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Treated Wastewater Use for Maintenance of Urban Green Spaces for Enhancing Regulatory Ecosystem Services and Securing Groundwater

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Abstract: Rising land surface temperature (LST), urban heat island (UHI) effects, and stress on surface-, processed-, potable-, and ground-water resources are some undesirable ecological changes due to rapid urbanization. Treating and reusing city-generated wastewater for maintaining urban green spaces (UGS) helps in reducing/preventing groundwater extraction, ensuring sufficient supply of potable water, and bringing down LST. However, the benefits of reusing treated wastewater in UGS for enhancing regulatory ecosystem services (RES) and ushering in a circular economy are yet to be realized. In view of these, the transportation costs of treated wastewater for irrigating the UGS of Panaji city—proposed to be developed as a smart city—were assessed. Field surveys were conducted at seven gardens/parks to collect the primary data on vegetation type (ground cover, hedge plants, and trees) and their daily water requirement. As the main focus of this study, a cost–benefit analysis of (a) drawing the groundwater using borewells versus use of treated wastewater from the city's STP, and (b) two modes of treated wastewater transport: water tankers vs. pipeline was performed. Our analyses suggest that the copiously available 14 MLD treated wastewater from the STP, which meets all the safety standards, is far in excess of the current requirement of 6.24 MLD for watering the vegetation in all 17 parks/gardens in the city. Pipeline is an efficient (less energy, labor, and time) and economical (~47% more than water that is tanker-based) transportation mode. By utilizing the otherwise unused treated wastewater, which is processed at a cost of over USD half a million annually, the RES offered by the use of treated wastewater are (a) partially curtailing a combined loss of ~16 MLD due to the extraction of groundwater plus evapotranspiration (@8.86 mm d^{-1}) from Panaji city's 1.86 km^2 UGS, and (b) reduction in LST ~3–4 °C in all of Panaji city. In addition, with the proficient and sustainable management of UGS and the meeting of many UNSDGs, the enhanced vegetation growth plus elevated carbon sequestration rates in the UGS are possible through the reuse of treated wastewater.

Keywords: urban green spaces; treated wastewater; sustainable urban vegetation; cost–benefit analysis; circular economy; UNSDGs

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1. Introduction

In many developing countries experiencing rapid urbanization, over 80 or even 90% of sewage and other wastewaters are discharged directly into open streams or coastal water, thus, severely polluting and harming the environment, leading to water-borne diseases, along with hindering tourism and economic development [1–3]. The United States Environmental Protection Agency [4] identifies that different patterns of the utilization of water resources in urban settlements play a significant role in the preservation, development, and maintenance of urban green spaces (UGS). Although some studies [5,6] have focused on how the water resource management practices in urban settlements affect the UGS cover, adequate attention has not been paid to the treatment and reuse of wastewater for UGS management.

Wastewaters, discharged from buildings and several other domestic/industrial processes, can be reused for irrigation and certain industrial processes [4]. In water-scarce regions, and at times of drought in many locations, such reclaimed/recycled wastewater can become reliable alternative sources of water to facilitate/ease the hard situations [7,8]. It is becoming more common for local municipalities to reclaim wastewater and sell it at a cheaper price to customers to help lower the community's demand for freshwater [9]. Indeed, the reclaimed water seems to be a way forward in drought-hit places. As per Veolia Group [8], "instead of being thrown into the sea, the purified wastewater will be given a complementary treatment to feed a dam where a drinking water factory captures the resource". Such sustainable water management and utilization efforts can substantially support the community's needs [9]. With increased frequency of droughts and heightened water stress, reuse of processed wastewater in industries, in the countryside, and as tap water, is increasing worldwide [8].

Many recent studies suggest the use of constructed wetland technologies [10,11], algae-based systems [12], and highly economical consortia of algae–bacteria as an alternative to activated sludge treatment [13]. These nature-based solutions can play a major role in urban water management [14]. Despite these nature-based wastewater treatment solutions being natural and quite cost-effective [15], suitable location/s for ponds/lakes are hindered by adequate space issues and, above all, public health-related disputes in city settings of high-priced real estate. In this regard, it is imperative to note that the treatment costs of domestic wastewater/sewage effluents would be far more inexpensive (presently in India [16] it is <0.1 USD/m^{-3} and efficient than the above-mentioned nature-based treatment technologies. Further, in most of the developing nations, the safe discharge limits of treated sewage effluents are achievable by traditional, sequential batch reactors [17].

The Millennium Ecosystem Assessment (MA, 2006) defined ecosystem services as "the benefits people obtain from ecosystems". The MA delineated them as supporting, provisioning, regulating, and cultural services. Among the many ecosystem services that the UGS offer, the urban tree and soil systems are significant in reducing nutrient pollution concentrations in urban catchment by trapping and metabolizing the surge of inorganic nutrients received during storm surges or monsoonal run-off [2]. As for cultural services, the UGS serve inspirational, therapeutic, recreational and tourism, biodiversity conservation motifs, as well as science and educational interests [6]. Sustainable management of UGS, including the use of treated wastewater, when and however necessary, ensures the adequacy of all such ecosystem services.

Wastewater treatment and reuse offers manifold advantages in urban settings. It provides more reliable and regular water supply that can usher in circular economies [18], eliminate pollution, and benefit society and the environment in varying ways [3]. The concept of a circular economy [3], in cost-effective ways, can be adapted to wastewater treatment and use as an alternative resource. By elucidating the relationships between water markets and public and environmental resources, opportunities open up for "promoting sustainable and resource-efficient policies and practices" [3].

Further, any analysis on daily water requirement in the UGS, carbon stocks, and sequestration potential, as well as the LULC changes of a given location are of considerable significance [19]. Estimating water requirement in UGS and their carbon sequestration potential is necessary to: (a) evaluate whether treated wastewater in a given city's sewage treatment facility adequately meets the requirements of trees and other vegetation in the UGS during non-rainy seasons and (b) provide details of cost analysis of transporting treated wastewater using different modes to UGSs. In addition, an assessment of such efforts, leading to societal benefits that accrue through employment/infrastructure creation in the UGS would be helpful.

Although wastewater treatment and reuse have been used in practice, the collection of pertinent information, its collation for pragmatic insights on transformation, sustainable management of UGS, and improved wastewater treatment technologies and reuse can assist policymakers and urban planners for long-term sustainable urban development through an environmentally friendly approach [2]. We hypothesize that treating and reusing wastewater generated from municipalities and other urban/town settlements, for maintaining UGS or for various other uses helps in reducing/preventing groundwater extraction and helps avoid diversion of processed/potable water from its assured supply for domestic uses. It can also help in bringing down the LSTs in the densely populated urban settlements. With this major focus, the emphasis in this study was on cost–benefit analysis of wastewater treatment and on its non-potable reuse for maintenance of UGS [20] and to point out some key advantages and challenges.

