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Process for Sustainable Solid Waste Management in Tuti Island, Sudan, during Nile Flood Season; Comparison with International Standards

Khogali Hind[1]

[1] College of Architecture Engineering and Digital Design, Dar Al Uloom University, Riyadh city, Saudi Arabia

Correspondence: Khogali Hind, College of Architecture Engineering and Digital Design, Dar Al Uloom University, Riyadh city, Saudi Arabia. Tel: 1-1494-9123. E-mail: ahind@dau.edu.sa; hind_50abde@yahoo.com

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Abstract

Tuti Island is at the confluence of the White and Blue Niles and lies at the center of Greater Khartoum. The solid waste volume from houses is estimated at 20 tons, which has a significant impact on human health, the environment, and climate change.

This study aims to investigate the process of solid waste management on Tuti Island. Solid waste includes food remains, construction debris, wood, scrap iron, discarded furniture, and collecting and reusing flood and rainwater International standards state that the solid waste disposal process passes through specific stages.

This study adopts a scientific methodology to analyze the current scenario of measuring the types and quantities of solid waste and find appropriate methods for its collection, transportation, classification, treatment, recycling, reduction, and reuse. The study additionally uses questionnaires for the identification of issues, the types of solid waste, and proposed solutions.

The results demonstrated that 37% of the respondents agreed that solid waste management is addressed it means there's a process, 45% agreed that they should pay for this service, and 75% agreed that one solution for waste management could be to increase people's awareness. It was proposed to continue this project by supporting people, demanding legislation from the government represented by the Ministry of Environment and policies that support the recycling process.

Keywords: Tuti Island in Sudan, sustainable solid waste management, recycling, economic, environmental, and social aspects

1. Introduction

Tuti Island is an island located at the confluence of the Blue and White Niles in Sudan, in Khartoum city, the capital of Sudan. The island covers an area of approximately 950 acres. The entire island is covered with lush greenery, with orchards of lemon, mango, guava, and fruits other vegetables. Its eastern sandy shore is surrounded by lemon groves, making it the most favorable place for swimming in Khartoum city, attracting a large volume of tourists. The population of the island is estimated at 20,000, and the volume of domestic solid waste is estimated at 20 tons. This imposes a significant impact on human health and the environment and adversely contributes to the phenomenon of climate change. This research is aiming to study the present situation of solid waste management in Tuti island, what are the procedures, and the requirements to increase solid waste management and a awareness, many literature were reviewed limited local literature were found. The outcome of the research is identified the solid waste process, the requirements, the cost, compared the results with other international solutions to determine vision to future solutions.

2. Research Objectives

- Studying the status of solid waste, inventorying, sorting, and classifying quantities
- Identifying the nature of the problems, solid waste collection and removal, and finding a classification of the area for the solid waste.
- Identifying the cost of the classification area, hiring people, trucks, and containers

- Identify the process of solid waste management.
- Comparing with other's international experience.
- Determining a vision for the future and a scientific and innovative mechanism for solid waste disposal

3. Literature Reviewed

3.1 Geographical Location

Tuti Island is located at the confluence of the Blue and White Niles in Khartoum city, the capital of Sudan. It is accessible through the Tuti Island Bridge, established in 2008, linking the island to the triangular capital. [1] stated that the Tuti New Bridge was established in 2009, linking the island to North Khartoum. Figure 1 demonstrates the changes in the island area and land utilization from 1965 to 1988. Figure 2 presents Tuti Island in 2022.

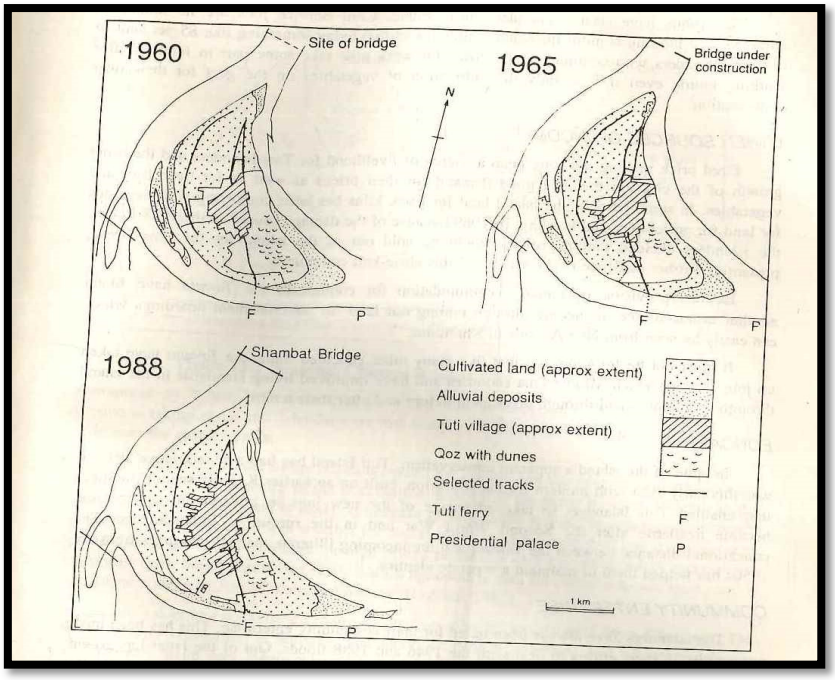

Figure 1. Change in the area and land utilization from 1965 to 1988

Source [2]

