WATER AND CLIMATE IN MEGACITIES AND THE CONTRIBUTION OF NUCLEAR SCIENCE AND TECHNOLOGY TO ECOSYSTEMS AND THEIR SERVICES

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KEYWORDS

SDGs; Sustainable Development Goals; Ecosystem services; Water security; Human well-being; 2030 Agenda; Nuclear and isotopic tools, Nuclear science.

ABBREVIATIONS

CO_2 Carbon dioxide

ES Ecosystem Services

GDP Gross domestic product

GHG Greenhouse gases

HWB Human well-being

IAEA International Atomic Energy Agency.

IPBES Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services

MEA Millennium Ecosystem Assessment

NST Nuclear science and technology

SDGs Sustainable Development Goals

UN United Nations

UNEP United Nations Environment Programme UN-DSDG

Division for Sustainable Development Goals UN-HABITAT

United Nations Human Settlements Programme

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ABSTRACT

The loss of the services provided by ecosystems affects the well-being of people and compromises development in its multiple dimensions. In megacities, the promotion of human well-being and the conservation and restoration of ecosystems and their services are urgent global challenges, especially as a function of the growing expansion of water scarcity and its tendency to worsen due to the effects of climate change. This article addresses the growing use and application of nuclear science and technology for the conservation, assessment, and restoration of ecosystems and their services. It focus on water security and climate change, and on how this contributes to the fulfillment of the Sustainable Development Goals (SDGs). Tools based on nuclear science provide solutions for the development of "climate-smart" agricultural methods; the study of terrestrial, aquatic and atmospheric systems; monitoring how climate change affects the environment and GHG routes, and their distribution and impact on ecosystems, among other aspects. Nuclear technologies are used for wastewater treatment, identification of pollution sources, studies on the quality and quantity of water resources, and adaptation to climate change. The demystification of nuclear science and technology and the increase in collaboration between the ecosystem services and nuclear areas, and society as a whole, are fundamental for facing the global challenges related to water and climate in large cities.

1 INTRODUCTION

The concepts related to ecosystem services (ES) are useful ways to understand the interdependence between human beings and nature, providing tools that communicate with different audiences. The loss of these services affects people's well-being and compromises development in its multiple dimensions. Promoting the well-being of all human kind and protecting the environment are the most urgent global challenges and figure in the central ideas of the Sustainable Development Goals (SDGs) (UN-DSDG, 2020; United Nations, 2015).

Adopted in 2015 as a part of the 2030 Agenda, the SDGs were established as a new international plan of action to address the challenges of sustainable development, with 169 targets and 244 associated indicators (United Nations, 2015; 2019; Lucas et al., 2019; UN-DSDG, 2020). Ecosystem services support all dimensions of human well-being (HWB). The direct connection between ES and the reach of SDGs considers humanity's dependence on ecosystems. This interaction is influenced by factors such as population growth and changes in demographic structure, distribution of wealth, consumption patterns, human mobility and intensification of urbanization processes (Ward et al., 2018; Wood et al., 2018; Dangles and Casas, 2019; Geijzendorffer et al., 2017).

In a predominantly urban world, more than half of the global population occupies 1% of the planet. The projected number of megacities for 2030 is 43, an increase of one third to the current number. These spaces rapidly compromise already scarce resources, and place water security at the center of the 2030 Agenda, especially in the face of current and future shocks due to climate change (Adeel, 2017; McDonald et al., 2014; United Nations; 2018; UN-HABITAT, 2016; Jalilov et al., 2017; Ahmadi et al., 2020).

With the recognition of the role of science in the development of solutions that increase urban resilience in megacities (Jalilov et al., 2017), this study aims to assess the application of nuclear science and technology (NST) for the conservation, evaluation and recovery of ES and its contribution to SDGs, focusing on water and climate change. To this end, the water supply in megacities is discussed; the interactions between water, ecosystem services and HWB; and the contribution of the NST to the Sustainable Development Agenda.

2 METHODS

To determine the links between ES and the nuclear field, we systematized information obtained from official records of the International Atomic Energy Agency, available on its website and publications on the application of nuclear and isotopic tools for the treatment of environmental issues, with a focus on the evaluation, recovery and conservation of ES (IAEA, 2016; 2018a; 2018b; 2020; UNEP, 2018).

