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Wastewater Management Strategy for Resilient Cities—Case Study: Challenges and Opportunities for Planning a Sustainable Timor-Leste

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Abstract: High population growth, a lack of wastewater treatment plants and poor wastewater management are major challenges in wastewater management in Timor-Leste (East Timor). One of the approaches of the government of Timor-Leste is to separate wastewater into greywater and blackwater from domestic, commercial, residential, and industrial areas. Three methods were applied to obtain insight into the locations and discharge of grey- and blackwater to develop a cost-effective wastewater strategy: a field survey and data collection, interviews with over 130 participants from local authorities and communities, and the open-source mapping of locations of wastewater discharge. This research concluded that 47.7% of the grey wastewater is discharged into open sewers connected directly to the sea. Most communities discharge their wastewater directly due to the absence of wastewater management, policies and regulations, and lack of communities' understanding of the possible health impacts of wastewater. The impact of poor wastewater management showed that most of the children in these communities have suffered from diarrhea (73.8%), and in the rainy season, there is a high possibility of infection with waterborne diseases. The literature review, field mapping, and interviews show that there is high demand for a cost-effective wastewater strategy for health improvement. Low-cost nature-based solutions such as constructed wetlands and bioswales can be implemented with local skills and materials to improve the wastewater situation and address other challenges such as biodiversity loss, heat stress, drought, and floodings. These installations are easier to rebuild than large-scale grey infrastructure given the multiple hazards that occur in Timor-Leste: landslides, earthquakes, strong wind, and pluvial and fluvial floodings, and they can serve as coastal protection.

Keywords: wastewater; domestic wastewater management; impact; water quality; climate change

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1. Introduction

1.1. General Overview

Timor-Leste, a young country in Asia and the Pacific region, is experiencing rapid population growth each year. From 2015 to 2022, the total population increased from about 1,183,643 to 1,341,737, with an average annual growth rate of approximately 1.81% [1]. The population growth has implications for expanding water supply and sanitation services to rural areas and growing urban centers [2]. With the high population growth, Timor-Leste shows increasing business and economic activity, industrialization, urbanization, increasing demand for water supply [3] and higher wastewater production [4]. Wastewater contains inorganic and organic matter, which may be toxic to the various life forms in ecosystems [5] and will have impacts on human health, environment, water resources, and the resilience of Timor-Leste.

In cases where new buildings are not equipped with adequate sanitation systems, wastewater flows through open sewers and contributes significantly to pollution, the degradation of land, and losses of biodiversity, affecting the marine and urban environment and posing a risk for public health and clean water security. Macro- and mycobacteria in wastewater can negatively impact human health through the spread of diseases, such as cholera, typhoid fever, and tuberculosis; viruses can cause hepatitis; and protozoa can cause dysentery [5]. These issues mainly occur in developing countries including Timor-Leste, where wastewater treatment and management are lacking [6] and surface water and sanitation systems are of a very poor quality and affect the groundwater quality [7]. Even in Dili municipality, the state capital, the wastewater flows through several open sewers, discharging wastewater directly into the sea. Therefore, the assessment and characterization of the wastewater quality is important for a new cost-effective wastewater strategy with sustainable treatment processes to minimize health impacts and the impact on the environment [8]. Assessments focusing on wastewater management through scientific and technological methods, legal and policy development, institutional frameworks, and partnerships play an important role in supporting the prevention of and reduction in wastewater pollution from untreated or inadequately treated wastewater discharges, restore biodiversity losses, and improve human well-being [9].

It is important to understand the potential issues regarding wastewater management and treatment in Timor-Leste, as the progress in the last two decades has not adequately included water, wastewater, and solid waste management or environmental protection. Therefore, insights into the current wastewater management is fundamental to better understand the potential issues of wastewater and solutions to improve the management of the disposal, conservation, and protection of wastewater in towns and villages across the national territory of Timor-Leste.

Timor-Leste needs to put into practice the management of its wastewater and other environmental issues. This research will help to identify and better comprehend the real circumstances and potential issues regarding wastewater treatment and management in the country. The management of wastewater is needed by the country to maintain environmental and human health, including improving the resilience of cities and towns for the future [10]. Wastewater could be reused as a potential or valuable resource for groundwater recharge or recharging aquifers, agriculture, commercial-grade fertilizers, industries, domestics, and environmental enhancements [11]. Practically, wastewater management or treatment is needed to remove pollutants from wastewater and protect the environment and public health, avoid biodiversity losses, and maintain economic resilience [12]. Wastewater treatment with the aims to extract pollutants, remove coarse particles, and eliminate toxicants and potential pathogens would enable clean water to be discharged back into the environment for various purposes [13].

1.2. Objectives

The objectives of this research are as follows:

1. To map out the wastewater management challenges and strategy for resilient cities in Timor-Leste.
2. To identify, gather, and compile the potential issues, challenges, and opportunities regarding wastewater treatment and reuse.
3. To review the existing government policies on wastewater management and treatment in Timor-Leste.
4. To produce alternatives and recommendations to the relevant government entities relating to integrated wastewater management and treatment including reuse.

1.3. Methodology

The methodologies which are adopted for conducting this research are composed of several phases: (i) field survey and data collection; (ii) interviews with local authorities and communities; (iii) open-source mapping of locations of wastewater discharges and possible solutions for sustainable wastewater management.

Field survey and data collection

Field surveys and data collection for wastewater management were carried out in the municipalities of Bobonaro, Dili, including the Atauro sub-district, Ermera, Aileu, Covalima, Manatuto, Liquiça, Baucau and the Maubisse sub-district of the Ainaro municipality. During data collection, information was gathered related to wastewater issues, treatment, and management. Wastewater data from the Ministry of Public Works (DNSB, 2017) and water disease data from the Health Center (Comoro and Becora Health Center, 2017) were utilized. An inventory was made of related policies and regulations through the Ministry of Public Works, Department of Water and Basic Sanitation, NGOs, and civil societies including the other stakeholders in Timor-Leste.

Site visits were performed for the observation, description, and mapping of wastewater conditions. During the field visits, interviews were conducted with over 130 participants from local authorities and communities (local authorities and community households and owners of small industries that produce wastewater); Table 1.

Table 1. Participants of the interviews.

Participants	Quantity	Percentage (%)
Local Authorities	46	35.4
Car Wash Company	19	14.6
Home Industry	10	7.7
Restaurants	5	3.8
Community Households	50	38.5
Total	130	100.0

Semi-structured interviews included the following:

(i) Site visits were performed to discuss, observe, and describe the wastewater treatment conditions through wastewater channels or sewers around the country.
(ii) Related policies and regulations were gathered and compiled through the Ministry of Public Works, Department of Water and Basic Sanitation, including the other stakeholders.

The questionnaire included the following:

(i) Demographic information of the community households: gender, education level, occupation, family size.
(ii) Actual wastewater management conditions in Dili city: the infrastructure of septic tanks, distance of the septic tank from the water supply, the depth of the septic tank, the discharge wastewater network, the domestic wastewater deposit, the water supply.
(iii) The community understanding and perceptions on wastewater management; attitudes toward and knowledge about the impact of domestic wastewater treatment; community perspectives on wastewater treatment; the cost of wastewater transport; the knowledge to reuse wastewater; whether family members were suffering from diarrhea; the community opinion on arranging an alternative solution for WWM, such as off-site wastewater systems, onsite wastewater systems, ecological sanitation, other related infrastructure.

The proposed method used in this research was exploratory analysis and the chi-squared test was applied to determine the relationship between two or more features [14]. The chi-squared test utilizes a contingency table of data which is classifid according to a categorical database questionnaire.

The statistics for the chi-squared test are computed as below.

$$X^2 = \sum_{i=1}^{R} \sum_{j=1}^{C} \frac{(o_{ij} - e_{ij})^2}{eij} \quad (1)$$

where

o_{ij} is the observed cell count in the ith row and jth column of the table.
e_{ij} is the expected cell count in the ith row and jth column of the table, computed as below:

$$e_{ij} = \frac{row\ i\ total\ x\ col\ j\ total}{grand\ total} \quad (2)$$

In this data processing and analysis, IBM SPSS Statistics 21 software was used for data entry and processing and the analysis of the questionnaire.

1.4. Identification of Problems

The potential problems which are identified regarding the wastewater management and treatment in Timor-Leste are as follows:

1. Awareness: poor education and lack of understanding in communities about wastewater management and risks.
2. Most of the wastewater (except from the toilet septic tank) is discharged directly into open sewers or directly onto land surface.
3. Most of the existing principal drains or wastewater channels are open and flow directly to the sea.
4. Some wastewater is infiltrated underground.
5. Some open wastewater channels are used to cultivate vegetables for consumption with a lack of understanding of the possible health impacts of wastewater.
6. There are three wastewater treatment stations existing in Timor-Leste: Tibar Wastewater Treatment (ETAR), Covalima Wastewater Treatment, and Baucau Wastewater Treatment. Only Tibar is currently in use; both Covalima and Baucau are closed and were only functional during the UN mission in Timor-Leste.
7. Solid waste is frequently thrown into the open wastewater channels. Maintenance and fecal sludge removal from septic tanks is not provided by the government and individuals need to pay to transport their wastewater to the ETAR.
8. There is a lack of integrated policies and regulations for managing wastewater and solid waste in both urban and rural areas.
9. There is no integrated master plan for urban and rural community house construction that would ensure that new housing would have access to piped sewage outlets.

2. Wastewater Characterization and Management Challenges

Wastewater can be generated and/or produced from restaurants and convenience stores, cafeterias, hospitals and clinics, meat processing and slaughterhouses, car washes, photography laboratories, beauty salons, laundromats and dry cleaners, schools, and mortuaries [15]. The quality of and substances in wastewater will vary over time and between locations since it is the product of the water that is used for several domestic, industrial, commercial, and agricultural activities with different production scales and quantity of volumes over time. Many industries and economic businesses, cities, farming lands, commercial regions, and urban areas all produce large quantities of highly polluted wastewater [3].

Domestic wastewater is divided into two main types: blackwater and greywater [16]. Blackwater is the wastewater from toilets that contains fecal matter and urine. Meanwhile, greywater is wastewater from hand basins, showers, spa baths, washing machines, laundry tubs, kitchen sinks, and dishwashers [17]. Industrial companies use water for many purposes, such as cleaning products.