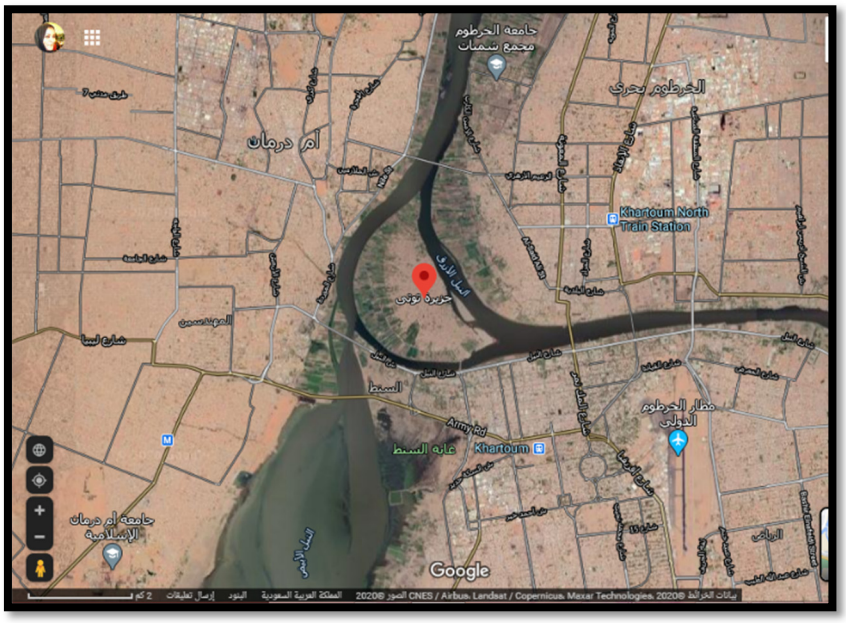

Figure 2. Tuti Island 2022

Source [3]

3.2 Geological Aspect

Tuti Island was formed by the accumulation of mud, silt, and sand on the banks of the River Nile at the confluence of the Blue and the White Nile.

3.3 Religious Aspect

Eltayeb [4] stated that Tuti is the home of Sheikh Arbab Al-Aqid belonging to the Al-Mahas tribe, who settled on Tuti Island in the 17th and 18th centuries.

3.4 Sustainability

The use of natural resources without depletion ensures the rights of future generations to use these materials. Sustainability in solid waste treatment: Sustainability in solid waste treatment comprises recycling and treating solid waste in a certain percentage by following local and international standards to ensure its reuse. Figure 3 presents the relationship between the three aspects of sustainability—environment comprising biodiversity, air and water, and land; society including culture, identity, accessibility, stability, and equity; economy, including sustainable development; and circular economy.

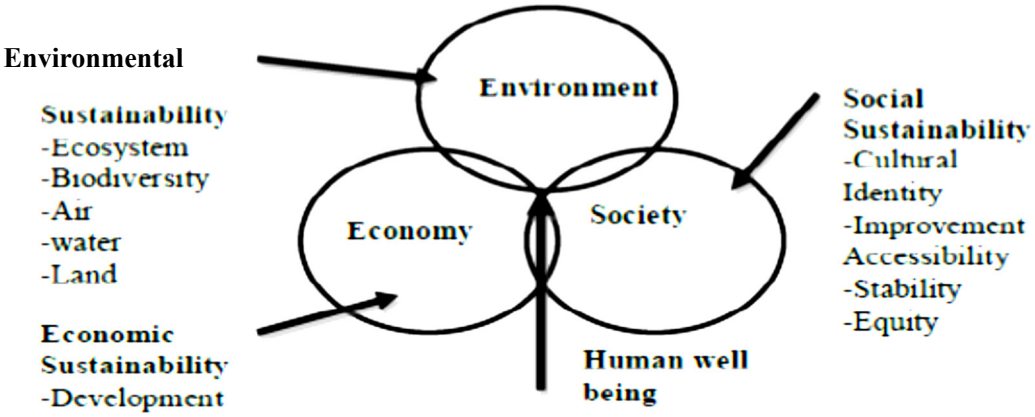

Figure 3. The relationship between the three aspects of sustainability—environmental including biodiversity, air, water, and land; social including culture, identity, accessibility, stability, and equity; and economic including sustainable development, and circular economics. The main aspect is working for human wellbeing

Source [5]

3.4.1 Environmental Sustainability

Environmental sustainability emphasizes the preservation of the environment, resources and their optimal utilization, the preservation of plant and biological diversity, the management of solid waste, water, and energy, and their optimal recycling in a manner that preserves the environment and restores balance [6]

3.4.2 Social Sustainability

It is necessary to benefit from the energy of youth, women, and children who may be involved in the collection, classification, and transportation of solid waste to the sorting area. Social sustainability also comprises raising awareness and educating the population about the culture of preserving the environment and collecting solid wastes. There should be adequate provision for small income-generating projects, especially for young people, such as small workshops that aid in the recycling process.

3.4.3 Economic Sustainability

The recent inclusion of the concept of circular economy, which benefits financially and economically from solid waste recycling and reusing, comprises the following points:

- Benefiting financially and economically from the recycling of construction solid waste and leftovers from homes and construction. These solid wastes may be collected as bricks, asphalt, stones, and sand and reused in the construction of the buffer near the Nile flood risk area.
- Storage of the Nile floodwaters in large cement basins to be reused later in agriculture.
- Recycling of biological solid waste for the production of biogas through new and scientific methods.
- Use of solar energy as an alternative energy source for the national grid and recycling of the surplus to light streets, mosques, and schools [7].
- Recycling ceramic solid waste and using it for paving streets and public squares.
- Recycling wooden furniture for use in schools, mosques, and public squares
- Using sand and bags for building buffers for floods in the river Nile
- Using construction for building buffers for floods in the river Nile
- gear to make the Nile flood buffer, flood 2021.

