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A Low-Cost Innovation Design for Portable Rubbish Cage Trap (PRCT) in Drain System

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Abstract. One of the primary contributors to water pollution is the presence of solid waste or rubbish within the drainage system. Moreover, the presence of an obstruction within the drainage system would impede the movement of water, so leading to the occurrence of a flood. Based on the given circumstances, a recommended solution to address the issue involves the utilisation of a Portable Rubbish Cage Trap (PRCT). This research seeks to investigate and assess hydraulic features such flow rate, total amount of collected garbage, and rainfall distribution, in addition to proposing an innovative design of a PRCT employing reusable and recycled materials from a building site. The components of PRCT are cable ties, grey polyvinyl chloride (PVC) tubing, and green netting available in two sizes. To produce a low-cost project, these materials are collected from rubbish found on building sites. The drainage line under investigation is situated in Taman Universiti, Johor Bahru. The study aims to compare the data obtained from previous data using Mesh type cage and analysis performed in this study includes the measurement of the weight of the collected waste in the PRCT, the examination of rainfall patterns, and the assessment of the hydraulic properties affecting the effluent flow rate over a two-week period. The investigation reveals that the Mesh Type wall has a higher weight of imprisoned waste 388.52 kg compared to the PRCT with 339.3 kg. The mean flow rates for the Mesh type cage and PRCT are 7.43 mm^3/s and 39.2 mm^3/s, respectively. The highest recorded rainfall distribution in October 2020 was 39 mm, while the highest recorded weight was 57.3 kg. The market potential of the PRCT can be enhanced by ensuring cost-effective measures for collecting construction waste materials and labour, as well as by improving the durability of the PRCT.

1. Introduction

Solid waste or gross pollutants in the drainage system contribute to water and air pollution. Gross pollutants such as suspended solids, heavy metals, oxygen-demanding substances, nutrients, and hydrocarbons (oil and surfactants) often cause the clog of a drainage system. This type of waste usually comes from residential, commercial, and sometimes coastal areas produced by the public. According to Sadri et al,[1] production of plastic increased rapidly in years of the 1950s, from 5 million to 280 million tons in 2011. Due to its distinct characteristics and wide range of uses, plastic has become an essential component of modern life. Urban litter reduction and removal are challenging issues, especially in developing nations. The development of an integrated catchment litter management strategy by each local authority, comprising planning, source, and structural controls, is ultimately necessary to find a solution [2].

Both structural and non-structural technologies reduce the amount of trash in the effluent that is discharged into the drainage system. To separate and contain large pollutants, structural methods are installed inside entry trenches in gutters or within stormwater channels, whereas non-structural methods involve changing the attitudes and behaviours of the community [3]. Rubbish trapping devices have emerged as a viable approach for mitigating river pollution, offering a range of options to address this issue. Nevertheless, there is a scarcity of data regarding their efficacy in trap removal [4]. A rubbish trap is an effective method for reducing water pollution at the source. It can remove litter, debris, and coarse sediment from runoff. It can also be used to minimize the amounts of pollution in the water before discharge into a river, pond, or wetland, such as trace metals, bacteria, nutrients, and oil and grease, as well as coarse particles before the wastewater enters an infiltration device, which it could clog up ahead of time.

The performance of a rubbish trap is determined by its trapping efficacy, which is defined as the proportion of the total mass of gross pollutants carried by stormwater that is retained by the trap. In the late 1970s, the first gross pollutant traps were constructed using uncomplicated designs, whereas the most recent technologies have developed high-tech design and construction [5]. The main objectives of this study are to propose an innovative design for a PRCT by using recycled and reusable items from the construction site and analysis and evaluation on hydraulic characteristics including flow rate, total amount of collected rubbish, and rainfall distribution.