Based on this research, it has been identified that there are three main wastewater sources in Timor-Leste: domestic, commercial, and small-scale industries, which are categorized into urban and rural areas.

Wastewater management is a critical component of sustainable development, ensuring the protection of public health, the environment, and economic prosperity. In Timor-Leste, like many other countries, the effective management of wastewater presents both challenges and opportunities. As a young nation striving for progress and stability, Timor-Leste recognizes the urgent need to address wastewater issues comprehensively and strategically. Wastewater management professionals are needed with expertise in the characterization and purification of wastewater in small-scale and large treatment plants (WWTPs) and the characteristics of influent and effluents and the bioremediation of industrial and residential wastewater [18].

The government of Timor-Leste has commanded decree-laws and formulated master plans aimed at establishing robust frameworks for wastewater management. These legislative measures and strategic plans are designed to mitigate the adverse impacts of inadequate wastewater management on public health, natural ecosystems, and socio-economic development. The decree-laws and the master plan of wastewater treatment plants will be incorporated in the following:

(1) Almost all the facilities in the project area utilize a pit or septic tank or directly discharge into public water. There is one wastewater treatment plant (WWTP) receiving and treating septage located in Tibar in Timor-Leste, which was inaugurated in 2015 to treat sludge from septic tanks. Fecal sludge is collected by private operators based on septic tank owner requests. There is no centralized off-site wastewater system in the country.
(2) Decree-Law No. 41/2020, of 25 September 2020, created the state-owned company Bee Timor-Leste, E.P. (National Water Company, Dili, Timor-Leste) to manage the water services related to the national water supply and sanitation network. The corporate objectives of Bee Timor-Leste, Empresa Publica (BTL, E.P.), include promoting the efficient use of water, ensuring public water supply (through the design, construction, operation, and management of water supply systems), ensuring public sanitation (through the design, construction, operation, and management of wastewater sanitation systems), and establishing control and inspection measures for the prevention of illegal connections to the public water supply system and injections into the public water sanitation system.
(3) The estimated amount of wastewater is derived from the Dili Sanitation and Drainage Master Plan (DSDMP): domestic wastewater constitutes 80% of its daily consumption.
(4) In 2012, the Dili Sanitation and Drainage Master Plan (DSDMP) including sewerage and drainage was approved by the Council of Ministers. Projects on sewerage and drainage have been implemented pursuant to the DSDMP as of August 2014. After 2025, based on its activity, the DSDMP recommends a review of the plan and its modification based on its progress and achievements and issues occurring in its implementation in order to study the unification of decentralized WWTPs by replacing some of these with pumping stations.

Development and planning issues of wastewater management

In the JICA Dili Urban Master Plan of 2016, the Dili Sanitation and Drainage Master Plan (DSDMP) [19] laid out the direction and proposed development plans in the sewerage/drainage sector. The proposed plans for the sewerage sector were the construction of a community sewage treatment system; a decentralized water treatment plant; the strengthening of the National Directorate of Basic Sanitation (DNSB); establishment of the standard of the sewerage systems for buildings; the review and revision of the DSDMP; communication with communities on the sewerage system and instructions to the communities for the cooperative maintenance of the sewerage system. And for the drainage system, the proposed plan from JICA in 2016 was the removal of dust and dirt from drainage channels; the improvement of the inclination of drainage channels; the re-shaping of sections of drainage channels; the establishment of technical standards of curbside rainwater collection pits and connection pipelines to drainage systems between the responsible organizations for roads and drainage

systems; instructing communities on the cooperative maintenance of the drainage system; the surveillance of rainfall; and the study and construction of retention ponds.

As of 2022, the current conditions for the sewerage and drainage sector are as follows:

- There is still no centralized off-site wastewater system in the country. However, there are projects related to the design and construction of a new wastewater treatment plant (WWTP) in Bebonuk, Dili, as part of The Water, Sanitation, and Drainage (WSD) Infrastructure Project from 2022.
- An improvement to the drainage infrastructure in Dili is proposed in the Dili Drainage Infrastructure Improvement Project (DDIUP) in 2020–2024, including the proposed rehabilitation/new construction of a drainage system with a 25-year return period capacity. A study about retention ponds is also available in the DDIUP.
- The Council of Ministers of the VIII Constitutional Government of Timor-Leste signed a contract with the Millennium Challenge Corporation (MCC, Washington, DC, USA) for The Water, Sanitation, and Drainage (WSD) Infrastructure Project in 2022. Included in the WSD Project are drainage channel improvements designed to reduce flooding in Dili.

2.1. Wastewater Characteristics in Urban Areas

Geographically, Timor-Leste is composed of 13 municipalities: Dili, Ermera, Bobonaro, Baucau, Covalima, Ainaro, Aileu, Liquiça, Manufahi, Manatuto, Viqueque, Lautem, and the special economic zone of Oecusse. The capitals of these municipalities are categorized as the urban areas of the national territory. The field survey and data collection regarding wastewater treatment and management challenges covered some of these municipalities, such as Bobonaro, Dili, including the Atauro sub-district, Ermera, Aileu, Covalima, Manatuto, Liquiça, Baucau, and the Maubisse sub-district of the Ainaro municipality (Figure 1).

Figure 1. Field survey and data collection for wastewater management of selected urban areas in Timor-Leste.

The wastewater sources produced from domestic, commercial, and industrial activities from these municipality capitals lack management, treatment, and conservation. Most constructors used their own methods to build their houses, toilet septic tanks, and kitchens based on their economic circumstances. Therefore, household greywater and commercial and industrial wastewater is directly connected to the open drains around their residencies (Figures 2 and 3). In Timor-Leste, most domestic greywater including commercial and industrial wastewater, such as water from washing cars and motorbikes, is directly disposed of into the open sewer discharging directly into the sea. There are several main wastewater channels within the Dili capital, such as the Comoro drain, Pantai Kelapa channel, Aitarak Laran and Maloa channels, Colmera channel, Bidau Santa channel, and the other sub-channels (Figure 2a,b). Over 80% of all wastewaters is discharged into the environment without an adequate treatment plant [4].

Figure 2. Some of the main open sewers in Dili municipality: (**a**,**b**) communities disposing and letting their bathroom and kitchen wastewater into the open sewers; (**c**,**d**) some of the main open sewers in Pantai Kelapa and Aitarak Laran within the Dili municipality; (**e**) some of communities are using the wastewater channels to plant vegetation, such as kangkung; (**f**) and some taxi drivers are reusing wastewater from the open sewer for car washing.

Most of the wastewater flowing through the open sewers is a mixture of water and solid waste, such as that presented in Figure 3c,d. The solid waste consists of plastics, empty bottles, empty cans, and other materials such as glass.

Some communities hire wastewater trucks from private companies to maintain their septic tanks and transport their blackwater to treatment stations, such as the ETAR in the Tibar area, for treatment. Most communities do not rent wastewater trucks and leave the waste to infiltrate the underground soil (when the bottom of the septic tank is not sealed). The management of urban wastewater is important to avoid disease and environmental degradation. Therefore, urban wastewater generation and treatment must be supported

by wastewater assessments and legal policies and frameworks, providing a review of innovative, sustainable, cost-effective, and energy-efficient solutions to treat urban wastewater. International knowledge exchange could help in multiple case studies through skill integration and new technologies for capacity building and raising awareness of urban wastewater management [18].

Figure 3. Wastewater flowing to the sea surface which mixes with solid waste: (**a**,**b**) the wastewater from the stream flows directly into the beach area to the sea level; (**c**,**d**) wastewater mixture and contamination with solid waste; (**e**) coastlines are littered with solid waste, such as plastics, empty bottles, empty cans, etc.

2.2. Wastewater Characteristics in Rural Areas

Wastewater in rural areas, such as villages and hometowns in Timor-Leste, are different from urban areas in terms of the wastewater production volume and waste deposit sites. The volume of wastewater in rural areas is low due to the lower population density compared to densely populated urban areas [20]. In rural areas, the greywater from communities is mostly discharged directly into their own properties, such as farms, gardens, and rivers (Figure 4). There are wastewater drains and open sewers that are in poor condition due to their age and lack of maintenance.

Figure 4. Wastewater discharge conditions in rural areas: (**a**,**b**) wastewater from the community's toilet septic tanks (from Suco Holsa, Maliana); (**c**,**d**) discharged wastewater to unplanted soils around community's houses; (**e**–**g**) wastewater disposed in community's farms.

2.3. Management of Wastewater Treatment in Timor-Leste

a. Wastewater treatment stations

Related to the management of wastewater treatment in Timor-Leste, there are three provisional wastewater treatment stations that were built in 2000 during the United Nations Transitional Administration of East Timor (UNTAET) mission in Timor-Leste that are in three different municipalities, such as Dili (located in Taci-Tolu area), and the other two stations are in Baucau and Suai, with the purpose of responding to the UN requirements for wastewater deposits. During the UN mission in Timor-Leste, these three wastewater treatment stations were well functioning, but after the UN mission left Timor-Leste, both the Baucau and Suai treatment stations fell into disuse. The stations closed, due to the limitation of human resources and unsupported operational and maintenance costs.

Since 2009, the government of Timor-Leste, through the Ministry of Public Works, has constructed new treatment stations in Baucau and Suai. In 2010 to 2012, the government also constructed a new station for wastewater treatment, Estação de Tratamento de Água Residuais (ETAR), located in the Tibar area within the Liquiça municipality. This treatment station is functional and takes in wastewater, especially blackwater from Dili, Baucau, Ermera, and Liquiça.

There are several steps of wastewater treatment that need to be applied to change wastewater into a valuable resource for reuse, namely, preliminary treatment (to remove coarse solids and grit from the incoming wastewater: plastic waste, rags, sticks, floating objects), primary treatment (to separate the large suspended solids and solid organic matter from wastewater), secondary treatment (to remove mainly organic matter), tertiary treatment (to remove any residual suspended solids and other nutrients, and for disinfection), advanced treatment (to eliminate micro-pollutants) and sludge treatment (to reduce the weight and volume of the nutrient-rich organic residue or sludge resulting from the wastewater treatment process). In the Tibar Wastewater Treatment Station, only primary (physical) treatment and secondary (biological) treatment (Figure 5) are available.