A similar project in Khartoum

A scientific paper [8] discussed solid waste treatment in the city of Khartoum. The paper indicated it is not just adequate to set plans and goals. It is necessary to benefit from external experiences in the solid waste management

process to avoid environmental disasters. [9] and [10] discussed the management of household solid waste in Ghana, where they sorted the solid waste into paper, tin, glass, food solid waste, rubber, metal, and plastic.

Additionally, Vitenko [11] discussed and developed solid waste management in European Union as a step towards international environmental safety standards. LEED for neighborhood development LEED [12] is GIB credit solid waste management and encourages footprints.

4. Local and International Legislation in the Management and Treatment of Solid Waste

4.1 Legislation for Local Solid Waste Management

The Sudanese environmental law (Environmental Protection and Natural Resources Law 2001) is based on a hierarchy in solid waste management and treatment, which ranges from the highest to the lowest priority, as demonstrated in the following sequence.

1) Avoiding solid waste generation.
2) Reducing solid waste generation
3) Reusing as much solid waste as possible
4) Recycling as much Reuse as much solid waste as possible
5) Disposing of any remaining solid waste in an environmentally appropriate manner

This hierarchy is followed along with the use of appropriate collection and sorting.

It is also a requirement that the following facilities be available in each area—general domestic garbage bins, storage area for combustible solid waste, storage area for non-combustible and non-corrosive solid waste, storage area for non-combustible and non-biodegradable solid waste, and temporary storage area for hazardous solid waste.

The volume of the storage areas and bins are calculated based on the number of the buildings, activities, and population.

All the storage bins and locations must be constructed with leak-proof foundations. It is considered preferable to protect the storage areas from weather conditions to reduce stormwater leakage during the rainy season.

4.2 International Solid Waste Management Legislation

The American Green Building Council V.4.1 LEED [13] has issued a set of standards for the treatment of all types of solid waste to dispose of and backfill solid waste on land designated for this purpose. It additionally specifies that the objectives of the project must be defined before project initiation. No less than three materials of construction solid waste, such as bricks, gravel, sand, stone, and ceramic residues, must be determined, followed by defining a sorting area and a work plan. In addition to the company supervising the process, the recycling will be carried out by following local or international standards [14]. [15] added a method of solid waste management that starts with collecting and classifying solid waste, followed by treating and recycling it by sending it to factories or internal workshops.

5. Methodology

The methodology was conducted in three phases, as described below.

SWOT analysis and a brainstorming workshop were first conducted to identify the weaknesses, strengths, opportunities, and threats. The process of solid waste management was then applied on Tuti Island. This was followed by conducting a survey with the residents to record their responses to the solid waste management process. The research method was also compared with an international case study to apply new solutions in waste management on Tuti Island. This is discussed in detail in the following sections.

Following the LEED system orientation in sustainable solid waste management apply the three aspects of sustainability

- Recycle usable materials
- Weigh these materials by determining the weight or volume
- Utilize the organic solid waste for the generation of organic gas
- Review the European Convention on Solid waste Treatment and Utilization in Energy Production, European Commission Solid Waste Framework Directive 2008/98/EC.
- Convert at least 50% of construction solid waste into usable materials after treatment and recycling.
- [19] and [20] discussed the LEED system by comparing it with the BREEAM system.

At least 50% of the construction debris, such as bricks, asphalt, sand, and ceramics should be converted to at least three materials in the building solid waste.

5.1 SWOT Analysis

The strengths, weaknesses, opportunities, and external influences were analyzed through the SWOT analysis.

