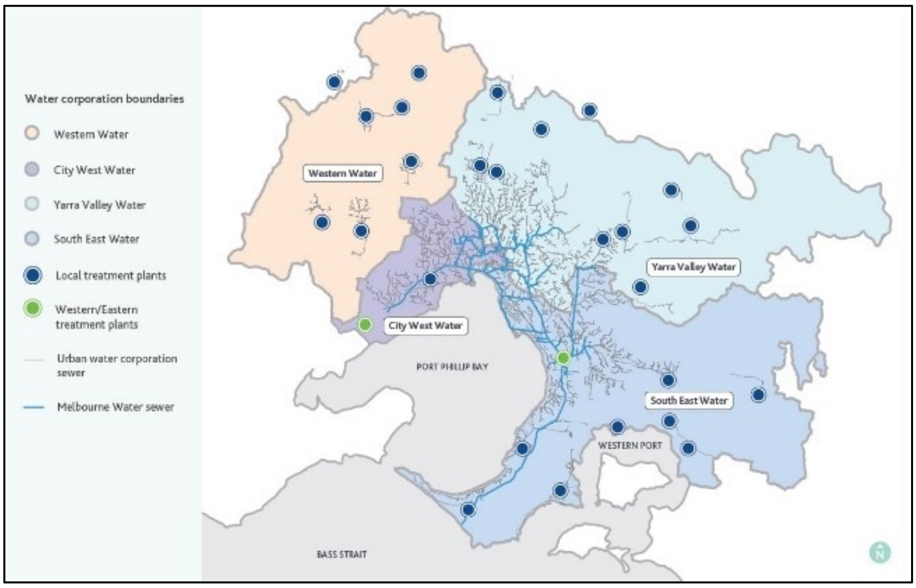

Figure 5: Melbourne sanitation System
Source: Melbourne Sewerage Strategy, (2022)

- network of pipes and pumps exceeding 25 000 km;
- Land on which sanitation assets are located or that act as buffer zones;
- 28 wastewater treatment plants. Provide recycled water or safely release it to the receiving environment, in accordance with EPA licensing requirements;
- Resources recovered from wastewater include recycled water, biogas; and
- Treated water-receiving environments, which include Port Phillip Bay, Bass Strait, and several inland waterways, such as the Yarra River, Jackson Creek.

Melbourne Water transports the majority of its wastewater to two large treatment plants: Eastern (Plantine Bangulmere) and Western (Plantyne Werribee). The plants treat approximately 90% of the total wastewater generated, while the remaining 10% is processed by the remaining 26 smaller local stations.

Thessaloniki city (Greece)

Thessaloniki city is located in northern Greece and is the second largest city in Greece. It is a coastal city located on the coast of Thermaikos Gulf. with a population of 1.9 million. Its port is the second largest in the country. It has a historical, cultural, and economic extension. It has been inhabited since 315 BC. The city is exposed to many climate risks, including surface floods, forest fires, and earthquakes, (Aristotle University of Thessaloniki, 2016).

Greater Thessaloniki's water supply comes from the springs of Aravissos and the Alikmonas River where water is diverted via a 50-kilometer canal down the Axios River, (CWRA,2018), and then to the Thessaloniki Water Treatment Plant. The water supply necessitates the maintenance of numerous pipes. Underground resources (wells) in the Axios-Galikos River Basin provide small amounts of water supply. The Axios River is transboundary, 83% in Macedonia, which has built 11 hydroelectric dams along the river, (Aristomenis P, K., and others, 2006).

Thessaloniki Water Sector Resilience Strategy, (CWRA,2018):

- The existence of a structure for basic services;
- Risk management;
- Strong human resources;
- European Water Framework Directive 2000/60/EC;
- Effective participation of communities;
- Low pollution; and
- Planned upgrade to the sewerage system.