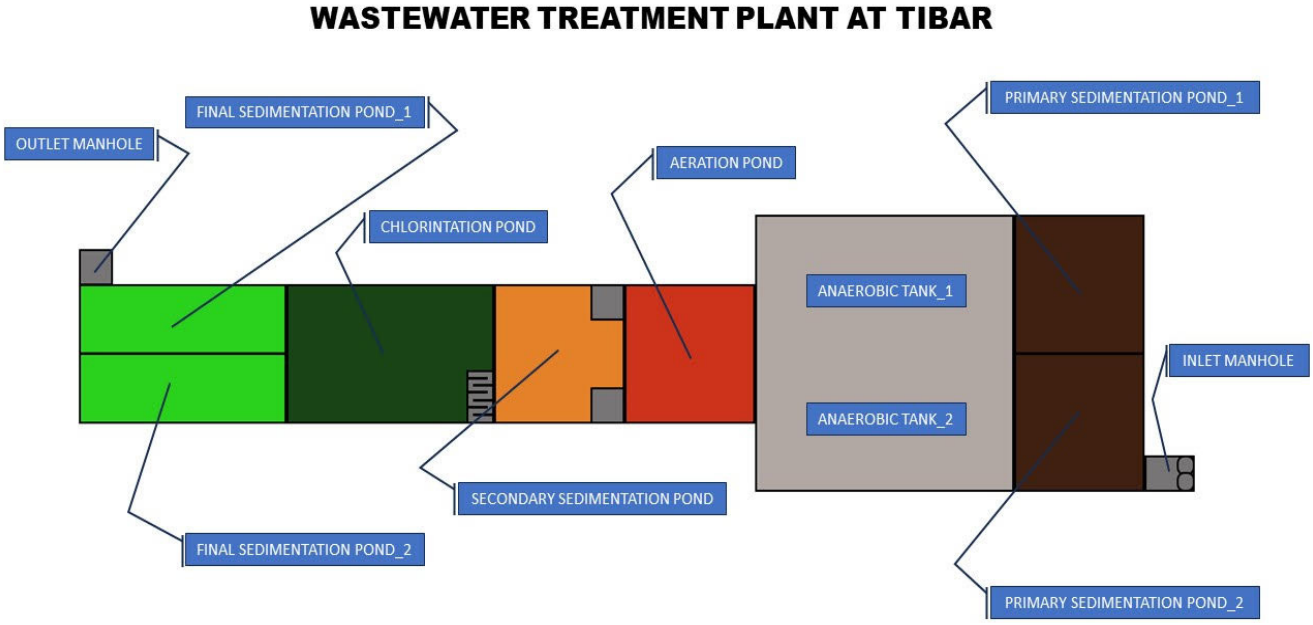

Figure 5. Wastewater treatment plant in Tibar.

Primary treatment is a physical settling process that removes solids, and secondary treatment is a biological treatment process used to stabilize the dissolved solids [21]. The removal or separation of solid waste materials from wastewater is an important step to ensure human and public health and environmental safety [22].

The wastewater treatment process in Tibar (Figure 6), Timor-Leste, is a crucial process that involves a series of well-coordinated steps to ensure the effective removal of contaminants and pollutants from the water before it is discharged back into the environment (exact location and pictures are available at https://climatescan.org/projects/10239/detail, accessed on 19 May 2024 and Figure 7).

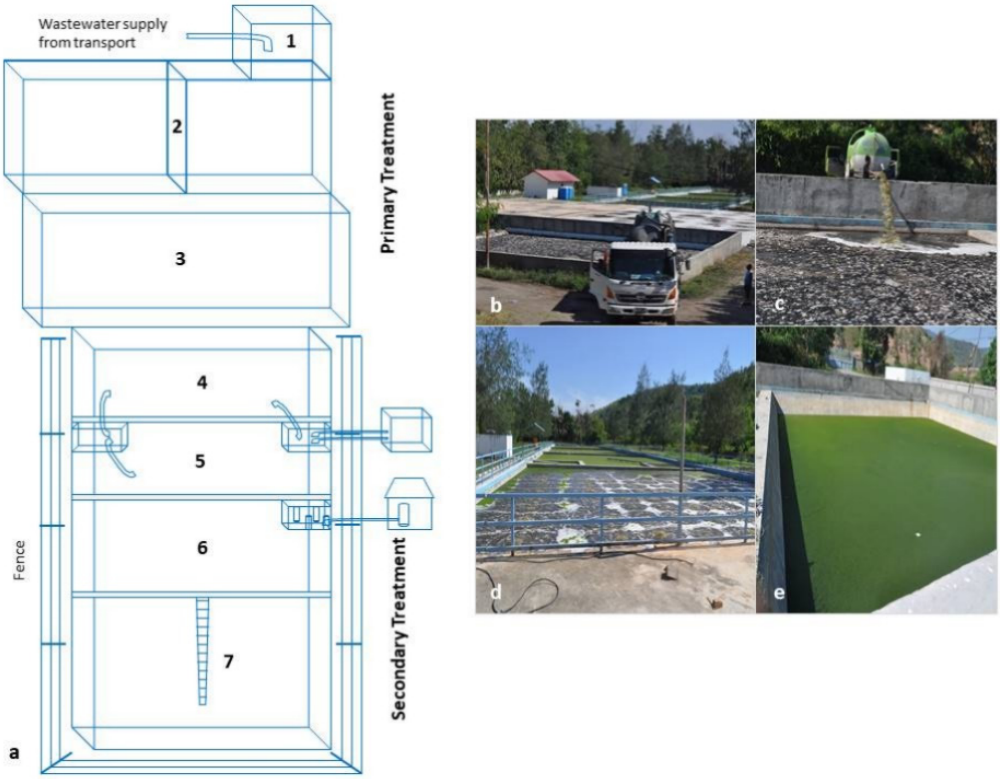

Figure 6. The Tibar Wastewater Treatment Plant Station: (**a**) manual schematic design of Tibar Wastewater Treatment Station; (**b**,**c**) wastewater trucks discharge blackwater in primary treatment tank; (**d**) whole view of primary and secondary treatment tanks; (**e**) secondary treatment tank.

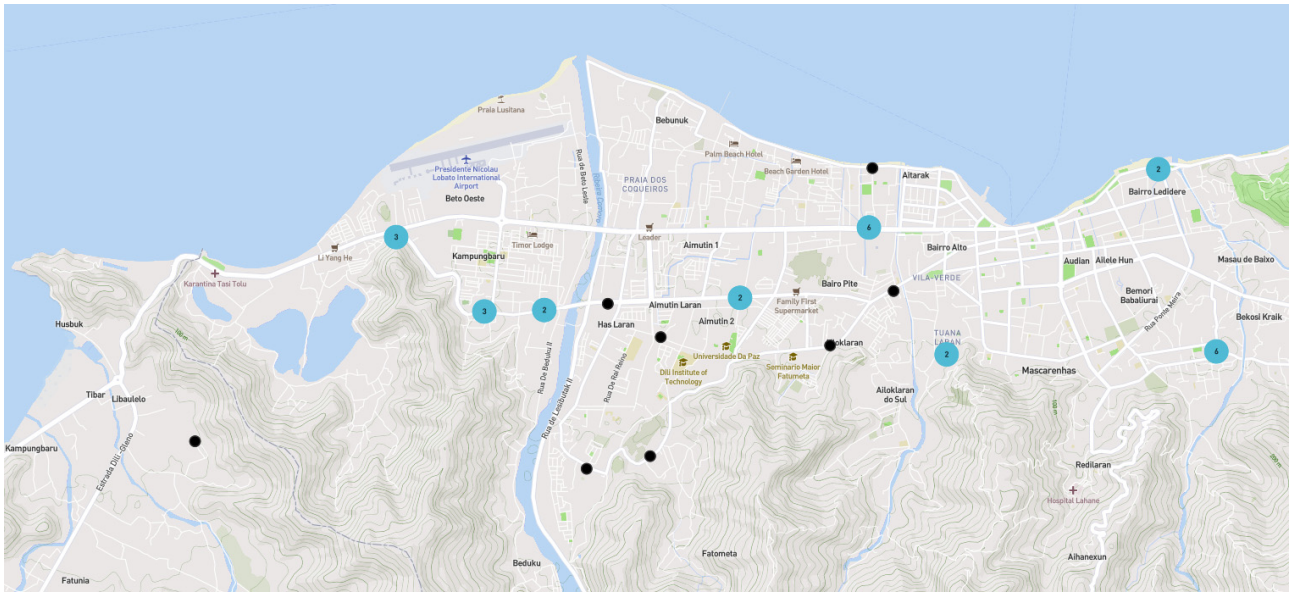

Figure 7. Mapped locations visited in this study (available online: https://www.climatescan.org/#filter-9-198, accessed on 19 May 2024).

The journey of wastewater begins at the inlet manhole, where raw sewage is directed into the treatment facility. Here, the primary sedimentation tank acts as the first line of treatment, allowing larger particles to settle, and forming a sludge layer at the bottom. The partially clarified water then moves to anaerobic tank 1 and anaerobic tank 2, where organic matter undergoes biological degradation in the absence of oxygen, producing biogas as a byproduct.

Following the anaerobic treatment, the water progresses to the aeration pond, where oxygen is introduced to support aerobic bacteria, promoting the further breakdown of remaining pollutants. Subsequently, the treated water enters the secondary sedimentation pond, allowing any remaining suspended solids to settle. The clarified water then undergoes chlorination in the chlorination pond to disinfect and eliminate harmful microorganisms.

The wastewater deposit processing in ETAR Tibar is divided into several stages, as well as collection, transportation, treatment, and disposal (Figure 8). In the collection process, the government (Ministry of Public Works) gives licenses to private companies to collect wastewater deposits from sanitary and domestic septic tanks of communities, public institutions, commercial properties, and industries. The communities, public institutions, commercial properties, and industries must pay the private companies for wastewater collection and private companies pay tax to the government. The collected wastewater is directly transported to the Tibar Wastewater Treatment Station for treatment. In the treatment process, as mentioned above, there are seven treatment tanks (Figure 6a). The treated wastewater is tested before being discharged into surface water, and if the wastewater meets the World Health Organization (WHO) standards [23] for disposal or reuse, the government, in partnership with communities, plans to reuse the treated wastewater for supporting horticultural activities around the Tibar area.

