Metabolism of Jaffna town: Special reference to Settlement

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Abstract

This research assesses the metabolism of Jaffna town special reference to settlement to promote circular metabolism, and to achieve urban sustainability. Metabolic analysis of towns and cities could help planners improve the efficient use of materials and energy in cities and reduce environmental footprint. The research aims to formulate strategies to enhance the sustainability of Jaffna Town by assessing the consumption of materials and energy and, the pattern of material and energy flow in and out of Jaffna Town. This study was confined to settlements in Jaffna Town, considering the consumption and disposal of food, water and materials. Primary data on the consumption of food, water, energy and material and disposal of waste per day were collected using questionnaires based on a stratified random sampling method from households. Collected data on input and output were analysed using SPSS packages. Further, key informant interviews with officers of UDA, field observation for the study area, and discussion with each sample household were conducted. Data on waste generation and management of the Municipal Council were also collected and analysed. The research concluded that three of four sectors in Jaffna town's metabolic process are semi-circular. 14 % of food, 31% of water, 33% of cloth, 61.3 % of solid waste and whole animal wastes are recycled to circulate in the environment in an eco-friendly manner except energy that is not recovered. Most of the demolished building materials are recycled. In addition, the total input and output of Food, water and energy are 64 and 60 tons respectively, 48 tons of them end up in waste streams causing environmental consequences and 12 tons are recycled as input. Building materials, clothes and furniture consumed remain in the loop as a stock because of one-time consumption. Appropriate strategies to promote from a semi-circular pattern to a circular metabolic pattern such as urban agriculture, climate-sensitive building design, lean development, green urbanism, and neighbourhood development are suggested.

Keywords: Urban metabolism; urban sustainability; resource efficiency; resource flow

Introduction

The concept of urban metabolism is defined by Wolman (1965). it can be understood as the process by which a city attains resources from its local environmental hinterland or through trade, consumes them for the production of economic outputs and social services which are ideally, but not actually, equitably distributed and releases the wastes into the environment (UN Environment report 2012). Kennedy et al. (2007) define urban metabolism as the sum of the technical and socio-economic processes that occur within the cities, resulting in growth, production of energy, and elimination of waste. The flow of natural resources into the cities and wastes out of them represents one of the largest challenges to urban sustainability and the linear processes by which

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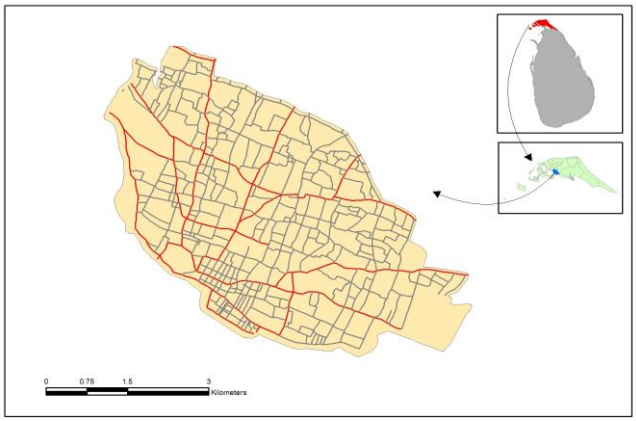
cities transform environmental resources into waste products is disruptive of the planet's life support systems (Herbert Girardet, 1990). The concept of metabolism simplifies our understanding of sustainability and streamlines the process towards sustainability. Rapid urbanization in Jaffna town leads to more consumption of resources and disposal of large volumes of waste into the environment, creating many issues (UDA Report 2020). Therefore, this research tries to assess the nature of the metabolic pattern of Jaffna town defined by Jaffna MC's administrative boundary and aims at improving the efficient use of resources and contributing to urban sustainability. Primary data were gathered from selected households in the MC area on the consumption of material, food, energy, and water, as well as disposal of material, human and food wastes, emissions, and wastewater. Interviews with planners and professionals provided data on Strategies for waste reduction and management, enhancing energy efficiency, and promoting environmentally friendly construction practices. Additionally, field observations were conducted to gather data on the town's current situation. Secondary data on solid waste, environmental issues and the institutions involved in urban management were also collected. The data on the input and output of resources were summarized and analysed using SPSS to determine what per cent of the resources are recycled and reused within the town.