Considering these aspects, we examined whether the use of treated wastewater as a reliable option for facilitating some RES of the UGS. The challenges of ferrying over 6.25 MLD of treated wastewater to 17 parks and gardens of Panaji city, safety concerns regarding water quality, and cost factors were handled. Possible solutions and various UNSDGs met by opting for treated wastewater use in the UGS in Panaji city, which treats over 14 MLD of its sewage effluent every day, are included for highlighting the importance of treated wastewater use for sustainable maintenance of UGS. Costs of transporting treated wastewater either through water tankers/trucks or through the pipeline options were estimated.

2. Materials and Methods

2.1. Study Area Details

Panaji city, one of the cities to be developed as a smart city in the State of Goa (India), was chosen for this study. Pertinent data were collected between January–February 2019 and between August–October 2020. Key informant survey questionnaires (Supplementary Tables S1–S4) were prepared for collecting required information from different gardens/parks, sewage treatment plants, and city development agencies. Additionally, details obtained through interactive discussions with the garden staff and officers in charge were collated. For brevity, a summary of geographical and climatological features of the study area is presented in Table 1. The sampled sites are marked in Figure 1. Main details of these parks are compiled in Table 2.

Table 1. Summary of geographic and physical features of Panaji city.

Parameters	Panaji (Goa)
Elevation (above MSL; m)	11 #
Annual average temp (Min–Max)	25.9–30.2 #
Annual average rainfall (mm)	2774 ^
City area km^2	21.60
Recorded LST (°C) ranges	38–42 °C
Population (millions, 2019) *	0.268
Population density/km^2	12,444
No. of vehicles (millions, 2019) @	0.19
Carbon emission (Million Tons, 2018) USD	0.52
Urban water supply (mld) ^	26
Wastewater generated (MLD) ^	20
Wastewater treated (MLD) ^	15

Table 1. *Cont.*

Parameters	Panaji (Goa)
No. of sewage treatment plants	2
~No of gardens/parks	17 (3 large)
Roadside plantation length (km)	16
Ca. Green cover (% of total area)	8.6

#, Climatedata.org; @, distancesto.com; *, Timeanddate; ^, Ramaiah et al (2020); USD, at 1.94 tons per capita; ^ reported by staff.

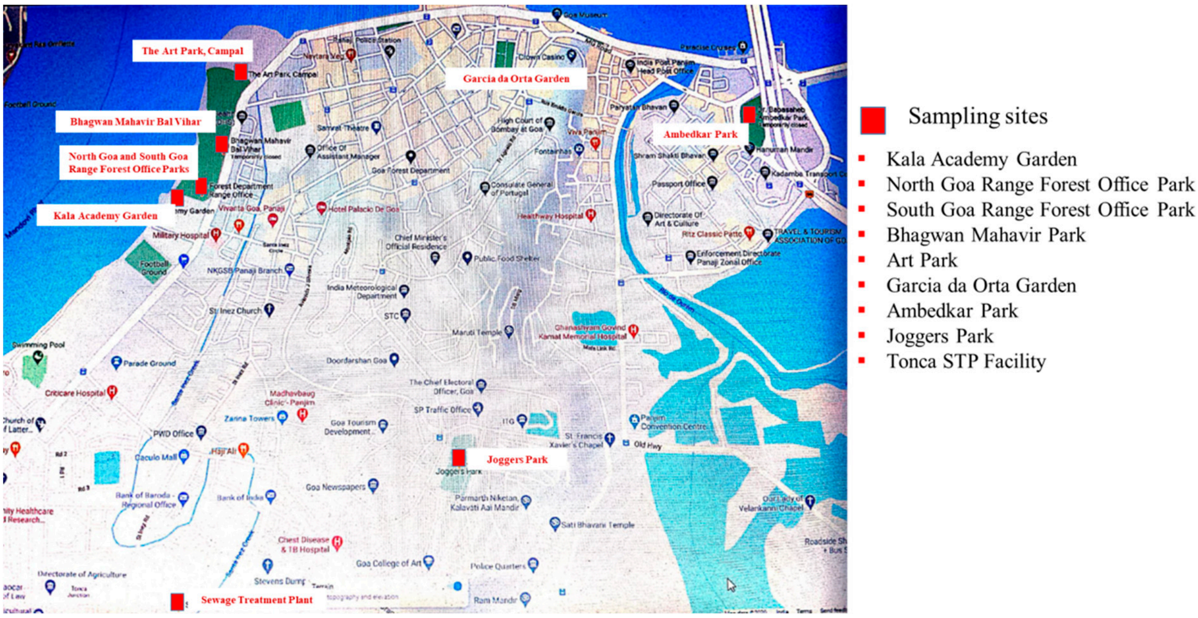

Figure 1. Parks and Gardens in Panaji city surveyed for this study for calculating water requirements of hedge plants, groundcover (=lawn), and trees. Details from the sewage treatment plant (STP) located at Tonca were collected.

Table 2. Important details of different parks in the city of Panaji surveyed for this study.

Park	Area (m^2)	No of Species: Trees (Total #)	No of Species: Ornamental (Hedge Length; m)	Grass Cover (m^2)	Source of Water	Daily Water Used (L)	Annual Litter Fall (Tons)	# of Staff
Kala Academy	10,630	21 (300)	6 (400)	2675	Borewell	10,000	15	6
North Goa Range Forest Park	5000	18 (390)	6 (200)	2250	Borewell	4800	10	3
South Goa Range Forest Park	6500	9 (200)	52 medicinal	1625	Borewell	8400	6 *	5
Mahavir Park	18,312	27 (3130)	17 (3000)	6410	Borewell	15,000	60	22
Art Park	18,999		0	0	Not watered	0	30	

Table 2. *Cont.*

Park	Area (m^2)	No of Species		Grass Cover (m^2)	Source of Water	Daily Water Used (L)	Annual Litter Fall (Tons)	# of Staff
		Trees (Total #)	Ornamental (Hedge Length; m)					
Garcia da Orta Garden	4000	12 (180)	6 (450)	1500	Corporation water + Borewell	4000	6	5
Ambedkar Park	10,000	15 (400)	17 (1800)	6500	*Treated wastewater*	16,000	25	12
Joggers Park	11,500	8 (400)	12 (2600)	6900	Borewell	36,000	12	22