The PRCT is specifically engineered to accommodate the drainage system in both residential and commercial settings, with the purpose of effectively capturing and containing waste materials. The primary objective of developing this prototype was to mitigate the accumulation of solid waste within the drainage line, while concurrently addressing concerns related to water pollution. The primary purpose of the PRCT system is to effectively capture and contain various forms of waste, including plastic materials, dried foliage, and residual food particles that are discharged from washbasins and similar sources. By removing solid debris from the effluent, the PRCT system ensures that the subsequent stormwater drainage system receives a cleaner and unobstructed flow. The suggested PRCT aims to incorporate recycled and reusable construction waste materials, including reinforced concrete, green net, plastic bottles, and other items, as cost-effective and environmentally friendly components. [6]. In order to establish the efficacy of the newly developed rubbish cage trap, it is imperative to conduct a comparative analysis encompassing the robustness of the design model under rainy conditions and the capacity to withstand high-velocity water flow. Additionally, it is crucial to ascertain the maximum quantity of debris captured within a specified timeframe during field operations. This study aims to compare the performance of PRCT and previous product: Mesh Wall Rubbish Trap [7].

2. Materials and Methods

2.1 Study Area

The study locations were selected in the residential area of Jalan Kemajuan 10, Taman University, Johor Bahru (Fig. 1).

(a) (b)

Figure 1. (a) Location of the study site and (b) selected study at residentials area drainage system.

The primary objective of this study is to investigate the hydraulic properties of the effluent both before and after it undergoes treatment in the PRCT. The PRCT is intended to be implemented in the drainage system of a residential area located in Taman Kemajuan 10, Taman Universiti Johor Bahru. Each of the designated drainage systems has a sequential flow pattern, wherein smaller drainage sources converge into a secondary, bigger drainage system before ultimately merging into a collector drainage, typically a river.

2.2 Design of prototype of Portable Rubbish Cage Trap

The developed rubbish trap consisted of grey polyvinyl chloride (PVC) pipe, square plastic mesh netting and cable tie (Fig.2). The conceptual design of the trap was based on the size of the drainage and the suitability of the location. These materials were chosen because the flow in an open conduit can reach as high as 8.0 m/s and as low as 6.0 m/s [8] in the absence of additional water, such as rainfall. As a result, it is expected that these materials can withstand and last in a subcritical flow of water. While the subcritical flow region has a Froude number less than 1.0 and is distinguished by low velocities and deep depths [9]. According to Chow [10], equation of Froude number,

$$Fr = \frac{V}{\sqrt{gD}} \qquad (1)$$

At critical flow conditions in open channel flows, it is strongly encouraged to define the Froude number, such as Fr = 1. That is, for subcritical flow (d > dc), Fr 1 and for supercritical flow (d< dc), Fr > 1 [10].

(a) Green mesh netting **(**b) Grey PVC pipe (c) Cable tie

Figure 2. (a)(b) & (c) Materials of PRCT

The PRCT exhibits a trapezoidal configuration, featuring an open upper section and an intake located within the enclosure. The dimensions of the cage are 2100 mm in length, 650 mm in width, and 950 mm in height, respectively. Additionally, the cage features a mid-screen angle of 90°. According to the British Standard [11], the dimensions of rectangular shapes, including widths and heights, exhibit variations. Consequently, the design of the upper section of the trap cage is specifically aimed at facilitating the passage of excess water beyond the prescribed PRCT box form, as outlined in the BS 8110-97 standard from 1997. The prototype of PRCT, as depicted in Figure 3, was developed using the SketchUp software. Figure 3(a) and (b) present a thorough representation of the PRCT, which is depicted in Figure 3(a) and installed within an open channel drainage line in Fig 3(b).

The PRCT is designed with an unobstructed entrance to the cage, while the exit of the cage is restricted by a mesh netting in a green color. The portable waste containment device is engineered with an elevated central component to accommodate the increased flow velocity experienced during periods of precipitation. The incorporation of a diagonal element serves to enable the diversion of water, so facilitating its evacuation from the trap while holding the accumulated debris. Figure 4 depicts the implementation of a PRCT within the context of a site study.

(a) Prototype modelling PRCT using sketch up software.

(b) Installation of the PRCT in drainage line.

Figure 3. Prototype PRCT using SketchUp software.

