Regional Sustainability 3 (2022) 269–280

Contents lists available at ScienceDirect

Regional Sustainability

journal homepage: www.keaipublishing.com/en/journals/regional-sustainability

Full Length Article

Latent dimensions between water use and socio-economic development: A global exploratory statistical analysis

Edson Elídio Balata [a], Hugo Pinto [b,c,*], Manuela Moreira da Silva [a,d,e]

[a] *Institute of Engineering, Universidade do Algarve, Faro, 8005-139, Portugal*
[b] *Centre for Social Studies, University of Coimbra, Coimbra, 3000-995, Portugal*
[c] *Faculty of Economics, University of Algarve, Faro, 8005-139, Portugal*
[d] *Centre for Marine and Environmental Research (CIMA), University of Algarve, Faro, 8005-139, Portugal*
[e] *Centre of Engineering and Product Development (CEiiA), Matosinhos, 4450-017, Portugal*

ARTICLE INFO

Keywords:
Water reuse
Circular economy
Water management
Urban water cycle
Socio-economic sustainable development
Country clusters
Factor analysis

ABSTRACT

Water use and socio-economic development are interconnected in complex ways. Causalities are not easy to identify but it is evident that a nexus between water use and socio-economic development does exist. Considering the diversity of national situations relating to these interrelated phenomena, its study should be considered from a global perspective. This article critically reviews the literature and information from official sources on the relevance of water use and circular economy in order to create a global picture, linking water with socio-economic development. Data from 195 countries was analyzed statistically. A factor analysis defined five essential latent dimensions on the nexus between water use and socio-economic development: development and basic services, population and resource, economic volume, health and well-being, and population density. Based on the identified factors, countries were classified into six groups: Global South in difficulty, global semi-periphery, advanced economy, Middle East and other Global South developing economy, global weight, and small highly developed economy. The clustering results clarify connections between water use conditions and socio-economic development. Understanding the variety of national profiles is helpful to reveal the magnitude and urgency of dealing with the nexus between water use and socio-economic development for many countries.

1. Introduction

Natural resources need to be managed by balancing societies with ecosystems. It is only in this way that economies may become robust (UNESCO and UN-Water, 2020). Water is a kind of resource that is intrinsically related to development. Currently, 6.63×10^8 people, approximately 9.00% of the world population, still lack access to safe drinking water and the many forms of urban water infrastructures. Despite advance in sanitation system, global progress remains slow. Around 2.20×10^9 people in the world use a source contaminated by waste, and 4.20×10^9 people do not have access to safe sanitation services. More than 80.00% of wastewater resulting from human activities is discharged into rivers or the sea without any treatment (WHO, UNICEF, 2017a). Weak governance measures combined with low per capita income and low cost on water treatment and distribution services, make it difficult for poor people to access safe drinking water. An important question is the connection of water with the socio-economic development trajectory of a country. The answers to this fundamental interrogation remain vague even if there is strong evidence that variations in water

* Corresponding author. Centre for Social Studies, University of Coimbra, Coimbra, 3000-995, Portugal.
E-mail address: hpinto@ces.uc.pt (H. Pinto).

https://doi.org/10.1016/j.regsus.2022.09.004
Received 16 March 2022; Received in revised form 19 July 2022; Accepted 30 September 2022
Available online 27 October 2022

availability impact significantly in a myriad of socio-economic domains, such as agriculture, population, and conflict, while evidence of impacts on socio-economic development and other measures of aggregate economic activity remains ambiguous (Damania, 2020).

Since the mid-1970s, the development target has shifted to eradicating poverty, inequality, and unemployment. From 1980 onwards, the World Bank explicitly assumed that the challenge of development is to improve the quality of people's life, especially in underdeveloped countries. Development is now seen as a multidimensional process that includes strengthen the economy, reduce inequality and eradicate poverty but also encompassing the changes in social structure, citizen attitude, and public institutions (Todaro and Smith, 2021; Xu et al., 2022).

Although many countries have achieved high rate of economic growth, the living condition of their people has sometimes remained unchanged, indicating a narrow view of the concept of development. GDP remains the most common measure of economic growth in countries (Heidecke, 2006; Todaro and Smith, 2021), but presents limitations as an indicator for understanding development as a multifaceted phenomenon.

The 1990s was marked by the United Nations Development Program (UNDP), within which numerous reports about the human development index (HDI) have been published, such as those prepared by Sagar and Najam (1998) and Hou et al. (2015). This index seeks to mitigate the economic approach to development centered on the GDP as a single indicator by adding other dimensions associated with education and longevity, revealing significant asymmetries between countries in the Global North and South.

In 2002, Sullivan et al. (2003) added a new perspective to this debate with the definition of the water poverty index (WPI). The authors attempted to report the existing conditions of domestic water use and its availability, considering its physical existence and the technologies available in each geographic context. The WPI is constructed from five main components: existing water resources, access to water, technological capability, water use, and environment.

Environmental sustainability is a cross-cutting interest in several branches of science, due to global problems in the use of natural resources (Brown et al., 2014). Given that water is one of the fundamental supports for life, it is essential to guarantee the quantity and quality of the supply required to satisfy current needs and those of future generations. Moreover, water is a source of financial income, due to growing needs associated with health, hygiene, food, as well as technological and industrial development. In a context increasingly affected to global crisis, the problem of water scarcity poses a threat to many types of needs. Thus, it becomes necessary to guarantee access to water without jeopardizing its availability.

The circular economy paradigm is a recent approach which introduces a new perspective for environmental sustainability. Throughout the process value chain, the materials that have no apparent use are no longer seen as waste but as resources for other products. However, scientific study on the link between the water use and circular economy remains marginal.

The main research objective of this article is to analyze the linkage of water use and socio-economic development. This article aims to combine three major themes: the socio-economic development, water use, and circular economy. Considering the urban water cycle in conjunction with the circular economy from a global perspective provides a transversal vision of the existing water management challenges, present and future scenarios, and alternatives to improve the availability, access, and competitive advantages of water, identifying ways of obtaining more economic and social benefits from water and increasing its economic circularity.