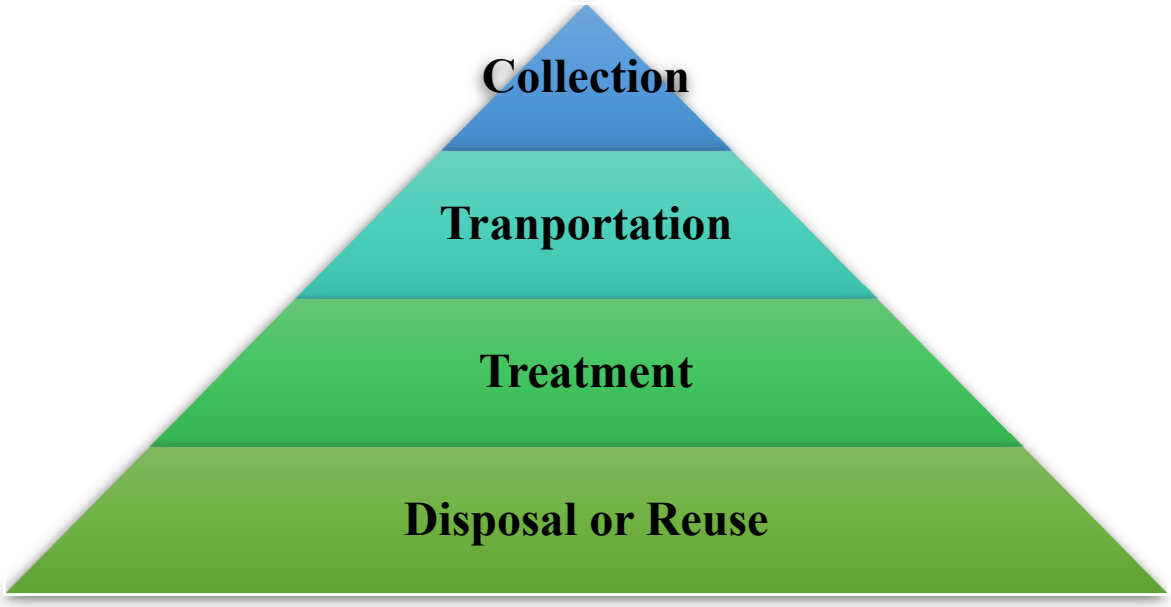

Figure 8. Wastewater management model in Tibar treatment station, Timor-Leste.

Based on key informant interviews, the transportation of wastewater to this treatment station is the responsibility of communities, at their own cost, and is not provided by the government. The transportation is provided by several private companies, such as MTD, ANTEATER, WASTE CONTROL, ALFMMA, ELEMLOI, CALTECH, EDS, PAX, 3 CORENTES, FICA, and JYL. The operators have mentioned that there are at least 15 wastewater tank trucks that transport wastewater to this station. Most of the wastewater transport is from the Dili capital and some is from other areas, such as the Baucau and Ermera municipalities. Normally, wastewater deposits for this station are from commercial and domestic septic tanks of communities, public institutions, and industries (Figure 9).

Figure 9. The generated volume of wastewater from different sources deposited in Wastewater Treatment Plant in Tibar from the period of 2 March to 16 March 2017.

The amount of wastewater from municipalities deposited in the ETAR Tibar is about 1000 m^3 L/month. The maximum amount of generated wastewater is more than 80 tons L/day (Figure 10).

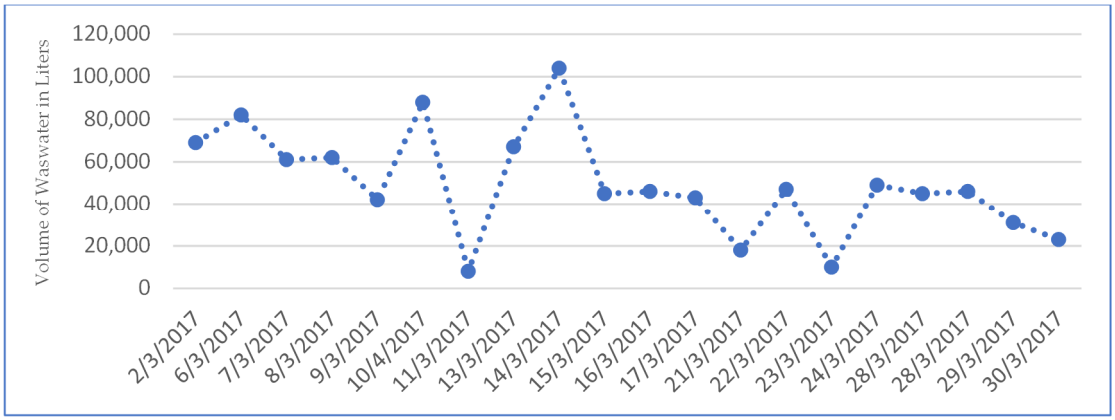

Figure 10. The daily wastewater volume transported to Tibar WW Treatment Plant in March 2017.

The challenges faced by the operators in this station include a lack of suitable safety equipment provided by the government to secure the operator's health and safety, including from airborne pollutants. Therefore, the operators are frightened for their health.

The other gaps that have been identified in the Tibar treatment station relate to government and private companies' revenues. The cost for wastewater collection from each community's and/or company's septic tank is about USD 65.00, and the cost provided by the government for the maintenance of the Tibar treatment station during 2015 and 2016 was about USD 25,000.00 and USD 20,000.00. Table 2 contains the calculated budget based on invoices from the Tibar Wastewater Treatment Station regarding the government's and private companies' revenues.

Table 2. The fees during five months of collection of wastewater [data from National Direction of Basic Sanitation of Ministry of Public Works in Timor-Leste, 2017].

Time	Volume of Wastewater (L)	Company Revenue	Government Revenue
March	1,097,000	$10,970.00	$548.50
April	125,700	$1257.00	$63.85
May	1,239,000	$12,390.00	$619.50
June	1,006,000	$10,060.00	$503.00
July	1,186,007	$11,860.07	$593.00
Total	4,653,707	$46,537.07	$2327.85

Based on Table 2, the company's revenue is 1%/L from the communities' fees and the government's revenue is 5% from the company's revenues. So, the difference is USD 46,537.07 for the company's revenue and the government's revenue is only USD 2326.85. There is no balance between the government's and private company's incomes; the company grand total revenue is about USD 44,210.22.

b. National policies on wastewater management

In terms of national policies on wastewater management, there is Decree-Law No. 33/2008 from 27 August about Hygiene and Public Orders, which is considered the national basic sanitation policy [24]. This decree-law established requirements for administrative policy for urban zones of municipalities in hygiene and public orders. This law prohibited leaving solid waste and wastewater in public places. This decree-law is an important tool for regulating communities' actions regarding solid waste deposits, and applies to wastewater in urban areas.

The other related national policy on wastewater management is the Timor-Leste National Basic Sanitation Policy from 2012. This policy outlined some of the fundamental components regarding the improvement of sanitation and hygiene, such as hygienic toilets, hand washing facilities, liquid and solid waste, sanitation for all, and the prohibition of defecation and urination in public areas.

The National Directorate of Basic Sanitation (NDBS) has reported that "we have the specific regulation for wastewater management", but this is still in draft form, and currently, the treatment of wastewater is included in the master plan for the establishment of domestic wastewater treatment in Timor-Leste. The NDBS has also reported that there are four phases of Dili sanitation and drainage development within the master plan. Phase 1 started from the Pilot Testing of Community Sewage Treatment Systems (CSTS) between 2011 and 2012 in Mascarenhas and Bidau-Santana. Phase 2 (from 2013 to 2017) was a short-term program expansion of the wastewater system, but this was not successfully realized due to the limited funding provided by the government. Phase 3, from 2018 to 2025, is projected as a medium- and long-term expansion program. Lastly, phase 4 extends beyond 2025 for long-term improvements.

c. Timor-Leste's government strategy on wastewater management

The Strategic Development Plan (SDP) for 2011 to 2030 is an important guideline and one of the government's efforts to reduce or minimize the wastewater management issues in this young country by aiming to rehabilitate and construct new facilities for clean water and sanitation in Timor-Leste. Therefore, the government has aimed to remove the health risks caused by human contact with wastewater in drains; this can be achieved through minimizing the contamination of drains in the first place by collecting raw sewage and septic effluent, treating it, and disposing of it safely in municipalities' urban areas. Regarding this plan, in the Dili area, some potential issues related wastewater management include the fact that septic tank effluent flows into open drains and out to beaches. Children play in these drains and women tend crops up to their waists in sewage and wastewater, which may transmit dysentery, meningitis, and other diseases. Therefore, the government has planned to improve the Dili drainage system through sustainable infrastructure for the collection, treatment, and disposal of sewage in Dili.

d. Community's understanding and perception of wastewater management

Wastewater collection requires sources of funds, one of which comes from the community through charges to users. These charges are levied and used by the company, who will manage transportation, facilitation, and fees to the state. During interviews, some communities suggested that they are willing to pay for wastewater treatment together, but other communities are not willing to pay for wastewater collection as the cost is relatively expensive for them and they have no funds for supporting this wastewater collection. Therefore, they reported that "we must leave wastewater for sewage to flow to the river or sea, or we can reuse to water the plant or soils. We know that wastewater may contaminate

drinking water, but each community has their own view on water based on their necessaries and urge the government to create regulations and prepare wastewater treatment". They would be very happy if the government or researchers implemented some new technologies for wastewater treatment that they could reuse themselves, because it would provide an alternative solution to the water supply problems in their households. Wastewater can be considered a resource, a source of health information, and part of the circular economy, but social challenges remain, including public acceptance and access to basic sanitation [25].

3. Results and Discussion

Demographic Information

The demographic characterization of the 130 participants who completed the questionnaire revealed a slight majority of females (57.7%) compared to males. Regarding occupation, the majority of the respondents were employed (51.5%), followed by those who owned their own companies (26.2%), and the unemployed (22.3%). The average age of the participants was 37 years old, with the highest number falling within the 30–40 age group. A significant portion of the participants (72.3%) reported having a high level of education, while 27.7% reported lower levels of education. In terms of the family size, the majority (53.8%) reported living with 6–10 people in one household, followed by 30.8% with 1–5 people, and 15.4% with other arrangements (Table 3).