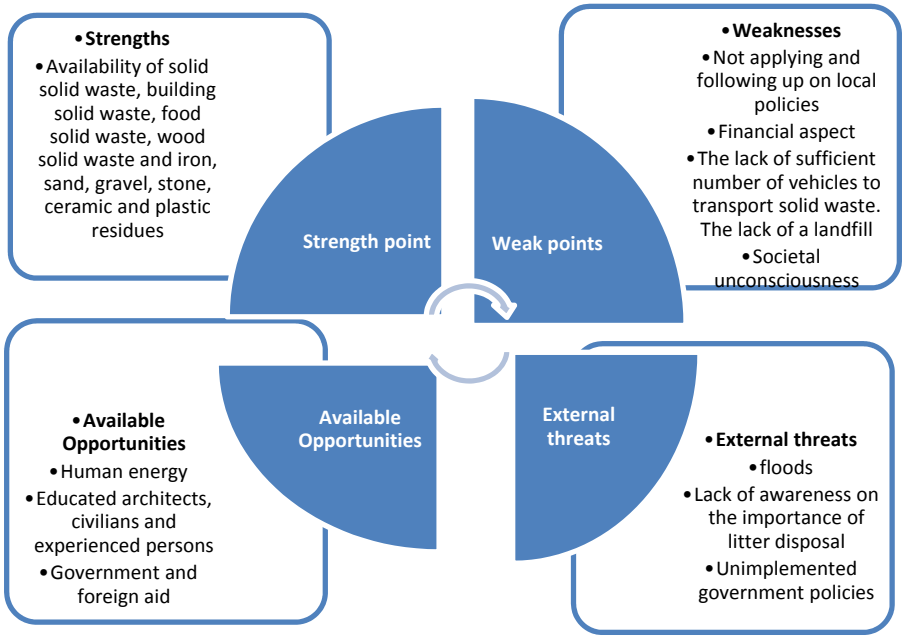

Figure 4. The SWOT Analysis conducted

5.2 Phases of Implementing a Solid Waste Management Process

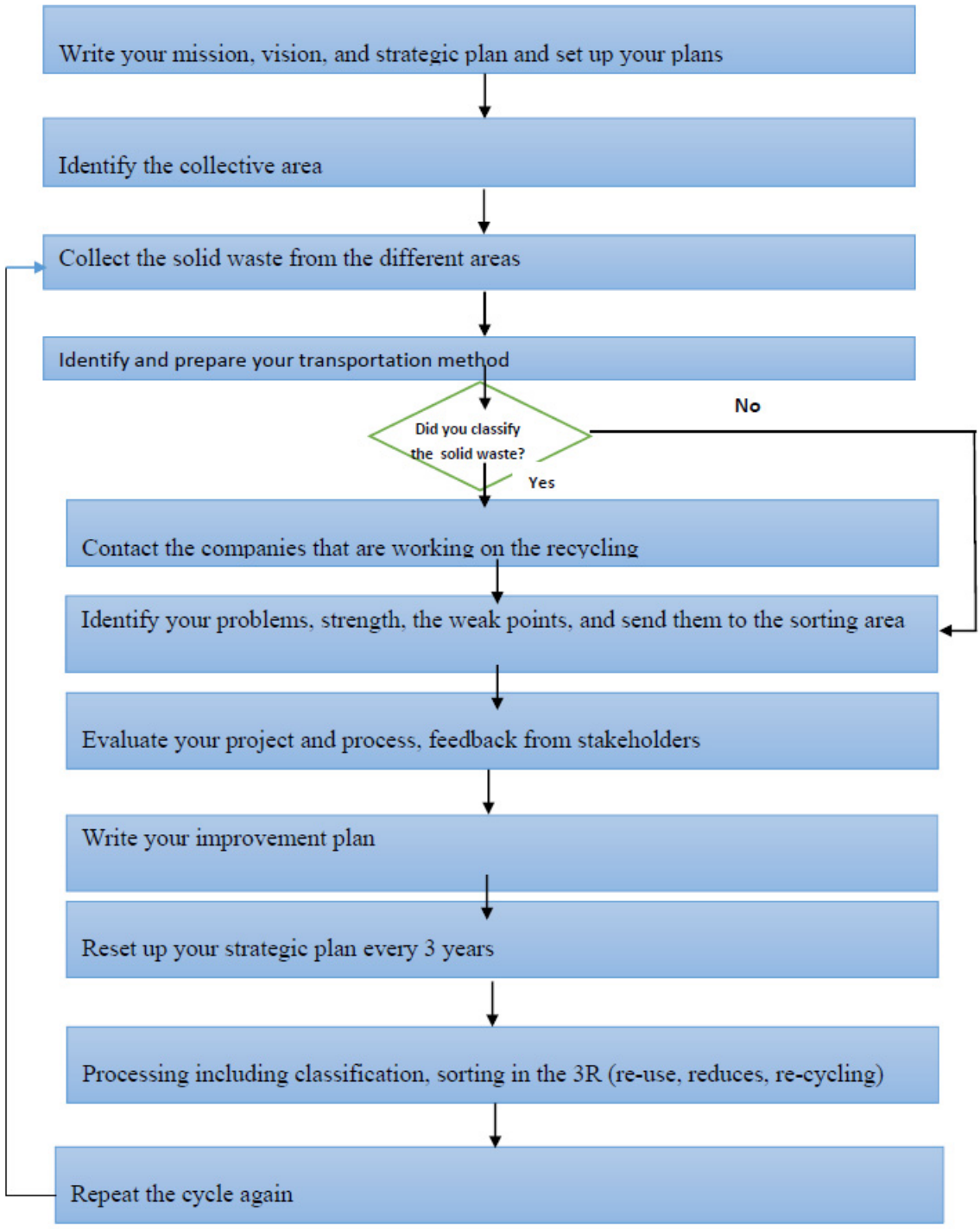

Figure 5. Sustainable solid waste management process

The process began with the identification of the mission, vision, and strategic plan. The collective area was then identified, which is a plot with min 1000 m2, followed by the collection of solid waste from different areas. There are five main areas on Tuti Island. This was followed by the identification of the transportation method. Once the waste was classified, the companies were contacted for recycling. This is followed by the identification of the issues, receiving feedback from stakeholders, evaluating the project, and setting up the improvement plan. The most important aspect considered was sustaining the project.

1) Calculating the feasibility and cost of the project is a prerequisite, including the cost of the land plot, cost of light- and heavy-duty vehicles, labor cost, cost of bins, fuel cost, running cost, and maintenance cost.

2) Comparing the case study on Tuti Island with other case studies in the European Union, Germany, Singapore, and Saudi Arabia.

6. Results and Discussion

The questionnaire was distributed to the people of Tuti Island, where the target group was all the neighborhoods of the island. Here, 50% of the residents answered the questionnaire. Figure 6 to Figure 13 demonstrate the results in the pie diagram which present the survey results.