After reviewing the above mentioned three topics, we developed a statistical analysis by using variables related to the urban water cycle, circular economy, and socio-economic development. We used a vast number of countries' official data to perform a factor analysis to aggregate variables that are statistically interrelated in latent dimensions, then utilized a cluster analysis to display a typology of countries concerning the nexus of water use and socio-economic development. However, although the factor analysis used official data, many crucial variables remain unavailable for a large number of countries. Lack of data limits an exercise of this type, creating a trade-off between detail (i.e., the number of available variables) and global reach (i.e., the number of countries included). Data availability remains one of the major limitations on the management of socio-economic development, water resources, and sanitation, particularly in developing countries. This article aims to create a balanced dataset for a large number of countries that not only provides a satisfactory global perspective but also offers an interesting number of variables about water use and other key socio-economic dimensions.

2. Review

2.1. Water scarcity as a global issue

While the world population increased roughly fourfold in the 20th century, the global water consumption increased about 5 times for agricultural purposes, 18 times for industrial uses, and 10 times for municipal purposes (Nazemi and Madani, 2018). It is estimated that more than 55.00% of the world population live in cities, with 394 cities around the world having a population over 1.00×10^6 (McGrane, 2016). In the last century, the increase in income and the growth of middle class led to an increase in water consumption, which in some cases exceeded the recharge capacity of aquatic systems, resulting in water scarcity and a fall in economic growth. In the last few decades, the growth rate of demand for water has doubled with the rate of population growth (Shiklomanov, 1998). Now, the annual world population growth is 8.00×10^7 (U.S. Department of Commerce, 2019), and by 2050 the world population is expected to reach 9.80×10^9, of which 2.10×10^9 will live in sub-Saharan Africa, the region with the most uneven distribution of water resources (UN-Water, 2019). Demand for water is expected to increase in all productive sectors and to continue growing at an annual rate of roughly 1.00% since the 1980s (WWAP and UN-Water, 2012). Recent figures from UN-Water (WWAP, 2019) underline the same scenario. Water use has been increasing worldwide, driven by a combination of population growth, socio-economic development, and consumption pattern change. Global water demand is expected to continue increasing at a similar rate, 1.00%, until 2050, accounting for a total accumulated increase of 20.00%–30.00%. It is estimated that by 2030 the difference between water demand and supply will be around 40.00% (Water Resources Group, 2012).

Nowadays the enormous pressure on water use is approaching the point of no return. The perception that natural resources are inexhaustible must end, and some views must be reinforced, like natural resources should be used efficiently and reasonably and the resources are essential to guarantee the basic needs of the global population (Brown et al., 2014).

Challenges in the nexus of urban water cycle and socio-economic development vary from region to region (UN-Water, 2019; WWAP, 2019). In Asia and the Pacific region, the greatest difficulty is guaranteeing access to safe drinking water and sanitation due to the enormous water demand for multiple uses. The high degree of water pollution, the sustainable management of groundwater, and the establishment of resilience mechanisms for water-related natural disasters are other important aspects to consider. In Arab countries, the excessive consumption of surface water and groundwater is the biggest threat to sustainable development. Solutions are being studied and implemented in the Arab region to improve the collection and supply of water, e.g., treated wastewater reuse and seawater desalination by solar energy. In Latin America and the Caribbean region, the main priorities are to formalize the institutional water resources management capacity in an integrated and sustainable way, to promote socio-economic development, and to reduce poverty. Another major priority for these countries is to ensure universal access to water and sanitation (United Nations General Assembly, 2010). A fundamental objective for Africa is to be integrated in a sustainable way in the global economy, using natural and human resources and avoiding recurrent conflicts in certain regions that impede development. Currently, only 5.00% of existing water resources in Africa have been tapped and the per capita water storage capacity is only 200 m^3 (compared to 6000 m^3 in North America); only 5.00% of cultivated land can be irrigated; and less than 10.00% of hydroelectric potential is used for electricity production. In Europe and North America, efforts are focused on improving the efficiency of water use, reducing water losses, water pollution, and carbon emissions, changing the water consumption pattern, and exploiting more sophisticated technologies that consume fewer water. Alternative sources of water are being studied for various purposes, and water reuse in particular is becoming an increasingly common reality. Creating mitigation measures for different water uses on the scale of river basins and improving the coherence of national and cross-border policies will be priorities for the coming years.

Water scarcity can be natural or anthropogenic in origin, and is measured on the basis of water quality and quantity and water demand in each context and specific time (Garcia and Pargament, 2015). There are three dimensions to water scarcity, which can occur individually or in combination: (1) physical or environmental, (2) economic, and (3) social or political water scarcity. Physical or environmental water scarcity refers to the natural availability and quality of water, economic scarcity refers to the costs associated with water, and social or political scarcity is often the result of poor water management, access, and allocation problems. The first two dimensions can be mainly addressed through technical solutions aimed at using water effectively, but social or political water scarcity results from management practices (Máñez et al., 2012).

During the 20th century, water consumption increased by 800.00%, with the supply of safe drinking water still remaining a problem in many regions of the world (Vaz et al., 2017). The unsustainable consumption of water, together with the increased level of groundwater and surface water pollution reduced the water availability. Water scarcity affects more than 40.00% of the world population and the proportion is still increasing (United Nations, 2017). It is estimated that around 2.00×10^9 people currently live in areas with water scarcity, and more than 8.00×10^8 people do not have adequate access to safe drinking water. These scenarios have created socio-economic tensions over declining water availability, which makes water management and allocation extremely complex and sensitive (Zhou et al., 2017; Nazemi and Madani, 2018). The water resources carrying capacity (WRCC) is influenced by climate change and human activities, while economic and technological factors present bidirectional and more complex impacts on WRCC (Yang and Yang, 2021).

In theory, there is enough fresh water for the entire world population, but it is not available in the same way for everyone. Approximately one fifth of the population live in geographical areas with physical or environmental water scarcity, while another quarter face economic water scarcity or, in other words, live in countries where the necessary infrastructures for water capture (from river and/or aquifer), treatment, and distribution do not exist or are not enough (Watkins et al., 2006). Currently, around 35.00% of the world population live in regions with severe water scarcity (Kahil et al., 2015), and around 65.00% of surface aquatic ecosystems are at risk of degradation with a level of severity ranging from moderate to severe (Alcamo et al., 2000; Vörösmarty et al., 2010; Lu et al., 2021; Bhat et al., 2022).