*, # Total number of trees in Mahavir Park and Art Park as per lists provided by the park offices. Within the precincts of Mahavir Park are North Goa Range Forest and South Goa Range Forest office parks. In the former, the water is used only for ca 200 m long hedge of ornamental plants. There is a saplings nursery, measuring 800 m^2 in the South Goa Range Forest office park. Year-round regular rearing of tree/forest plants and saplings of as many as 52 different species of ornamental/medicinal plants. Except Joggers Park (established during 2002), the soil is mostly sandy type in all the gardens adjacent to, and including, Mahavir Park (from 1963). Garcia da Orta garden (1876) has sandy: silty (66:33%) soil. The levelled laterite base of the Joggers' Park is topped with soil from elsewhere to grow hedge plants and to support nutrients to existing vegetation. Ambedkar Park (established 1992) exclusively uses treated wastewater of 16,000 L every day during non-rainy period from 15 October to 15 June for maintaining the grass-cover and long hedge rows in the garden of ca 11,000 m^2 total area.

The general practice of watering in all the parks is that there is no watering during the monsoon months of mid-June to mid-October. There are instances of acute water shortage, from mid-February until the onset of monsoon/pre-monsoon showers (sometime during late May/early June). During this mostly hot and humid period, the plants, particularly the ornamental plants and the lawns (grass cover), suffer from water scarcity. Over 95% of the trees in the UGS are never watered manually.

Most parks sourcing borewell water have drilled bores of varying lengths usually less than 40 m deep due to their vicinity to the lower stretches of River Mandovi to their west (Figure 1), except the deepest borewell of 130 m in Joggers Park, which is ~30 m above mean sea level, and at a distance of ~3 km from the northwestern banks of River Mandovi. Notably, in Ambedkar Park, the borewell located within 800 m south of River Mandovi that was drilled back in mid-1980s, yielded saline waters unsuitable for plant growth. For many years, a certain volume of potable water was diverted once or twice a week by the city corporation for too long from mid-1980s. It was not sustainable, owing to increased demand for potable water for domestic consumption. Thus, the use of treated wastewater became regular from 2007 onwards. A daily volume of 16,000 litres are drawn on all days during the non-rainy months (early October–mid June) from the discharge point of the Tonca STP and transported to this park by a water tanker of 8000 L capacity twice daily making two round trips of ~10 km each by road. This volume is used for irrigating the groundcover (6000 m^2, including a 1500 m^2 commercial nursery of many ornamental, exotic, local plants, and plantation saplings) and hedge plants (1800 m^2).

Striking differences in the maintenance practices between each of these parks are as follows: In Mahavir Park, the water is pumped out directly onto the grass cover and lane edge plants. In the Kala Academy (established 1982) park, the water is pumped out into two overhead tanks from where it is distributed through sprinklers to groundcover and through handheld pipes to the hedge plants. There are also ornamental and hedge plants reared in Mahavir Park and in Ambedkar Park. In the Art Park, which is right on the banks of River Mandovi, there are big trees (most of them older than 20 years and some planted within the last 6 years) and shrubs, which are not watered manually. In most of these parks, watering is done for three hours in the morning and three hours in the afternoon for only the grass cover (lawns) and ornamental plant hedge along the walkways.

2.2. Sewage Treatment and Treated Wastewater Handling

Panaji city began treating its sewage effluent back in 1967. The sewage treatment facility with improved continuous-operation technique (C-Tech; Sequential Batch Reactor)-based practices is located at an elevation of 3 m above sea level. From 2018, there are STPs with current handling capacity of 65 MLD domestic sewage. It currently receives only ca 15 to 17 MLD through underground sewage network of 45 km, mainly from the Corporation of the City of Panaji (CCP) and Taleigao *Panchayat* units. As much as 14 MLD treated wastewater of safe environmental discharge quality is produced from this facility. A sample dataset of various parameters of quality of treated wastewater documented (and overseen by a research institute; see Table 3 footnote) by the STP office are provided in Table 3. Such acceptable water quality, certainly for all non-potable uses notwithstanding, over 99% of the treated wastewater—produced at quite a cost and power input—is let away into the nearby polluted creek, connecting the lower reaches of River Mandovi.

Table 3. Typical values of major parameters of raw sewage effluent received for treatment and treated water quality at Tonca wastewater treatment plant Panaji, Goa, India. Permissible/tolerance limits of each parameter for safe discharge (and also suitable for plant/tree irrigation of almost all tropical species) are listed *.

Parameters	Tolerance Limit **	Raw Sewage	Outlet Values
Colour/odour	-	–	Clear, odorless
Suspended solids (mg.L^{-1})	100	400	10
Particle size suspended solids units	<850 u.	140	5
Dissolved inorganic solids max. (mg.L^{-1})	2100	480	246
pH	5.5–9.0	6.88	7.56
Oil and grease. Max. (mg.L^{-1})	10	86	NA ^
Ammoniacal nitrogen as N. Max. (mg.L^{-1})	50	74	NA
Total Kjeldahi nitrogen as N. Max. (mg.L^{-1})	100	28	NA
BOD_5 at 20° Max. (mg.L^{-1})	30	540	33
COD. Max. (mg.L^{-1})	250	960	64
Mercury as Hg. Max. (mg.L^{-1})	0.01	0.097	BDL #
Lead as Pb. Max. (mg.L^{-1})	0.1	0.035	0.002
Hexavalent chromium as Cr^{0+} Max. (mg.L^{-1})	0.1	0.147	NA
Zinc as Z. Max. (mg.L^{-1})	5	0.369	0.008
Nickel as Ni Max. (mg.L^{-1})	3	0.214	0.08
Chloride as Cl. Max. (mg.L^{-1})	1000	2400	20
Dissolved phosphate as P. Max. (mg.L^{-1})	5	14	0.01
Sulphate as SO_4 Max. (mg.L^{-1})	1000	550	11
Sulphide as S. Max. (mg.L^{-1})	2	5	0.8
Coliform count (number/100 mL)	25 to <60/100 mL	240×10^6	Nil to 40

* STP authorities receive periodic guidance on operation and maintenance, and necessary consultancy from the Indian Institute of Technology Chennai. # Below Detectable Limit; ** as per [21,22]; ^ Not Analyzed. In raw/domestic wastewater, total nitrogen (TN) concentration is reported to vary between 20 and 35 mg L^{-1} and, accounting for up to 82% of the TN, ammonia nitrogen (NH_4-N) is the main nitrogen form [23]. Assuming similar reduction seen for BOD, the TN in the outlet values may be about 6% of that at the inlet.