Table 3. The demographic characterization of the 130 participants.

Features	Quantity	Percentage
Gender		
Female	75	57.7
Male	55	42.3
Location		
Dom Aleixo	34	26.2
Vera Cruz	33	25.4
Nain Feto	34	26.2
Cristo Rei	29	22.3
Education Level		
Higher education	94	72.3
Lower education	36	27.7
Occupation		
Employer	67	51.5
Unemployed	29	22.3
Owner of a private company	34	26.2
Members of family	5	3.8
1–5 people	40	30.8
6–10 people	70	53.8
Over 10 people	20	15.4
Age group		
20–30 years	43	33.1
30–40 years	44	33.8
40–50 years	35	26.9
50–60 years	8	6.2

3.1. Actual Condition of Wastewater in Urban Areas

To explore wastewater information, an understanding is needed on the sources of water used by the community. A proportion of 56.9% of the participants responded that they obtain their water from public taps, 32.3% obtain it from their own boreholes and also buy water from commercial water tanks. Most of the community disposes of their wastewater in open sewer or streams (47.7%), while 27.7% use their own sinkholes, and only a small percentage use it for their garden or farms. Regarding the expense associated with transporting wastewater, a significant majority (82.3%) of the community perceives the cost to be expensive, while a smaller portion (17.7%) does share this view.

The infrastructure of septic tanks shows that 60% have a bottom layer using sea sand or coral, while 40% do not use sea sand. The majority (67.7%) of septic tank pump-outs occur every 1–3 years, while 17.7% pump out every 3–6 years. Only 3.1% of the tanks are pumped out every 6–9 years, and 11.5% of the tanks are pumped out every 10 years or more. This result suggests that the regular maintenance of septic tanks is most commonly performed within a 1–3 year period. Regarding the septic tank depth in the community, the most common depth is 3 m, found in 47.7% of the cases, followed by 2 m, at 36.9%. Tanks with depths of 4 m and 5 m account for 13.1% and 2.3% of the total, respectively. Concerning the distance between septic tanks and water sources, the majority (61.5%) of the septic tanks are located 1 to 5 m from water sources, while a smaller portion (20.0%) are situated 6 to 10 m away, and 18.5% are more than 10 m away (Table 4).

Table 4. The summary of actual wastewater conditions.

Features	Quantity	Percentage
Source of water supply		
Own borehole	42	32.3
Public tap	74	56.9
Commercial water tank	14	10.8
Discharge wastewater network		
Well follow	47	36.2
Inflowing	83	63.8
Location of domestic wastewater deposit		
Open sewer	62	47.7
Farm/garden	32	24.6
Constructed sinkhole	36	27.7
Infrastructure of septic tank		
Septic tank bottom is sea sand/coral	78	60.0
Septic tank bottom is without sea sand/coral	52	40.0
Pump-out of fecal septic tank		
1–3 years	88	67.7
3–6 years	23	17.7
6–9 years	4	3.1
≥10 years	15	11.5
Community perspectives on cost of wastewater transportation—expensive		
Yes	107	82.3
No	23	17.7

Table 4. *Cont.*

Features	Quantity	Percentage
Depth of septic tank (meters)		
2 m	48	36.9
3 m	62	47.7
4 m	17	13.1
5 m	3	2.3
Distance between septic tank and a water source		
1 m–5 m	80	61.5
6 m–10 m	26	20.0
Over 10 m	24	8.5

3.2. Community Perspective on Wastewater and Its Impact

Based on the result of community perspectives on wastewater (WW) treatment, a significant portion, 41.5%, believe wastewater treatment is necessary. Meanwhile, 19.2% of the community have no knowledge about WW treatment, and 34.6% think it does not exist. Only a small percentage, 4.6%, consider WW treatment to be unnecessary. These results indicate that while many recognize the importance of wastewater treatment, there is still a considerable lack of awareness or misinformation among the community. But on the other hand, the community shows an awareness of wastewater reuse, showing that 62.3% have knowledge of it, while 37.7% lack awareness.

The data reflect the community's attitudes toward wastewater management in their environment, with 59.2% viewing it positively as "Good" and 40.8% expressing a less favorable opinion as "Not So Good". Related to this, the respondents revealed the instances within families where members experienced diarrhea three months prior, with 73.8% reporting 'Yes' and 26.2% reporting 'No'. Based on this result, the opinion of the community on an alternative solution for domestic wastewater management shows that 34.6% prefer continuing with off-site wastewater systems, 15.4% opt for on-site wastewater systems, 46.2% favor ecological sanitation, and 3.8% choose other low-cost options (Table 5).

Based on the research data, an analysis has been performed showing that the sources of wastewater in Timor-Leste are derived from domestic, commercial, industrial, and hospital environments. Domestic wastewater—wastewater from bathrooms, showers, kitchens, and laundry—is mostly discharged directly into the public open sewers. The data show that 47.7% of domestic wastewater is disposed of into open sewers, 24.6% disposed it into home gardens, and 27.7% discharged it into septic tanks (Table 3). There is a wastewater treatment station in the Tibar area, but it is mostly for blackwater or toilet wastewater treatment, and it does not cover all the domestic greywater of Timor-Leste. A proportion of 35.4% of the domestic blackwater is treated in this Tibar station and 64.6% is not treated, because the cost of blackwater absorption and transport is very expensive; therefore, it is often just left to infiltrate into the ground (Table 6).

There is no specific treatment station provided for domestic wastewater treatment in Timor-Leste and some communities have just developed their own models or systems for domestic wastewater treatment. Based on the research findings, some households have either built open boreholes for their households or share them. After constructing the borehole, they would deposit or accumulate only wastewater from the kitchen without oil or detergent, and they would plant Xanthosoma sagittitolium and banana plants around the borehole. The infiltration of wastewater would contribute to the survival of the plantation around the borehole. Commercial wastewater is that produced from car and motorbike washing, restaurants, and hotels.

Table 5. The summary of community perspective on wastewater management and its impact.

Features	Quantity	Percentage
Community perspective on WW treatment		
WW treatment is necessary	54	41.5
Have no knowledge	25	19.2
It does not exist	45	34.6
Not necessary	6	4.6
Knowledge of reuse of wastewater		
Have knowledge	81	62.3
Lack knowledge	49	37.7
Suffered from diarrhea 3 months before		
Yes	96	73.8
No	34	26.2
Community attitude toward WWM		
Good	77	59.2
Not so good	53	40.8
Alternative solution for domestic wastewater		
Continue to use off-site wastewater system	45	34.6
On-site wastewater system	20	15.4
Ecological sanitation	60	46.2
Others (low-cost)	5	3.8

Table 6. Domestic wastewater deposits based on interviews and questionnaire responses of 130 respondents about wastewater management.

Location of Domestic Wastewater Deposit		Frequency	Valid Percent
Valid	Open sewer	62	47.7
	Farm/garden	32	24.6
	Constructed sinkhole	36	27.7
	Total	130	100.0

Car wash companies' wastewater treatment

There are 19 car washing companies in the urban areas, such as in Dili capital, where 18 companies are classified as private and 1 is public, or state-owned. A total of 8 of them are registered or licensed by the government and 11 companies are not registered. Their water sources are mostly from groundwater; 11 companies use groundwater, 6 companies use water provided by the SAS/government, and 2 companies use water from rivers (Table 7).

Table 7. Water sources provided for car washing.

		Frequency	Valid Percent
Valid	Groundwater	11	57.9
	SAS/government	6	31.6
	Rivers	2	10.5
	Total	19	100.0

The wastewater generated from car washing can reach an average of 3000 L per day depending on the number of cars. The volume of produced wastewater is similar to the quantity of used clean water and 73.7% of this wastewater is disposed of directly into open public sewers by 14 companies; 2 companies dispose of their wastewater in gardens; 3 companies discharge their wastewater into constructed sinkholes (Table 8 and Figure 11).

Table 8. Wastewater deposit sites of washing car company.

		Frequency	Valid Percent (%)
Valid	Open sewers	14	73.7
	Farm or garden	2	10.5
	Wastewater sinkhole	3	15.8
	Total	19	100.0

Figure 11. Produced wastewater from car and motorbike washing: (**a**–**c**) car washing location; (**d**,**e**) washing cars and motorbikes; (**f**,**g**) disposed wastewater in sinkhole and open drain.

All their produced wastewater is contaminated with detergents that will have an impact on human health and the environment.

Restaurants' and hotels' wastewater treatment

There are 21 restaurants and 35 hotels in the urban area of Dili including the capitals of other municipalities. Most of their water sources are from groundwater provided by the SAS/government. Their greywater is commonly disposed of into open sewers and only blackwater is transported to the ETAR in Tibar. Meanwhile, some restaurants and hotels have developed their own systems for wastewater treatment, for example, Barry's Place—an Eco-Lodge in Atauro Island, Dili municipality (Figure 12). The main water sources are provided by the SAS/government and from groundwater extraction. Barry's Place has created its own water conservation method for the treatment of greywater from the kitchen, bathrooms, and composting toilets, small sinks, bucket showering, and laundry services.

Barry's Place's wastewater treatments are natural and ecological without any chemicals or modern technology. The final treated wastewater can be reused for plantations (Figure 12).

Home industries' wastewater treatment

Ten small-scale home industries were identified, which produce tofu and tempeh, in Timor-Leste. Six home industries use groundwater, and three home industries use the water supply from the SAS/government. Four companies discharge their wastewater into open sewers. One company disposes of their wastewater into their garden and five home industries discharge their wastewater into constructed sinkholes or wastewater treatment tanks (Table 9 and Figure 13).

Figure 12. Wastewater treatment in Barry's accommodation and restaurant on Atauro island, north of Timor-Leste: (**a**) water supply from the government; (**b**) toilet and bathroom; (**c**) deposit of toilet blackwater left for one year, and then reused as compost for plantation; (**d**) kitchen wastewater treatment through three open tanks.

Table 9. Home industries' wastewater disposal sites.

