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Caribbean small island developing states must incorporate water quality and quantity in adaptive management of the water-energy-food nexus

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The 10 Small Island Developing States (SIDS) of the Caribbean in this study have unsustainable water-energy-food Nexus conditions, with stress becoming more acute via climate change, population demographics and increasing tourist demands. Water resources are limited, and wastewater treatment is inadequate or missing. Nature-based solutions (NBS), especially constructed wetlands, are effective treatment options for all SIDS and have added value for recreation, conservation and product development. On islands with abundant rainfall, NBS treated water adds little to total water resources, but can be important for small scale agriculture. Rainwater harvesting is an important alternative water source for individual households and small communities, but water reuse from tourist infrastructure has the greatest potential for SIDS to reach water sustainability, while protecting coastal waters from sewage pollution. Tourism is a two-edged sword. It swells populations and associated water demand significantly and can degrade coastal waters if wastes are not treated effectively. However, a partnership among the tourist industry, local communities and national government must be given top priority to ensure sustainability of the Water-Energy-Food (WEF) Nexus in the face of progressively increasing tourist numbers and pressures. Effective governance is needed at the island and regional level to develop sound adaptative management approaches for sustainability.

KEYWORDS

caribbean, SIDS, nexus, sustainability, nature-based solutions

1 Introduction

Of the 58 Small Island Developing States (SIDS) recognized by the United Nations in 1992 for their unique social, environmental and development issues, the vast majority are in the Pacific (67%) and Caribbean (25%) basins (United Nations, 1993; UNCTAD, 2021). Shared features include remoteness, limited natural resources, fragile environments, susceptibility to natural disasters, and excessive dependence on international trade. Their small but increasing populations tend to be concentrated in coastal areas <5 m above mean sea level (SIDS average 30% of population) (UN-OHRLLS, 2013).

Interactions among the three major components of sustainability (water, energy, food) are conveniently conceptualized via the WEF nexus. Castillo and Crisman (2019) envisioned the nexus as a wheel, whose spokes are water, energy and food that join at the hub (health)

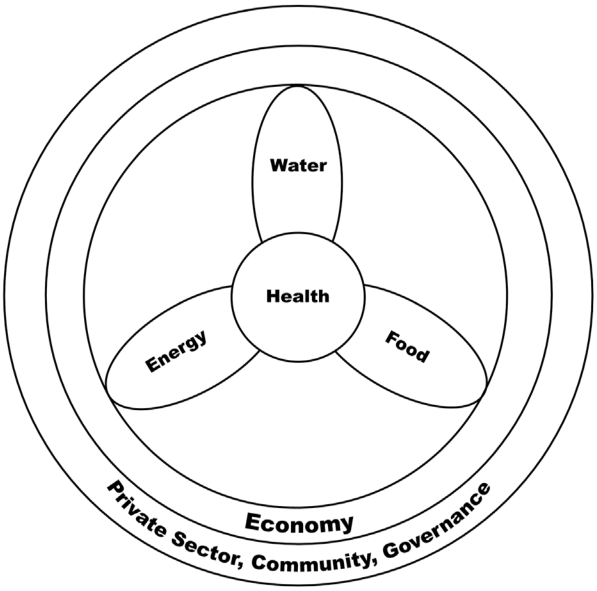

FIGURE 1
WEF nexus model. Adapted from Crisman et al. (2022).

and whose rim is economics. Economics is the overall control over the resources and their interactions, and imbalances in inter sector relationships can adversely affect human health. Application of the nexus approach to 10 Caribbean SIDS (Winters et al., 2022) and Puerto Rico (Crisman et al., 2021) concluded that none of the islands are sustainable. While infrastructure and governance are either unable to address requirements of the nexus under current or projected conditions, local communities and the natural environment are amazingly resilient even when devastated by natural disasters (Crisman et al., 2022) (Figure 1).

Although Castillo and Crisman (2019) recognized the negative impacts of the nexus on human and environmental health, most nexus research has largely focused on quantitative aspects of each component while ignoring quality issues. Water resources in Caribbean SIDS are increasingly taxed by expanding population demands, projected reduced precipitation associated with climate change and losses to evapotranspiration (Jordan and Fisher, 1977; Gohar and Cashman, 2017; IPCC, 2022). Watersheds tend to be small and steep, thus magnifying nutrient and pollutant discharges from human sources (ECLAC, 2000; Winters et al., 2022). Impacts to coastal marine areas including reefs (the principal fishing area) and beaches, where recent infestations of seaweed (Langin, 2018), have added to economic damage to the tourist industry contributed by fecal contamination (Siung-Chang, 1997; Sutherland et al., 2010; Ali et al., 2018; Compton and Forde, 2020).

Infrastructure for wastewater treatment is either mostly antiquated or non-existent, and few Caribbean SIDS have resources to improve the situation. Islands can never become sustainable as long as environmental impacts from the WEF nexus exceed balanced conditions and maximum efficiency of the nexus. In keeping with the spirit of the nexus, nature-based solutions (NBS) to waste management are the best option of Caribbean SIDS but their implementation has languished (Castillo and Crisman, 2019; Rodriguez-Dominguez et al., 2020). As demonstrated globally (Masi et al., 2010; Gorgoglione and Torretta, 2018), constructed wetlands are inexpensive and highly effective treatment alternatives for traditionally engineered infrastructure and have the added benefit of contributing nexus sustainability via water reuse for domestic and agricultural purposes, product development for the local economy and nature conservation (Mycoo et al., 2015; Peters, 2015; Corbi et al., 2021; Valero et al., 2021; Carvalho et al., 2022).