2. Study area

Jaffna town, located in the southern part of the Jaffna Peninsula in Sri Lanka, spans 22.38 square Kilometres. In 2020, it had a population of 84,340, resulting in a population density of 4,159 people per square kilometre (UDA 2020). Jaffna Town is the largest city in the Northern region of Sri Lanka, serving over one million people. More than 63% of its land is used for residential purposes, while its primary income comes from commercial and business activities (UN-Habitat 2018). The town consists of 21 657 households from the Divisional Secretariats of Nallur and Jaffna.

Map 1: Jaffna Town



3. Statement of problem

The town has experienced rapid land use and land cover expansion in the last decade, driven by increased migration (UN-Habitat 2028). The rise in migration and commuter demand has led to increased consumption of materials, water, energy, and food, resulting in waste accumulation and various negative environmental impacts. (World Bank 2019). The growing residential and commuter populations in Jaffna Town have increased the demand for construction materials, leading to environmental degradation due to the extraction and processing of these materials. Demolition waste in most places in the town ends up in waste dump sites. The water consumed

by the town is extracted from outside of the town and supplied because groundwater in the town area is contaminated with faecal materials and agrochemicals (Dusyanthi). Food and water consumed by the city population turned into wastewater and sewage and untreated and disposed of in the lagoons causing many issues in the ecosystems of the town. The solid waste produced by the town ends up in an open dump site in Kallundai that causes serious issues of pollution and emission (Tellipalai sanitary Landfill projects). Household energy is consumed in the form of electricity and gas. Electricity is obtained from the national grid which is fed by more than two-thirds generated by thermal sources (Annual report of CEB 2020).

4. Aim and objectives of this study

The research is formed to achieve the following aims and specific objectives. The main aim of the study is to formulate strategies to improve the efficient use of resources to achieve urban sustainability. The research also has the following specific objectives: to assess the metabolism of settlements in Jaffna town (MC), to identify causes for this metabolic pattern and its associated environmental consequences and to assess strategies to promote the existing patterns of metabolism into the circular pattern.

5. Research Method

Primary and secondary data representing the metabolic process of the town have been gathered from different sources to conduct this study. For this study, questionnaires, observation, discussion and interview methods were applied to collect data. Usage of materials, water, energy and food were collected via questionnaire survey from households. the questionnaire was used to collect data on input or consumption resources such as food, water energy and material and output or disposal of material/wastes such as material disposal, human wastes and food wastes, emission and wastewater disposal from selected 100 sampled households within Jaffna Municipal Council area. A stratified random sampling method was used to select households from the town. Households in the town were stratified into low, middle and high-income groups with samples distributed proportionately among each stratum. Households were classified according to income level into three strata: low-income households included samurdhi beneficiaries earning below Rs. 5000 per month, Middle-income households have incomes ranging from Rs.5000 to Rs. 50000 per month, and High-income households earned above Rs. 50000 per month. Samples were then allocated to each stratum based on these income categories. professionals of built environment such as planners, engineers of MC, technical officers and executives of Urban Development Authority as key informants were interviewed concerning environmental degradation, its causes and further solutions, recommendations on environment-friendly construction practices and policies, reduction of waste, people's attitude on waste disposal, volume of material for a house and reuse of demolition waste. Condition of each household and open dumping of wastes, stormwater disposal, sewerage, energy-saving strategies and activities were observed in the field to facilitate the data analysis. Each householder was discussed on the attitude and perception concerning the resource use and waste disposal, and energy efficiency of houses. secondary data were collected concerning waste generation, collection and disposal from Jaffna Municipal Council. Reports and development plans published by the UDA concerning Jaffna Town, planning and building regulations applicable to settlements were also collected. Primary and secondary data on the inflow and outflow of resources to and from the town were collected and analysed using the input-output analysis method. The total input of materials, water, food and energy as well as the output of resources, wastewater, sewage, and solid waste was evaluated. The percentage of each output that was reused, and recycled was considered to determine the circular metabolism of the town. The information derived from interviews, observation and discussion were analysed to propose strategies to improve the metabolism towards circular patterns.