Several authors [24–27] offer caution on ensuring safe limits of quality for all parameters. These authors also advise continuous monitoring of the use of reclaimed water for UGS irrigation. With no cases of ill-health reported so far from its use in Ambedkar Park in the last 15 years or so, it is to be considered that the wastewater treatment by Tonca STP meets all the set safety limits. It is important, however, to note, as Zalacáin et al. [28] cautions, that long-term use of reclaimed water for irrigation of urban parks can lead to the modification of some important soil properties.

2.3. Estimation of Transport Costs of Treated Wastewater and Related Considerations

There have been a variety of approaches to develop theoretical models for cost estimations of water supply distribution systems [29,30]. For instance, Clark et al. [29] presented the following equation to derive cost functions related to placing a pipe in a trench and making it operational. This equation represents the linear effects of the independent and indicator variables, as well as the interactive effect between the two variables.

$$y = a + b(x^c) + d(u^e) + f(xu) \quad (1)$$

where y is the cost of a particular component in USD/ft; x, design parameter (for example, pipe diameter); u, indicator variable; and a, b, c, d, e, and f are estimated using regression techniques. For example, the cost of some pipes is based on a class type, such as wall thickness, and u is the categorical variable used to make this differentiation.

Akintola and Solomon [30] used the following formula for piping and operation cost.

$$C_2 = C_P d^n (1 + F)(a + b) \quad (2)$$

where C_2 is the operating cost; C_P, the cost per unit length of pipe (Nmm^{-1}); F is the ratio of total cost for fittings and installation to purchase cost for new pipe, which ranges from 1.5 to 6.75; a, the capital charge (%); b, maintenance charge (%), and n is dependent on the current cost of piping.

The procedures of Clark et al. [29], Akintola and Solomon [30], and Dahasahasra Waternet Solutions [31] were considered appropriately for detailing of equipment/installation costs, power requirement (costing based on current tariff in Goa State). Major equipment/resources (water tankers and manpower, as well as fuel) were factored in for working out the costs.

The general estimated costs range anywhere from 50 to 250 USD per meter length of pipeline laying [16]. The cost for Pimpri-Chinchwad continuous pressurized water supply was also referred to for costing [31]. In that project, the laying of 81 km long heavy density polyethylene (HDPE) pipeline of different diameters, ranging from 300 to 500 mm during 2013, costed 112,649,031 INR (=ca 19 USD.m^{-3}). In this study, a cost of 100 USD/m^3 is used to calculate the costs for 15 km (actual length may be shorter). In the entire city of Panaji, with the top layer being sandy/lateritic nature, the excavation costs may be minimal, but cement concreting the pipeline laid with the excavated ground may be essential. In view of that, a higher cost estimate of 100 USD.m^{-3} is adapted.

In Panaji City, over 2.66 MLD groundwater is drawn from borewells using submersible pumps for irrigating *only* the hedge plants and grass cover in 17 public parks of Panaji city. If all of ca 76,750 trees in all these parks are also to be watered, the daily requirement of water would be about 6.24 MLD. All details of cost estimates are provided in Tables 4–6.

Table 4. Costing of 2.66 MLD groundwater pumping using borewells for Panaji parks.

A. Equipment/Resources	Cost (USD)	Explanatory Note
20 borewells (average 150 ft deep in Goa) with bore pipes	810.80 (@40.54/unit)	Cost details not shared; current rates for drilling @INR 200 ft^{-1} used for calculations
15 numbers of 2 HP submersible motors (+ 3 nos. of 5 HP in Joggers park)	8107.95 (@540.53/unit)4053.51 (@1351.17/unit)	Assuming all parks except Ambedkar Park have at least one borewell. A 2 HP motor costs INR 40,000 and a 5 HP motor, INR 100,000.
16 pump operator staff on monthly wage basis	203.63/unit	Water is drawn out for at least 6 h daily.
Total	12,972.26	Pumps work only for 1–2 years
B. Routine annual requirements		
Wages	39,096.96	@12,000 INR $month^{-1}$ (semi-skilled category employees) to maintain/run the pumps
Electricity charges for pumps water filling	3449.05	To draw 2.66 MLD for watering in 16 parks 15 nos of 2 HP submersible motors and 3 nos of 5 HP submersible motors are run for 7 hrs. Power consumption is 1.50 Kwh for 2 HP motors and 3.75 Kw for 5 HP motors. A total of 236.25 Kw power needed daily to draw 2.66 MLD groundwater. For 240 days watering, 56,700 Kw power is required. Current tariff for industry use is INR 4.50/Kwh.
Total	42,546.01	Wages already added to A
C. Recurring annual requirements (Total at 40% of A + B above)		
Operations/ maintenance	22,207.31	Regular servicing, repairs, replacement of motors, new bore wells, incidentals, insurance cover, medical allowance, etc.
Total of A + B + C [15%]	77,725.58	If 6.24 MLD were to be drawn the annual cost would be USD 182,654.64; Groundwater extraction in 240 days 1497.60 MLD or 149,7600 m^3

Table 5. Transport of 6.25 MLD treated wastewater using water tankers.

A. Equipment/Resources	Cost (USD)	Explanatory Note
110 water tankers of 10,000 L capacity	1,866,719.80 (16,970.18/unit)	Each costing INR 125,000. Daily 104 tankers need to be used. Each to make six trips.
220 drivers (monthly wage)	203.63/unit	50% of the drivers to work in day/night shift
220 assistants (monthly wage)	162.90/unit	Spared tankers/personnel to meet any exigency
200 numbers of 5000 L capacity high quality (syntex) water storage tanks	101,820.00 (509.10/unit)	Each park would need to store treated wastewater received through tankers for watering as per their daily schedule. The storage capacity would vary in lieu of parks size and vegetation DWR. Up to 8–12 numbers may be needed in each of the 17 parks
8 numbers of 10 HP motors	2868.80 (@358.60)	For filling the water tankers. Two standby motors included for costing.
Total	1,971,408.60	Can work for 10–12 years with proper upkeep