Sewer and storm sewer pipes collect sewage throughout much of the city. Storm water pipes in the central area led to the sea, while sewage pipes feed the central sewer pipeline, which transports wastewater to the Sindos treatment facility. The Gulf of Thermaikos receives its effluent discharge, (Andreas, I, and others, 2014). 35 sewage pumping stations operate to cover all suburbs. The systems operate using programmable controllers. All automated stations are wirelessly connected to the control center, which receives all necessary information for monitoring purposes. The control center contains information technology with appropriate hardware and software to control operations, handle faults, and ensure remote control to enable the stations to operate without interruptions. Treatment is capable of receiving 1,200 m3/day of wastewater from tanker trucks. (S. Yannopoulos, and others, 2017).

Municipal water treatment has adopted a variety of different technologies. Among them, 88% are activated sludge systems, 10% are natural systems, and 2% are connected growth systems. Activated sludge systems consist of 85% expanded aeration systems, 10% conventional systems, and 5% sequential batch reactors, (Andreas Ilias, and others, 2014). Extended ventilation is the prevailing system, as it offers great advantages for Mediterranean climatic conditions. Treated wastewater was used on farmland and forests. Recently, water recycling, rather than disposal, has been adopted to irrigate crops, forests, and landscapes.

Thessaloniki Sanitation Resilience Strategy, (SUWANU EUROPE, 2022):

- Develop a realistic regional action plan for using reclaimed water;
- Increase administrative capacity and procedures to move forward with the implementation of reclaimed water for irrigation in agriculture;
- Integrate the concepts of water reuse and capture;
- Exploit the opportunities provided by European networks;
- Public awareness to increase acceptance of reused water for crop irrigation;
- Fiscal policy provides incentives to use reclaimed water for irrigation;
- Motivate stakeholders to invest in research and technology to improve and expand the use of reclaimed water in agriculture; and
- Exploit the development of the European and national legal framework that increasingly encourages the use of reclaimed water in agriculture.

Calculating the CC Resilient Infrastructure Index (water and sanitation Sectors)

By Applying the previous equations to determine the value of the resilience index for the water and sanitation sector for case studies. Table (4), (5)

Table 4: Calculating the CC Resilient Infrastructure Index (water Sector).

Climate resilient infrastructure plans			wi	New York		Melbourne		Thessaloniki	
				Rj	R	Rj	R	Rj	R
Structural plans	1	Equitable access to safe drinking water for all	1.233	4	4.933	4	4.933	3	3.700
	2	Provide a good water network	1.277	3	3.830	3	3.830	2	2.553
	3	Maintenance of water transmission and distribution networks	2.620	2	5.240	2	5.240	2	5.240
	4	Ensure that the materials from which water networks are made conform to specifications.	3.887	2	7.773	2	7.773	2	7.773
	5	Improving water quality and providing high-quality water:	2.275	5	11.375	4	9.100	2	4.550
	6	Reduce greenhouse gas emissions associated with the operation of water systems	5.680	4	22.720	2	11.360	2	11.360
	7	Use various sources to charge environmental water.	3.403	4	13.613	4	13.613	4	13.613
	8	Addressing increased evaporation in water sources	3.762	3	11.285	3	11.285	0	0.000