The current study revisited the 10 Caribbean SIDS for which current and projected WEF nexus sustainability was based on water quantity (Winters et al., 2022) to evaluate nexus impacts on water quality and whether these could be reduced by implementation of NBS wastewater treatment systems. Scenarios considered both human and climate projected future impacts. Particular emphasis was placed on the potential for treated water to supplement local water resources and community stability.

2 Study sites and methods

Ten of the 16 Caribbean SIDS were selected for this study based on data availability. Countries spanned the Caribbean basin and included: Antigua and Barbuda, the Bahamas, Barbados, Dominica, Grenada, Jamaica, St. Kitts and Nevis, St. Lucia, St. Vincent and the Grenadines, and Trinidad and Tobago (Figure 2). Demographic and physical characteristics of islands were compiled. Most countries had a population of under 1 million; however, populations ranged from around 53,000 (St. Kitts and Nevis) to 3 million (Jamaica). GDP values varied from nearly $546,000,000 (Dominica) to approximately $21 billion (Trinidad and Tobago). Surface area ranged from 260 km^2 (St. Kitts and Nevis) to nearly 14,000 km^2 (Bahamas) and agricultural area from 60 km^2 (St. Kitts and Nevis) to 4,540 km^2 (Jamaica) (Table 1).

2.1 Suitable NBS site analysis

Four GIS layers were utilized to evaluate parameters critical for evaluating potential NBS sites for each SIDS (Table 2). From the LULC shapefile, "open areas" were extracted from the following land cover classes in the Copernicus Global Land Operations product use manual (https://land.copernicus.eu/global/sites/cgls.vito.be/files/products/CGLOPS1_PUM_LC100m-V3_I3.4.pdf): shrubs, herbaceous vegetation, bare/sparse vegetation, permanent water bodies and herbaceous wetland. "Open areas" were used as the land use parameter for finding suitable sites for NBS, with a focus on constructed treatment wetlands.

Clipped elevation data were used to develop slope shapefiles for each island. Slopes less than or equal to 26° were selected as the slope parameter for locating suitable sites for NBS. Typical constructed wetland design requires slopes less than 26.6° (2:1 ratio of horizontal to vertical distance) (Davis, 1995; Crisman et al., 2021).

Areas with population density at or greater than each country's 75th percentile of population density were extracted, as major cities across the Caribbean were within the 75th percentile of population density. A 1.6 km (1.0 mile) buffer was then created around these areas to serve as "High Population Areas", which was the population parameter for locating suitable sites for NBS. The intersects of "open areas", slopes at or under 26°, and "high population areas" were located, creating a shapefile of suitable sites across each country.

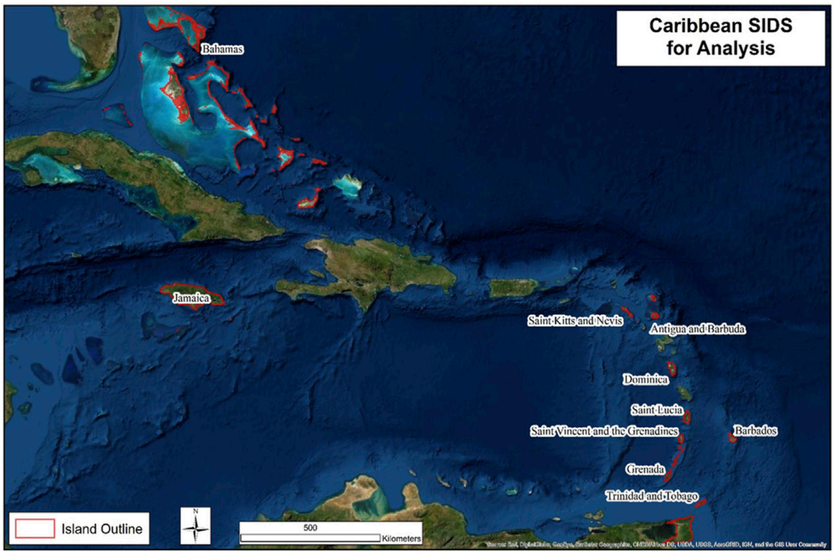

FIGURE 2
Caribbean SIDS included in this study.

TABLE 1 Demographic and physical characteristics of Caribbean SIDS used in analyses. Data obtained from the World Bank (https://data.worldbank.org/) and Worldometer (https://www.worldometers.info/world-population/caribbean-population/).

Country	2021 population	Population density (P/km^2)	Global density rank	Urban population (% of total)	2021 GDP ($)	Surface area (km^2) 2020	Agricultural area (km^2) 2020
Antigua and Barbuda	98,728	223	201	26.2	1,471,126	440	90
Bahamas	396,914	39	178	86.1	11,208,600	13,880	140
Barbados	287,708	668	183	31.2	4,900,800	430	100
Dominica	72,172	96	204	74.1	545,619	750	250
Grenada	113,015	331	195	35.5	1,122,083	340	80
Jamaica	2,973,462	273	138	55.4	13,638,231	10,990	4,440
Saint Kitts and Nevis	53,546	205	211	32.9	976,151	260	60
Saint Lucia	184,401	301	189	18.6	1,764,901	620	99
Saint Vincent and the Grenadines	111,269	284	196	52.9	889,775	390	70
Trinidad and Tobago	1,403,374	273	154	52.4	21,391,802	5,130	540

TABLE 2 GIS layers for determining NBS potential sites for each SIDS.