6. Analysis

6.1. Assessment of metabolism of Jaffna town (MC)

Jaffna town, like others, consumes resources, utilizes them and disposes them as waste. Consumption of resources is considered as input and disposal of used resources or waste is considered as output. Resources inflow into the town as consumption and outflow of the town as waste. In this research, the daily intake of food, water, energy and materials by households is evaluated as the inflow of resources. The total food intake and the daily household water usage for activities such as cooking, washing bathing, cleaning and drinking were collected. the daily energy consumption at the household level, including natural gas, firewood, kerosene, and electricity from both the national grid and renewable sources was also analysed. Additionally, the materials used in the construction of houses and buildings at the household level were assessed the following table 1 & 2 shows the total consumption of resources.

Table 1 Consumption

	Input	Total sum
Food	Rice, Flour, Vegetables, Cereals, Groceries, Meat, (Egg, Fish & meat) and other foods (Per day)	550.605 (Kg)
Water	(All kinds of use)	66 297 (Litre)
Energy	Natural gas (Per day)	26.04 (kg)
	Kerosene (Litre) (Per day)	32.3 (kg)
	Firewood (Kg) Per day)	242 (kg)
	Electricity (kWh) (Per day)	301.81 (kWh)
	Renewable energy (kWh) (Per day)	23 (kWh)
Materials	Building material in stock (Stone, Cement and Sand)	9, 047.832 billion (Kg)
	Clothes (Per day) (Approximately 2 clothes equal to 1 kg) (1081)	540.5 (Kg)
	Other materials at home (furniture (Chair-Plastic, Wood, Steel, table-Plastic, Wood, Bed-wood, Almirah- Wood& Steel, Showcase-wood & steel	41 412. 2 (Kg)

Source: Questionnaire survey 2020

Food, water and materials turning into waste, sewage and wastewater are as output. Energy consumed turns into carbon dioxide. Construction materials turn into demolition waste. The following table 2 shows the total disposal as output.

Table 2 Disposal of waste material

Source: Questionnaire survey 2020

Output		Total sum
Solid waste		801.5 (kg)
Wastewater	Waste water by Bathing, washing, rinsing and cleaning	55595(litre)
	Sewage wastewater	6527 (litre)
Sledge (477 person*400g- a healthy person's stool is 400g) based on the medical health Centre in U. S		190.800 (kg)
Demolition waste		474.23 million (kg)
Clothes and Other materials (wood, plastic and steel furniture)		It will be up to a lifetime

Domestic animals are fed a total of 309.6 kg of food and 100.9 kg litre of water each day as input resulting in 585.9 kilograms of animals' faeces as output.

6.2. Inflows and outflows

Inflow and outflow analyses of resources are necessary to know the urban metabolic pattern that shows where the town is in the sustainability continuum. The analysis shows how much resources are consumed, and disposed of and how much goes back to the environment by recycling, reusing and composting. Table 3 shows the inflow and outflow of resources to and from the town.

Table 3 Food and water

Input	Sum	Output	Total sum output (Kg)	Back to Circular Pattern	Total circulated Sewage -14 % (sealed pit)	Disposing Sewage -86% (Without treating)
Food (Kg)	550.605	Sewage (Kg) (Sledge 70 % 133.560)	190.800 (100%)	Composting Sledge 70%-18.698 kg	26.712(100%)	(190.800-26.712) 164.080
Water (Drinking & cooking (litre)	3486	Sewage (1L =1Kg) (Water 30% - 57. 240)		Recycling 30%-8.013 kg		
Water for toilets (litre)	Sewage water 3041		3041	Recycling Toilet flushing Water-425.74 kg	425.74 kg	(3041-425.74) 2615.26 (Toilet water)
Total			3231.8 (100%)		452.452 (14%)	2779.34 (86%)

Source: Questionnaire survey 2020

Households in Jaffna Town consume 550.6 kg of food and 3,486 litres of drinking water daily, disposing of 190.80 kg of sewage, with 70% sludge and 30% water (calculations based on medical centres, in the United States of America). Additionally, 3,041 litres of water are used for flushing. The Jaffna Municipal Council collects and treats 14% (452.112 kg) of sewage from sealed pits, recycling the sludge as compost for gardening and using treated water for plants. The remaining 86% (2,779.34 kg) is disposed into soakage and septic pits, seeping into the ground. Only 14% of the 3,231.8 kg of sewage (8.013 kg + 425.74 kg), is recycled, indicating a semi-circular metabolic pattern in the food sector. Water consumption also follows a semi-circular pattern, with 55,595 litres used for bathing, washing, and cleaning, and 31% of the resulting wastewater is reused, while 69% is discharged untreated into the environment.

