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TOPSIS in Toilet to Tap: A Novel Approach to Address Water Scarcity in Beijing

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Abstract:

The specter of water scarcity takes on a much graver form, especially given the rapid pace of global development. If present trends continue unabated, the rate of water resource depletion will surpass even the most pessimistic projections. This is exemplified starkly by the water-scarce condition of Beijing, where per capita water resources hover precariously at a mere 119[1] cubic meters falling significantly below the internationally recognized threshold for severe water scarcity, which stands at 1000[2] cubic meters. This dire situation necessitates not only a comprehensive analysis of Beijing's current water crisis but also a blueprint for addressing existing shortcomings. In light of these challenges, formulating. Toilet-to-Tap encompasses both immediate remediation and long-term sustainability becomes imperative. Identifying and rectifying the structural deficiencies in water management, investing in cutting-edge infrastructure to enhance distribution efficiency, and implementing rigorous regulations to curtail pollution all constitute critical steps in this arduous journey. Concurrently, fostering global awareness about responsible water consumption, integrating innovative technologies for water purification and desalination, and providing support for scientific research to optimize water conservation techniques become indispensable aspects of this multifaceted endeavor.

Keywords: Toilet-to-Tap, Water Scarcity, TOPSIS, Megacities, Case Study

1. Introduction

Water is among the most basic resources life needs in most living conditions on Earth. As a resource, water is an asset essential in survival, industries, and ecosystems. However, despite its very valuable nature, water scarcity exists in most regions of the world. Recent World Resources Institute reports state that approximately 400 regions experience "extreme water scarcity," where 2 billion people are affected worldwide. Furthermore, 3.6 billion people lack satisfactory sanitation facilities. Since 71% of the Earth's surface is composed of water, only 1% of that comes to be fresh, hence usable by humans. With

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constantly growing populations and accelerating climate change, there is great concern regarding water shortages. Indeed, this oncoming water crisis does threaten devastating disruptions-to name a few, conflicts and displacements.

An increasing population, polluted water supplies, inefficiency, and mismanagement of shared water resources all feed into the global shortage of fresh water. The increased demand for more water and lower available supply shows that this crisis needs immediate intervention. Coordinated effort, ingenuity, and dedication can save the world's water resources for generations to come.

1.1 Current Solution

The current solution is transporting water from the southern area to the north-The South-to- North Water Diversion Project[4]. First, the cost of maintenance is very high. The Project involves large-scale water transfer and engineering construction, which may lead to the destruction of the ecosystem of water sources. During the water source transfer process[5], the water quality may be subject to the risk of pollution and cross-infection, especially during long-distance transportation; the pollutants in the water body may affect the water quality of the water source and have a negative impact on the water quality and ecology of the receiving area. Therefore, we propose the method-Toilet To Tap to help Beijing with its current water shortage situation, which is a wastewater treatment system recycling wastewater into drinking water.

1.2 Toilet to Tap

The "Toilet to Tap" technology of turning wastewater into drinking water should first be applied in Beijing as it is one of the cities with the worst shortages of water. This way, it decreases the burden of having to draw water from natural sources supplying the city, and at the same time, it allows treated water to be used for non-potable purposes like irrigation and industrial activities. It also helps in attaining sustainable development along with ensuring water conservation in Beijing through better quality of water.

1.3 Comparison

Various factors prevail that define the viability of "Toilet to Tap" systems in cities.

Population size accounts for 30% of the influence: the larger the population, the more water is needed. Climate and precipitation account for 25% of the influence due to the low rainfalls recorded in certain regions where there is a desperate need for alternative sources of water. Reservoir capacity at 25% shows it is capable of storing and processing wastewater. Quantity of wastewater produced yearly at 20%: this shows a potential for conversion of wastewater into a useful resource.