Table 5. *Cont.*

B. Routine annual requirements		
Fuel costs for 240 days	56,309.10	Calculated @21 km L^{-1} diesel at USD 1.05 (=INR 77.55) present day rate of in Panaji. Each tanker runs on an average 45 Km d^{-1} for 240 days
Wages	967,639.20	@ INR 15,000 (=USD 203.63) $month^{-1}$ for drivers (skilled category employees) and @ 12,000 INR $month^{-1}$ for assistants (semi-skilled category employees) to maintain/clean the tankers
Electricity charges for pumps water filling	9482.66	To fill 10,000 L, 6 min needed for a 10 HP pump. Six such pumps must run for 14 hrs. Power consumption is 7.7 Kwh for 10 HP motor. A total of 646.8 Kw power needed daily to fill 104 tankers. For 240 days watering, 155,232 Kw power is required. Current tariff for industry use is INR 4.50/Kwh.
Total	1,033,430.96	
C. Recurring requirements (Total at 15% of A + B [3,004,839.56] above)		
Operations/maintenance	450,725.93	Regular servicing, repairs, replacement of tires, incidentals, insurance cover, medical allowance, etc.
Total of A + B + C [15%]	3,455,565.89	

Table 6. Cost estimates for transporting 6.24 MLD treated wastewater by pipeline system.

A. Equipment/Resources	Cost (USD)	Explanatory Note
15 km long pipeline	1,500,000 (@100 USD/m^{-3})	The farthest distance between two parks at extreme/distal points is 12 Km along roadsides (see Figure 2 for additional points). Laying of pipeline involves many steps briefly mentioned under Section 2.3
4 electricians and motormen	203.63/ person	Two each per shift for smooth operation of pumps
200 numbers of 5000 L capacity water storage tanks	101,820 (509.10/unit)	For storing water for distribution later
2 units of 75 HP electric motors	3975.06	To fill 6.24 MLD in 15 h each day. Two motors can work alternatively pumping 450,000 L per hour. Each motor costs INR 147,130
Total of A	1,605,795.06	Can work for 35–40 years with proper upkeep
B. Routine Annual Requirements		
Electricity charges for pumps water filling	12,799.68	Power consumption is 58.5 kwh for 75 HP motor. Power needed daily to pump out 6.25 MLD is 877.5 Kw. For 240 days watering, 210,600 Kw power is required. Current tariff for industry use is INR 4.50/Kwh.
Wages	9774.24	@INR 15,000 (=203.63 USD) $month^{-1}$ per electrician (skilled category employees)
Total of B	22,573.92	

Table 6. *Cont.*

C. Recurring Annual Requirements (Total at 15% of B above)		
Operation and Maintenance	3386.08	Regular servicing, repairs, incidentals, Insurance cover, medical allowance, etc.
Total of A + B + C	1,631,755.06	

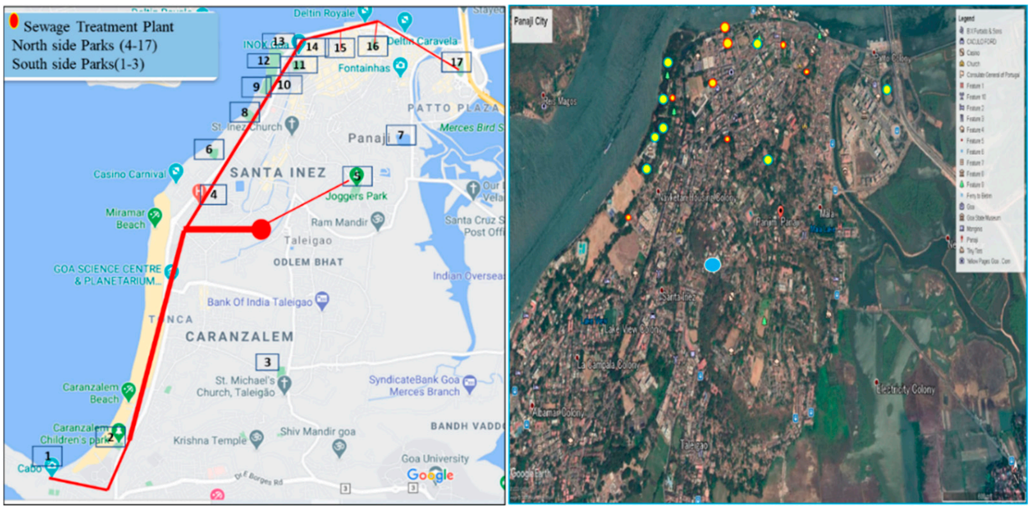

Figure 2. Map indicating pipeline routing (not to scale) to carry treated wastewater from the STP (red dot). Notes for Figure 2. The *indicative* pipeline of a length of ~14 km from the garden point of Cabo Raj Niwas to Ambedkar Park can be laid all along the side of coastal road, which can reach the treated wastewater to 14 of the 17 parks. Treated wastewater from the STP to Joggers Park (5) ~2.6 km away might need two booster pumps to reach the water to an elevation of 30 m above sea level. Much smaller sized public gardens nearer to St. Michael's Church (marked 3 on the map) and on the slopes of Altinho Hill (marked 7) can also be suitably connected by an additional 2 km long pipeline of much smaller diameter (<25 cm). The numbers marked on the map are 1: Cabo Raj Niwas Garden (The largest of the parks needs a pipeline distance of ~4.5 km from STP along the roadside); 2: Caranzalem Children's Park; 3: St Michael's Church Park; 4: Bal Bhavan; 5: Joggers Park; 6: Campal Garden; 7: Military Garden; 8: Kala Academy; 9: South Goa Range Forest Office Park; 10: North Goa Range Forest Office Park; 11: Francisco Luis Gomes Park; 12: Mahavir Park; 13: Art Park; 14: Menezes Braganza Garden; 15: Azad Maidan Park; 16: Garcia da Orta; and 17: Ambedkar Park. Google Map on the right side shows all seven parks surveyed (yellow dots with blue outline) and some other parks (yellow dots with red outline) and Tonca STP (blue dot with white outline).

3. Results

3.1. Characteristics of the Raw Sewage and Treated Wastewater

The characteristics of the pooled sewage and at various stages of treatment are provided in Table 3. From the routine and officer-in-charge verified documents maintained in the plant's office, it was evident that the plant invariably achieves safe discharge limits for all the various parameters routinely measured. From these data (a mean of 10 different days), it is evident that the wastewater handling and operations are of high stringency. As mentioned before, ~99% of the treated water is let out daily into the ca. 4 km long tide-influenced creek running in to the lower stretches of the River Mandovi north of Art Park.