Table 4 Energy

Use of energy	Input	Total sum and carbon in per litre	Output (co2) (kg)	Circularity
For household internal need	Natural gas (kg)	26.04*(453g)	11.822	No recovery from Energy (Releasing to environment directly)
	Kerosene (litre)	32.3 *(0.82 kg)	26.486	
	Firewood (kg)	242 *(475g)	114.950	
	Electricity (kWh)	301.81 *(0.32 litre diesel) =96.579 * litre diesel. Carbon in per litre diesel 720g	69.536	
For household external needs (transport)	Petrol (litre) for motorbike-73.4 and three-wheeler- 4 and car-23.60	101* (653g)	65.953	
	Diesel (litre) for van	20 *(720g in per litre diesel)	14.4 kg	
	Total carbon		276.925	

Source: Questionnaire survey 2020

The emission from energy consumption is calculated based on literature, and the generation of 1 kWh of electricity consumes 0.32 litres of diesel. Households in the town area consume energy for various internal and external needs. Electricity needs in the town are met from the national grid which is fed by thermal power generation fuelled by diesel and coal. Each household releases a total of, 276.925 kg of carbon into the atmosphere daily through energy consumption. a very insignificant amount of energy comes from renewable sources. Here, energy consumption follows the linear metabolic pattern.

Table 5 Material: Building

input	Amount of materials used in houses	Output (demolition waste)	Circularity	Rest of input (kg)
Stone (kg)	1566.7 billion	89.856 million (0.089 billion)	Total output using as material to road and buildings	Being in stock in the environment as structure
Cement (kg)	2193.371 billion	81.110 million (0.081 billion)		
Sand (kg)	5287.761 billion	303.264 million (0.303 billion)		
	9047.832 billion	0.473billion	0.473billion (0.005%)	9047.359 billion (99.995%)

Source: Questionnaire survey 2020

The quantities of materials consumed for building construction were determined based on the literature. Building construction in Jaffna Town requires 120 kg of stone, 108.32 kg of cement, and 405 kg of sand per square foot. The total material usage was calculated based on the sample population's building area (13049 million sq. feet, including the foundation of 748800 sq. feet, approximate estimation by technical officers). Buildings, being long-term environmental stocks, exhibit a circular metabolic pattern, with only a minimal volume (0.005%) of materials like stone, cement, and sand being demolished and reused for road work and foundations. Furniture materials such as steel, plastic, and wood remain in the environment for extended periods and may eventually be recycled or reused. Annually, 540.5 kg of clothes are consumed and disposed of without a precise timeframe however these are recycled, reused and disposed of whenever

discarded. 38% of clothes are recycled for making pillows, cleaning and mopping the house and decorating, and 33% of reused by providing to others for use. Remaining 29% is released to the environment. Here, more than 50% of discarded clothes replace some things and reduce the requirement for clothes. it represents a semi-circular metabolic pattern.

Table 6 Solid waste

Way of disposing	Amount(kg)
Collection of Municipal Council from resident	472.5
Burning	136.2
Disposal to roadside	10
Disposal to own land	32.5
Disposal to water bodies	14
Reuse	1
Other waste disposal methods	17
Fertilizer for flowering plants and gardens	118.3
Total	**801.5**

Source: Questionnaire survey 2020

According to Municipal Council statistics, approximately 88. 2% (60 tons) of total solid waste (68 tons) collected from different sectors such as resident, commercial places, hospitals etc. are processed by machinery for recycling and reusing purposes and then exported to Colombo. 11. 8% (8 tons) of total waste which is mostly biodegradable, is dumped at Kallundai open dumping. Approximately, a partial amount of total solid waste generated from households is disposed of in different ways as shown in Table 7. Specifically, 118.30 kg (14.7%) of total household waste is recycled as organic fertilizer for flowering plants and gardens at home while nearly 136.2 kg (16.9 %) is burnt. However almost 590.8 kg (73.6 %)-comprising 472.5 kg (58.9 %) and 118.3 kg (14.7%) from recycling and reuse returns to the loop of environment and 209.7 kg (26.4%) emitted directly to the environment as co2 and ashes due to burning as its environmental consequences. In conclusion, a solid waste outflow that follows a semi-circular metabolic pattern, (491.8 kg or 61.3% including collection by the municipal council, recycling as a fertilizer for plants and reuse) returns to the environmental cycle.