Wastewater Discharge Site		Frequency	Valid Percent
Valid	Open sewers	4	40.0
	Farm or garden	1	10.0
	Wastewater sinkhole	5	50.0
	Total	10	100.0

Figure 13. Home industries' wastewater treatment: (**a**) wastewater is discharged into an open tank and infiltrates into the ground without any treatment; (**b**) wastewater is disposed of into a ground hole or closed tank; (**c**,**d**) wastewater is discharged directly into open channels or streams.

The level of communities' knowledge and abilities, including an understanding of wastewater management, treatment, and reuse, are vital for maintaining human health and environmental quality. Most Timorese communities have limited knowledge about wastewater management and treatment; 41.5% stated that it is necessary to perform wastewater treatment and 4.6% mentioned that it is not necessary to treat their wastewater (Table 10). And in terms of communities' knowledge on wastewater reuse, 62% understood the importance of reusing wastewater and 38% did not understand the purpose of reusing wastewater.

Table 10. Communities' perspective on the need for wastewater treatment.

		Frequency	Valid Percent
Valid	Wastewater treatment necessary	54	41.5
	Do not know	25	19.2
	Does not exist	45	34.6
	Is unnecessary	6	4.6
	Total	130	100.0

Correlation Analysis

The study found that the understanding of what constitutes "good" wastewater management is statistically significant, with a *p*-value of 0.024. Among respondents, 55.9% know good management practices, while 44.1% do not. This suggests that educating the remaining population could significantly enhance wastewater management. Additionally, the functionality of the discharge wastewater network is considered statistically significant with a *p*-value of 0.01965. About 74.5% of respondents find the discharge network functioning well, while 25.5% do not. Ensuring efficient network operation is crucial for the successful reuse of wastewater (Table 11).

Table 11. The correlation table between knowledge to reuse wastewater and others features.

No	Features	Knowledge to Reuse Wastewater					*p*-Value
		Have Knowledge		Lack of Knowledge		Total	
		n	%	n	%	N	
1	Community Participation using Domestic Wastewater Management System						0.024
	Good	46	55.4%	37	44.6%	83	
	Bad	35	74.5%	12	25.5%	47	
2	Discharge wastewater network						0.014965
	Well, flowing	23	48.9%	24	51.1%	47	
	Inflowing	58	69.9%	25	30.1%	83	
3	Community perspective on WW treatment						0.215
	Necessary for WW treatment	32	59.3%	22	40.7%	54	
	Have no knowledge	20	80.0%	5	20.0%	25	
	It's Doesn't Exist	25	55.6%	20	44.4%	45	
	Not Necessary	4	66.7%	2	33.3%	6	
4	Location of domestic wastewater deposit						0.019
	Open sewer	32	51.6%	30	48.4%	62	
	Farm garden	26	81.3%	6	18.8%	32	
	Constructed sinkhole	23	63.9%	13	36.1%	36	

Regarding wastewater treatment, 59.3% of respondents consider it necessary, yet a significant portion, around 80%, lacks awareness about it. Moreover, 55.6% believe that wastewater treatment doesn't exist, and 66.7% view it as unnecessary. The locations for domestic wastewater deposits vary, with 51.6% acknowledging open sewers, 81.3% preferring farm gardens, and 63.9% recognizing constructed sinkholes. These findings underscore the importance of education and awareness campaigns to improve wastewater management practices and promote sustainable alternatives. By addressing knowledge gaps and encouraging community involvement, more effective wastewater treatment and reuse practices can be achieved. According to Kabito, It is clear that improving knowledge, attitudes, and practices towards wastewater management is crucial for addressing public health issues.

We observed in Table 12 that the residents with higher education had less diarrhea than those with lower education, as indicated by the odds ratio of 4.24 and a significant p value of 0.004. Similarly, having a knowledge of the health impact untreated wastewater correlates with fewer cases of diarrhea, with an odds ratio of 3.51 and a p value of 0.0014. Attitude also appears to play a role; those with a "good" attitude had less diarrhea than those with a "poor" attitude, with an odds ratio of 4.24 and a significant p value of 0.004. These data are relevant to public health studies assessing risk factors associated with disease prevalence.

Table 12. Correlation table referring to education, having knowledge, attitude and health.

No	Features	Suffering Diarrhea 3 Month before Done the Research					OR	*p*-Value
		Yes		No		Total		
		n	%	n	%	N		
1	Level of Education							
	Higher education	71	76.3%	22	23.7%	93	4.235795	0.00039
	Lower Education	16	43.2%	21	56.8%	37		
2	Having knowledge of health impact untreated Wastewater							
	Yes	67	76.1%	21	23.9%	88	3.51	0.001354
	No	20	47.6%	22	52.4%	42		
3	Attitude							
	Good	42	54.5%	35	45.5%	77	0.2133	0.000217
	Not so Good	45	84.9%	8	15.1%	53		

Results of survey and field visits

Based on the findings of the field investigation, it was observed that in rural areas such as the Bobonaro, Baucau, Ainaro, Covalima, and Liquica municipalities, there is no wastewater treatment infrastructure, and the existing legal framework inadequately addresses these issues. The majority of residents transport their wastewater and use flush toilets, with the Tibar Wastewater Treatment Plant in the capital being the primary disposal point.

The demographic profile showed a slight majority of women compared to the male respondents. Most respondents were employed, with the next largest groups being employed and business owners. The average age was 37, with many participants in the 30–40 age range. A significant number of participants had a high level of education, while the rest had lower levels. In terms of family size, the majority lived with 6–10 people, followed by those with 1–5 people, and a smaller percentage had other arrangements.

Understanding wastewater information requires examining the community's water sources. Most participants (56.9%) obtain water from public taps, 32.3% from boreholes, and others purchase water from commercial tanks. The wastewater disposal habits reveal that 47.7% of the participants use open sewers or streams, 27.7% utilize sinkholes, and a minority repurpose the wastewater for gardening or farming. Regarding wastewater

transportation costs, 82.3% perceive them as expensive, contrasting with the 17.7% who do not share this view. The septic tank infrastructure analysis indicates 60% have a bottom layer of sea sand or coral. The pump-out frequency analysis shows that 67.7% occur every 1–3 years, suggesting regular maintenance, while the tank depths primarily range from 2 to 3 m. The majority (61.5%) of the tanks are situated 1–5 m from water sources. This proximity suggests a high risk of groundwater contamination in the city.

The community's perspectives on wastewater (WW) treatment reveal a nuanced understanding: 41.5% recognize its necessity, yet 19.2% lack knowledge on it, and 34.6% believe it does not exist, with only 4.6% deeming it unnecessary. This suggests a significant awareness gap despite the recognition of its importance. Conversely, regarding wastewater reuse, 62.3% are knowledgeable, highlighting a better understanding in this aspect. The community attitudes towards wastewater management show a split, with 59.2% viewing it positively and 40.8% expressing a less favorable opinion. Moreover, 73.8% of the families reported instances of diarrhea three months prior, indicating potential health concerns. Regarding alternative solutions for domestic wastewater management, preferences vary: 34.6% prefer off-site systems, 15.4% opt for on-site systems, 46.2% favor ecological sanitation, and 3.8% choose other low-cost options. These findings underscore the complexity and diverse perspectives within the community concerning wastewater management and its alternatives.

Impact on Human Health

Wastewater's impacts on human health and environment quality should be considered by all Timorese communities within the national territory because pollution by wastewater can affect human health with various diseases, such as asthma, itchy skin, diarrhea, etc., (Figure 14) as documented in the several public health centers in Timor-Leste. Carawan et al. (1979) described that the public health aspects of wastewater reclamation to reuse the renovated wastewater for human consumption or in processes that normally require potable water (i.e., food processing) must be evaluated with potential health risk and hazards [26]. Therefore, UN Sustainable Development Goal 6 described that by 2030, the availability and sustainable management of water and sanitation must be ensured for all. Thus, with inadequately managed wastewater being the key driver of water pollution, this target represents the principal action for achieving the overarching goal of an improved water quality environment [27].

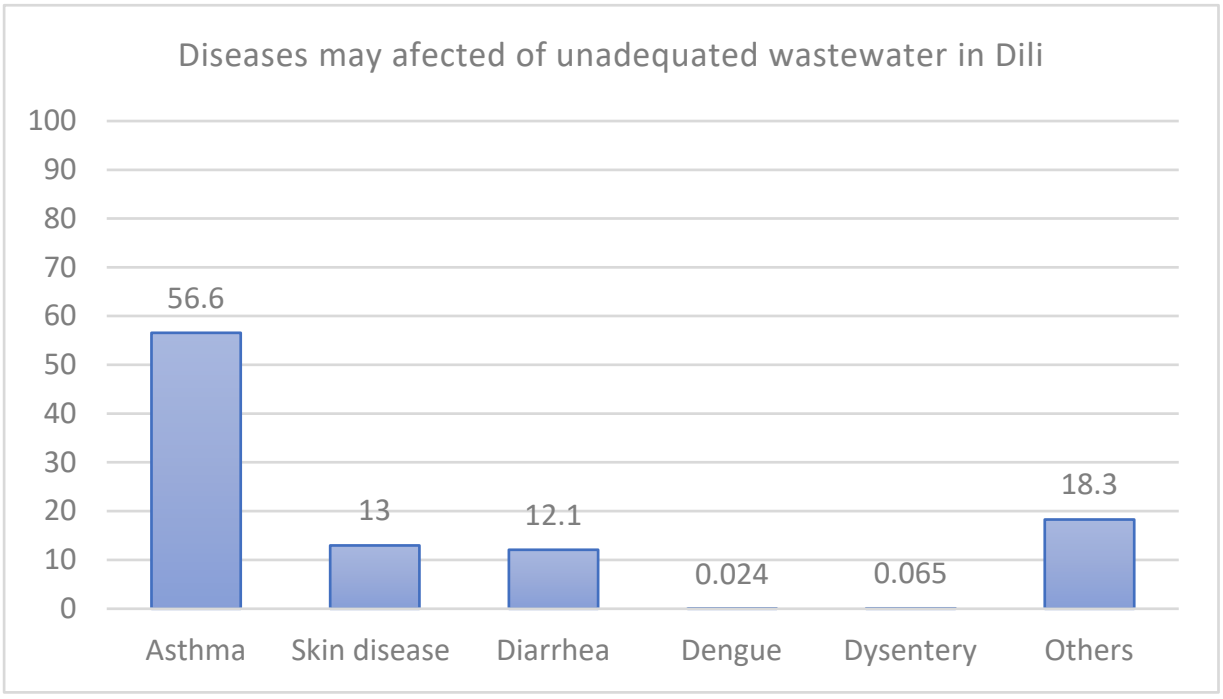

Figure 14. Diseases caused by wastewater impacts in several public health centers in Timor-Leste.