Source	Layer/Use	Resolution
USGS EROS GMTED 2010 (https://earthexplorer.usgs.gov/)	Slope	7.5 arc-seconds
IPUMS International (https://international.ipums.org/international-action/variables/group#)	Island Shape	N/A
Copernicus Global Land Service 2019 (https://land.copernicus.eu/global/products/lc)	Land Use Land Cover (LULC)	100 m
WorldPop Hub (https://hub.worldpop.org/)	Population Density	30 arc-seconds

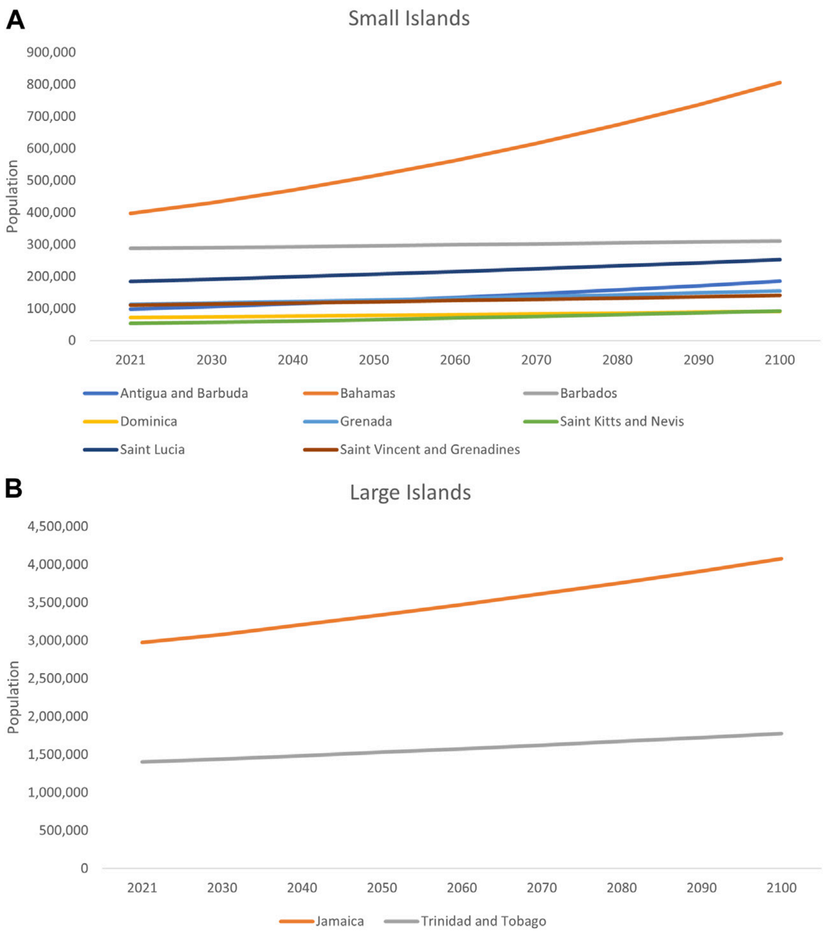

FIGURE 3
(A) Small island population growth through 2100. Figure 3 **(B)** Large island population growth through 2100. Data from the World Bank Database.

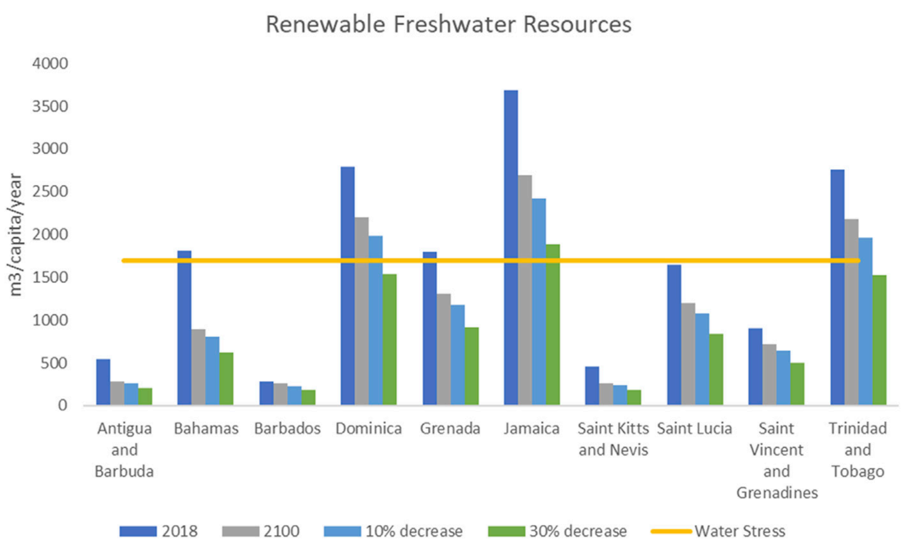

FIGURE 4
Current and projected changes in renewable water resources from 2018 to 2100. Data from World Bank Database.