3.2. Cost Estimation for Transporting Treated Wastewater

Cost estimations along with necessary explanatory notes are provided in Table 4 for drawing using borewell, in Table 5 for tanker transportation of 6.24 MLD treated wastewater to 17 parks, and in Table 6 for laying pipeline. From the regulatory ecosystem services (RES) point of view, supplying 6.24 MLD treated wastewater will save 2.66 MLD of groundwater currently extracted for watering only the hedge plants and lawns/ground cover). More advantageously, it will also help irrigate over 76,750 trees in the 17 parks of Panaji city.

In the overall, if all of 6.24 MLD groundwater were to be drawn, the annual cost would be USD 182,654.64, requiring more borewells plus drawing groundwater for longer duration than the 6–7 h daily during the working days. Notably, ca 1497.60 million liters (or 1,497,600 m^3) of groundwater would be extracted in 240 days, which can be avoided by using treated wastewater.

From the many details provided in Tables 5 and 6, it is apparent that pipeline would be serving for a greater number of years (at least 20 years without major replacements) than the water tankers, which can last to a maximum of 7 years. Its durable equipment cost is ~20% lower than the high maintenance/repair/replacement requiring and fuel-consuming, carbon-emitting trucks. The annual maintenance cost would also be far lower (<2.2% of the water tanker-based transportation). With just ~1% manpower annual wages than those to be paid to tanker staff (~967,640 USD) or to the borewell running staff (~39,100 USD), the pipeline mode is far superior than either tanker (or groundwater-drawing borewells). Its carbon footprint is much smaller. Moreover, the extraction of 2.66 MLD groundwater by borewells cannot irrigate the trees in any of the 17 parks.

4. Discussion

Wastewater reclamation from a variety of sources can be a valuable (and 'renewable') resource. As the EPA noted [4], treating and reusing wastewater is beneficial for agriculture and irrigation, potable water supplies, groundwater replenishment, industrial processes, and environmental restoration. Further, any adaptable and practical approach for water distribution, sewerage handling, and storm water control are essential for integrated water management. From the hydrological perspectives, the reclaimed water serves indeed as a critical alternative to existing water supplies in enhancing water security, sustainability, and resilience.

From the schematic diagram (Figure 3) it can be highlighted that the RES is aided by reusing the treated wastewater. Through rearing a variety of species of plants and trees, well-kept ground cover (lawns), and hedge rows, the urban greenery would meet many regulatory and cultural services.

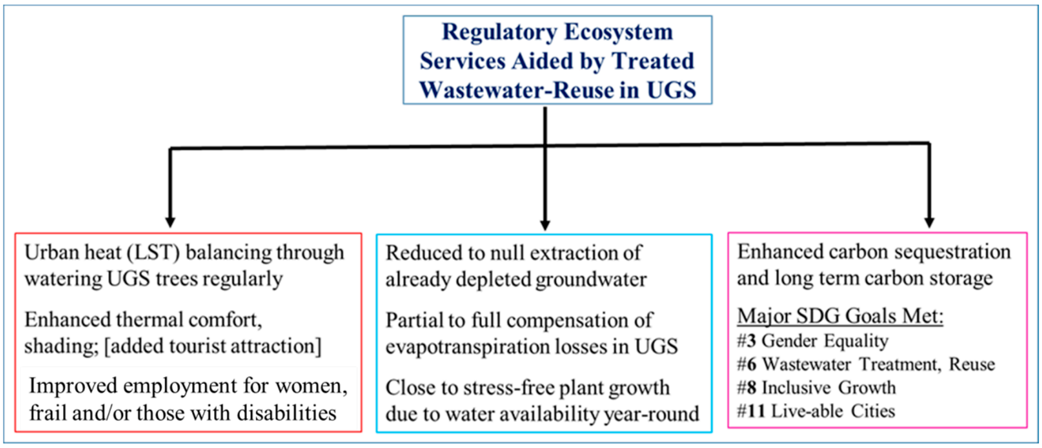

Figure 3. Qualitative indicators of benefits offered by reusing treated wastewater in the urban green spaces to enhance regulatory ecosystem services. For instance, the LST can be reduced by >2–4 °C, thus, improving thermal comfort. Over 80% compensation of evapotranspiration losses of 16,000 m^3 water daily from 1.86 sq km UGS in Panaji can be achieved by watering the UGS (including the hitherto >76,500 UGS trees not watered at all). Similarly, many advantages listed in the figure are achievable.

4.1. Importance of Treated Wastewater Use in UGS

Although the concept and practice of using treated wastewater for irrigating crops and UGS is neither unique nor novel [6,32], the ecological and economic perspectives of its use for managing the UGS are yet to receive the attention they deserve [20]. A lot of ecological benefits are feasible. For example: (a) avoiding groundwater extraction, (b) conserving urban hydrological reserves, and (c) significant compensation of evapotranspiration losses. In terms of living comforts, the trees would perform at acceptable limits when supplied with adequate applicable water. This will enable shading, pedestrian thermal comfort, and increased outdoor work hours.

Wastewater treatment and reuse is an endeavor to safeguard ecosystems, societies, and economies [18]. Regular and assured availability of treated water would eliminate/reduce the water stress of trees and other greenery all year round. With enhanced plant growth through elevated rates of photosynthesis, there would be expanded carbon fixation, storage, and sequestration potential. Its use would enhance evapotranspiration from the UGS and ease UHI impacts [33]. Additionally, as Wilcox et al. [18] suggest, with favourable societal/public perception, acceptable public-health-safe water quality, environmentally friendly infrastructure, and technology applications, the marketability of reuseable water is enhanceable. By using the information derived in this study, it can be suggested that uninterrupted supplies of treated wastewater would irrigate the UGS and containing the LST in these times of global warming [34].

In many rapidly expanding urban locations, reduction in adverse impacts can be highly effective and possible speedily by increasing green spaces, such as parks, gardens, terrace agriculture, and vertical vegetation [35,36]. Livesley et al. [2] acclaim that by creating UGS, carbon can be sequestered for decades or centuries in urban trees, durable social forestry, and into their products.

As noted previously and has been widely accepted, the intensity of heat islands can be reduced by providing shade and evapotranspiration-induced cooling [2]. Norton et al. [34] emphasize that "urban trees are perhaps the most effective and least costly approach to urban heat island mitigation and adaptation".

While it is beyond the scope of the present study, it may be suggested that the greatly receding groundwater reserves year on year are posing severe water crises in many parts of the globe [20]. By using ca. 6.25 MLD treated water from Tonca STP, meeting all the safe-limits criteria, a complete stoppage of groundwater extraction, currently of estimated 2.66 MLD in 17 parks in Panaji for watering UGS, can be possible.