The current situation of wastewater management has caused several diseases impacting public health, indicating that sewage treatment plants could be a solution. Sewage treatment plants discharge toxic metals and pesticides, affecting the environmental quality, human health, and agriculture in areas receiving wastewater, with potential risks to human health [28].

This research has observed that in 3 years, the existing population has been affected by waterborne diseases (Figure 14). The occurrence of asthma is very high at 56.6%, and skin disease (13%) and diarrhea (12.1%) are also prevalent. Data from four health centers in Dili city indicated that diseases such as asthma, skin problems, and diarrhea, potentially caused by inadequate wastewater treatment, were more prevalent (Figure 15). According to the World Health Organization's reports in 2022, at least 1.7 billion people globally used water contaminated with feces. Access to safe water is crucial to the prevention of diseases like diarrhea, cholera, dysentery, typhoid, and polio, which cause an estimated 505,000 deaths annually. Despite the global significance of the issue, during 2015–2020, the proportion of the population with access to safely managed drinking water services improved from 70 to 74% [29].

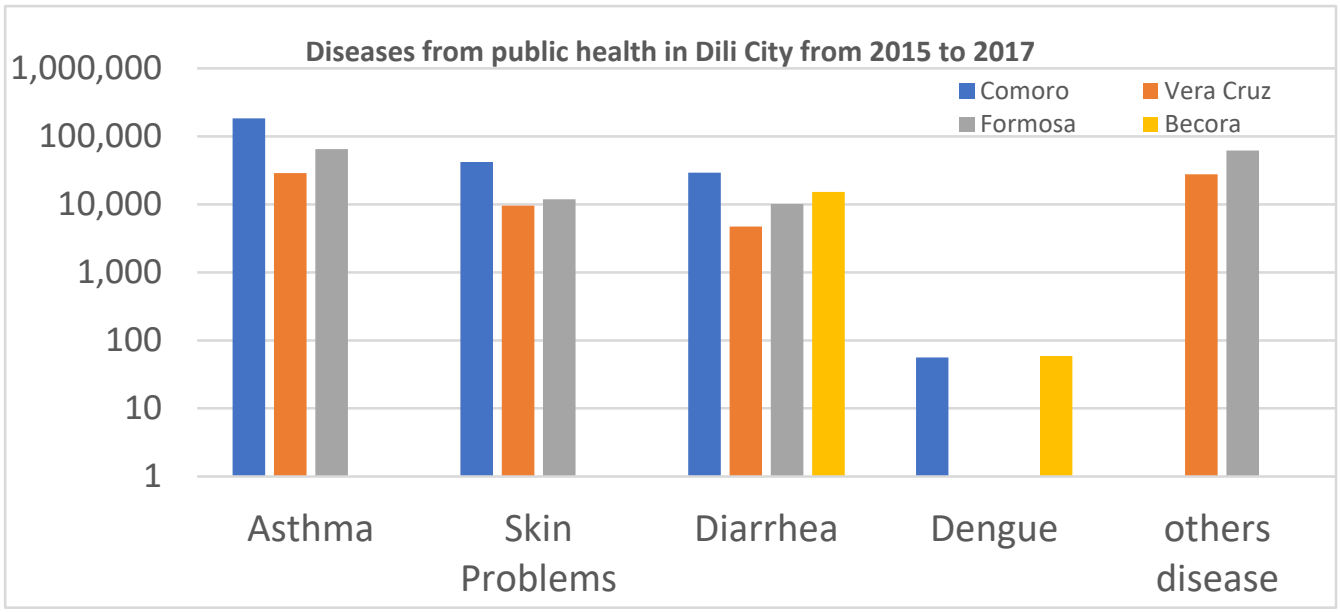

Figure 15. Diseases caused by wastewater impacts in several public health centers in Timor-Leste. [primary data from 4 different health centers in Dili city].

A WaterAid report documented that 75 children under the age of five die every year due to diarrhea diseases caused by poor water and sanitation in Timor-Leste. Addition lay, 174,000 people do not have access to clean water near their homes, and 558.000 people lack adequate toilets. According to the report, many do not have a decent toilet of their own [30] and the high infant, under-five, and maternal mortality rates in Timor-Leste are associated with the poor access to and utilization of health care [31]. On the other hand, children living in households using unimproved water facilities or surface water are more likely to die before five than those with basic water facilities [32].

Intensive rainfall events can bring large-scale flooding that washes pollution into bodies of water. This water quality is often poor, and malaria was a major problem during the last 3 years in this country. The climate is favorable to mosquitoes, and the poor sanitation in the cities means that malaria is one of the major causes of diseases, which impacts economic and educational development [33].

Figure 16 shows that during February–April and June, asthma is very frequent. Skin problems occur later on from December to February. It is confirmed that in the rainy season, there is a high possibility of infection with waterborne diseases.

Based on the results of the research questionnaire, most of the children suffer from diarrhea (73.8%). Most participants in a household have children who suffer diarrhea once per month (45%) and who need to be transported to hospital for treatment (74.6%).

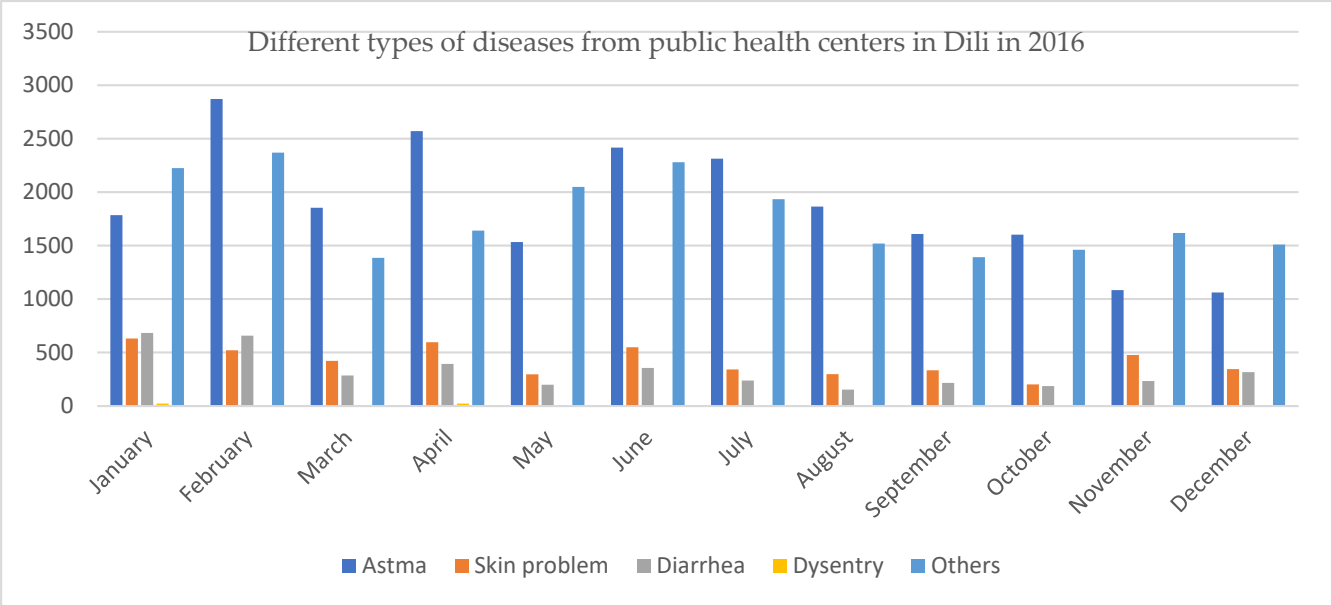

Figure 16. Different Diseases from several public health centers in Dili, Timor-Leste.

Regarding the management of household wastewater, car washing companies and home industries in Timor-Leste dispose of their wastewater directly into open sewers and sinkholes. Inadequate wastewater management and sewage systems will impact the water quality and public health in the region. For example, in Kupryś-Lipińska, Kuna and Iwona [34] stated that desiccant air affects human health in two ways; firstly, by causing dryness and damage to the skin and mucosa, making it easier for bacteria, viruses, and allergens to have a detrimental effect on the body. Secondly, particulates and pollutants are more easily suspended in dry air and hence there is an increased risk of disease. Recently, WHO, reporting on the water quality in Timor-Leste, calculated that 70% of the water sources were contaminated with a microbiological unit, and this was frequently connected to the possibility of disseminating diseases like typhoid and cholera.

In addition, the water quality monitoring data from the national laboratory of water supply showed that the drinking water in Dili city has been contaminated by physicochemical and microbiological entities from four types of water such as groundwater, surface water, tap water, and process water (Figure 17). The contamination of the water supply can be explored, focusing on groundwater as the main source of water supply in Timor-Leste. In this case, the government authorities may apply certain technological approaches such as artificial intelligence and machine learning in the management of water treatment and wastewater management sectors [35]. The application of advanced wastewater treatment technologies can help in improving the quality of treated wastewater and minimize the risk of waterborne diseases because it will play a pivotal role in addressing complex wastewater contaminants and achieving higher purification standards in industrial wastewater treatment [30].

The lack of wastewater collection and treatment facilities in urban municipalities are critical issues for the local government to act on in wastewater management. Therefore, the improvement of the drainage systems in Dili, including the management and the construction of sewerage collection and treatment facilities, is needed [33]. For this reason, we have mapped several points of interest related to the water system in Dili on the open-source platform climatescan (Figure 18a) [36].