We correlated the data to the state and trends of ES (MEA, 2003; 2005; IPBES 2019; 2020), which is the benchmark of the study. We addressed the urbanization processes (United Nations, 2019; UN-HABITAT, 2016), and analyzed the convergence between the NST contribution to the ES and the Sustainable Development Agenda, and established a correlation with the SDGs 11 - Sustainable Cities and Communities (United Nations, 2015; UNEP, 2019; UN-DSDG, 2020; United Nations, 2015).

3 RESULTS

Water Supply in Megacities

Urbanization has transformed people's living environment by concentrating more than half of the population in less than one percent of the total area of the planet (McDonald et al., 2014; Ahmadi et al., 2020). This extreme concentration of people has led to the increasing depletion of natural resources. Aggravated by the impact of climate change, the availability and supply of water has become a key challenge worldwide (Ahmadi et al. 2020; Adeel, 2017). Water security is especially significant for large urban agglomerations, designated as megacities when their population is greater than ten million (Folberth et al., 2015; UN-HABITAT, 2016; United Nations, 2019; MEA, 2005).

By concentrating the demand of millions of people in small areas, large cities and megacities, the stress on the finite supply of freshwater available near urban agglomerations is increased. Despite urban growth has increased the demand for water resources, in global terms, the water sources of the world's major cities have only been incipiently evaluated (McDonald et al., 2014; Ahmadi et al., 2020; Padowski and Gorelick, 2014).

An analysis of water supply and demand in 12 large cities and megacities made by Ahmadi et al. (2020) has revealed a deficit in 11 of them (Cairo, Delhi, Dhaka, Ho Chi Minh City, Jakarta, Kolkata, Lagos, Lahore, Mexico City, Mumbai and Tehran), which altogether sum 178 million inhabitants. This analysis suggests that water companies have difficulty in meeting consumers' demands with the current supply. Manila is the only city of the analysis where water supply exceeds estimated demand, contrasting with Lagos (79%), Mumbai (60%), Dhaka (44%), Delhi (40%) and Mexico City (35%), where deficits are considerable.

The total supply deficit for the 12 cities is 5.27 billion m^3 $year^{-1}$, with a projected increase of 118% by 2035. The most worrying situations are Lagos (649% increase in demand) and Jakarta (419%). Mumbai, Mexico City, Dhaka and Delhi are the cities with the highest projected deficits (approximately 1.61, 1.42, 1.25 and 1.21 billion m^3 $year^{-1}$). Water crises are very likely to occur in these cities if the urban water management sector is not improved; moreover, climate factors may reduce the already vulnerable supply (Ahmadi et al., 2020).

McDonald et al. (2014), analyzing the water stress in urban agglomerations with more than 750,000 people, found out that these large agglomerations have built extensive urban supply systems that include dozens of sources located up to hundreds of kilometers away. For only one-third of the cities included in the analysis, the combination of economic and political power is sufficient to build infrastructure to escape water stress. The twenty largest cities with water stress are Rio de Janeiro (Brazil); Chongqing, Beijing, Shenzhen, Tianjin, Shanghai, Wuhan (China); Los Angeles (United States); Bangalore, Calcutta, Chennai, Delhi, Hyderabad (India); Tokyo (Japan); Mexico City (Mexico); Karachi (Pakistan); Lima (Peru); London (United Kingdom); Russia (Moscow), Istanbul (Turkey).

In a global analysis of the vulnerability of the urban surface water supply, Padowski and Gorelick (2014) distinguished "vulnerable cities" – those exceeding minimum limits for human, environmental and storage requirements – from "threatened cities" – those exceeding some but not all three limits. The authors assessed vulnerability in a baseline condition (2010) and future scenario (2040) for 70 cities in 39 countries with surface water supply, no diversity of water sources, and more than 750,000 inhabitants. The impact of climate change was not considered. They found out that 35% of the large cities were vulnerable in 2010, with an estimated increase to 45% in 2040 (Table 1). Most of these cities are supplied by rivers with so low flow rates that they have already experienced "chronic water scarcity".

Table 1. Number of large vulnerable or threatened cities

Year	Category	Number of cities by category			Percentage by category		
		All urban systems	Supplied by reservoir	Supplied by river	All urban systems	Supplied by reservoir	Supplied by river
2010	Vulnerable	25	2	23	36%	7%	55%
	Threatened	33	20	13	47%	71%	31%
	Not threatened	12	6	6	17%	21%	14%
	Total	70	28	42	100%	100%	100%
2040	Vulnerable	31	5	26	44%	18%	62%
	Threatened	30	20	10	43%	71%	24%

Source: Padowski and Gorelick, (2014).