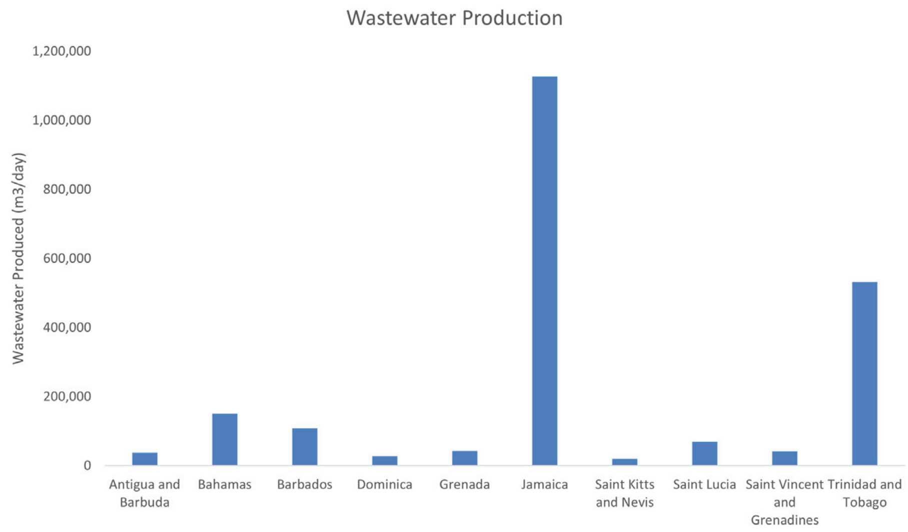

FIGURE 5
Wastewater production for each SIDS in this study. Population data were multiplied by the wastewater production rate of 0.379 m^3/capita/day. Data was compiled from the World Bank Database and Kadlec and Wallace (2009).

TABLE 3 Comparison of annual tourist numbers with resident populations of each SIDS of this study. The tourist:population ratio is how many times the local population is increased by tourists.

Country	2021 population	2019 tourists	Tourist: population
Antigua and Barbuda	98,728	1,035,000	10.5
Bahamas	396,914	7,250,000	18.3
Barbados	287,708	966,000	3.4
Dominica	72,172	322,000	4.5
Grenada	113,015	526,000	4.7
Jamaica	2,973,462	4,233,000	1.4
Saint Kitts and Nevis	53,546	1,107,000	20.7
Saint Lucia	184,401	1,220,000	6.6
Saint Vincent and Grenadines	111,269	392,000	3.5
Trinidad and Tobago	1,403,374	480,000	0.3

2.2 Long-term sustainability under current conditions

Each island was then evaluated to determine if potential sites were sufficient for implementation of NBS to support a stable WEF Nexus. Kadlac and Wallace (2009) suggested constructing wetlands for wastewater treatment with a ratio of 1 km^2 of wetland to treat 12,500 m^3/day, assuming wastewater production of 0.379 m^3/person/day. Using these metrics, each country's population was multiplied by the projected amount of wastewater per person to determine the total wastewater produced for each country daily. This value was divided by the ratio of 1 km^2 to 12,500 m^3/day to determine the amount of land area each country would need to convert to constructed wetland to treat their wastewater. Wastewater reuse was then reduced by 70% as a conservative estimate of water lost from wetlands via evapotranspiration (Bidlake et al., 1996; Jacobs et al., 2004; Exner-Kittridge and Rains, 2010).

2.3 Sustainability under future conditions

To understand how sustainability classifications might change over time with increasing climate change impacts, water availability as a function of population growth and modeled sea level rise was calculated for each country. Population was modeled using current population growth estimates from the World Bank (https://data.worldbank.org/) and combined with precipitation rate changes (Hall et al., 2013) to calculate water use through 2,100. Sea level rise was modeled based on the RCP 8.5 (Representative Concentration Pathway; warming of an average 8.5 W per square meter

TABLE 4 Current wastewater treatment in Caribbean SIDS.

Country	Wastewater management
Antigua and Barbuda	<50% of population served by centralized wastewater system Adhikari and Halden, (2022)
Bahamas	<50% of population served by centralized wastewater system Adhikari and Halden, (2022)
Barbados	<50% of population served by centralized wastewater system Adhikari and Halden, (2022)
Dominica	No centralized wastewater treatment Peters, (2015)
Grenada	No secondary treatment of sewage in Grenada Compton and Forde, (2020)
Jamaica	97.3% of wastewater treatment plants are dysfunctional
St. Kitts and Nevis	Limited septic tanks and soakaways Chapman et al., (2012); Peters, (2015)
St. Lucia	Pit latrines and septic tanks IWT, (2016)
St. Vincent and Grenadines	<50% of population served by centralized wastewater system Adhikari and Halden, (2022)
Trinidad and Tobago	<50% of population served by centralized wastewater system Adhikari and Halden, (2022)