6.3 Input and output for animals

In 21 sample households, animal waste, including 581 kg of cow and goat dung, is fully composted and used as organic fertilizer for paddy fields and gardens. Additionally, animal liquid waste is repurposed as a pesticide for plants. This process demonstrates a circular metabolic pattern, where only the food fed to the animals within the household is considered.

6.4. Local, regional and out of the region consumption

Cities are significant consumers of energy and material, which are either stored for more or less extensive periods or left in the form of exported and imported products or more often in the form of waste, emissions into air, water and heat. These modus practices of cities have a significant environmental impact both upstream of the city due to the bulk importation of resources extracted outside of urban territories, and within the city and downstream of it, due to various emissions which contribute to air, water and soil pollution.

6.4.1 Consumption of food

The transition between territories is very resource-hungry and primarily linear and more energy is consumed for transportation and materials which are additionally imported, which is the factor for environmental consequences. therefore, analysing local consumption defined as "within Jaffna town or municipal council area as well as regional consumption as within Jaffna district and outside the region consumption as outside the Jaffna district helps to understand the extent of energy consumed for transporting food, water, goods, material, groceries etc. from outside the Jaffna to the territory of Jaffna town, its extent of generation of waste and how local consumption can reduce demand for resources and generation of waste. Local consumption requires less energy while regional consumption demands more energy and out-of-region consumption even higher energy expenditures.

Table 7 Consumption of food

Type of food	Unit	Conversion	Total Amount (kg)
Vegetable			4.75
Coconut	50 (number)	Per coconut weight in kg -1.4	70
Fruits			9.7
Milk	135 litres	The density of a litre of milk-1.03	135
Egg	20 (number)	per egg weight in grams-55	1.1
Total			220.55(40%)

Source: Questionnaire survey 2020

In Jaffna, about 40% of food (550.605 kg) consumed locally helps reduce demand for external food and transport energy, promoting self-sufficiency and minimizing waste. Regarding regional consumption, approximately 42.2% of food (550.605kg) is consumed from various parts of the Jaffna district. Vegetables predominantly are sourced from Punalakattuvan, Neerveli, Achuveli, Urumpirai, Kopay, Kodikaamam, Chavakacheri, and Sanguveli in Jaffna to Theruneliveli from where distribution occurs to local markets. Paddy cultivation in Jaffna is sufficient to meet local demand for rice and animal products such as egg, fish and animal meat as well. However, only fish needs of Jaffna town are sourced from Paasaiyoor, Gurunagar and Kaakaidhivu. This regional supply chain will require increasing transport energy and CO2 emissions which contributes to additional waste downstream of Jaffna town. Furthermore, 17.8% of food is sourced within the region and outside the region. Vegetables are obtained from Dambulla and Kilinochchi as well as flour from international sources, biscuits from Colombo, fruits from Jaffna and cereals and groceries from both Jaffna and international regions (such as grams from Canada and India) as a result of this supply chain, a large amount of energy is consumed and ultimately leading to waste. Local and regional consumption which accounts for 82.2 % of food consumption is desirable on account of consuming less energy and reduction of waste within Jaffna town.

6.4.2. Consumption of water

94% of the total water (66,297 litres) is consumed locally from underground and tube wells, reducing energy demand and supporting self-sufficiency. Regionally, 5.4% of the water is supplied by the Jaffna municipal council from areas of the region like Therunelveli and Kondaavil, contributing to energy consumption despite being a smaller portion. Additionally, 0.6% of the water, sourced as bottled water from Colombo, is consumed due to low-quality municipal water and polluted underground resources, leading to unnecessary energy use and generating plastic waste.