Water stress affects a third of the European Union territory throughout the year. During the summer months, it is most pronounced in the southern European river basins, but is becoming increasingly evident in the northern European river basins as well, including in the UK and Germany. The frequency and intensity of drought and its environmental and economic damages appear to have increased over the past 30 years (European Commission, 2015). The past decade was seen as the most intense drought years, with severe impacts on forest and cropland productivity (EEA, 2022). Water scarcity is an increasingly frequent and worrying phenomenon, affecting at least 11.00% of the European population and 17.00% of EU territory. It is estimated that 20.00%–40.00% of available water in Europe is being wasted due to losses in water supply systems, lack of water-saving equipment, inefficient irrigation systems, faulty taps, etc. (Garcia and Pargament, 2015; European Commission, 2019).

In 2015, 95.00% of the population in Latin America and the Caribbean region used improved water sources, and 3.40×10^7 people used inappropriate water sources. It was also found that literate and better educated families have greater access to water and sanitation services (WHO and UNICEF, 2016). In many water-scarce regions, intense industrial and urban development coupled with population growth, especially in cities, has placed great pressures on local water resources. Climate change could further compromise the quality and availability of water supply, as well as the functioning of aquatic ecosystems, thereby increasing the need to find sustainable solutions (Garcia and Pargament, 2015; Wakeel and Chen, 2016). Drought and flood hazards due to water-related natural disasters account for nearly 90.00% of all natural hazards worldwide and are the most destructive for human societies. According to United Nations (2021), flood and drought are the two main water-related disasters. Over the period 2009–2019, flood caused nearly 5.50×10^4 deaths (including 5110 in 2019 alone), affected another 1.03×10^8 people (including 3.10×10^4 in 2019 alone) and cost USD 7.68×10^{10} in economic losses (including USD 3.68×10^{10} in 2019 alone) (CRED, 2020). Over the same period, drought affected over 1.00×10^{8} people, leading to an additional 2000 deaths and directly causing over USD 1.00×10^{10} in economic losses (CRED, 2020). In 2010 alone, water-related disasters were responsible for around 3.00×10^{5} deaths, forced around 2.08×10^{8} people to relocate, cost approximate USD 1.10×10^{11}. Previous studies (Gosling et al., 2011; European Commission, 2019) reveal that with a 2 °C increase in the planet's average temperature, 15.00% of the world population will experience a significant decrease in available water resources and the proportion living with water scarcity will rise to 40.00%. If this trend continues, domestic, industrial, and agricultural water consumption will increase by 16.00% by 2030.

By 2030, the UN aims to achieve universal and equitable access to water and sanitation, improve the quality of natural water resources, reduce pollution, and substantially increase the efficiency of water use in all sectors. Universal access to water will be especially difficult for the 41 countries where more than one fifth of the national population still use untreated drinking water. These countries are mainly located in sub-Saharan Africa, but also in other less developed regions of the world. -Countries which depend directly on rivers, lakes, and irrigation canals as sources of drinking water face the greatest public health risks. Women and girls are usually responsible for providing water for every 8 of 10 households without safe water in water scarcity area. The burden of transporting water falls disproportionately on females: in 53 of the 73 countries in the world where there are homes without water facilities, females are responsible for transporting water (WHO and UNICEF, 2017b).

Although the economic returns can be quite varied in different regions of the world; in different stages of socio-economic development, the supply of drinking water and sanitation generates high economic return for society, with earnings higher than costs for all types of interventions (Hutton, 2015). There is an urgent need for a stronger emphasis on achieving global water and sanitation goals and it is now becoming clear that the economic sphere supports this call for action (WaterAid, 2021).

2.2. Circular economy and water management

Over the past few decades, climate change and socio-economic development have led to changes in hydrological cycles, threatening human health, water quality, natural habitat, and biodiversity (Liu et al., 2016). Water cycle is the basis for the formation of water resources and the main driving force in the evolution of aquatic ecosystems. The sustainable management of water cycle is fundamental to human societies (Zhang et al., 2017) and in urban areas it is particularly critical because of human pressure.

In developing countries, contaminants from industry, agriculture, and domestic wastewater are often released directly into natural waterways, and the lack of adequate sanitation system and treatment process for the different types of effluents has contributed to the progressive degradation of aquatic ecosystem. In developed countries, due to education, technological development, and the existence of legislation, the national and international authorities have made some progress in meeting the necessary requirements for the discharge of effluent from different sources (McGrane, 2016).

The concept of circular economy has gained ground since the late 1970s, when the need to balance the economy and the environment emerged (Geissdoerfer et al., 2017). Twenty years later, the concept was popularized in countries such as China, in response to unrestrained economic growth and to constrain the depletion of natural resources (Winans et al., 2017). It results from the transition from a linear model for the production of goods including extraction of raw materials, and production, use, and rejection of products, which assumes the unlimited availability of natural resources and energy, to a circular model in which materials and waste are returned to the production cycle through reuse, recovery, and recycling processes. The circular economy is an innovative approach to production and consumption which allows for the development of new products, services, and business models that contribute to a more balanced and creative relationship between companies, consumers, and natural resources (BCSD Portugal, 2017; Pomponi and Moncaster, 2017; Zhang et al., 2018). It is estimated that the reduction and the reuse of waste can cut the financial burden for companies in the EU by approximately EUR 1.00×10^{9} and create over 2.00×10^{6} jobs, in addition to reducing greenhouse gas emissions (Kalmykova et al., 2018).

The circular economy is seen as a new business model that should lead to more sustainable development and more harmonious societies (Anand and Sen, 2000; Ghisellini et al., 2016). On an international level, there are several initiatives of a more global nature, including the Paris Agreement (United Nations, 2015), the United Nations Sustainable Development Goals (SDGs) (United Nations General Assembly, 2015), but also some that are European, such as the European Union Action Plan for the Circular Economy (European Commission, 2020). It is also worth mentioning that the recent Regulation (EU) 2020/741 of the European Parliament and of the Council of 25 May 2020 on minimum requirements for water reuse, ensuring protection of the health of environment, human, and animal, promoting the circular economy, and supporting adaptation to climate change, as well as contributing to addressing the problems of water scarcity and the resulting pressure on water resources in a coordinated way throughout the European Union member states.

Aiming to maintain products at their highest level of utility and value, the circular economy has become a hub of opportunities and challenges for more inclusive, sustainable, and resilient societies (Geissdoerfer et al., 2017; Vaz et al., 2017), and has been attracting increasing attention. In a circular economy, the value of products and materials is maintained for as long as possible, the production of waste and the use of resources are reduced to a minimum, and when products reach the end of their useful life, resources remain in the economy to be reused and to generate value again (European Commission, 2015; Vaz et al., 2017).