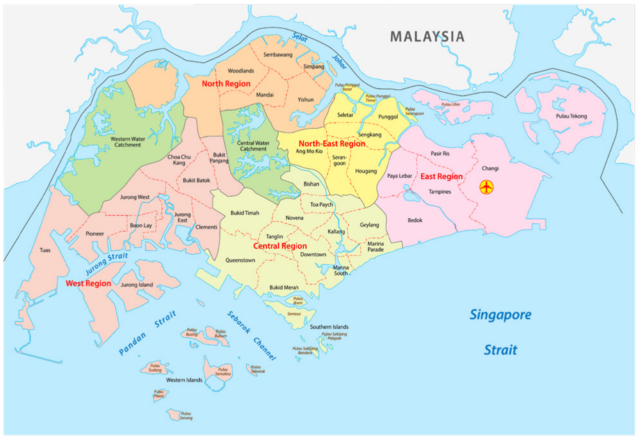
Another essential factor to manage in order to have safe drinking water is the microorganisms in the water. The Water Quality Index, WQI, is important as it measures the quality of the water. The treatment percentage of water accounts for 30% reflecting efficiency in the systems.

Lastly, a city's wealth determined by its GDP takes 20% since this is the only way through which such systems can be funded and maintained.

1.3.1 Singapore

Despite receiving heavy rainfall, Singapore faces water shortage challenges. With 5.45 million people in its area and modern infrastructure, Singapore is an economic hub. In addition, Singapore addressed its water resource challenges with the use of sustainable technological measures. This technological measure has initiated rainwater harvesting and desalination plants. Besides, the "NEWater" project was developed to transform used water into drinking water.

Success in Singapore can be attributed to farsighted policies, advanced technology, and public education campaigns. Its ability to return 40% of its treated wastewater as NEWater should, in no small measure, ensure a certain percentage of the island state's water requirement for both domestic and industrial use, and act as a model for other cities struggling with their water supply. This is also caused by geographical traits as shown in figure 1.



1.3.2 Los Angeles

Los Angeles, having a population of 3.8 million, faces the same issues in water supply due to its arid weather conditions and depending on other resources outside the metropolitan area. It holds a capacity of up to 330 billion liters in its reservoir and reuses wastewater through its "Toilet to Tap" system. On record, LA treats 722 billion tons per year, which is primarily used in non-potable purposes, and the city strives for a 100% wastewater recycling goal by 2035.

Recycling water is, therefore, started in the city to alleviate the stresses posed by the drought conditions and provides a continuous supply of water into the future. This move means Los Angeles secures a future water supply despite the fact that it has limited natural water resources through minimizing reliance on supplies coming from elsewhere.

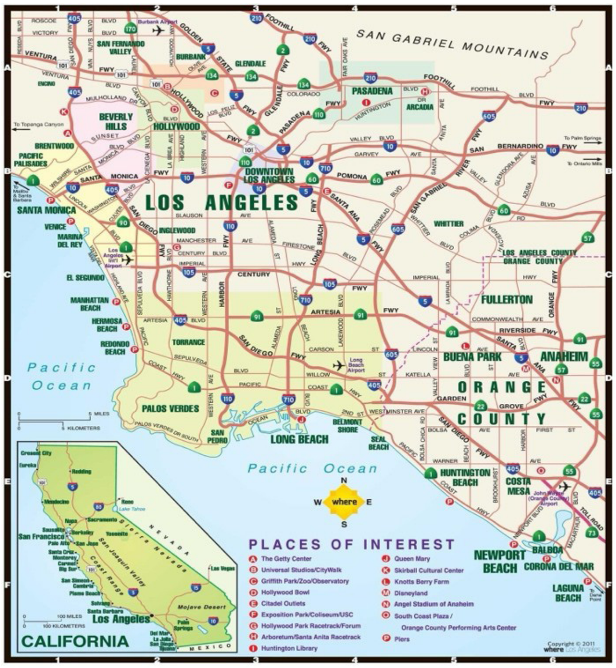


Figure 2[33]

1.3.3 Sydney

Sydney, capital of the state of New South Wales, with its magnificent harbor, is known as one of the most significant ports in the South Pacific region as shown in figure 3. As the largest and most populous city in Australia, Sydney has a population of over 5.3 million [35]. The climate of Sydney, a city that is lying on the southeast coast of the country, is humid subtropical, with 2500 mm of precipitation [36]. As a typical megacity, Sydney produces 133 billion tons of wastewater per year due to its scale and population[37].