As seen in Table 1, the number of vulnerable cities will increase from 25 to 31 by 2040 (an increase of 24%). In 2010, the vulnerable cities were: Rajshahi (Bangladesh); Florianópolis, Fortaleza (Brazil); Phnom Penh (Cambodia); Dalian (China); Cali (Colombia); Guayaquil (Ecuador); Alexandria, Cairo (Egypt); Agra, Kozhikode, Pune (India); Baghdad (Iraq); Maputo (Mozambique); Seoul (South Korea); Bangkok (Thailand); Atlanta, Austin, McAllen, Minneapolis, Philadelphia, Pittsburgh (United States of America); Montevideo (Uruguay); Tashkent (Uzbekistan); Harare (Zimbabwe). By 2040, the cities of Ouagadougou (Burkina Faso), Guangzhou, Nanjing, Wuhan (China), Dublin (Ireland), and Charlotte (United States of America) will be added to this list (Padowski and Gorelick, 2014).

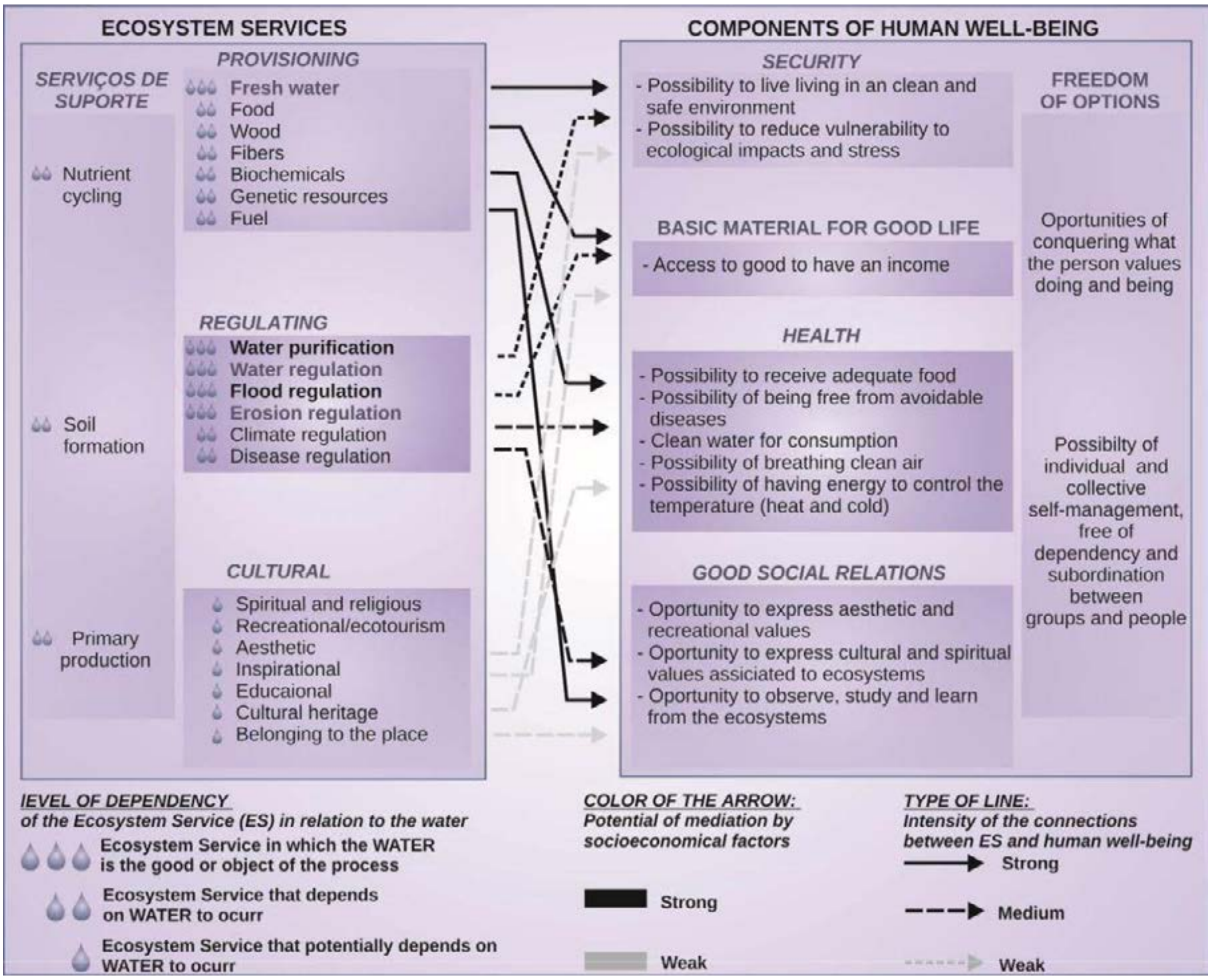
Water security is one of the key elements of the 2030 Agenda, either because it is a goal of its own – SDG 6 (ensuring the availability and sustainable management of water and sanitation for all)