Figure 4. Installation of the Portable Rubbish Cage Trap in the drainage system in Taman Universiti Johor Bahru

2.3 Sampling and methodology

2.3.1 Amount of Rubbish trap

The PRCT collects the debris containment device, which thereafter undergoes multiple procedures. Initially, the trap would be left undisturbed for a duration of 24 hours after its placement within the drainage line. Subsequently, the entirety of the refuse ensnared by the contraption will be gathered and subjected to the process of solar desiccation. The object would be subjected to solar radiation for a duration of 48 hours. The garbage would subsequently be measured via a weighing instrument [12]. The weight of the garbage is documented in a tabular format, and a comparative analysis will be conducted between two waste containers. The process would be iterated over a span of fourteen consecutive days, equivalent to a duration of two weeks.

2.3.2 Rainfall distribution

The collection of rainfall distribution data is conducted by the Department of Irrigation and Drainage (DID) in Johor. The two nearest collecting locations for this data are situated at Sungai Skudai and Kampung Laut. The measurement of precipitation distribution duration was conducted for a period of 31 days in October 2020, as depicted in Table 1. The data collection period is from October 11, 2020, to October 25, 2020, encompassing a duration of two weeks.

Table 1. Rainfall Distribution Data provided by the DID JOHOR

Station No.	Station Name	Day	11	12	13	14	15	16	18
57 (Week 1) & Week 2)	Sg Skudai @ Kg Laut	Rainfall (mm)	39	0	0	0	3	8	10
		Day	**19**	**20**	**21**	**22**	**23**	**24**	**25**
		Rainfall (mm)	0	14	4	5	0	13	16

2.3.3 Open channel flow

The flowrate in an open channel is determined by the volume of water flowing through it and the cross section of the drainage line. Due to a few constraints, we will return to a manual and basic process to obtain the flow rate in the drainage line. The flowrate of the drainage will be obtained using the ping-pong ball method [13]. Table 2 shows an equation used to calculate rectangular channel section.

$$V = \frac{d}{t} \qquad (2)$$

Where, v= speed /velocity, d =distance travelled and t = time taken

The velocity above will be used to calculate the flow rate (Q) of flow in drainage system [14].

$$Q = AV \qquad (3)$$

Q = flow rate (m^3/s), A = cross sectional area and V = speed/velocity (m/s)

3. Results and discussions

3.1 Data on rubbish collected and rainfall distribution

As previously mentioned, the collection of rubbish occurs daily from the 11th of October to the 25th of October. The waste material was subjected to solar drying daily prior to being enclosed in a plastic bag and afterwards weighed in the laboratory. The data has been tabulated below. The data is summarised in Figure 5. The quantity of rubbish gathered during Week 1 and Week 2 was determined by the volume of water flow that converged the waste into the trap enclosure. The prevailing waste composition within the trap consists primarily of dry leaves, twigs, and aged coconut remnants. In addition to plastic and glass bottles, sediment is also present.

The bar graph illustrates that there was a higher level of dominance during Week 2 compared to Week 1. The cumulative waste generated during the first week and second week amounted to 145.88 kg and 192.95 kg, respectively. It is significant that, despite changing weather conditions, there persists a steady inflow of liquid originating from adjacent drainage systems, alongside the discharge of grey water from residential sources into the drainage network. The recorded precipitation on October 15, 2020, showed the lowest magnitude, measuring only 3 mm. The relationship between the amount of rubbish collected and the distribution of rainfall is depicted in Table 2.

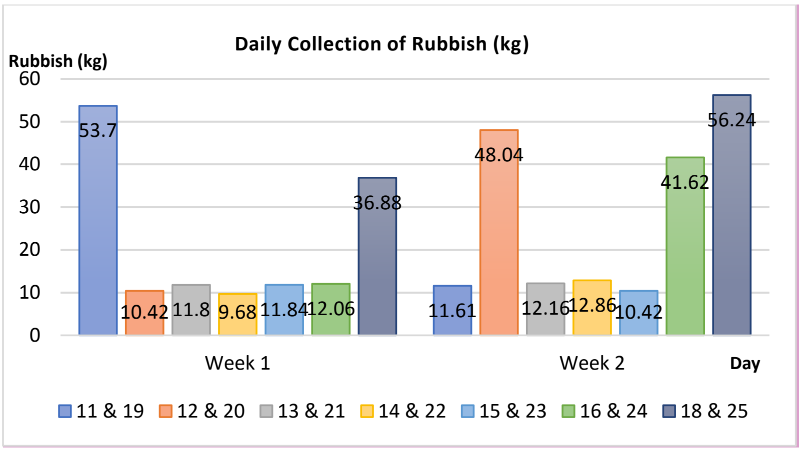

Figure 5. Graph of rubbish collection in 2 weeks.