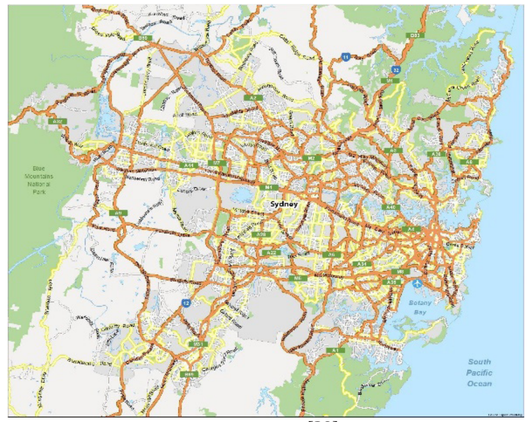


Figure 3[38]

Besides, as water scarcity has worsened in Australia, environmental engineers suggest that applying 'Toilet to Tap' technology, or recycling sewage water as drinking water, is a cost-effective and feasible approach for Sydney. The California Water Authority approved the addition of recycled water to reservoirs in 2018 and is working on regulations for "direct drinking reuse" through 2023, in which recycled water will be combined directly with drinking water[39]. Currently, recycled wastewater is only used for non-drinking purposes: for instance, agricultural irrigation and toilet flushing.

1.3.4 Mumbai

As the largest city in India, the tropical climate of Mumbai translates into two major seasons: one furiously wet and another then extremely dry, making it have the greatest water challenge. Fast urbanization has left the city producing as much as 860 billion tons of wastewater annually generated with inadequate water infrastructure, especially in slum areas. An incredible 78% of community toilets are without water supply, and it is for this reason that executing good water policies remains difficult for Mumbai, not to mention adopting advanced recycling technologies like "Toilet to Tap."

1.3.5 Lagos

Lagos is a major African financial center[49] and is the economic hub of Lagos State, and Nigeria at Lagos faces severe water problems. Lagos is suffering the significant lack of access to safe and affordable water and in accord with the data, the city's daily water demand[50] is far beyond the production by the municipal utility Lagos Water Corporation (LWC). The situation in Lagos is similar to that of Beijing in that the people in both cities lack access to safe water.

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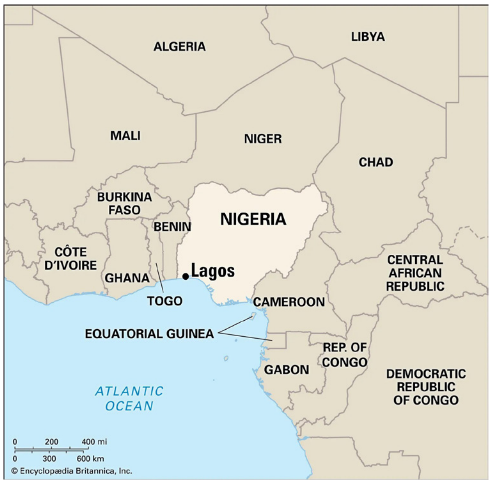

Water shortage is a global problem affecting both developed and developing countries.

Solutions such as the "Toilet to Tap" system instituted in Singapore and Los Angeles do hold a certain kind of promise to help supply the growing urban demand for water. But it works only according to the size of a population, climate, reservoir capacity, and economic investment. It is in learning from cities like Singapore that proved to the world that water management and recycling truly work, thereby helping other regions to develop sustainable solutions that assure them of long-term water security.