By 2030, there will be 8.50×10^{9} people living on the planet, more than half (56.00%) of whom will be middle class consumers, and 59.50% will be living in large urban centers. This is a trajectory set in motion by the Industrial Revolution: rising global GDP, fewer people in extreme poverty (44.00% of the world population in 1981; 10.00% in 2015), better living conditions, and population growth. The global economy annually operates at the rate of 6.50×10^{10} t. If the population growth trend continues, in 2050 it will more than double. On average, each inhabitant will use 70.00% more resources than they needed in 2005 (Portugal Council of Ministers, 2017; Vaz et al., 2017). Waste reduction, eco-design, reuse, and other similar measures could bring EU companies high net savings. Currently, Europe lost around 6.00 × 10^8 t of waste which could be recycled or reused. Only around 40.00% of the waste produced by EU households has been recycled, with recycling rates ranging from 80.00% in some regions to less than 5.00% in others. Transforming waste into resources is crucial to increasing process efficiency and closing the loop in an economy.

Probably 80.00% of wastewater worldwide is still discharged without any treatment (Masi et al., 2018). In Europe, more than 4.00 × 10^{10} m^3 of wastewater is treated annually, but only a small fraction of the treated wastewater is reused. Wastewater is the only kind of water resources always available and whose volume increases almost proportionally to economic development and consumption (Vaz et al., 2017). The reuse of rainwater and gray water is increasingly being promoted worldwide in order to reduce imports into the urban water cycle. Water reuse is an accepted practice in several EU member states, in particular those subject to water scarcity conditions (e.g., Cyprus, Spain, Italy, and Malta). The current annual volume of reused water in the EU can be estimated at around 1.10 × 10^9 m^3, corresponding to around 2.40% of treated urban wastewater. Currently, 37.00% of water reuse in the southern Europe is for urban or environmental purposes (BIO by Deloitte, 2015). Water management has been dealt with essentially at sectoral level (domestic, industrial, or agricultural) and rarely in an integrated manner, taking into account interactions at the river basin level in terms of quality as well as quantity.

These matters are crucial to achieving the SDGs. Even if interconnected, they are of particular relevance to SDG 6 which intends to achieve clean water and sanitation for all. The most recent figures (UN-Water, 2021) show that there is still a long road to follow, as many sub-objectives fall far short of the original targets, and in many cases, the situation has worsened due to the COVID-19 pandemic. Another concern underlined in this document is that the difficulty in managing what is not measured, for example, in the case of water and sanitation, where a huge data gap still exists in many countries.

The pandemic is highlighting the critical role of water in public health, since household water insecurity creates complications for COVID-19 prevention and control (Stoler et al., 2021). The pandemic is also exacerbating socio-medical inequalities in high-income nations (van Dorn et al., 2020), while water insecurity exists everywhere, and its effects are especially evident in lower-middle income countries. An analysis of 8297 households across 29 lower-middle income sites illustrated the difficulties in implementing WHO COVID-19 guidelines in such deprived contexts. It was found that around 71.00% of households had experienced water-related problems which could potentially undermine COVID-19 control strategies or intensify the spread of the disease. Around half faced specific challenges regarding handwashing and physical distancing, both core elements for COVID-19 prevention and control. Using a case study of Zimbabwe, Gondo and Kolawole (2022) showed that access to water poses several challenges. Obtaining water from installed tanks, for example, requires gathering people together, generating large queues and interaction between people with no possibility of following health protocols, thus increasing the risk of the disease. Moreover, when a country successfully manages the pandemic, and social and economic development returns to a quasi normal level, the total water use may present a sharp slope with a clear "V" shaped trend, as happened in China (Jia et al., 2022). The total water use, i.e., the sum of industrial, residential, agricultural, and environmental water use, reached a low point in 2020, but the recovery of social-economic activities and the reopening of industry and service sectors may significantly increase the total water use beyond limits agreed in the pre-pandemic period. Other environmental impacts should also be considered, such as the increase in wastewater generation and discharge due to the complexity of the water pollution following the increase in the disposal of medical waste.

3. Methodology

The following analysis aims to contribute to the discussion on the nexus between the urban water cycle and socio-economic development in global terms. It covers a set of distinct geographic and socio-economic realities and analyzes possible interfaces between these domains. In contemporary societies, variables for sustainable urban water management are not only taking the quantity, quality, and accessibility of drinking water and sanitation into account, but also the circularity of water in cities. Cities with more versatile and resilient infrastructures can balance water resources better by integrating freshwater, saltwater, wastewater, and stormwater, thus minimizing the amount of water entering and leaving the urban aqueous system boundary (Maurya et al., 2020; Kakwani and Kalbar, 2022). In addition, nature may play an important role in cities: green infrastructures retain the water in urban environments and provide a wide array of benefits for human and wildlife (Liu and Jensen, 2018).

The analysis in this study is inspired by composite indicators that provide a multi-dimensional perspective on a specific phenomenon. One example is the development of the already mentioned WPI, created with the aim of developing a holistic tool which combines physical, economic, and social variables in the field of water, applicable throughout the world and allowing politicians and governments to analyze cross-cutting issues (Sullivan, 2002; Zhang et al., 2012; El-Gafy, 2018). The WPI involves the quantification of five main components, namely resource, access, capacity, use, and environment. Predictably, its five components and the index itself show a positive correlation with the HDI, as already demonstrated by some authors for different geographic realities (Lawrence et al., 2002; Ladi et al., 2021).

In this study, we chose to perform a data-driven process instead of an *ex ante* definition of the dimensions that would aggregate the specific pre-selected variables. The data-driven factor and cluster analyses are, in our view, useful as they highlight statistical patterns that are not necessarily clear when we assume an *ex ante* understanding of the phenomenon, as in the case of predefined sub-dimensions for the index calculation. Factor analysis was used to simplify the data by reducing the number of variables needed to describe the data variance, and used to express what is common in the original variables. It assumes the existence of a smaller number of unobservable variables underlying the data. A cluster analysis was subsequently performed to detect homogeneous groups of countries. Cluster analysis is a good procedure for exploring data when there is a suspicion that the sample is not homogeneous.