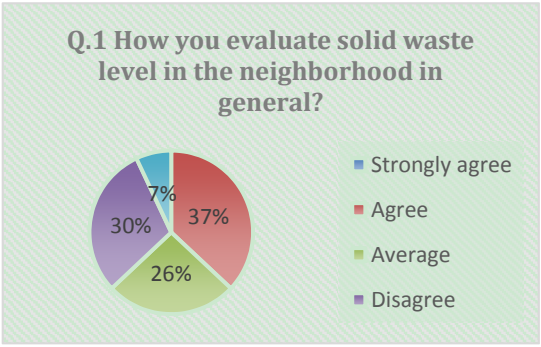

Figure 6. Solid waste level in the neighborhood

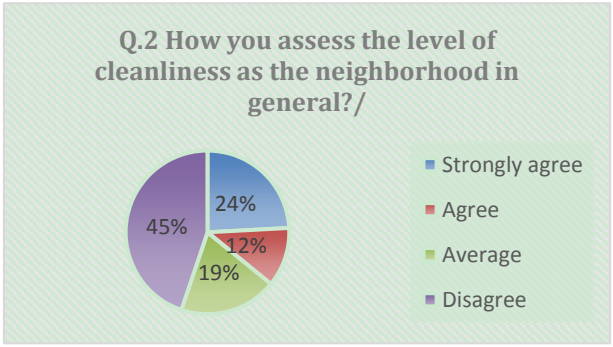

Figure 7. Cleanliness of the neighborhood

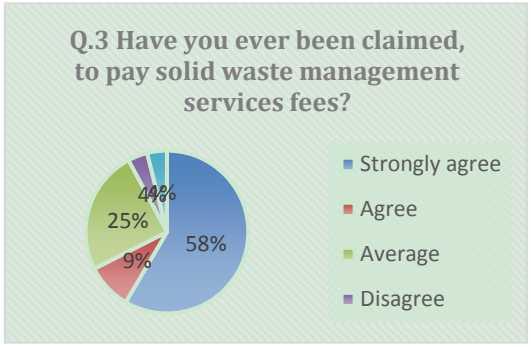

Figure 8. Payment of solid waste service fees

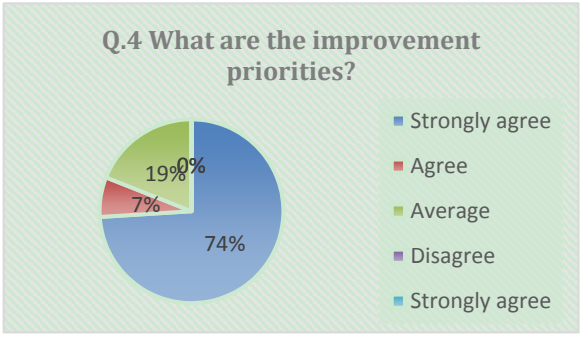

Figure 9. Improvement priorities

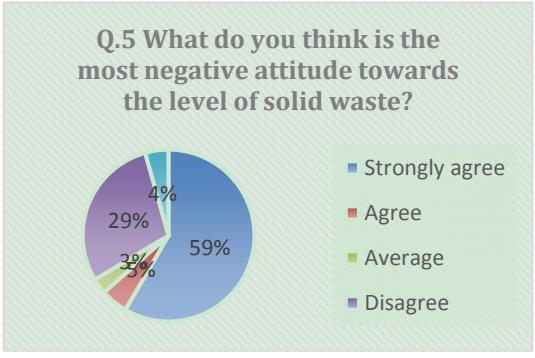

Figure 10. Shows the most negative attitude toward solid waste

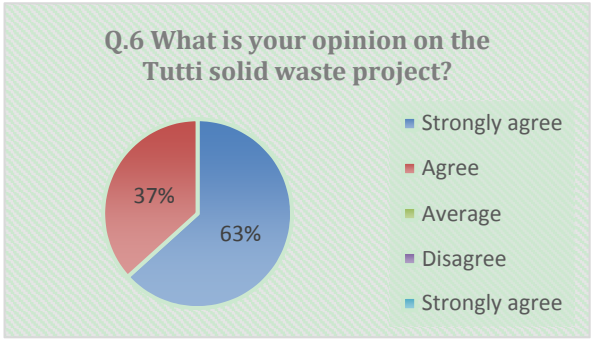

Figure 11. Opinion on solid waste projects on Tutti Island

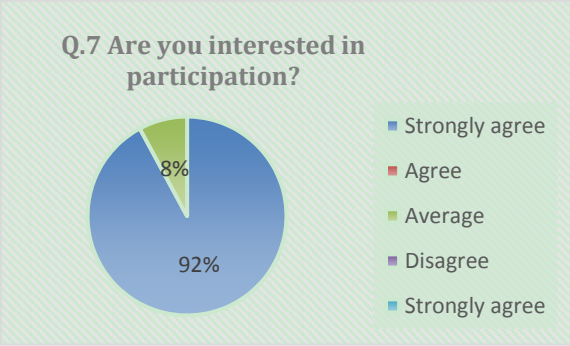

Figure 12. Percentage of interest participation

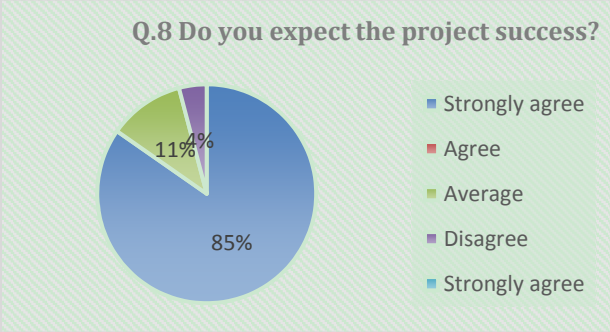

Figure 13. Percentage of people expecting success

Table 1. Results of the questionnaire in percentages

S	**The Question**	Strongly agree	Agree	Average	Disagree	Strongly Disagree
1	How do you evaluate the solid waste level in the neighborhood in general?	-	37%	26%	30%	7%
2	How do you assess the level of cleanliness in the neighborhood in general	35%	17%	28%	65%	**0%**
3	Have you ever been claimed, by any person, to pay solid waste services fees	45%	**7%**	19%	% 3	3%
4	what are the improvement priorities?	74% Awareness	%7 Awareness campaign	19% Supervision	-	-
5	What do you think is the most negative attitude towards the level of solid waste?	**80%** All kinds of solid waste	**7%** Sewage wells overflow	4% Abandoned scrap	%4% Rubble residue	Other %
6	What are your opinion on the Tutti Sons project in Riyadh and overseas countries?	69% An excellent idea	41% Great idea	-		-
7	Are you interested in participating?	**82%**	-	**7%**		-
8	Do you expect project success?	83%	-	**11%**	4%	-

The first question inquired about the level of cleanliness on Tuti Island. Here, 37% of the residents responded that it was good, 26% said it was at a medium level, 30% said it was not good, and 7% said it was bad.

The second question inquired if the residents you ever been claimed by any person to pay solid waste services fees. Here, 35% said that they were asked for money, while 65% said that they were not being asked for fee payments.

The third question; here, 45% noted that the government failed to collect solid waste, 17% noted the responsibility of the cleaning companies, 28% of the residents believed that negligence was from the population themselves, and 3% of the residents believed that the problem lies with the owners of the shops.

The fourth question revealed that 74% of Tuti residents believed that the priorities for improvement lie in educating the people themselves, 7% believed in forming awareness campaigns to raise awareness among the people, and 19% of Tuti residents believed in the necessity of continuous supervision of the solid waste disposal process.

The fifth question revealed that 80% of the island people believe that the most harm is from all types of solid waste, 7% believe that the grave harm is from the overflow of sewage wells, 4% see that the most harm is from discarded scrap, and 4% of the people see that the most harm is the distortion of the environment as rubble residues.