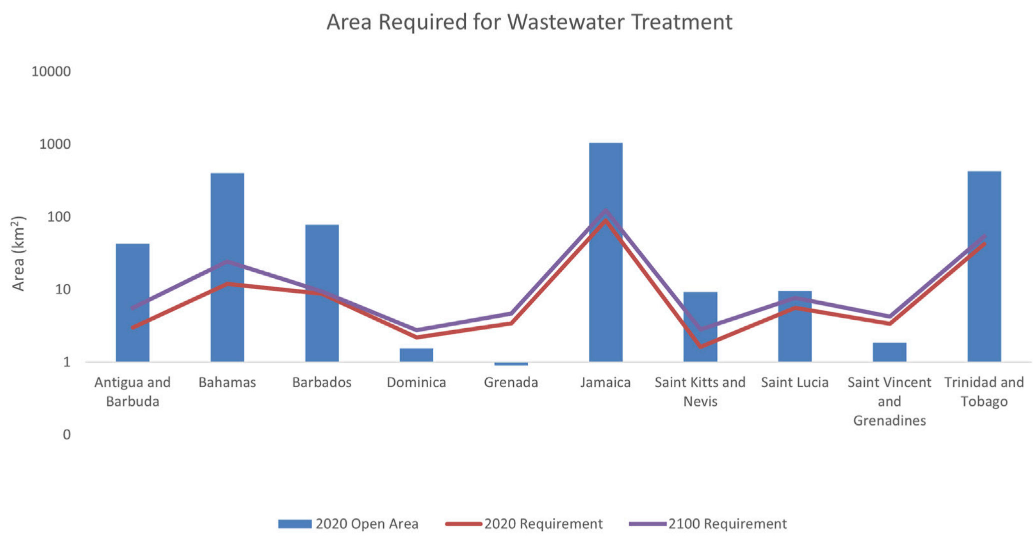

FIGURE 6
Required area to treat wastewater for each country. Population was multiplied by 0.379 m^3/person/day to give produced wastewater, which was then divided by the ratio of 1 km^2 to 12,500 m^3/day to give the area required for treatment in km^2.

globally), which estimates that sea level rise will vary between 0.3 and 1.35 m in the Caribbean by 2100 (Strauss and Kulp, 2018). Sea level rise shapefiles were added to potential site shapefiles to determine if potential site locations would remain above water by the year 2100, based on sea level rise projections.

3 Results

3.1 Population demographics and water resources projections

With the exception of Jamaica, Trinidad and Tobago and Barbados, populations of the Caribbean SIDS are relatively low, with most below 200,000 (Figure 3). The populations of two SIDS (Antigua and Barbuda, Bahamas) are expected to double potentially by 2021, but those of the other SIDS will increase only moderately (mean 1.3 times) (https://data.worldbank.org/). Population projections are complicated by both migration trends and tourism. Although low when considered globally, all but three of the SIDS of this study displayed major populations emigration. The impact of tourism on island WEF nexus sustainability is complicated by seasonal influx of visitors tending to consume resources at higher rates than resident populations.

Population densities of the SIDS ranged from 39 to 668 persons/km2, values representative of moderately dense nations globally (Table 1). The percent of the population considered urban was highest in Bahamas (86%) and Dominica (74%) but was considered low for the remainder of the study SIDS.

Water availability *per capita* (m3/capita/year) for each SIDS in 2020 and projections to 2100 (Figure 4) were based on resource

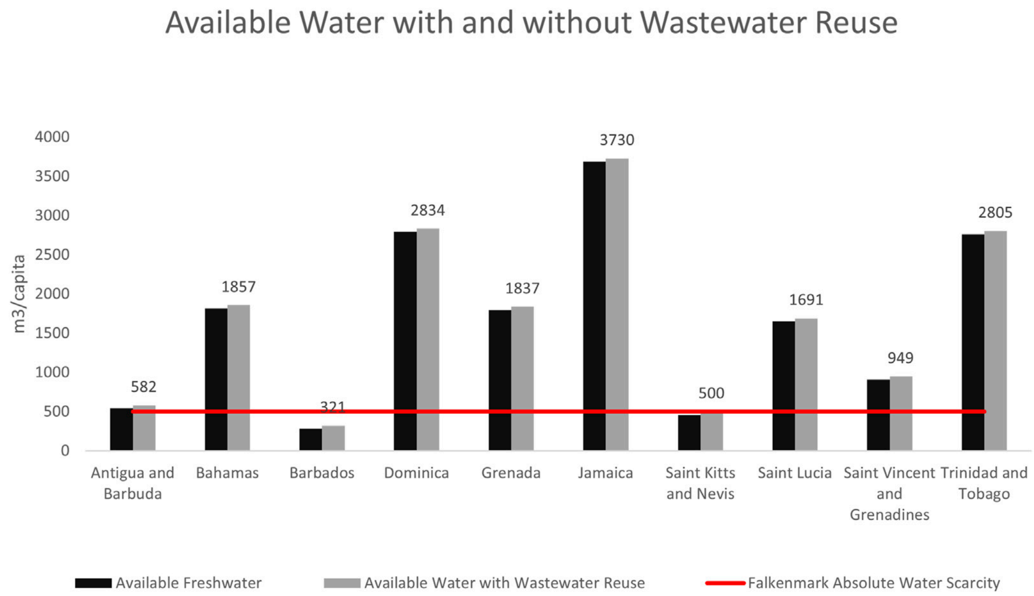

FIGURE 7
Available water for each SIDS utilizing wastewater reuse. The Falkenmark Absolute Water Scarcity constant (500 m^3/capita) is graphed alongside annual renewable freshwater resources (m^3/capita). Wastewater generated is a constant at 0.379 m^3/capita/day. This was converted to 138 m^3/capita/year, which was then decreased by 70% to account for evapotranspiration. This value was added to the annual renewable freshwater resources. Data compiled from the World Bank Database and Kadlec and Wallace (2009).