2. Methods

2.1 TOPSIS Modeling

The Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) model, as a multi-criteria decision-making method, exhibits numerous advantages in practical applications. To begin with, the TOPSIS model showcases a comprehensive evaluation feature. It is capable of considering multiple evaluation criteria, integrating the weights and importance of various indicators into the decision-making process, thus achieving a thorough assessment of alternative solutions. This comprehensive analysis provides a more accurate reflection of the merits and drawbacks of each solution, aiding decision-makers in making prudent choices when confronted with intricate and dynamic scenarios.

Furthermore, the TOPSIS model possesses the advantage of intuitiveness. By comparing the alternative solutions with the ideal and negative ideal solutions, calculating their relative proximity, and ranking them based on their comprehensive scores, the model offers decision-makers an intuitive ranking result. This intuitiveness assists decision-makers in quickly comprehending the quality of each solution, enabling them to make decisions within a short span of time.

The versatility of the TOPSIS model is also a major asset. It is applicable to various domains and issues, ranging from project management and investment decisions to environmental assessments. Regardless of the indicators and objectives involved in a problem, as long as there are multiple alternative solutions to be compared, the TOPSIS model can provide reliable decision support.

Another notable feature is that the TOPSIS model considers the weights of indicators, fully reflecting the significance of these indicators in the decision-making process. This enables decision- makers to more accurately reflect the actual situation when evaluating alternative solutions, rather than relying solely on subjective judgments. Furthermore, the model can handle non-linear relationships and complex decision-making problems, aiding in capturing the comprehensive relationships between indicators.

In the actual decision-making process, the TOPSIS model is straightforward and easy to understand, with relatively direct calculations that do not require complex mathematical knowledge. Decision-makers can apply and comprehend it relatively easily. Moreover, the model is flexible, allowing for customization and adjustments according to specific circumstances, to meet the requirements of different decision-making problems.

In summary, the TOPSIS model, as a multi-criteria decision-making method, provides decision-makers with a powerful tool through its comprehensive, intuitive, widely applicable, weigh consideration, and non-linear relationship handling characteristics. It assists decision-makers in making informed choices in complex and dynamic scenarios. Whether facing engineering, economic, environmental, or other field-related decisions, the TOPSIS model can offer valuable decision support.

2.2 Mechanism

After explaining why we chose TOPSIS, we will explain how this method works during modeling. Firstly, it is important to note that we collected data in the form of a matrix. Therefore, the equations will operate with such a premise. For example, our data will look like Table 1, as a comparison for water stress and effects of Toilet to Tap, after being formatted as a matrix.

Table 1.

Cities	Effectiveness of Toilet to Tap				Water Stress			
	Microorganis m	Water Quali- ty	Treate d Sewag e	Wealth	Populatio n	Precipitatio n	Reservoi r	Wastewate r
Singapore	3.5[51]	75.5[52]	86[53	397[54]	5.45[55]	3012[56]	65.45[57	5.4[58]
			]				]	
Los	100[59]	39.02[60]	81[61	711[62]	3.8[63]	375.45[64]	330[65]	722[66]
Angeles Sydney	1[67]	68.29[68]	] 99[69	473[70]	5.31[71]	2530[72]	2351[73]	133[74]
Mumbai	3300[75]	24.13[76]	] 36[77	300[78]	17[79]	2502[80]	717[81]	860[82]
			]					
Lagos	70000[83]	18.91[84]	22[85]	477.39[86]	15.38[87]	1783[88]	305[89]	7080[90]

The above data is collected from more than 40 databases; moreover, we collected from various websites including but not limited to the country's municipal bureau, environmental non- governmental organizations (NGOs), newspapers and more. Although we made sure that within the criteria, they are calculated in the same units. Noticeably, each criteria has varying scale during comparison; hence, TOPSIS can only function after normalizing the matrix. This is the first step of the model operating under the equation below:

$$\overline{X}_{ij} = \frac{X_{ij}}{\sqrt{\sum_{i=1}^{n} X_{ij}^{2}}}$$

After performing the process of normalizing the matrix, our matrix would look like Table 2.

Table 2.