The Sixth Question revealed that 69% of the residents believed the idea of an environmental sanitation project on Tuti Island is an excellent idea, and 41% of Tuti Island residents said that it good idea.

The seventh question revealed that 82% of the respondents stated that they wanted to take part in the project, 7% were indifferent, and 11% abstained from expressing their opinions.

The eighth question revealed that 83% said they fully believed in the success of the project, and 11% said they did not believe in the success of the project.

Through the quadripartite analysis researchers were able to develop a clear plan for environmental sanitation projects and the sustainability of solid waste disposal.

Discussion

The survey was distributed to all the residents of Tuti Island residents in 2021, and 50% of the respondents comprising 15000 people and 5000 houses answered. The study demonstrated the need for 200 bins. Sustainable solid waste management practices were applied to three aspects—environmental, social, and economic aspects. It is, therefore, determined that one should reduce, reuse, and recycle solid waste as much as possible.

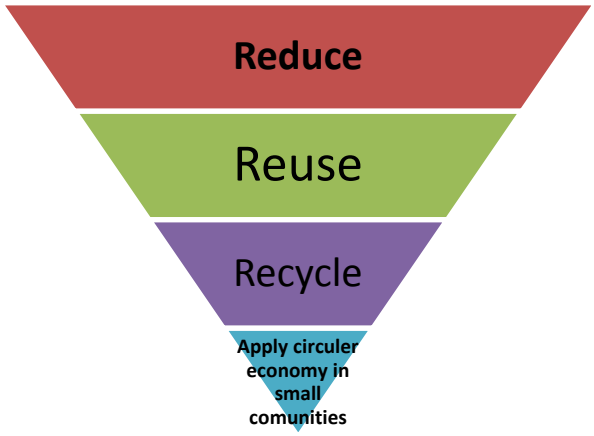

Figure 14. Sustainable waste management model

6.1 Environmental Aspect

Recycling of solid waste available on Tuti Island, such as gravel, sand, construction solid waste, wood, steel, paper, and food waste

Reuse the goods by sending them to the workplace and factories and applying the concept of reducing solid waste.

Table 2. The total population

Approx. Population Number.	Houses Number	Bins Number	Bin Capacity
30,000 people 2020	5,000 homes approx.	200	250 liters or a quarter of a cubic meter

The research project demonstrated that people produce organic solid waste of 15 tons/per day, paper and cardboard solid waste of six tons/per day, and plastic of 11.7 tons/per day. Other waste (glass, wood, etc.) was reported to be 3 t/day. As presented in Table 3. the total solid waste of 36 tons/day part of this solid waste was discussed by [10].

Table 3. Total amount of solid waste

Type	Total solid waste per person (kg /day)	The population of Tutti Island (people)	Total solid waste produced per day (tons/day)	Total solid waste produced per month (tons/month)	Total solid waste produced per day (tons/year)
Organic household solid waste	0.5	30000	15	450	5,400
Paper and cardboard	0.21	30000	6.3	189	2,268
Plastic	0.39	30000	11.7	351	4,212
Other	0.1	30000	3	90	1,080
Total	1.2	30000	36	1,080	12,960

6.2 Social Aspect

All the residents of Tuti island took part in this project. During the flood season, all people share inbuilt the buffer wall to protect the island, youths, children, women, and men shared in filling in the sandbags to build the buffer wall shown in Figure 14.