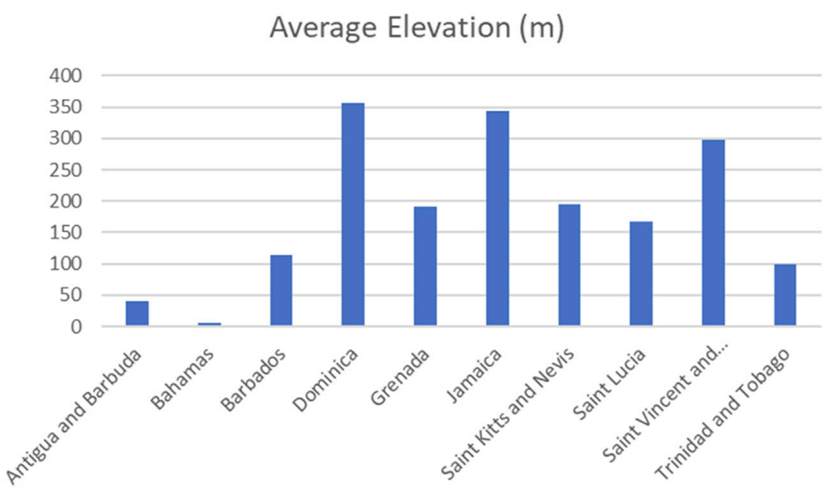

FIGURE 8
Average elevation in meters for each SIDS of this study. Data from the World Bank Database.

estimates from the FAO AQUASTAT database (FAO, 2020) and population estimates (World Bank (https://data.worldbank.org/) and Worldometer (https://www.worldometers.info/world-population/caribbean-population/). Falkenmark Water Stress Indicators (Falkenmark, 1989) were calculated for each SIDS for 2020 and projected to 2100. Per capita values for water security categories are: Water stress (<1,700 m^3/capita/year), Water Scarcity (<1,000 m^3/capita/year), and Absolute Water Scarcity (<500 m^3/capita/year). Water stress, the indicator selected for this study, means that a nation is not meeting water thresholds regularly for agricultural, domestic and industrial purposes.

Five nations were considered water secure in 2020, two of which were marginally above the water stress level for the Falkenmark indicator (Figure 4). By 2100 these marginal nations are expected to have lost water security. Antigua and Barbuda, Barbados and St. Kitts and Nevis are currently experiencing Absolute Water Scarcity (<500 m^3/capita/year), with the situation becoming dire by 2100.

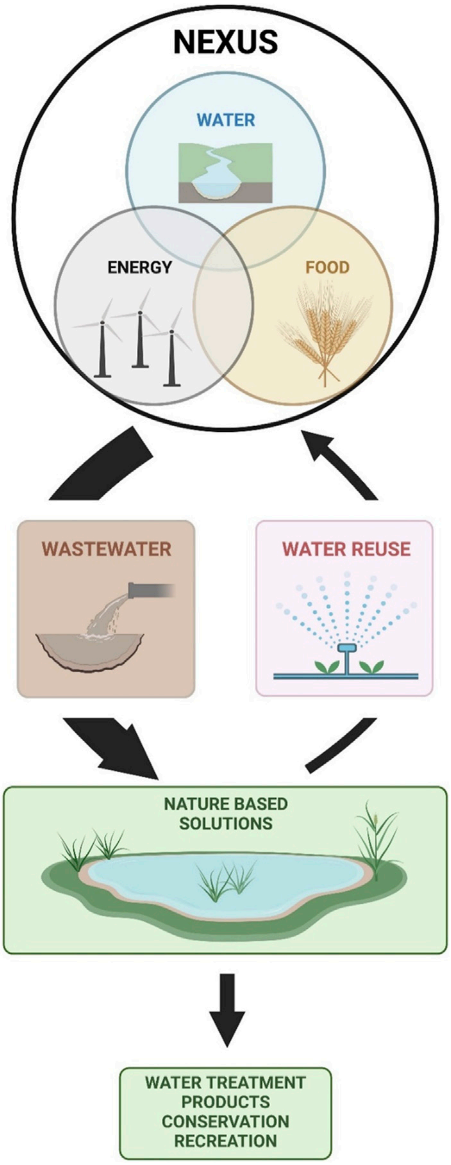

FIGURE 9
WEF Nexus model for long term sustainability recognizing wastewater as a potential water resource and nature-based technologies for water treatment and ecosystem services. Created with BioRender.com.

Although impacts will not be uniform throughout the basin, the Caribbean SIDS are expected to experience significant sea level rise, increased temperature and reduce rainfall by 2100 (Portner et al., 2022). The Greater Antilles are projected to see temperatures increasing 1°C to 5°C annually (Cashman et al., 2010) and 10%–30% reduction in precipitation (Hall et al., 2013). Climate change impacts on water resources for our Caribbean SIDS associated with scenarios of 10% and 30% precipitation reduction were combined with population related resource projections to 2100 (Figure 4). Dominica and the two largest islands of our study (Jamaica and Trinidad and Tobago) will retain water security with a 10% reduction of precipitation by 2100, but Jamaica will be the only SIDS under a rainfall reduction of 30%.