Cities	Effectiveness of Toilet to Tap				Water Stress			
	Microorganism	Water Quality	Treated Sewage	Wealth	Population	Precipitation	Reservoir	Wastewater
Singapore	0	0.67	0.54	0.36	0.22	0.6	0.03	0
Los								
Angeles	0	0.34	0.51	0.65	0.16	0.08	0.13	0.1
Sydney	0	0.6	0.62	0.43	0.22	0.51	0.94	0.02
Mumbai	0.05	0.21	0.23	0.27	0.7	0.5	0.29	0.12
Lagos	1	0.17	0.14	0.43	0.63	0.36	0.12	0.99

Moreover, we also identify beneficial and non-beneficial criterias, and their influence in our results. As mentioned in Section 2.1, the method of system dynamics from this study was really helpful to our study through vensim software that found relationships with impact of variables. A simple explanation of how it works is fluctuation from original value, increase (like the top), decrease (like the middle), and small or resulting effect (like the bottom). A quick example would be if birth increases, population increases from original. This would rely on two data sources, random sampled respondents and aggregated data from Qingdao bureau[91].

Moreover, it is important to note that after combining city assessment from the United Nations, and system dynamics to determine whether it is a beneficial relationship there are still many limitations in deciding the value of weighting. Overall, due to the above reason, we changed its weighted matrix with the equation below.

$$V_{ij} = X_{ij} \overline{\times} W_{j}$$

The specific weighting would be shown in Table 3.

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Table 3.

Effectiveness of Toilet to Tap		Water Stress			
Microorganism Water Quality Treated Sewage	Wealth	Population	Precipitation	Reservoir	Wastewater
0.25 0.25 0.3	0.15	0.15	0.2	0.5	0.15
- + +	+	-	+	+	-

After performing the process of weighting the matrix, our matrix would look like Table 4.

Table 4.

Cities	Effectiveness of Toilet to Tap				Water Stress			
	Microorganism	Water Quality	Treated Sewage	Wealth	Population	Precipitation	Reservoir	Wastewater
Singapore	0	0.17	0.16	0.02	0.03	0.12	0.01	0
Los								
Angeles	0	0.09	0.15	0.03	0.02	0.02	0.07	0.02
Sydney	0	0.15	0.19	0.02	0.03	0.1	0.47	0
Mumbai	0.01	0.05	0.07	0.01	0.1	0.1	0.14	0.02
Lagos	0.25	0.04	0.04	0.02	0.09	0.07	0.06	0.15

Due to the consideration of whether or not the criteria is beneficial, while we are determining the ideal best and ideal worst for our result, we define the ideal best for beneficial to be the maximum and ideal best for non-beneficial to be the minimum, and vice versa. If we pick out our ideal best and ideal worst, it would look like Table 5.

Table 5.

Singapor e		Cities					V+	V-
		Los Angeles	Sydne y	Mumbai	Lago s			
	Microorganis	0	0	0	0.01	0.25	0	0.25
	m							
Effectivenes s of Toilet to Tap	Water Quality	0.17	0.09	0.15	0.05	0.04	0.17	0.04
	Treated	0.16	0.15	0.19	0.07	0.04	0.19	0.04
	Sewage							
	Wealth	0.02	0.03	0.02	0.01	0.02	0.03 0.01	
	Population	0.03	0.02	0.03	0.1	0.09	0.02	0.1
	Precipitation	0.12	0.02	0.1	0.1	0.07	0.12	0.02
Water Stress								
	Reservoir	0.01	0.07	0.47	0.14	0.06	0.47	0.01
	Wastewater	0	0.02	0	0.02	0.15	0	0.15

From this ideal best and ideal worst, we can find the Euclidean distance from them through utilizing the equation below.

$$S_i^{+} = [\sum_{j=1}^{m}(V_{ij} - V_j^{+})^2]^{0.5}$$

The result from this equation would then demonstrate cities deviating from negative or most water stress, and from positive or most water surplus in Table 6.

Table 6.