(United Nations, 2015; UN-DSDG, 2020) – or because it is part of a series of targets linked to other SDGs related to health, cities, consumption, marine resources and terrestrial ecosystems (Adeel, 2017). To mitigate water scarcity, especially in large urban centers, in addition to investments in infrastructure and adequate governance, the protection and recovery of ecosystems responsible for water production and reserves is necessary.

Water, Ecosystem Services and Interactions with Human Well-Being

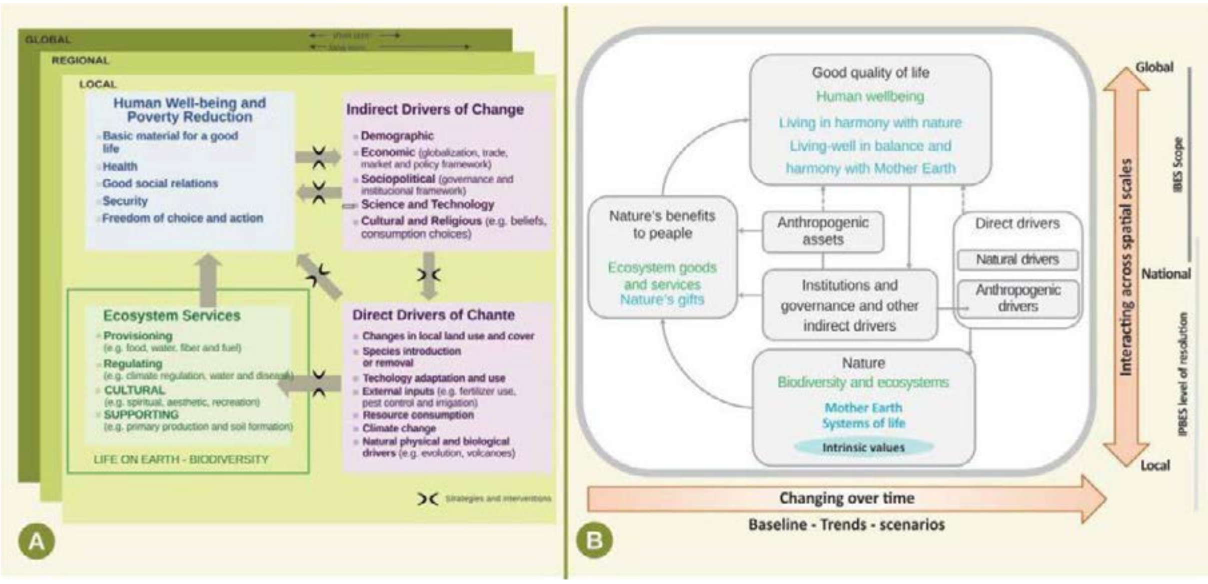
Anthropic actions, especially those concentrated in megacities, cause deep oscillations in the natural water supply and put the dynamic balance of natural ecosystems at risk, with loss of their benefits and biodiversity. The benefits that nature can provide are "ecosystem services" (MEA, 2003; 2005) or "nature's contributions to people" (Díaz et al., 2018). Ecosystem services of water (Figure 1) refer to the provision, regulation, cultural and support services, and play a fundamental role for humans and the maintenance of all the benefits provided by nature (Victor et al., 2018).

Figure 1. Water in the context of ecosystem services and its relation with human well-being. *Source*: Victor et al. (2018).



Even with a growing demand for ES, there is also an increasingly dramatic degradation of the capacity of ecosystems to provide them. With the expansion of the research on ES in the 1980s, its popularization and exponential trajectory resulted from the work developed by MEA (2003; 2005; Daily et al., 1997; Gómez-Baggethun, 2010; Costanza et al., 1997; 2017), the first scientific task force to evaluate the consequences of change in ecosystems for HWB and scientific basis for action (MEA, 2003; 2005; La Notte et al., 2017; UN-CBD, 2007; Bennett, 2017). The Intergovernmental Platform on Biodiversity and Ecosystem Services (IPBES) created in 2012 as a successor to MEA is a major global effort to develop a synthesis on ES and knowledge on biodiversity (IPBES, 2019; 2020). The conceptual framework of these two initiatives is presented in Figure 2.