Studies involving large datasets are plagued by a significant and frequent cited limitation. Lack of data for many countries, in particular those in more deprived circumstances without sufficient knowledge to develop measures, is also present in our analysis and is also a restriction on obtaining more meaningful results. The scarcity of indicators for these themes becomes an added difficulty as we try to expand the group of countries under analysis, especially when including developing countries. A total of 50 variables were collected from the World Bank and United Nations electronic databases for 216 countries. Due to lack of data for certain variables or countries, it was necessary to determine which countries had a relevant number of variables, and which variables had sufficient information on the number of countries to allow for a robust analysis. The following iterative approach therefore was used as a rationale for selecting variables and countries: (1) variables that do not have information for 2/3 of the 216 countries were excluded; (2) countries that do not have information for 2/3 of the 50 variables were excluded.

Thus, 21 countries and 16 variables were removed from the original samples, leaving 34 variables in 195 countries. The 34 variables were selected referring to 6 thematic areas: water and sanitation (6 variables), population (6 variables), health (7 variables), economy (5 variables), education and environment (5 variables), and energy (5 variables). Bearing in mind that each variable for a factor analysis should capture relatively distinct aspects, before the factor analysis was carried out, a new round of check was implemented on the remaining 34 variables that still had no information for the complete set of countries. In this way, 19 indicators were eliminated and 15 indicators were conclusively defined for 195 countries (FAO, 2019; UNDP, 2019; WHO, 2019; World Bank, 2019). The data presented in this study refer to 2015, as it was the most recent year that had the most information available. The final variables selected are listed in Table 1.

In this study, we utilized IBM SPSS software v.24 (IBM Corporation, New York, USA) for the descriptive statistics analysis, factor analysis, and cluster analysis (Pereira, 2003; Verma, 2013; Pestana and Gageiro, 2014).

Factor analysis is a multivariate statistical method used to describe the variability between observed variables in a potentially smaller number of unobserved variables designated as factors. Thus, it is possible that combinations of several observed variables can be explained by only one factor. Unlike other statistical methods, such as regression analysis, where one of the variables is identified as the dependent variable, the whole set of relationships between variables is examined. Thus, factor analysis allows the original data to be summarized, describing it in a smaller number of items when compared with the original number of observed variables. It facilitates the characterization of the different cases analyzed by calculating individual scores for each latent dimension. In order to carry out the factor analysis, the first step necessary is to assess the adequacy of the data for this type of analysis. We used the Kaiser-Meyer-Olkin (KMO) and Bartlett's sphericity tests to measure the quality of correlation between variables (Shrestha, 2021). KMO is a statistic that indicates the proportion of data variance that can be considered common to all variables. A KMO statistic between 0.500 and 1.000 is considered high and indicates that the factor analysis is appropriate (Kaiser, 1974). Bartlett's test checks the level of redundancy between the observed variables. The null hypothesis of the test is that the variables are orthogonal, i.e., not correlated.

In this study, the KMO is 0.871, therefore it shows that there is a good correlation between the variables. Bartlett's sphericity test has an associated *P*-value of 0.000. Both tests suggest that factor analysis can be used. We retain factors according to the Kaiser Criterion (Weiss, 1971), the most commonly used approach to select the number of factors.

Cluster analysis is a multivariate statistical method used to identify homogeneous groups in data based on variables or cases. Given a set of cases, for which there is information on several variables, the method groups the cases according to the existing information, so that those belonging to a cluster are as similar as possible to cases belonging to the same cluster and different from the other clusters. In order to carry out the cluster analysis, we used Euclidean squared distance and Wards method to perform a hierarchical analysis. Factor analysis and cluster analysis are performed closely to what is standard practice in textbooks about these methods, we followed in particular Pestana and Gageiro (2016). Studies using an analogous approach can be found in Pinto (2009) and Fernández-Esquinas et al. (2016).

Table 1
The weight of 15 original variables in 5 defined factors.

Variable	Factor loading				
	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
Percentage of the population with access to electricity	0.919	0.184	0.046	0.021	0.069
Percentage of the population with access to basic sanitation services	0.910	0.177	−0.032	0.170	0.073
Percentage of the population with access to clean fuels and technologies for cooking	0.898	0.102	−0.011	0.157	0.066
Percentage of renewable energy consumption over total energy	−0.888	0.122	−0.066	0.128	0.102
Percentage of the population with access to basic drinking water services	0.863	0.260	0.028	0.113	0.105
Human development index (HDI)	0.847	0.125	0.045	0.355	0.146
Average life expectancy	0.807	0.215	0.040	0.307	0.234
Annual population growth	−0.450	−0.634	−0.028	−0.136	0.086
Natural resources availability as a percentage of gross national income (GNI)	0.444	0.707	0.087	−0.064	0.044
Availability of energy as a percentage of GNI	−0.187	0.869	0.015	0.162	0.058
Population	−0.021	0.075	0.897	−0.184	0.000
National GDP	0.114	0.009	0.855	0.293	−0.009
Percentage of GDP for health	0.048	0.208	0.040	0.787	−0.245
GDP per capita	0.387	−0.062	0.044	0.606	0.502
Population density	0.047	0.039	−0.016	−0.131	0.874

Note: Factor 1, development and basic services; factor 2, population and resource; factor 3, economic volume; factor 4, health and well-being; factor 5, population density. Negative factor loading refers to negative relation between the original observed variable and the respective factor, and positive factor loading shows positive association of the observed variable and respective factor.

4. Results

4.1. Latent dimensions on the nexus between water use and socio-economic development

Factor analysis is centered in the proportion of the variance original observed variables explained by the extracted factors. In this study, all variables are well-explained by retained factors, the so-called commonalities. The lowest value after extraction is 0.632 over than the minimum acceptable commonality value of 0.500, and the highest is 0.895. Five factors were retained, in accordance with Kaiser Criterion, which explain 81.08% of the total variance of the original data. The scree plot also supports the retention of these five factors. Rotation makes it easier to understand the phenomenon and thus labeling the factors. Table 1 bellow shows the factor loadings, facilitating the interpretation of the association of the observed variables with the extracted factors. Each variable is associated to the factor where it presents the loading with the highest absolute value. Negative loadings refer to negative relations between the original observed variable and the respective factor, and positive loadings show positive associations of the observed variable and respective factor.

The five extracted factors were labelled as shown below.