Climate resilient infrastructure plans			***wi***	New York		Melbourne		Thessaloniki	
				Rj	***R***	***Rj***	***R***	***Rj***	***R***
	9	Use various water sources.	3.058	5	15.292	5	15.292	2	6.117
	10	Achieve gray water reuse	3.403	4	13.613	5	17.017	3	10.210
	11	Achieve black water reuse.	3.403	4	13.613	5	17.017	3	10.210
	12	Sustainability of irrigation methods	3.403	4	13.613	4	13.613	2	6.807
	13	Use modern technology to conserve water	3.467	5	17.333	5	17.333	1	3.467
	14	Establish watersheds	2.713	5	13.567	5	13.567	1	2.713
	15	Reduce water pollution and stopping the dumping of waste and hazardous chemicals	3.933	4	15.733	3	11.800	1	3.933
	16	Work on natural and human defenses against floods.	5.100	5	25.500	3	15.300	3	15.300
	17	Use of land to provide green spaces and water paths for shading and cooling	4.073	4	16.293	5	20.367	3	12.220
Administrative plans	**18**	Forming a water protection administration	6.273	5	31.367	4	25.093	4	25.093
	19	Establish departments and responsibilities for watershed management.	6.273	5	31.367	5	31.367	1	6.273
	20	Review water forecasts to ensure they meet community needs.	4.047	5	20.233	5	20.233	2	8.093
	21	Protect water resources and associated ecosystems	2.890	5	14.450	4	11.560	1	2.890
	22	Provide research on future water efficiency	2.090	5	10.450	5	10.450	3	6.270
	23	Monitor the flow of water streams, groundwater, and climate information	6.273	2	12.547	5	31.367	2	12.547
	24	Water prices are appropriate in relation to the income of individuals in those areas.	3.183	4	12.733	4	12.733	4	12.733
	25	Enhance the scope of cooperation and supporting capacity building in water-related programs	5.460	4	21.840	5	27.300	4	21.840
	26	Create an automatic leak notification program	3.652	5	18.258	2	7.303	0	0.000
	27	Raise population awareness of the need to conserve water	3.183	5	15.917	4	12.733	2	6.367
	28	Consider the correction of behaviors associated with the actions of community members	3.183	5	15.917	4	12.733	2	6.367
Emergency plans	**29**	Water-related risk management	5.460	4	21.840	5	27.300	4	21.840
	30	Develop emergency designs for water systems.	5.460	3	16.380	5	27.300	2	10.920
	31	Periodically review drought preparedness plans.	3.183	5	15.917	5	15.917	3	9.550
Total value of sanitation sector resilience plans				**484.21**		**481.47**		**270.35**	
RW				**15.62**		**15.5**		**8.72**	
IRW				**31.2%**		**31.0%**		**17.44%**	

Source: Author's Calculation

Table 5: Calculating the CC Resilient Infrastructure Index (sanitation Sector).

Climate resilient infrastructure plans			*wi*	New York		Melbourne		Thessaloniki	
				Rj	***R***	***Rj***	***R***	***Rj***	***R***
Structural plans	**1**	Achieve the goal of universal access to sanitation and hygiene services	0.530	4	2.120	4	2.120	3	1.590
	2	Provide a sewage network	1.277	4	5.107	4	5.107	3	3.830
	3	Maintenance of sewage transportation and treatment networks	1.967	2	3.933	1	1.967	1	1.967
	4	Separate sewage networks from rainwater networks	3.537	3	10.610	2	7.073	1	3.537
	5	The potential benefits of generating energy from waste are significant.	4.933	4	19.733	5	24.667	5	24.667
	6	The potential to use waste as organic fertilizer	4.933	4	19.733	5	24.667	4	19.733
	7	Reduce greenhouse gas emissions associated with the operation of wastewater systems	5.557	2	11.113	3	16.670	3	16.670
	8	prevent individuals from directly dealing with waste.	1.277	5	6.383	5	6.383	2	2.553
	9	Drainage treatment	3.588	5	17.942	5	17.942	5	17.942
	10	Completely dispose of sewage in a safe manner.	3.978	4	15.913	5	19.892	4	15.913
	11	Preserve water and natural resources from pollution resulting from sewage	3.370	4	13.480	4	13.480	2	6.740
	12	Support natural systems that absorb, delay, and treat rainwater.	6.210	5	31.050	2	12.420	2	12.420
	13	Raise public awareness to increase the acceptance of wastewater treatment products.	3.940	4	15.760	5	19.700	5	19.700
Administrative plans	**14**	Motivate stakeholders to invest in research and technology to improve and the use of wastewater treatment outputs.	4.220	5	21.100	5	21.100	5	21.100
	15	Enhance the scope of cooperation and supporting capacity building in sanitation-related programs	5.743	4	22.973	5	28.717	5	28.717
	16	Create an automatic leak notification program	2.558	5	12.792	0	0.000	0	0.000
	17	Availability of public and personal hygiene with various drainage systems	1.967	4	7.867	4	7.867	3	5.900
	18	Involve the community in developing appropriate drainage programs	1.967	2	3.933	5	9.833	2	3.933
Emergency plans	**19**	Sanitation risk management	5.460	3	16.380	4	21.840	3	16.380
	20	Develop emergency designs for sanitation systems.	5.460	4	21.840	3	16.380	2	10.920
	21	Periodically, review storm preparedness plans.	3.937	3	11.810	3	11.810	2	7.873
Total value of sanitation sector resilience plans				**291.4**		**289.45**		**241.92**	
RS				**13.87**		**13.78**		**11.52**	
IRS				**27.75%**		**27.567%**		**23%**	