Figure 2. Conceptual framework for the Millennium Ecosystem Assessment (A) and for the Intergovernmental Platform on Biodiversity and Ecosystem Services (B). *Source:* MEA (2003); IPBES (2020) Díaz et al. (2015).



In spite of the methodological differences between MEA and IPBES and the debates on conceptual structures, evaluation methodologies, valuation and classification (Díaz et al., 2019; Maes; Burkhard and Geneletti, 2018), in its pluralism, the concept of ES is operational (Ainscough et al., 2019) and adopts a series of perspectives and connects ecologists, economists and social scientists. The importance of this dialogue can be expressed by the cost of the loss of ES. Although difficult to measure, the evidence points to substantial and increasing values (MEA, 2005; IPBES, 2019). In 1997, the services provided by the planet's ecosystems were estimated at US$ 33 trillion/year. For 2011, the estimate totaled $125 trillion/year (for updates to biome values and areas), or $145 trillion/year (only updates to service values). Changes in land use corresponded to a loss of ES between $4.3 and $20.2 trillion/year in the period from 1997 to 2011 (Costanza et al., 1997; 2014).

Although cities are home to more than half the world's population and responsible for about 80% of the Gross Domestic Product (GDP), they are depleting their scarce resources to sustain life. With 33 megacities in 2020, an increase of 10 new megacities is expected by 2030, which will intensify the pressure on ES. This framework, together with the need for water management that integrates the trend of current and future impacts such as climate change, requires innovations and changes to science-based approaches that increase urban resilience and contribute to the 2030 Agenda (United Nations, 2019; Jalilov et al., 2017; Adeel, 2017).

CONTRIBUTIONS OF NUCLEAR SCIENCE AND TECHNOLOGY TO THE 2030 AGENDA

The secure supply of ES and their contribution to HWB is directly related to the SDGs. The wide range of issues addressed in the SDGs, from poverty and hunger reduction to cities, economies, and sustainable ecosystems, support a multisectoral approach in which rebuilding and strengthening ecosystem integrity and function benefits, to some degree, all SDGs (Ward et al, 2018; Wood et al., 2018; Dangles and Casas, 2019; Anderson et al., 2019; Geijzendorffer et al., 2017; IPBES, 2020; ICSU, 2015; ESPA, 2018; Leal Filho et al., 2018; Nilsson et al., 2018; Costanza et al., 2016).

Biodiversity and ES sustain all dimensions of human well-being – social, cultural and economic (MEA, 2003; 2005; IPBES, 2019; 2020; Costanza et al., 2014). Their unsustainable exploitation, however, compromises the reach of the SDGs (Lucas et al., 2019; UNEP; 2019). The least developed countries and regions, the world's large urban agglomerations and the poorest people who depend directly on access to ecosystems, are the most affected by the degradation of their services. The steady decline in the capacity of ecosystems to provide their services contributes to increasing inequalities and disparities between groups and populations (MEA, 2005), with implications to the level of success of the SDGs, which will differ widely among countries and regions (Lucas et al., 2019; UNEP, 2019).

The environmental dimension of the 2030 Agenda enables the adoption of integrated actions, with an impact on the economy and social aspects of sustainable development and vice-versa. This relation is evidenced in the Agenda's structure: of its 244 monitoring indicators, 93 refer to environmental issues (Lucas et al., 2019; UNEP, 2019). When considering the commitments of the 2030 Agenda – which recognizes the interdependence between poverty eradication, combat of inequalities, preservation of the planet, sustainable economic development and social inclusion (United Nations, 2015) – innovative tools need to be appropriated by the global community to achieve its goals.

Nuclear science is an area that enables the development of innovative strategies for the 2030 Agenda. The application of isotopic and nuclear techniques contributes to the achievement of SDGs 2, 6, 7, 9, 13, 14 and 15 (zero hunger; clean water and sanitation; clean and affordable energy; industry, innovation and infrastructure; climate action; life below water; and life on earth), which necessarily depend on the recovery and conservation of ecosystems and their services (Rodrigues et al., 2019).

To support the assessment of the NST scope for building resilient cities, we correlated information on the application of nuclear and isotopic tools to address environmental issues with the goals of the SDGs 11 – Sustainable Cities and Communities, which aims to make cities and human settlements inclusive, safe, resilient and sustainable and that have a direct relation with ecosystems and their services (Table 2).