3.2 Wastewater and treatment options

With the exception of the two largest islands, the resident populations of SIDS of this study each generated less than 200,000 m^3/day reflecting their relatively low populations (Figure 5). These data, however, do not consider the shift in local economies to favor tourist infrastructure and its impact on human populations. The flux of tourists to the SIDS is both seasonal and relatively short term, but many islands are encouraging retirement communities, which would add to year-round stress on water resources. Annual numbers of short-term tourists vary greatly among SIDS (Table 3), ranging from a minor impact on population levels (Trinidad and Tobago, Jamaica) to significantly elevated human pressures (10–20 times) on local water resources and wastewater generation (Antigua and Barbuda, Bahamas, St Kitts and Nevis). Tourists tend to consume more water *per capita* than local populations and generate larger volumes of wastewater (UNEP, 1999). SIDS with the largest ratio of tourists to resident populations are also either showing absolute water insecurity or water stress currently. This study did not address the extent that tourist infrastructure is integrated with local water resources and waste treatment.

Wastewater treatment in the Caribbean SIDS is woefully inadequate to meet current population needs (Table 4). Only two SIDS have urban populations exceeding 60% (Table 1), and centralized treatment systems are not practical due to widely dispersed populations and steep terrain on many islands. If existing, treatment is at the household level and mainly pit latrines and septic tanks. Steep slopes and proximity to streams hinder effective treatment.

Nature-based solutions for wastewater treatment, including constructed wetlands, provide comparable treatment efficiency as grey infrastructure at a fraction of the cost (Castillo and Crisman, 2019). Their use in Latin America is gaining rapid acceptance, but only to a limited extent in Caribbean SIDS. Available open areas (minus forests) were determined for each SIDS and evaluated as potential treatment options for current and projected (2100) populations and associated waste generation (Figure 6). Dominica, Grenada and St. Vincent and the Grenadines lack sufficient open space for constructed wetlands to be an effective option, while the remainder of SIDS currently have sufficient open space to treat current and projected waste loads. Applicability in St. Lucia, however, is questionable beyond 2100. The assessment did not include the impact of tourists on waste loads, which could overwhelm wetland treatment in most SIDS.

The potential for treated water generated from constructed wetlands to supplement available water resources of each SIDS was evaluated for current resident population levels multiplied by 138 m^3/capita/year wastewater generation and assuming 30% return of treated water to the resource base allowing for evapotranspiration losses (Figure 7). The potential replenishment of water resources in all SIDs was extremely low (mean 4%, range 1%–15%) and was only able to keep Antigua and Barbuda and St. Kitts and Nevis slightly above the absolute water scarcity threshold. Only when considering the massive seasonal population increase in many of the SIDS from tourists (Table 3) and associated disproportional increase in water demand does reuse of treated wastewater hold potential for increasing water resources availability.

Populations and infrastructure are usually concentrated in low lying coastal areas of SIDS globally and are highly susceptible to inundation from sea level rise (UN-OHRLLS, 2013). Unlike coral islands of the Pacific, which are under imminent threat of total submersion, the average elevation of the Caribbean SIDS of this study ranges from 6 m (Bahamas) to 357 m (Dominica) (Figure 8). If undeveloped, open areas remain close to current extents on each island, the estimated range of sea level rise by 2100 (0.3–1.35 m) for the Caribbean basin (Strauss and Kulp, 2018) would reduce available land for nature-based solutions less than 1% for all SIDS, including the low lying Bahamas. Low lying areas of all SIDS, however, will face increased threats from storm surges and king tides, especially in the Bahamas, where 72% of the land area is below 5 m elevation. (UN-OHRLLS, 2013).

4 Discussion and conclusion

Since its inception in 2011, the WEF Nexus has been used increasingly as the preferred approach to predict societal and ecosystem sustainability via interactions among the three principal controlling variables: water, energy and food (Simpson and Jewitt, 2019). Most research has emphasized quantitative aspects of the WEF Nexus, but Castillo and Crisman (2019) stressed that wastewater generated from each sector has a profound impact on human health. Heal et al. (2020) stressed that both water quality and quantity are critical for facing the complex multidisciplinary challenges of WEF Nexus sustainability.

The ten SIDS of this study (Winters et al., 2022) and Puerto Rico (Crisman et al., 2021) currently fail all three components of the WEF Nexus. Both the environment and local communities in all displayed a great deal of resilience, but governance and economics clearly were not adapting to changing conditions and were a root cause of sustainability failure, as highlighted by Mycoo and Bharath (2021). In their literature review, Simpson and Jewitt (2019) identified both governance and the environment as key missing components of WEF Nexus assessments.

Isolation, small size, limited resources and vulnerability to natural hazards and climate change have profound implications for sustainability of SIDS populations and environments (Scandurra et al., 2018; Nel et al., 2021). Optimized use and reuse of existing water resources and identification of alternative water resources are key for sustainability of Caribbean SIDS (Figure 9). All three components of the WEF Nexus generate wastewater of differing quantity and quality that can be collected and treated with various nature-based solutions, especially constructed wetlands, and tailored to meet the conditions of each waste stream. Key to successful treatment is avoidance of centralized grey infrastructure and implementing treatment as close to waste source as possible.