(a)

(b)

(c)

(d)

Figure 15. (a) The use of construction solid waste in Nile flooding 2021, (b) Use of sandbags as barriers for Nile flooding in 2022, (c) The use of rubble and leftover stones, sand, and gravel to make the buffer during the 2022 flood, (d) Utilizing youth energies to collect solid waste and fill sandbags during the 2022 flood

6.3 Economic Cost and Feasibility Study

Conducting a feasibility cost study for the project is a prerequisite, and should include the costs of the land plot, light, and heavy-duty vehicles, labor, bins, fuel, and maintenance.

6.3.1 Estimation of Financial Cost

Capital cost

1) Light and heavy-duty trucks

It is necessary to calculate the cost of light and heavy trucks and at least one vehicle of each size.

2) A land plot with an area of 500 square meters

The project requires a land plot with an area of 500 square meters for the collection and sorting of materials to be recycled. The land plot purchase may be arranged by donations from the residents or as a grant from the government.

3) A model for calculating the cost per neighborhood.

Table 4. Estimated cost

Statement	**Cost in USD**
Two-ton capacity light vehicle	20,000
Medium iron boxes (40)	1,1500
Administrative expenses	157.000
Other expenses	104.000
Total	300.000

Running cost

If one vehicle is considered to work in two shifts, day and night, and in each shift, it travels 15 km to calculate the number of kilometers covered in one year, as follows:

Two shifts × 365 days × 20 km= $10,950

Table 5. Fuel cost

Statement	Frequency	Consumption rate	unit cost in USD	Total in USD	Remarks
Fuel	10,950 km	0.45	1.3	6,406	Kilometers per year / 20,000 *4 (replacement of four tires every 20,000 km for $300
Tires	10,950 km	20000	300	657	Kilometers per year * Oil consumption of 0.3 liters per 100 kilos at $6 (cost per liter)
Engine oil	10,950 km	0.003	6	197	Number of km per year * Consumption: 45 liters per 100 km * Price per liter
Hydraulic oil	10,950 km	0.0003	4	131	Kilometers per year * Oil consumption of 0.3 liters per 100 kilos at $4 (cost per liter)
Cost of maintenance	2.5%	a	20,000	1,000	From the value of the car 2.5% * the number of shifts
insurance, licensing, etc...	1%	0.0003	20,000	200	1% of the cart value

Table 6. Cost of salaries

Statement	Frequency	Number of months /years	salary/month$	Salary Amount/Year in USD	Noticeable
Drivers' salaries	2	12	100	2,400	2 drivers for 12 months with a salary of $100 per month
Workers' salaries	4	12	70	3,360	4 workers for 12 months, with a salary of $70 per month
Supervisors' salaries	0.5	12	150	900	Day hours part-time supervisor and a night part-time supervisor for 12 months, with a salary of $150 per month
Total amount				**15,251**	

Distribution of bins in neighborhoods

One bin was kept opposite every eight houses. Preliminary sorting from the source is the most important process in solid waste recycling as this leads to clean recyclable materials that may be sorted and delivered to recycling companies on Tuti Island. To reduce costs, it is suggested to use only two bins in each site—one bin for the collection of all recyclable materials (paper, cardboard, cans, and plastic) and the other bin for collecting organic materials. The problem of glass remains to persist, considering it leads to difficulty when mixed with the other materials as it is breakable, affecting the rest of the materials. It is, therefore, better to collect it as separate from the source.

6.4 Circular Economy

6.4.1 Government Legislation That Supports Recycling

The most significant dilemma facing the recycling industry is finding a market for recycled products, which is a constantly changing market. In several cases, recycled products are not economically profitable. A safe recycling market, therefore, does not operate through legal legislation that encourages and supports the recycling industry.

It is, therefore, recommended that solid waste be sorted on the island to deliver recyclable materials to recycling companies under long-term contracts. It is recommended to follow up on market changes in the long run and investigate the recycling market to amend contracts with recycling companies.

6.4.2 Conducting Workshops Accompanying the Project on Reusing

It is possible to conduct workshops accompanying the project how to re-use and recycling furniture, iron, and reuse broken gravel and tiles to create external tiles for paving mosques and corridors on the island of Tuti.[18] encourages e-learning.

6.4.3 Energy Production from Organic Solid Waste

During the beginning of the eighties, the National Council for Research, implemented a project to produce biogas from household solid.

6.4.4 Contracting with Plastic Recycling Factories

Table 7. Discretionary calculations for recycling (conducted in 2021)

solid waste type	Quantity ton/year	Price per ton $	annual return $
Organic	5,400	10 - 20	81,000
Papers and cardboard	2,268	10 - 15	22,680
Plastic	4,212	25 - 30	115,830
Other	1,080	10	10,800
Total	$230,310		

6.5 Comparison of the Results with Others

[16] presented a concrete production system on-site to reduce solid waste. One of the most effective ways of production is considered to be casting on-site, which could be followed by civil engineers to reduce solid waste at the site.