The correlations presented in Table 2 show the importance of using and applying nuclear science-based tools to address challenges related to environmental protection, water availability and climate change in urban spaces. Stable isotopes and nuclear techniques are used to assess freshwater resources, biological systems, atmospheric processes and ocean ecosystems, as well as to assess impacts on the environment, particularly the fingerprints of natural and man-made pollution, and to study the processes in which pollutants are integrated into biological, geological and chemical cycles (IAEA, 2018b; 2020).

Nuclear technologies provide solutions to help combat hunger and malnutrition and improve environmental sustainability. In Africa, cassava cultivation using improved methods in nuclear science has tripled productivity by applying nitrogen isotopes to monitor water and fertilizer use (IAEA, 2020). As large urban centers rely on urban and peri-urban agriculture for food supply, the application of nuclear techniques can promote better land and water use and optimize production in order to contribute to sustainable regional development and resilience of cities.

Water security is a critical issue for human development and for megacities and their environmental and economic sustainability. Nuclear isotopic techniques provide important information on water sources and methods for their recovery and conservation, as well as the human impact on the climate (IAEA, 2018a; 2018b; 2020). Since land-based sources of pollution, notably those from large urban settlements, account for about 77% to 100% of marine pollution (UNEP, 2018), nuclear and isotopic techniques can mitigate their impacts.

Table 2. Nuclear Science and Technology and contribution to the Sustainable Development Goals.

Goal	Contributions of NST to the SDGs and their relation to ecosystem services
1.4 Strengthen efforts to protect and safeguard the world's cultural and natural heritage	Studies and applications of nuclear techniques for quality and quantity of water resources; surface and underground. Use of nuclear and isotopic tools to study the impact and movement of pollutants in terrestrial environments and the endangerment of ecosystem services.
11.5 To significantly reduce the number of deaths and the number of people affected by disasters and substantially reduce the direct economic losses caused by them, including water-related disasters	Adaptation to climate change. Control and monitor how climate change affects the environment. Identification of pollutant sources and GHG emissions. Development of crops that reduce emissions and favor the capture/retention of CO_2 in the soil and "climate intelligent" cultivation methods – optimization of food production in adverse weather conditions (drought and high temperatures) and for the conservation and preservation of natural resources (soil and water). Studies of natural processes that influence the global dissemination of pollutants and their deposition rates on land and sea. Monitoring of GHG and other pollutants routes in the atmosphere, their distribution and impacts on ecosystems. Development of models to predict changes in the global carbon cycle and climate.
11.6 Reduce the negative environmental impact per capita of cities, including with special attention to air quality, municipal waste management and others	Development of efficient methods of soil management and conservation and crop production; identification of isotopes in different contaminants to measure their concentration and trace their origin. Restoration of contaminated areas. Production of clean and low carbon energy. Use of radiation for wastewater treatment and cleaning of air contaminants. Monitoring and tracking of building sediments, dredging or dumping in coastal areas. Use of radiation for treatment of nitrogen oxides (NOx) and sulfur oxides (SOx) present in combustion gases (exhaust gases produced in industrial plants), as well as effluents from industry and to make sewage sludge suitable for application in agriculture.

Although nuclear scientists and researchers in the ES area conduct studies on ecosystems and their services, these two areas of knowledge are working in an isolated and segmented manner, and their approximation is urgent. It is also urgent to expand the development of science-based technologies and bring the academic community closer to decision makers in order to adopt strategies based on these technologies that reflect the latest innovations and are integrative, adaptable to change, technically sound and financially viable (Rodrigues et al, 2019; Jalilov et al., 2017).

CONCLUSIONS

Considering the intrinsic relationship between SDGs and ecosystem services, their approach to the urban context highlights the challenge of achieving a universal agenda for sustainability and resilience that reaches a population that grows rapidly, and which influences and is influenced by the concentrated occupation of the territory.

The depletion of natural resources and their impacts on humanity, notably freshwater scarcity and its multiple consequences, amplifies the list of challenges facing humanity. In this complex context, the NST are tools to achieve SDGs in areas such as energy; human health; food production; environmental protection; management, conservation and environmental and water resource recovery.

In addition to the integration between nuclear scientists and researchers in the ES area, it is necessary to approach the scientific community with decision makers, so that the governments of the world's megacities can promote supportive environments for the application of science-based tools for the recovery and conservation of ecosystems and their services. Innovative strategies and approaches are especially urgent for urban water resilience, which includes a broad process of popularizing science for its use, especially nuclear science and technology.

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