4.2. Regulatory Ecosystem Services Achievable Using Treated Wastewater in UGS

The large quantities of wastewater generated daily from households and workplaces are often disposed without any consideration of the deleterious impacts these polluted waters cause [37]. In some cities [38], huge volumes of untreated domestic wastewater are diverted unsafely to grow vegetable plants and fruit trees. The RES by UGS vegetation are enhanced by the reduction of water stress. This will be advantageous in various ways, as the acceptable performance is enhanced in all types of vegetation. Assuming a 10% better growth in water stress-free vegetation, the amounts of carbon storage and sequestration would be higher. This could amount to carbon footprint reduction/neutralization of urban residents. Adequate water supply in the UGS, including trees, is among the most desirable requirements, which can help in increased carbon sequestration. As many as 48.30, 53.92, and 116.60 tons ha^{-1} of CO_2 is estimated to be sequestered, respectively, by the hedge plants ground-cover and trees in Panaji city UGS [19]. With trees also getting regularly watered, there could be increased CO_2 sequestration, likely 10 to 15% more.

Wastewater recycling is becoming more common [18] for sustainable local and regional hydrological environment of the cities. Such insights lead to evolving policies and regulatory steps for utilizing the treated wastewater for non-potable and industrial, civil construction, road cooling, etc., or even direct and/or indirect potable uses. For implementing wastewater reuse, modalities need to consider minimal or highly suitable alterations to existing infrastructure, energy needs, public acceptability, and freshwater demand/availability.

4.2.1. Reduction in Urban Heat Island Effect via UGS Irrigation

Reduction in LST and regulation of many microclimate (urban climate regulation) parameters are among the widely regarded ecosystems services [20,39–41] offered by the UGS. This will also be in terms of improved thermal comfort, reduced UHI, shading (particularly during the hot/summer months), in addition to aesthetic appeal and other services. Additionally, Livesley et al. [2] recognized the role of urban trees in managing urban catchment hydrology. Overcoming local governance constraints, such as land use/availability, technology adoption, and marketing of water reuse [18], would augur well for enhancing the RES. The LST in Panaji, on an increasing trend (38–42 °C) in Panaji during 1990–2019 period [41], could be at least 3–4 °C lower with proper irrigation of UGS that is spread in 1.86 km^2.

4.2.2. Urban Heat (LST) Balancing

The urban heat island (UHI) is indeed an acknowledged adverse phenomenon. It is a discomfort for urban life and causes health problems [42]. Invariably, the UHIs lead to increased energy use for building space cooling. Several investigations and sophisticated climatic and physiological models (e.g.) Ballinas and Barradas [33] have helped recognize the potential of urban forests in mitigating heat island effects by reducing the LST [43]. Quantification of the heat balancing by regular watering of the UGS is not performed in this study. Certainly, it can be suggested that the UHI ill effects can be controlled by irrigating treated wastewater (that invariably meets the safety standards in the city of Panaji), which, in turn, can ward off the hazards due to heat stress with a potential of heat stroke [42].

Utilizing treated wastewater for maintaining UGS is a reliable and pragmatic strategy [3,20] and helps address the larger issues of depleting groundwater resources and mitigation of climate change impacts. Regional evapotranspiration rate of 8.89 mm m^{-2} d^{-1} was reported in Panaji city [19], where adequate irrigation of UGS can be inferred to help recognize their importance in achieving salubrious weather and urban heat balance.

There are many parks in Panaji city that are hardly watered between April–June, the intense summer months in India, mainly due to dried up borewells and/or to shortage of drinking water supply to many/some areas in the city. The absence of watering leads to the wilting of some—and drying up of many—plants. During these times of raised LST, there is discomfort for urban pedestrians, toiling peoples, and commuters, among others. The coastal Panaji city experiences annual LST variations in 38–42 °C ranges is rising rather unabatedly, although with fewer UHIs [41]. However, if watered regularly, over 76,750 trees in the city's UGS would help in reducing the LST, energy costs, and in avoiding groundwater extraction.

4.2.3. Elimination/Reduction in Groundwater Extraction

The concept and practice of using treated wastewater for irrigating crops and urban green spaces is not unique or novel [3,5,18]; the ecological and economic perspectives of its use for managing the UGS are yet to receive the attention it deserves [20]. The groundwater volume of ~2.66 million liters extracted daily through borewells equals 638,000 m^3 for a 240-day non-rainy period in the year for watering only the lawns (=grass cover) and hedge rows in these parks. This voluminous extraction can be avoided, plus over 76,750 estimated number of trees in the parks can also be watered by diverting 6.25 MLD (or 44.64%) of the ca. 14 MLD of treated wastewater of safe discharge limits that is produced every day by the city's STP, by spending over USD 510,000 (@INR 8.00 m^{-3} wastewater [16] a year on stopping the water that is let out into an already-polluted creek.

4.2.4. Compensation of Evapotranspiration Losses

Treated wastewater use can completely compensate for evapotranspiration losses. The regional evapotranspiration rates of Panaji (EToP of 8.86 mm d^{-1} m^{-2}) derived by Ramaiah [19] are useful to note that, annually, 76% of the 2774 mm of rainwater–recharged groundwater is evapotranspired during the non-rainy eight months. Meeting the water requirements in the 1.86 km^2 of Panaji UGS via wastewater reuse amounts not only partially compensates the daily evapotranspiration loss of ~ 16.50 MLD but also helps retain similar volumes of groundwater. Regular UGS use of treated wastewater helps percolation into the subsurface and would help in avoiding the tree roots accessing the groundwater in situ. Additionally, its above-ground evaporation helps retain the groundwater.

4.3. Challenges and Solution Steps Based on Cost–Benefit Analysis

The basic principles of cost estimation in laying water supply pipeline involves the type of pipe (e.g., ductile iron pipe, PVC pressure pipe, asbestos cement pipe, etc.), soil conditions, installation conditions, and the following associated activities (excavation, dewatering, sheeting, etc.) and costs as per Dahasahasra Waternet Solutions [31].

A. Construction costs include pipeline cost and pump station costs. Major pipeline costs are for land excavation for pipelines running under pressure, including trimming and dressing sides, levelling of beds of trenches to correct grade, cutting joint holes, cutting trees and bushes, etc.; refilling consolidation and watering of refill; restoration of unmetalled or unpaved surface to its original condition, including the cost of rainwater drainage, fixing caution boards, etc.; and disposal of surplus soil.