Factor 1, *development and basic services*, explains 46.02% of the total sample variance and is composed of 7 variables, i.e., percentage of the population with access to basic drinking water services, percentage of the population with access to basic sanitation services, average life expectancy, HDI, percentage of the population with access to electricity, percentage of the population with access to clean fuels and technologies for cooking, and percentage of renewable energy consumption over total energy.

Factor 2, *population and resource*, explains 11.54% of the total sample variance and is composed of 3 variables, i.e., annual population growth, natural resources availability as a percentage of GNI, and availability of energy as a percentage of GNI.

Factor 3, *economic volume*, explains 9.34% of the total sample variance and is composed of 2 variables, i.e., number of inhabitants and national GDP.

Factor 4, *health and well-being*, explains 7.42% of the total sample variance and is composed of 2 variables, i.e., percentage of GDP for health and GDP per capita.

Factor 5, *population density*, explains 6.76% of the total sample variance and is composed of only 1 variable, i.e., population density.

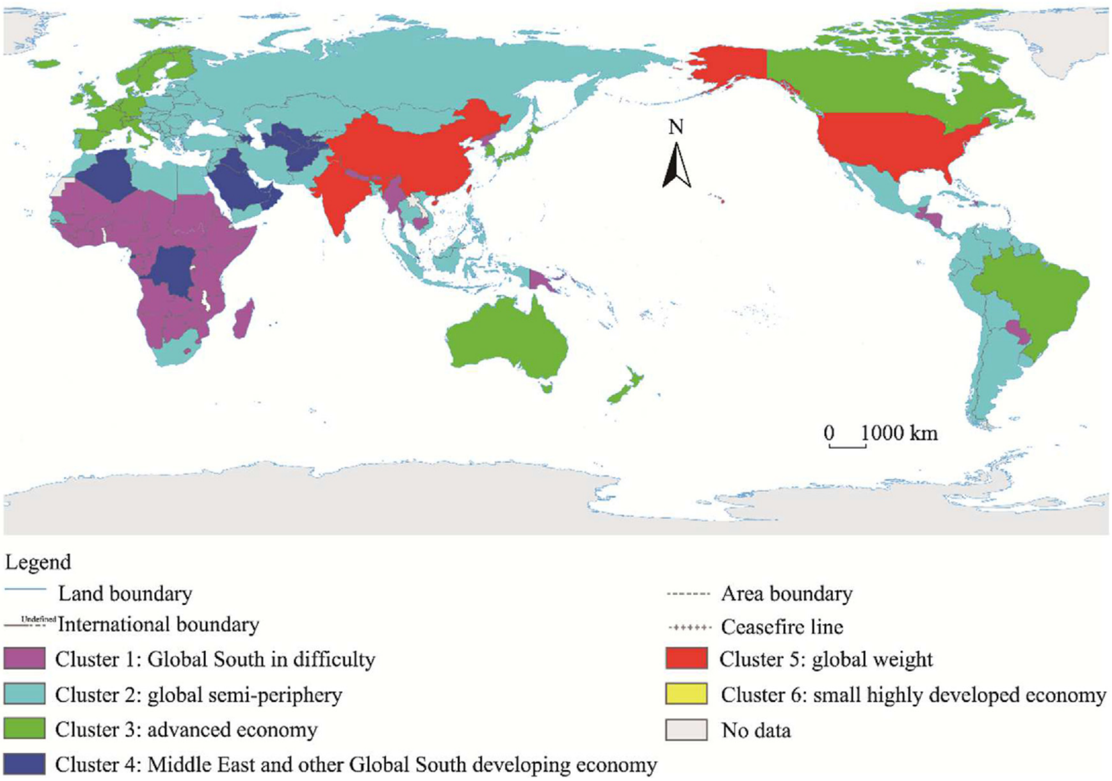

Fig. 1. Map of identified country clusters on the nexus between urban water cycle and socio-economic development. Note that the above map is based on the standard map (NO. GS (2016) 1633) marked by the Ministry of Natural Resources of the People's Republic of China, and the standard map is not modified. It should be noted that Monaco, the only case in cluster 6, which is located in the southeastern of France, is too small to see it from map.

4.2. Country clusters

Cluster analysis organized the 195 countries into 6 groups (Fig. 1). Cluster 1, the Global South in difficulty, consists of 56 countries, mostly in sub-Saharan Africa and a small part of South Asia. Cluster 2, the global semi-periphery is made up of a mixture of 90 countries from different continents, mostly from North Africa, Central and South America, Central and South-eastern Europe, South Asia, as well as some from the former Soviet Union. Cluster 3, the advanced economy, is composed of 29 countries which include 25 countries in Western and Northern Europe and Oceania, as well as Japan, South Korea, Canada and Brazil. Cluster 4, the Middle East and other Global South developing economy, is made up of 16 countries, the majority from the Middle East, and to a lesser extent, Africa. Cluster 5, the global weight, is made up of 3 global economy engines: China, the USA, and India. Cluster 6, the small highly developed economies, is only made up of Monaco, an outlier with aberrant performance in the score of factor 5 "population density".

The factor scores, for a review in its applications (DiStefano et al., 2009), can be analyzed to understand the clusters' behavior (Table S1). Cluster 1 is the only one with negative standardized values in factor 1 development and basic services (Fig. 2), meaning that a low percentage of the population in these countries has access to basic services such as drinking water, sanitation, electricity, clean fuels and technologies for cooking. They also have a low average life expectancy, low consumption of renewable energy, low percentage of renewable energy consumption over total energy, and low HDI. This is cluster 1 in the most worrying position, as it is known that the capacity and governance of many of the countries included in this cluster are insufficient to stimulate socio-economic condition improvement (Fagbemi et al., 2021). In contrast, clusters 2 to 5 have positive standardized values in factor 1, which means that a greater part of the population in these countries has access to basic services that provide drinking water, sanitation, electricity, clean fuels and technologies for cooking. They also have a high average life expectancy, greater consumption of renewable energy, higher percentage of renewable energy consumption over total energy, and higher HDI.

Clusters 1 and 4 have negative standardized values in factor 2 population and resource (Fig. 2), which means that these countries have low annual population growth rate, fewer shares of natural resources and energy in GNI. In contrast, clusters 2, 3, 5, and 6 have positive standardized values in factor 2, meaning that these countries have high annual population growth rate, and greater availabilities of natural resources and energy in GNI.