6.4.3. Consumption of energy

Within Jaffna town, 19.2% of the total 214 kg of firewood consumed is sourced from household land, while 2% of households produce renewable energy (23 kWh per day), reducing overall energy consumption. Regionally, 81.8% of firewood is sourced from local shops in Jaffna town, but this wood is indirectly supplied from areas outside Jaffna such as Murugandi, Mullativu, Poonagery, Mangulam and Manner. Discarded wood from timber shops, imported from other districts such as Polonnaruwa, Batticaloa, Monaragala, and Navulla (Mineraiya) is also repurposed as firewood. Electricity in Jaffna is supplied by a diesel-powered plant, contributing to CO2 emissions. Additionally, outside the Jaffna district, 32.3 litres of kerosene and 26.04 kg of natural gas are imported from Middle Eastern countries, further increasing energy consumption and emissions**.**

6.4.4 Consumption of building materials

Table 8 building materials

Type of materials	Amount of total house (kg)	Regional consumption of building materials (Within Jaffna) (kg)	Out of the region (out of the Jaffna) consumption of building materials (kg)
Stone	1566.7 billion	1159.358	407.342 billion
Cement	2193.371 billion	548.342 billion	16445.029billion
Sand	5287.761 billion	5287.761 billion	

Source: Questionnaire survey 2020

Until 1993, Kankesanthurai (K.K.S) cement factory was operational, supplying cement for building houses within Jaffna town. At that time, 25% (548.342 billion kg) of sample houses used cement from K.K.S. after the closure of the K.K.S cement factory, 75 % (16445.029billion kg) of cement has been imported primarily from India, Pakistan and Colombo. This reliance on cement from outside the region increases energy consumption and contributes to waste disposal issues in Jaffna town.

Before 2010, limestone from within Jaffna, including areas such as Kondavil, and Karainagar. Chunnagam, Maruthanaarmadam, Point Pedro etc. are commonly used. Although limestone continued to be used in small quantities as needed after 2010, the post-war context saw a shift towards using it as a building material. These black stones are now primarily imported into Jaffna town from Pitta Kotte and Nugekoda etc.The white sand is consumed within the regional areas such as Ariyalai, Nagar Kovil, Mankumpaan etc. and after 2010, kandavalai red fertile soil has been imported to Jaffna town only for plastering purposes. Only 6% of sampled houses used this sort of soil which was imported from Kilinochchi outside the region. This soil is often mixed with white sand, which is more commonly used. Consequently, the importation of black stone requires more energy than limestone and increases overall energy consumption. While the consumption of white sand also requires energy, it is to a lesser degree compared to the black stone.

6.4.5 Consumption of food and water for animal

71.7% (222.05 kg) of animal food, including kitchen organic waste and straw from local paddy fields, is consumed locally, while 28.3% (87.55 kg) is imported from outside the region, Colombo mainly for dairy cows. Local feed is preferred for its higher nutritional value, leading to lower energy consumption. Animal faeces are fully composted and used as fertilizer for paddy fields, plants, and gardens, completing the environmental cycle. All 585.9 litres of water used for animals are sourced from household-owned underground wells, conserving both water and energy involved in the supply and treatment process.