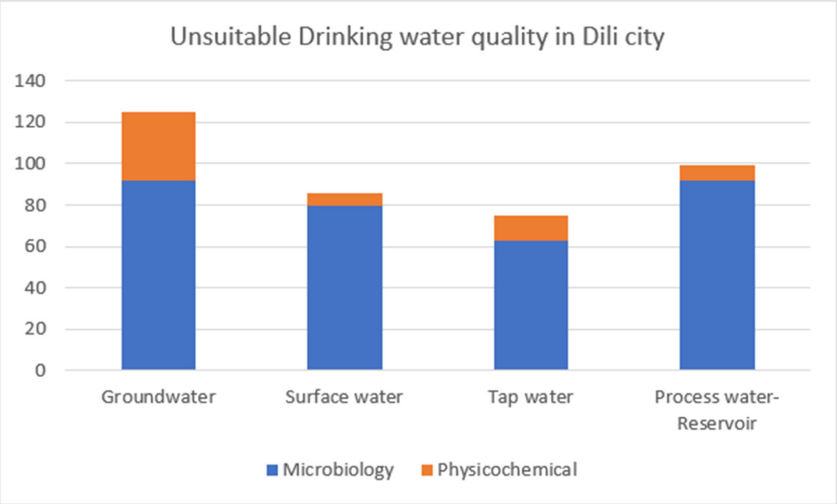

Figure 17. Drinking water quality polluted by microbiological and physicochemical entities.

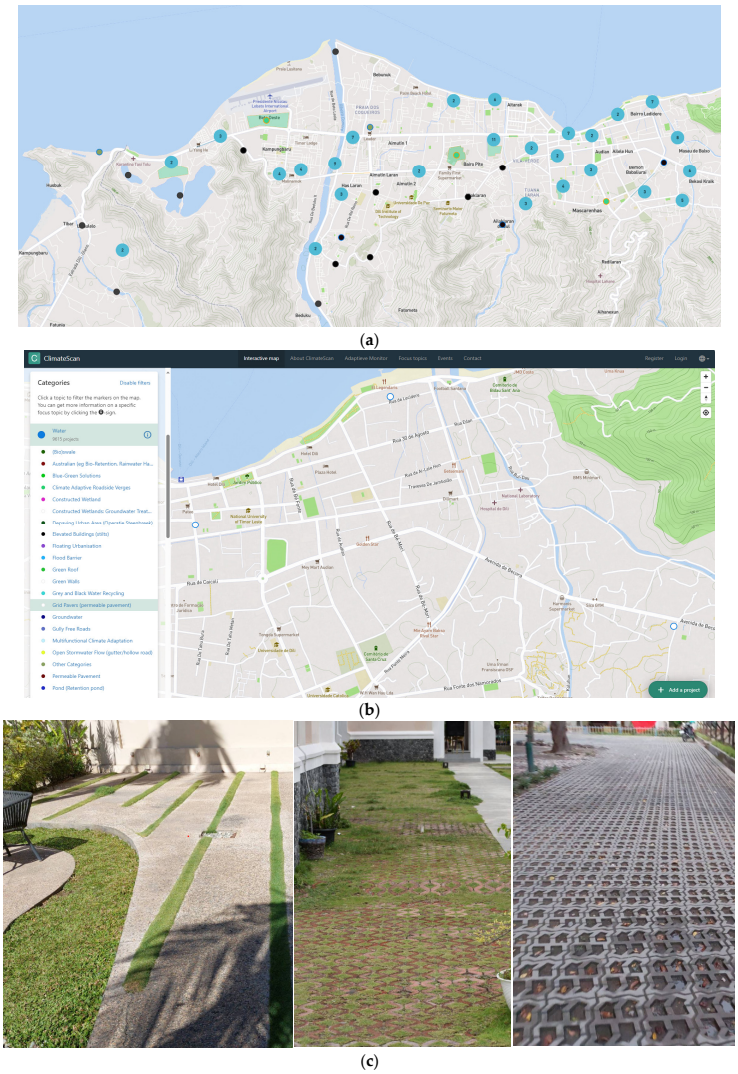

Figure 18. (**a**) Visited sites and climate adaptation-related projects for improvement of wastewater systems [climatescan.org]. (**b**) Category permeable pavements results in 3 locations in Dili. (**c**) 3 pictures of the 3 locations with permeable pavement in Dili (grass filled grid pavers) for infiltration stormwater to minimize wastewater.

Flood-related solutions such as permeable pavements (grass-filled grid pavers is a separate category in climatescan.org, see Figure 18b with 3 locations, see Figure 18c) and vegetated ponds are mapped that can be transformed in a cost-effective manner into constructed wetlands [37] for the purification of grey wastewater, as has been utilized in many other parts of the world (Figure 19). Low-cost nature-based solutions such as constructed wetlands and bioswales in The Philippines and The Netherlands can be implemented with local skills and materials from Timor-Leste to improve the wastewater situation and address other challenges such as biodiversity loss, heat stress, drought, and floodings. These installations are easier to rebuild and maintain than large-scale grey infrastructure (where only one is still in function of the three wastewater treatment plants) given the multiple hazards that occur in Timor-Leste: landslides, earthquakes, strong wind, and pluvial and fluvial floodings, and they can serve as coastal protection.

Figure 19. Small-scale nature-based wastewater treatment best management practices from The Philippines (constructed wetland for purification of black and grey wastewater from industry in Davao: https://www.climatescan.org/projects/10360/detail, accessed on 19 May 2024) and The Netherlands (constructed wetland for greywater from houses in Groningen: https://www.climatescan.org/projects/4020/detail) accessed on 19 May 2024.

4. Conclusions

In this research, several methodologies are applied to assess the challenges related to wastewater and possible solutions to minimize its impacts on health and the environment.

Field survey and data collection

The field survey and data collection for wastewater management showed that the municipalities contain a high proportion of the population and should consider the implementation of decentralized wastewater treatment in each municipality.

The interviews conducted with 130 participants from local authorities and communities showed that the management of wastewater in Timor-Leste can be divided into two categories. First, the wastewater from several public and commercial buildings is collected by private companies for treatment in the Tibar station. Secondly, the community discharges their wastewater into open drainage canals, farms, gardens, and sinkholes. There is a lack of understanding in communities on several impacts of wastewater, as well as wastewater pollution. The impact of a lack of wastewater management, based on the results of our questionnaire, show that most children suffer from diarrhea (55,38%), and especially in the rainy season, there is a high possibility of infection with waterborne diseases.

Timor-Leste faces a dual challenge in wastewater management with the presence of two distinct types of wastewater—greywater and blackwater—originating from domestic, commercial, and home industrial activities. In this study, encompassing field surveys, interviews, and questionnaires conducted, it became evident that the number of centralized wastewater treatment plants in the country remains notably limited. The primary facility, the wastewater treatment plant in Tibar, Timor-Leste, is tasked with addressing the wastewater concerns of a municipality marked by both a high population density and an ongoing

process of decentralization. To compile relevant data and information, local authorities and communities were engaged through interviews, on-site visits were conducted to observe and document the wastewater conditions in sewer systems nationwide, and pertinent policies and regulations were gathered from entities such as the Ministry of Public Works, the Department of Water and Basic Sanitation, NGOs, civil societies, and other stakeholders.

This holistic approach sheds light on the intricate dynamics of wastewater treatment in Timor-Leste, emphasizing the urgent need for a more expansive and decentralized infrastructure to meet the growing challenges posed by diverse sources of wastewater. As the nation grapples with both a burgeoning population and decentralization efforts, addressing these wastewater concerns becomes imperative for safeguarding public health, protecting the environment, and ensuring sustainable development. A proportion of 54% of the greywater is discharged into open sewers that flow directly to the sea; 32% is disposed of in farms or gardens, and 14% is disposed of into constructed wastewater sinkholes.

Most of the blackwater from the urban areas, such as Dili, are disposed and treated at the Tibar ETAR. Relatively poor communities do not hire private wastewater trucks to transport their waste(water).

A significant portion of wastewater is directly disposed of into the open public sewers. Therefore, there is a need to find an economical, sustainable, and mandatory practice to reduce water demand such as in car washing operations: the majority of vehicle washing establishments in Dili utilize groundwater, comprising 57.9% of their water source.

There is a need for raising awareness, civic education, and water use campaigns to minimize wastewater's impact on public health and the environment in urban and rural areas. A decrease in the water use volume will reduce wastewater quantities, and implementing and testing a low-cost, energy-efficient wastewater treatment at the community level could be very beneficial for Timor-Leste.

The water quality monitoring data from the national laboratory of water supply showed that the drinking water in Dili city has been contaminated by physicochemical and microbiological entities from four types of water such as groundwater, surface water, tap water, and process water. In this case, the government authorities may apply some technological approaches such as artificial intelligence and machine learning in the management of water treatment and wastewater management sectors. The application of advanced wastewater treatment technologies can help in improving the quality of treated wastewater and minimize the risk of waterborne diseases, playing a vital role in addressing complex wastewater contaminants and achieving higher purification standards in industrial wastewater treatment.

Furthermore, future work will explore a deeper analysis of water quality contamination and find suitable technologies to improve the water quality and wastewater treatment problem in Timor-Leste.

Recommendations

The following recommendations will be used to form a new strategy for wastewater management in Timor-Leste:

- The lack of wastewater collection and treatment facilities in urban municipalities are critical issues for the local government to take action on in wastewater management. Therefore, the improvement of the drainage systems in Dili, including the management and the construction of sewerage collection and treatment facilities, is strongly advised.
- The development of local policies concerning domestic wastewater.
- Integrated policies for water resource management which deal with the management of domestic wastewater with the participation of stakeholders.
- The overarching role of local leaders needs to be supported by non-governmental organizations, international agencies, and stakeholders.
- The lack of funding support for wastewater management as well as the maintenance of wastewater strategies needs attention from the government.
- The government should act on the implementation, monitoring, and evaluation of wastewater management.

- Sanitation in state buildings and other public services should serve as examples.
- The lack of communities' understanding and perception of domestic wastewater implications needs to be addressed for specific capacity building.

For the implementation of the new wastewater strategy, over 50 points of interest related to the water system in Dili are mapped on the open-source platform climatescan.org for international knowledge exchange. Flood-related solutions such as permeable pavement (grass-filled grid pavers) and vegetated ponds in Dili are mapped that can be transformed, in a cost-effective manner, into constructed wetlands for the purification of grey wastewater, as has been utilized in many other parts in the world.

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