Clusters 1, 2, 4, and 6 have negative standardized values in factor 3 economic volume (Fig. 2), meaning that these countries have a low number of inhabitants and a low national GDP. In contrast, clusters 3 and 5 present positive standardized values in factor 3, which means that these countries have a larger number of inhabitants and a larger national GDP.

Clusters 2, 4, and 6 have negative standardized values in factor 4 health and well-being, and cluster 1 scores 0 in factor 4 (Fig. 2), meaning that in these countries a low percentage of GDP is used for current health expenditure and they have a low GDP per capita. Conversely, clusters 3 and 5 present positive standardized values, which means a high percentage of GDP is used in current health expenditure and they have a high GDP per capita.

Clusters 1, 2, 4, and 5 have negative standardized values in factor 5 population density (Fig. 2), meaning that the countries have a lower population density when compared with the other clusters. In contrast, countries belonging to clusters 3 and 6 have a higher population density.

The cluster analysis facilitates a nuanced perspective, in particular of middle and low income countries which are often considered as a homogeneous category, and reveals some contrasts. Cluster 1, the Global South in difficulty, is struggling in particular with a very limited capacity in the development and basic services factor. Cluster 2, the global semi-periphery, is particularly well positioned in terms of population and resource factor, but is in the worst position in terms of the economic volume, health and well-being, as well as population density factors. Cluster 3, the advanced economy, performs above the average values of all factors. Cluster 4, the Middle East

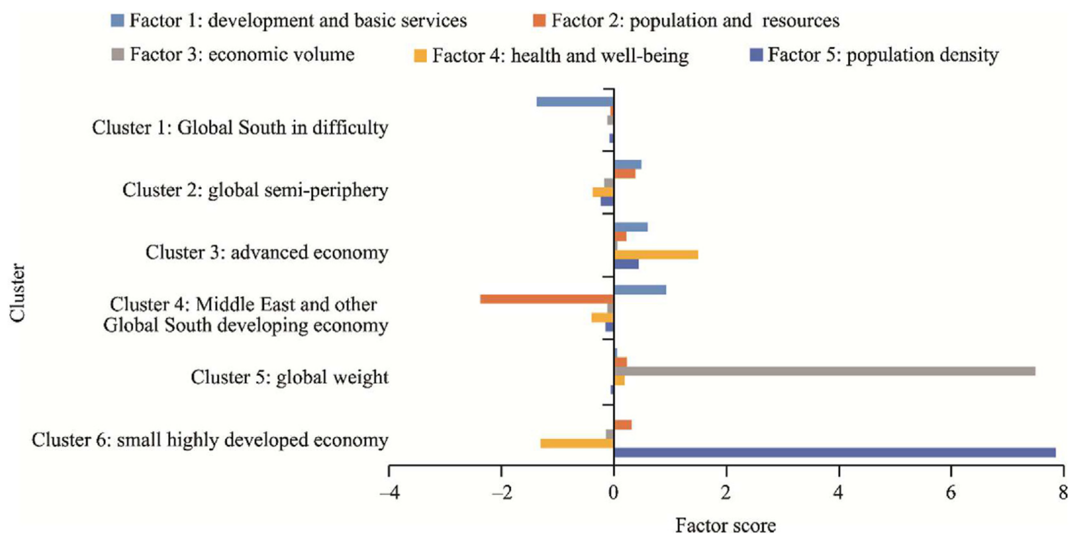

Fig. 2. Cluster performance in each identified factor.

and other Global South developing economy, performs well in terms of the development and basic services factor, but otherwise presents average behavior, and performs bad in terms of the population and resource factor. Cluster 5, the global weight, which includes the biggest world economies, also shows good results in all the factors. Cluster 6, the small highly developed outlier economy, presents robust performances in factors 2 and 5, but is the weakest as expected in terms of economic volume factor and also health and well-being factor (Fig. 2).

5. Discussion

The positive nexus between the urban water cycle and socio-economic development can provide financial gains for the public and private sectors, promote development, reduce unemployment, and create conditions for better public health (OECD, 2011; UN-Water, 2021; WaterAid, 2021). No individual or society, regardless of their geographic position or economic reality, can survive without water. Water is an irreplaceable resource in the biochemistry of life as we know, and therefore it cannot be viewed as a merely tradable commodity, only accessible to those who can afford to pay. Meanwhile, the current pressure on natural ecosystems is already exceeding the planet's biocapacity, especially in regions where local policies do not ensure technological solutions that provide access to safe water in an efficient and sustainable way. It has been verified that the continued growth of the world population, mainly in cities, will put great pressure on water resources. The COVID-19 pandemic also provided strong evidence of socio-economic inequalities in the world. Water and sanitation are fundamental to public health. The key measures for preventing the spread of this disease are washing hands and wearing mask. Nonetheless access and treatment of water are considered of secondary importance in this turbulent period (van Dorn et al., 2020; Gondo and Kolawole, 2022). In fact, after period of confinement and a subsequent reduction of water use, the return to pre-2020 level of socio-economic activity is putting intense pressure on global water resources (Jia et al., 2022).

In the Northern Hemisphere, climate change and the goal of carbon neutrality have imposed a reduction in consumption pattern to alleviate the pressure on natural resources, including water. This situation could be aggravated by poor access to water in some countries and certain changes in hydrological cycle caused by climate change tending to increase water scarcity. It is now a priority to place the tools created by scientific and technological advance in the service of humanity, to monitor different availabilities and consumptions, and to manage resources locally in an increasingly preventive and less reactive manner. In a modern digital world, the link between water and energy will be increasingly optimized and progressively associated with food production. Humanity is now beginning to explore the logic of the circular economy. This could be a solution to ensure quality of life for current generation without depleting the resources needed by future generations.

Current technological advance allows urban water cycle infrastructure to function as important element of circularity in the local economy. In addition to treating urban effluent, thus avoiding environmental and public health problems, a wastewater treatment plant can produce reclaimed water for crop irrigation, soil fertility improvement, and reducing the ecological footprint of food. Countries with a higher score on HDI have greater access to safe drinking water. One of the alternatives that can help formulate better policies to mitigate water scarcity is the usage of composite indicators that can evaluate the various components. Investing in water will help to increase the performance of national economy usually measured by GDP, since this will prevent illness and death among economically active people, while reusing treated wastewater substantially reduces costs in the agricultural and industrial sectors. This study intended initially to include more variables, in particular to relate the research findings to the urban water cycle and circular economy, including the percentage of wastewater produced, treated, and reused, the purposes for wastewater use, and the number of industries that use plastic and water as raw materials. We highlighted the main difficulty in this study that limits the definition of better policies is lack of reliable data. However, the data were not available in many countries, especially those which are more deprived and require deeper intervention, and this is, in fact, an important aspect of this statistical study. There is still a lot of work to be done by international organizations and national governments in terms of collecting, processing, and providing statistical information to citizens on this central theme. The path towards development requires reliable statistical information (Ramos, 2013), and in several countries planning and action require greater investment, both in data collection and its public availability.