With infrastructure and populations concentrated in a narrow zone fringing the coast (Cashman and Nagdee, 2017; Pathak et al., 2021), all SIDS of this study appear to have sufficient open spaces to implement nature-based solutions until at least 2100 based on projected trends in resident populations. Future impacts from rapidly expanding tourist infrastructure and profound seasonal swelling of water resource demands and wastewater generation from tourists are likely to overwhelm any centralized water sources and wastewater treatment. Nature-based treatment options can be moved inland and tailored to meet unexpected and rapid changes in wastewater streams and should be keystone components for adaptative management plans for all Caribbean SIDS.

Treatment wetlands can be important areas for nature reserves and passive recreation (Castillo and Crisman, 2019). They are the linchpin to stop pollution of coastal resources and environmental from untreated wastewater. The near shore marine environments, including coral reefs, are facing serious problems throughout the Caribbean from bleaching and disease of coral, *E. coli* and total coliform contamination, elevated nutrients and contaminants and excessive growth of Sargassum and deposition nearshore (Siung-Chang, 1997; Lewsey et al., 2004; Patterson-Sutherland et al., 2010; Langin, 2018; Oviatt et al., 2019; Compton and Forde, 2020). All studies attribute these problems directly to unsustainable land use practices and discharge of raw sewage. The methodology discussed by Aide et al. (2020) provides an excellent model for incorporating native and functional species for wetland construction.

Tourism development depends on relatively intact and pristine ecosystems, but potential negative impacts on the environment from tourist activities can spell doom for the industry. Ali et al. (2018) and Mycoo (2006) stressed the critical need for sustainable ecosystem management of coastal areas of the Caribbean. Over 50% of coastal development will be lost with a 1 m of sea level rise (Scott et al., 2012), and 80% of tourists surveyed on Bonaire and Barbados stated an unwillingness to return if marine wildlife became degraded and beaches were lost from sea level rise (Uyarra et al., 2005). Sustainability practices currently implemented by the tourist industry are insufficient for environmental preservation, government intervention is needed to protect vulnerable ecosystems from tourist development (Gandoit, 2005; Charles, 2013; Mycoo, 2014).

All SIDS of this study suffer from unsustainable water resources for resident populations, and alternative water sources must be found. Although stormwater treatment wetlands are effective at capturing nutrients and many contaminants, their impact on microplastics and personal medications is unclear (Reyes et al., 2023). Still, van Houselt (2021) calculated that runoff from roads and stored in reservoirs could supply 45% of annual non-potable water demand in arid Curacao.

Rainwater harvest (RWH) brings people closer to the water source, thus encouraging water conservation and building societal resilience during climate extremes (Waite, 2012). RWH can be an essential water source for households in hilly terrain where connections to centralized systems are extremely difficult, and poor residents often spend 10% of their expendable income to meet household water demand (Waite, 2012; Rovira et al., 2020). The Grenadine islands have long relied on RWH and storage in cisterns for their water supply (Peters, 2013), and Aladenola et al. (2016) estimated that a storage tank of 2.5–4.0 m^3 is sufficient to meet household needs during maximum dry season months in Jamaica. RWH currently meets 25% of household water needs in Jamaica and likely will meet 15% by 2080 after accounting for population demographics and climate change (Waite, 2012).

Development of communal RWH collection systems is often more efficient and innovative than household systems (Waite, 2012; Rovira et al., 2020). Stakeholders must take responsibility of financing, building and maintenance of RWH systems (Peters, 2016) in the absence of governmental guidelines for monitoring and maintaining systems throughout the Caribbean (Cashman and Carpenter, 2020). When implementing and expanding RWH however, it is imperative to understand and mitigate the potential negative health effects, such as growing mosquito populations, as highlighted by Moglia et al. (2016).

Tourism is two-edged sword for water sustainability in the Caribbean SIDS. Most economies promote expansion of the tourism industry despite unsustainable water demands from tourist inflated populations, especially during the dry season (Waite, 2012), and their distinct preference for high quality traditional water resources over desalinated water (Emmanuel and Spence, 2009). In Barbados, daily *per capita* water use by tourists is 3.6 times that of the resident population, and accounting of water demand by golf courses, cruise ships, seasonal expatriates, and short-term tourists is poorly documented (Emmanuel and Spence, 2009).

Tourist infrastructure has access to technology and funding to provide their guests with a quality and healthy experience. The demand for quantity and quality aspects of water will continue to grow as tourism increases its contribution to local economies. The key to sustainable water resources in Caribbean SIDS is a partnership between tourism development and residents to enhance water availability to local populations via potable water generation from tourism infrastructure and recycling of treated wastewater via nature-based solutions. Rather than increasing the burden on existing water resources, tourist development must develop desalination technologies and work to treat wastewaters from both their operations and local communities. Negative impacts on water quantity and quality on human consumption and the environment must be addressed by national policies developed through public-private consultation that incorporate adaptive management to address population dynamics, tourism and climate change.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Materials, further inquiries can be directed to the corresponding author.

Author contributions

TC developed the scope and direction of the manuscript and wrote major sections of the manuscript. ZW performed data analysis and designed figures and tables for the manuscript. All authors contributed to the article and approved the submitted version.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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