B. Supply and transportation plus laying of 36 cm diameter (PN8 grade [for water application; 8.0 $kgcm^{-2}$] HDPE pipes), joining, field testing, and complete at-site commissioning, including all cost of material, labor required costs.

In this study, the cost of intermediate storage tanks in the parks is included, as is also the cost of control and telemetering equipment for automatic, unattended operation of pump stations. Since the main pipeline would be all along the side of the public road (Figure 2), the right of way, engineering allowance, contingencies, and subsequent costs are not included in the estimate performed for this study.

Perhaps the first stumbling block in endeavoring an analysis such as this one is: how is it practical or workable to ferry out 6.24 million liters of treated wastewater daily? Other challenges include: (i) How can 624 trucks of 10 m^3 be handled and filled daily? (ii) What is the cost/investment for infrastructure to meet the daily water demand? (iii) How much investment is there for manpower, energy needs, space for water carriages (trucks) and related utilities? Keeping these aspects, and similar questions, in mind, and also the need for enhanced growth, aesthesis, and carbon storage as important considerations in the sustainable management of UGS, we attempted to provide a cost estimation, which is detailed below. A comparative account of costing under different headings is listed in Table 7. In the long run, the laying of the pipeline, as early as feasible, to supply treated wastewater to all the parks would help improve many of the RES of the UGS. It is more economic vis a vis water tanker-based transport, in terms of both capital and other costs.

Table 7. Capital, routine, and operation maintenance costs of three different processes applicable for meeting daily water requirements (DWR) in the parks of Panaji city.

Costing (USD) Details	Water Supply/Transport-Process		
	Borewell Based	Water Tanker Based	Pipeline Based
Capital	12,972.26	1,971,408.60	1,605,795.06
Annual Routine	42,546.00	1,033,430.96	22,573.92
Annual OM	22,207.31	450,725.93	3386.08

Table 7. *Cont.*

Costing (USD) Details	Water Supply/Transport-Process		
	Borewell Based	**Water Tanker Based**	**Pipeline Based**
Total cost	77,725.38	3,455,565.89	1,631,755.06
Source of water for parks	Groundwater within the parks	Treated wastewater from STP	Treated wastewater from STP
% DWR met (for only hedge plants + grass-cover)	60.18	100	100

In Panaji city, the farthest public garden (Governor Residence arena with over 100,000 m^2 green spread) is six km away, by road, from the STP. The next farthest is Ambedkar Park, five km away, by road, from the STP location. All other 15 parks are within 3.5 km reach. A suitably planned pipeline route, shown in Figure 2, not exceeding a total length of 15 km can reach the treated wastewater from the STP, which is continuously meeting all safe discharge quality for all the UGS of the city. The city is currently getting drinking water from a pipeline of over 55 km distance and could afford to use its environmentally highly safe treated wastewater for enhancing all the regulatory ecosystem services mentioned above. In many Indian cities and elsewhere in the world, the authorities ought to plan and install pipelines to draw treated water on a continuous/need basis to achieve reduction in carbon footprint, howsoever small it might seem. As Herbert Dreiseitl stated (cf. Margolis et al.) [44],"we would benefit from the creation of a stronger emotional and spiritual connection to water".

4.4. UN Sustainable Development Goals Met

Among the above 17 SDGs, Goal #6 (clean water and sanitation) is one of the "outcome-oriented targets". It places emphasis on, among other aspects, "on safe and affordable drinking water; end open defecation and provide access to sanitation and hygiene, improve water quality, wastewater treatment and safe reuse, increase water-use efficiency and ensure freshwater supplies, implement IWRM, protect and restore water-related ecosystems" [45]. The two "means of achieving" targets are to "expand water and sanitation support to developing countries, and to support local engagement in water and sanitation management" [46]. Thus, a pragmatic rethinking on wastewater management is mandatory. In addition, from other newer knowledge provided by this work, it can be briefly pointed out that the following SDGs are met in some capacity.

By and large, it can be suggested that SDGs 3, 6, 8, and 11 are addressed in this study. This is because a primary information input is based on the highlighting of the employment opportunities and employability of economically and more relevantly physically weaker folks covering gender equality (SDG 6) and inclusive growth (SDG 8) and SDG 11 of "making cities and human settlements inclusive, safe, resilient, and sustainable".

Of the six "outcome-oriented targets", SDG 6 includes wastewater treatment and safe reuse. This study has examined the availability of treated wastewater for use in sustainable UGS management. Possibilities of saving potable water for human consumption are advantageous. In particular, the objectives set for this study comply with SDG 13: "Take urgent action to combat climate change and its impacts by regulating emissions and promoting developments in renewable energy". The outcomes can be useful for implementing activities to formulate and practice national adaptation plans.

Results of this study relate quite closely to the Paris Agreement [47]. The enhanced regulatory ecosystems services of the UGS can help achieve the Paris Agreement's long-term goal of limiting global warming to well below 2 °C, vis-a-vis pre-industrial levels, to achieve a climate neutral world by 2050. In this context, the potential of sequestering ~116 tons of CO_2 ha^{-1} yr^{-1} by trees in the UGS [19] needs to be harnessed in many Asian cities in order move towards net-zero carbon emissions by 2050, as is the aim of Japan and

South Korea [48]. As such, it is technologically feasible to economically recycle wastewater produced copiously in all urbanized settlements worldwide.

5. Conclusions

This study explored the use of treated wastewater/recycled water in the UGS and how it can aid in the ecosystem services of Panaji city, which is proposed to become a smart city. Several types of costs involved for transporting treated wastewater either through water tankers/trucks or through the pipeline options are included. The transport of treated wastewater via pipeline (vis a vis water-tankers) serves as the highly cost-effective (overall 47% lower than water tanker), durable (low-to-nil maintenance costs), sustainable (least interfering, less energy requiring), and operationally appropriate mode (low skill requiring, high ease of working). Additionally, it helpfully strengthens many regulatory (and some cultural) ecosystem services, such as reduced LST, possibly up to 4 °C in all the city corporation's 21.60 km^2 area and conservation of groundwater to the tune of ~16.50 MLD during the 240 days of non-rainy period. Our analyses suggest that there would be enhanced and water-stress-free growth of trees and other greenery in the UGS, which, in turn, can help sequester and hold 10–15% more carbon than those UGS under water stress.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/hydrology9100180/s1, Table S1. Questionnaire for seeking information from Forest Department, Table S2. Questionnaire for Urban Planning Department, Table S3. Questionnaire for Municipal/City Corporation Office, Table S4. Questionnaire for Sewage Handling Department.

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