6. Conclusions

Using factor analysis which grouped related variables together, this study verified which variables affect each other either positively or negatively in the water-development nexus. The cluster analysis highlighted countries with similar characteristics associated with each of the factors. The national performance in the identified factors provides a global map of this nexus (Fig. 1). In the future, a more confirmatory method such as an econometric exercise could be useful in terms of estimating the impacts of water and sanitation on the economy.

The results obtained from this study can be used to define priorities for drawing up public policies to increase the percentage of population with access to basic drinking water and sanitation services. In developing countries, improving access will contribute to reducing the travel time needed to obtain drinking water. Hence, the time of children and women, the most affected by long distance from water sources, can be used in other activities that promote development or can be invested in education. The quality of drinking water can also be improved and the sources of water-related diseases should be eliminated in developing countries. In developed countries, the challenges are of different nature and include increasing the production effectiveness of treated water and reducing greenhouse gas emissions from water treatment plants. The consumption of energy from non-renewable sources must be reduced and the use of renewable energy sources should be stimulated. Business as usual is no longer a valid option for a sustainable future, and water management must be examined from the perspective of climate change resilience. A sustainable future requires difficult decisions on how to manage water resources in terms of competing water use. Therefore, national and regional climate policies and planning must adopt an integrated approach. Sustainable strategies, inspired by frameworks such as the 6 Rs, i.e., reduce, reuse, recycle, reclaim, recover, and restore, need to be implemented and adequately monitored within the urban water cycle in order to face contemporary challenges such as climate change. Water reuse must be encouraged and diversified, and more research is needed about different national economies to verify the nexus between the socio-economic development, circular economy, and urban water cycle. Whether these countries are considered advanced or not.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

Edson Balata is thankful to the Ministry of Science and Technology of the Government of the Republic of Mozambique for his scholarship to attend the Master degree in urban water cycle at the University of Algarve. Hugo Pinto acknowledges the support from the *Fundação para a Ciência e a Tecnologia* (FCT) Foundation for Science and Technology (DL57/2016/CP1341/CT0013).

Appendix

Table S1
Factor score of each cluster.

Factor	Cluster	Number of countries (n)	Mean	SD	Confidence interval (95%)		Minimum	Maximum
					Inferior Bound	Superior Bound		
Development and basic services	1	56	−1.3690	0.6745	−1.5497	−1.1884	−2.3871	−0.0971
	2	90	0.4917	0.3721	0.4138	0.5697	−0.7430	0.9918
	3	29	0.5981	0.3006	0.4837	0.7124	0.0145	0.9463
	4	16	0.9299	0.5028	0.6620	1.1978	−0.4953	1.5307
	5	3	0.0526	0.4337	−1.0248	1.1300	−0.4359	0.3924
	6	1	0.0141	0.1473	−1.3091	1.3373	−0.0900	0.1182
	Total	195	0.0000	1.0000	−0.1409	0.1409	−2.3871	1.5307
Population and resource	1	56	−0.0678	0.7278	−0.2627	0.1271	−2.1855	1.1469
	2	90	0.3804	0.5068	0.2742	0.4866	−1.1237	1.3032
	3	29	0.2162	0.3769	0.0728	0.3595	−0.7175	0.7356
	4	16	−2.3766	1.4668	−3.1582	−1.5951	−5.6461	−0.7548
	5	3	0.2302	0.7674	−1.6762	2.1366	−0.6176	0.8775
	6	1	0.3135	0.4617	−3.8348	4.4618	−0.0130	0.6400
	Total	195	0.0000	1.0000	−0.1409	0.1409	−5.6461	1.3032
Economic volume	1	56	−0.1157	0.1790	−0.1636	−0.0678	−0.3758	0.7555
	2	90	−0.1722	0.2813	−0.2311	−0.1133	−0.4434	1.1282
	3	29	0.0568	0.5479	−0.1516	0.2652	−0.4919	1.6370
	4	16	−0.1167	0.1093	−0.1750	−0.0584	−0.2741	0.0916
	5	3	7.4910	1.6585	3.3709	11.6110	6.0546	9.3062
	6	1	−0.1389	0.0063	−0.1959	−0.0818	−0.1434	−0.1344
	Total	195	0.0000	1.0000	−0.1409	0.1409	−0.4919	9.3062
Health and well-being	1	56	−0.0155	0.7266	−0.2101	0.1791	−1.3641	2.9072
	2	90	−0.3769	0.5491	−0.4919	−0.2619	−1.6416	0.9313
	3	29	1.4917	0.8636	1.1632	1.8202	−0.3586	3.8872
	4	16	−0.4025	0.4026	−0.6171	−0.1880	−1.1858	0.3741
	5	3	0.1917	3.8693	−9.4202	9.8037	−2.6880	4.5900
	6	1	−1.3049	1.5636	−15.3531	12.7434	−2.4105	−0.1993
	Total	195	0.0000	1.0000	−0.1409	0.1409	−2.6880	4.5900
Population density	1	56	−0.0729	0.3340	−0.1623	0.0166	−1.2564	0.5548
	2	90	−0.2403	0.2888	−0.3008	−0.1798	−0.9305	0.5201
	3	29	0.4341	1.2131	−0.0273	0.8956	−1.9487	3.6286
	4	16	−0.1511	0.5575	−0.4482	0.1460	−0.7162	1.1794
	5	3	−0.0551	0.3643	−0.9600	0.8497	−0.4350	0.2911
	6	1	7.8497	0.8632	0.0944	15.6049	7.2393	8.4600
	Total	195	0.0000	1.0000	−0.1409	0.1409	−1.9487	8.4600

Note: Factor scores are standardized values with mean zero, a negative factor score in a given cluster shows its performance is below average in that factor, and a positive factor score of a given cluster indicates a performance above average. SD, standard deviation.

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