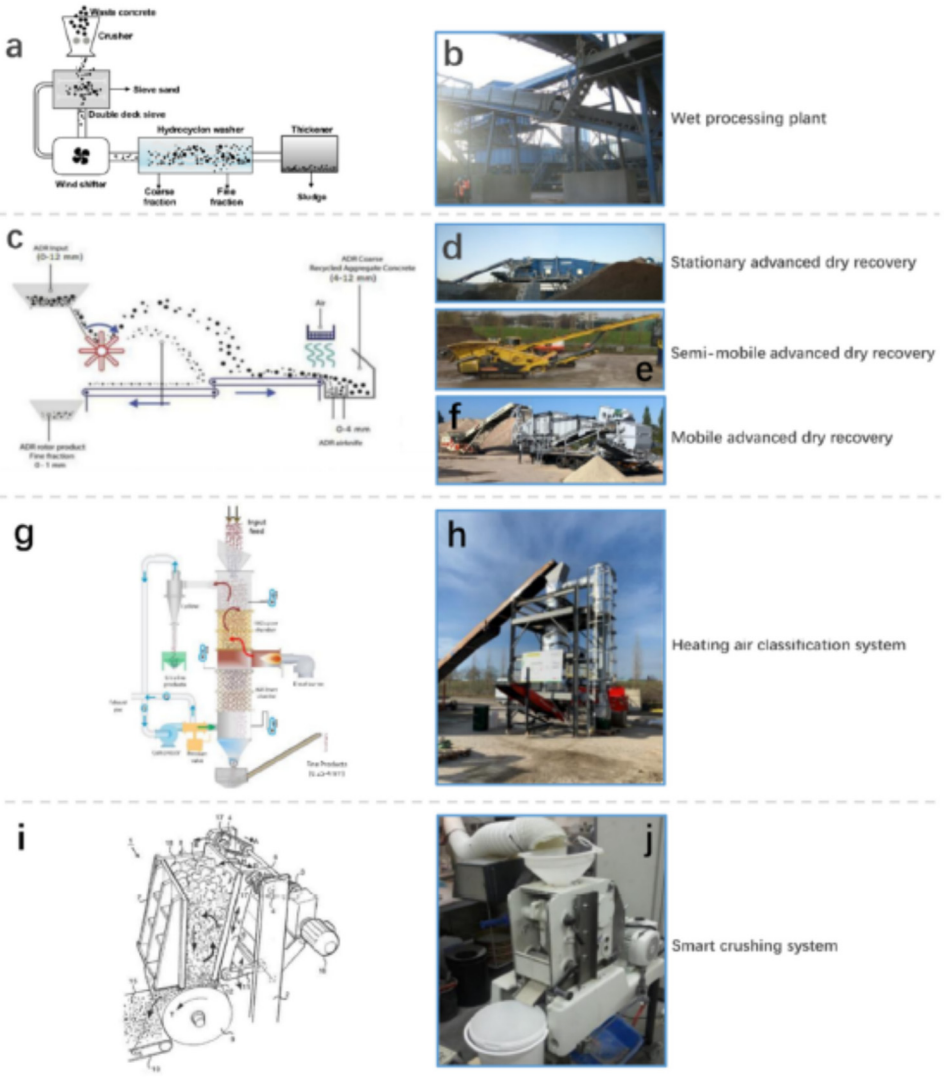

Figure 16. Concrete machines cast in sitio [16]

Another method that could be used in the future is the digitalization of solid waste management [17] identified as

key external and internal factors that drive or hinder the firms. Almost 90% of all respondents indicated that they use digital technologies for the management of containers. In Singapore, a factory was built to recycle 60% of the solid waste and burn 40% of the solid waste to produce energy. The Internet of Things (IoT) has recently been used in sorting solid waste; when the pin is full, it is sent to the cars, thus reducing time management and efficiency [18].

Table 8. Comparison of the system applied in Tuti Island with others (European Union, German, Singapore)

	Tuti Island Khartoum	**European Union (EU)**	**German**		**Singapore**	**Saudi Arabia**
Manual system	Use of solid waste containers	✓	✓		✓	✓
Cast in Cito	Cast in cito bricks and stone, concrete. (it means to be production in site) based on the theory of circular economy,	✓	✓		✓	✓
Smart solution	x	✓	✓		✓	✓
Apply digital technology	x	✓		90% Digital technology applied	✓	✓
Recycling	Recycling contact firms	✓	✓		60% Recycled 40% Burnt	✓

Recycling solid waste comparing with others method with European Union (EU) the applied Case in citio concrete based on the theory of circular economy. In Germany, 90% applied digital technology. In Singapore, 60% recycled and 40% burned to find fuure vision for Tuti island.

7. Conclusion

The main objective of this study was to determine the precise mechanisms of environmental sanitation. The solid waste management process is relatively complicated. It is, however, important to overcome the adverse consequences of the accumulation of solid waste. Based on an estimated population of 30,000, the estimated amount of solid waste in this study was 36 tons/day or 12,960 tons/year comprising various components (organic, plastic, cardboard, paper, etc.). The total cost of the entire solid waste management process on the island (capital plus operational cost for one year) was determined to be 204,722 USD / year. The total revenue of the proposed recycling project was 230,310 USD / year, as estimated in 2021.

Allocate a budget for the project after performing a full-blown feasibility study included in this research and the calculation of quantities. Prepare an area of a plot of land of around 500 m^2 for the sorting process and transfer useful materials to factories for recycling. Demanding the government represented by the Ministry of the Environment to enact laws, legislation, and policies that support recycling and urge citizens to classify household solid waste and assist in the household sorting process. The project must be executed in five stages—collection, transportation, sorting, reuse, and recycling. It is necessary to raise societal awareness of the importance of a project by conducting training workshops for all segments of society and creating advertisements, posters, and broadcasts. Study of the economic return of the project from recycling and reuse. Studying the economic income from energy production from organic solid waste. Studying the economic returns of reusing broken tiles and broken gravel in paving corridors, schools, and mosques. The environmental yield of reusing building remnants of asphalt, sand, and soil in backfilling, as observed in the flooding seasons. It is necessary to conduct professional workshops to tap the energy of the youth in reuse and sorting projects. Compared with other systems applied in the European

Union, Germany, Singapore, and Saudi Arabia, the future solution on Tuti Island may apply smart and digital solutions, recycling the solid waste in association with investment companies.

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