Source: Author's Calculation

DISCUSSION

Coastal cities are exposed to the risks of climate change resulting from global warming, especially the infrastructure of water and sanitation sectors. A method was developed to calculate the resilience index of the water and sanitation sectors' infrastructure to climate change. This was limited to 31 plans for water sector and 21 plans for sanitation sector which include structural, administrative and emergency plans through a study of planning principles and resilient infrastructure for CC in the water and sanitation sectors, and applying and evaluating the indicator based on the case studies, so that the results are:

The city of New York, USA, is the best at achieving infrastructure resiliency in the water and sanitation sectors', according to the resiliency index, as it achieved 31.2% and 27.75% respectively, followed by Melbourne city, Australia at 31.0% and 27.57% respectively. As for the city of Thessaloniki, Greece, it needs to make more efforts, as it ranked last according to the resiliency index, with 17.44% and 23% respectively. Figure (6)

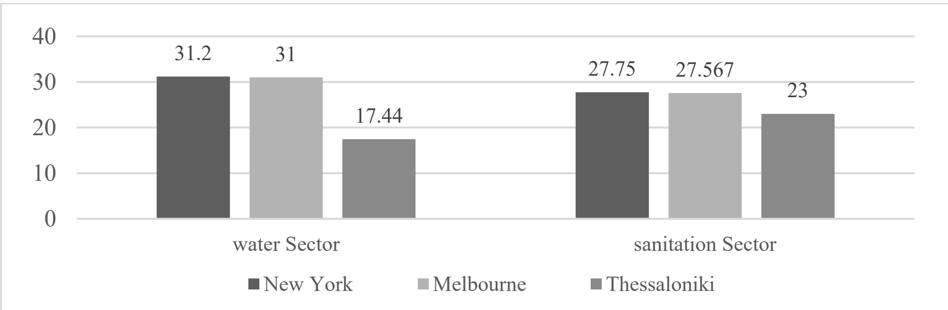

Figure 6: Climate change resilience indicators for the water and sanitation sectors for previous case studies (New York, Melbourne, Thessaloniki)

CONCLUSION AND RECOMMENDATIONS

Based on a study of climate change and infrastructure of the water and sanitation sectors, the study recommends to

- pay attention to resilient infrastructure planning based on resilience against climate changes, preparedness for them, adaptation to them, and rapid recovery after risks;
- Put the plans mentioned in the study, including structural, administrative, and emergency plans, into implementation, and paying attention to financing them and integrating them into development plans;

- Pay attention to coastal cities, especially cities exposed to climate risks and disasters, support research to predict them, identify weak points, and working to strengthen the city's defenses; and
- Generalize this study and measure climate change resilience index to other infrastructure sectors, such as the transportation sector, the electricity sector, and the communications sector

ETHICAL STATEMENT

The datasets used and analyzed during this study are available from the corresponding author upon reasonable request. The authors declare that they have no competing interests, and confirm that the study has not been copyrighted, published, or submitted for publication elsewhere. Additionally, this research did not receive funding from any source. All authors have contributed to the study and have reviewed and approved the final manuscript.

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