Table 2. The relationship between the distribution of rainfall and the amount of waste collected over a two-week period.

Week	Date	11	12	13	14	15	16	18
1	Rainfall (mm)	39	0	0	0	3	8	10
	Rubbish collected (kg)	53.7	10.42	11.80	9.68	11.84	12.06	36.88
	Date	19	20	21	22	23	24	25
2	Rainfall (mm)	0	14	4	5	0	13	16
	Rubbish collected (kg)	11.61	48.04	12.16	12.86	10.42	41.62	56.24

The relationship between the graphed data on rainfall and the amount of waste collected exhibits a reciprocal pattern, as seen by their simultaneous increase and decrease. This occurrence can be attributed to the reliance of water drainage on the presence of rainfall on a given day. The presence of precipitation on the ground surface might result in the displacement of leaves and other tiny objects into local drainage systems, ultimately leading to the PRCT. The peak rainfall occurred on Sunday, October 11th, 2020, with a recorded precipitation of 39 mm. Additionally, during this event, the PRCT accumulated 57.3 kg of rubbish, comprising various materials such as stones, glass bottles, leaves, twigs, and coconut shells. The second most significant precipitation event occurred on Sunday, October 25th, 2020, resulting in a 16 mm increase in the existing water flow. This event also led to the largest recorded amount of waste collected, totalling 56.24 kg. The association between the two events exhibits fluctuations throughout the day, however it retains a notable distinction between high and low levels as documented.

3.2 Flow rate

The evaluation of the area of each part of the drainage is conducted, followed by the summation of these areas. Subsequently, further assessments, such as the determination of velocity and flow rate, can be carried out for the full designated open channel. The velocity should be measured in millimetres and must be within the range of 600 mm/s to 4000 mm/s, corresponding to 0.6 m/s and 4.0 m/s, respectively.

This range is necessary to maintain a continuous flow and prevent the accumulation of stagnant water, while also ensuring drainage safety. The flow rate before and after the PRCT was determined and documented in Figure 6.

The observation can be deduced from the graph illustrated. The flow rate upstream of the trap exhibits a lesser magnitude in comparison to the flow rate downstream of the trap. The empirical findings diverge from the expected results, although they can be ascribed to the existence of a gradient slope inside the drainage system. An illustration of this phenomenon can be observed in the decrease in water velocity after its interaction with a trap that contains debris or small particles. On the other hand, the flow that occurs after the formation of a trap demonstrates a greater degree of surface drainage uniformity. Nonetheless, the downstream flow following the trap may entail an elevation in the gradient of the drainage, leading to a subsequent reduction in velocity and an augmentation in the flow rate.

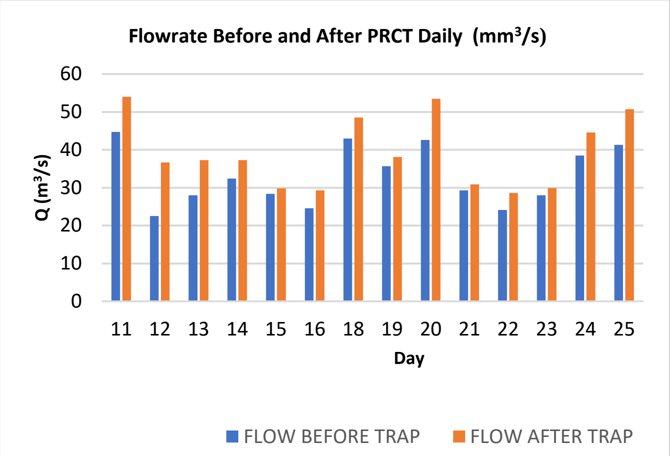

Figure 6. Graph Flow rate before and after Portable Rubbish Cage Trap Daily (mm^3/s)

3.3 Froude number

The determination of the Froude number is predicated upon the utilization of the mean daily velocity (54.2 mm/s) in conjunction with a depth range spanning from 22.0 mm to 85.0 mm. Consequently, the resulting Froude number falls between the interval of 0.12 to 0.06. Therefore, it may be concluded that the Froude number associated with this flow is in the subcritical range.