Cities	Deviation							
	Ideal Best				Ideal Worst			
Singapore	0.0001	0	0.209	0	0.005	0.0111	0	0.0219
Los Angeles	0	0.0111	0.1634	0.0002	0.0066	0	0.0028	0.0177
Sydney	0.0001	0.0004	0	0	0.0051	0.0074	0.209	0.0211
Mumbai	0.0066	0.0004	0.1068	0.0003	0	0.0072	0.017	0.0169
Lagos	0.005	0.0024	0.1675	0.0219	0.0001	0.0032	0.0023	0

In addition, the result would demonstrate cities deviating from negative or most “Toilet to tap” inefficient, and from positive or most “Toilet to tap” inefficient in Table 7.

Table 7.

Cities	Deviation							
	Ideal Best				Ideal Worst			
Singapore	0	0	0.0006	0.0002	0.0624	0.0156	0.0144	0
Los Angeles	0	0.0065	0.0011	0	0.0622	0.002	0.0123	0.0004
Sydney	0	0.0003	0	0.0001	0.0624	0.0119	0.0209	0.0001
Mumbai	0.0001	0.0129	0.014	0.0004	0.0566	0.0001	0.0007	0
Lagos	0.0624	0.0156	0.0209	0.0001	0	0	0	0.0001

This overall deviation would rank the cities of our choice that are closest to the best scenario, and the cities that are closest to the worst scenario. Specifically, it would be done through the equation shown below, where it set the standard of closer to 1 being closer to the best scenario while farther from 1 being closer to the worst scenario.

$$P_i = \frac{S_i^-}{S_i^+ + S_i^-}$$

From the application, we can obtain the ranking for level of water stress for the city and effectiveness of “Toilet to tap ‘’ technology to help the former in Table 8.

Table 8.

Cities	Si+	Si-	Pi	Rank
Singapore	0.46	0.2	0.3	3
Los Angeles	0.42	0.16	0.28	4
Sydney	0.02	0.49	0.96	1
Mumbai	0.34	0.2	0.38	2
Lagos	0.44	0.07	0.14	5
Singapore	0.03	0.3	0.91	2
Los Angeles	0.09	0.28	0.76	3
Sydney	0.02	0.31	0.94	1
Mumbai	0.17	0.24	0.59	4
Lagos	0.31	0.01	0.03	5

3. Results

We notice how the ranking demonstrates the effectiveness of “Toilet to tap” technology if implemented, and the changes that would occur to the ranking. For example, the cities that are climbing in the ranking are characterized by the usage of “Toilet to tap” technology, while the opposite occurs for cities that do not. However, we have to admit

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that the initial water resources that the cities start with are also very important, with Singapore and Lagos continuing with the same ranking. If we zoom into Singapore, even though it is a city by nature water stressed, due to the widespread implementation of "Toilet to tap" technology, it rose from ranking third in water surplus by city's nature to ranking second water surplus by city's reality. The same applies to Los Angeles, known for the "Toilet to tap" technology implementation. This could also partly be because of its rise from ranking fourth water surplus to third water surplus while assessing its inherent and natural traits to the situation in reality. The opposite can be said of Mumbai as a city not using "Toilet to tap" technology and leading to insufficient use of its water resources. Overall, "Toilet to tap" technology presents value for alleviating water stress, especially for cities situated in it by nature. Therefore, we strongly suggest the use of "Toilet to tap" technology for Beijing, and we will illustrate why in Section 4.

4. Conclusion

In conclusion, this paper comes up with a new method of analysis to understand the impact of the "Toilet to Tap" system on urban life. We applied the use of case studies from megacities like Beijing, and a type of data analysis-the TOPSIS method-which yielded a comprehensive ranking of cities that can provide many insights into this approach. While this is a relatively limited study due to the number of samples and not considering other influencing factors, further research has to cover more cities in terms of finding better methodologies for inclusive variables. This will surely bring a higher degree of understanding of the "Toilet to Tap" system in a wider range of urban scenarios.

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