7. Causes for metabolic pattern and its associated environmental consequences

In general, what is received from the environment, differs gently from what is returned to it in an eco-friendly manner. The assessed metabolic patterns for the Jaffna municipal council area reveal various trends. Food, accounting for 452.112 kg (14%), follows a semi-circular metabolism. Water, totalling 17,234.450 litres (31%), also exhibits a semi-circular metabolism. However, energy demonstrates a linear metabolism with no recycling or reprocessing. Material such as cloth, representing 178.365 kg (33%), adheres to a semi-circular metabolism. Building materials, amounting to 0.473 billion kg (0.005%), follow a circular metabolism as what is disposed of is returned. Animal faeces, totalling 581 kg (100%), are entirely managed through a circular metabolism. Solid waste shows a semi-circular metabolism with 491.8 kg (61.3%) being recycled or reused.To promote circular environmental strategies, it's essential to address the underlying causes of semi-circular and linear patterns. People's attitudes significantly contribute to environmental degradation. Although 95% of Jaffna town's population has basic environmental knowledge, 41% have taken no steps to conserve the environment, reflecting a lack of concern. Inadequate services from the Municipal Council exacerbate the issue, as only a portion (472.5 kg) of waste from 100 households is collected, while the remaining 329 kg is improperly disposed of through burning, dumping on private land, and polluting roads and water bodies. The Municipal Engineer highlighted that due to inadequate household waste segregation, 8 tons of solid waste are dumped daily at the Kallundai site, which is prone to waterlogging. Additionally, the Deputy Director of Urban Development noted that some residents illegally modify sealed pits to avoid paying for proper sewage disposal. The survey reveals that 86% of sampled households with septic and soak pits release sewage water underground, potentially contaminating groundwater despite septic systems filtering the water, environmental unawareness has led to increased resource use and poor waste management. Although only 5% of respondents admitted to lacking environmental awareness, all were unaware of the full consequences of their actions. Additionally, 43% of households reported no stormwater infiltration, with runoff directly entering the sea through drainage. Efficient energy and resource use, along with incorporating natural light and ventilation in homes, is essential to reduce energy demand and waste. The survey indicates that 29% of households incorporate side or air spaces, with 29% having extensive windows, 11% strategically placed windows, 89% roof glazing, 26% rear spaces, and 26% maintaining significant distances between front halls. Failure to follow these architectural guidelines leads to unnecessary electricity use. Transportation, a significant energy consumer in Jaffna town, shows 61% of the sample population using bicycles and other vehicles, with heavy reliance on private transport releasing 80.352 kg of carbon daily. Additionally, 70 households using water pumps lack efficient equipment, with 93% of taps being inefficient, leading to suboptimal water use. Green urban areas support physical activity, relaxation, and environmental health by producing oxygen, filtering air pollution, and moderating temperatures. In the survey, 46% of houses have 1/8 of their land covered in greenery, 9% have less than 1/8, particularly in Paasaiyoor, the town centre, and Gurunagar, while 32% have 2/8 covered. Many houses in Gurunagar and parts of Paasaiyoor lack greenery. According to Jaffna municipal regulations, 15% of houses have wastewater tanks, but these tanks are open at the bottom, leading to 8,339.25 litres of wastewater out of 55,595 litres being directly disposed of underground, causing groundwater pollution. Environmental impacts in Jaffna Town are a growing concern, particularly regarding groundwater, which is crucial for drinking, cooking, and gardening. Due to soaking and septic pits, 95% of groundwater was contaminated with E. coli (GTZ project 1998), with contamination now likely nearing 100%. The town also faces significant environmental challenges, including air pollution, reduced underground water recharge, waterbody pollution, diminished aesthetic appeal, increased flood vulnerability, environmental degradation from plastic and polythene, contributions to global warming and climate change, soil degradation, and resource depletion.

8. Conclusion and future direction

Urban metabolism is an effective approach for applying sustainable city principles, as it analyses Jaffna Town's sustainability based on input, output, and processes. Most sectors, such as water, food, and materials like clothing, follow a semi-circular metabolic pattern. Building materials, however, exhibit a circular metabolism, with demolished materials reused in construction. Furniture remains in the environment long-term, similar to buildings. Animal waste also follows a circular pattern, returning to agriculture as fertilizer. Energy outputs, however, follow a linear pattern, with carbon and ashes released into the environment. About half of the solid waste from households is collected and mostly circulated by the municipal council. Regional food consumption in Jaffna Town (232.583 kg) surpasses both local (220.55 kg) and external sources (97.412 kg). 94% of household water is sourced locally, while 19.2% of firewood is from residents' land, with renewable energy accounting for 2%. Other energy sources are mostly imported from outside the region. Most housing materials, including 75% of cement, are sourced from outside Jaffna. Around three-quarters of animal feed is consumed within the town. Consumption patterns vary across sectors, influenced by factors such as people's attitudes, unawareness of environmental impacts, dissatisfaction with municipal services, improper waste disposal, and the abundant availability of resources. These factors contribute significantly to environmental issues in Jaffna Town. Open solid waste dumping at Kallundai has further degraded the environment, causing resource losses like leachate contamination of the nearby lagoon. Post-war population growth has led to increased consumption and waste generation, significantly impacting the environment, often unnoticed by the public. This has resulted in emerging environmental issues, such as reduced groundwater recharge and underground water contamination with E. coli. Overall, three-quarters of sectors in Jaffna Town exhibit semi-circular or linear metabolic patterns, contributing to these environmental challenges. Attention is needed to promote circular metabolism in Jaffna Town by implementing strategies such as establishing a sewerage network or sealed pits, setting up a centralized sewage treatment plant, managing stormwater through the sewage system, and enforcing penalties for non-compliance. Additional measures include creating demand for organic fertilizer, setting up a municipal branch to buy plastic and polythene, ensuring effective municipal council operations, creating urban parks, increasing public transport use, promoting rainwater harvesting, encouraging green buildings, advocating for sustainable lifestyles, investing in renewable energy, and improving the quality of municipal water.

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