3.4 Relationship of Rubbish collected with Flow rate before and after PRCT

The graph in Figure 7 presented a reciprocal correlation between rainfall and the quantity of rubbish collected, wherein both variables exhibit a simultaneous increase or drop. This occurrence can be attributed to the reliance of water drainage on the prevailing precipitation levels on a given day. The deposition of precipitation on the terrestrial surface may have resulted in the transportation of leaves and other tiny debris towards the adjacent drainage system. Ultimately, one of the drainage conduits sent the materials onto the PRCT. On October 11, 2020, the recorded precipitation reached its peak, measuring 39 mm. Additionally, the PRCT accumulated a total of 57.3 kg of rubbish, comprising various materials such as stones, glass bottles, leaves, twigs, and coconut shells. The second most significant precipitation occurrence transpired on October 25, 2020, resulting in a 16 mm augmentation in the prevailing water flow. Additionally, it coincided with the greatest recorded accumulation of refuse, amounting to 56.24 kg. The link between these two occurrences exhibits fluctuations over the course of the day, although it consistently demonstrates both a notable peak and a notable trough.

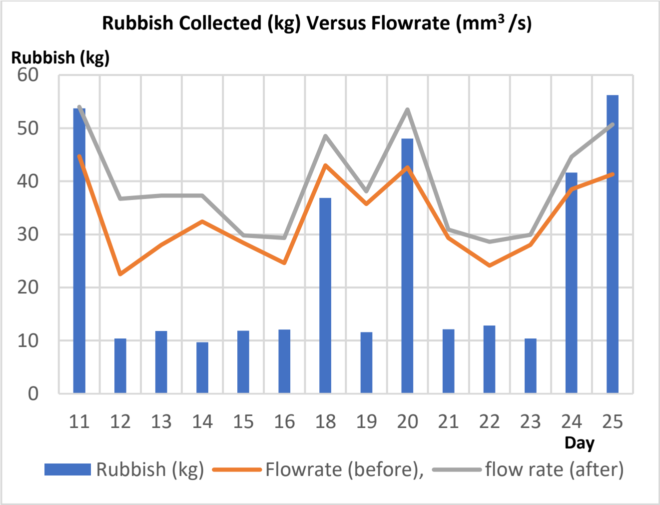

Figure 7. Graph of rubbish collected (kg) with flow rate (mm^3/s)

3.5 Comparison between both traps.

The data recorded by the Mesh-Type Wall trap and Portable Rubbish Cage Trap for the rubbish quantity are listed in Table 3.

Table 3. Data recorded by Mesh Type Wall and PRCT

	MESH TYPE		**PRCT**	
DAY	Quantity of Rubbish (kg	Flow rate (mm^3/s) x 10^6	Quantity of Rubbish (kg)	Flow rate (mm^3/s) x 10^6
1	230.00	25	53.7	54
2	3.23	15	10.42	36.7
3	5.20	4	11.80	37.3
4	2.00	4	9.68	37.3
5	3.03	3	11.84	29.8
6	4.60	3	12.06	29.3
7	120.62	3	36.88	48.5
8	2.50	18	11.62	38.1
9	3.24	2	48.04	53.5
10	2.00	15	12.16	30.9
11	3.20	3	12.86	28.6
12	2.00	4	10.42	29.9
13	2.50	2	41.62	44.6
14	4.40	3	56.24	50.7
TOTAL	388.52		339.34	

Table 3 presented the quantity of rubbish gathered for both traps. The comparison of data collected over a period of fourteen days reveals that the Mesh Type Wall Trap yielded a higher quantity of 388.52 kg, whereas the PRCT yielded a lower quantity of 339.3 kg. The amount of waste collected in the PRCT in 2020 was found to be lower compared to the Mesh Type Wall in 2008. This decrease can be attributed to improved waste management practices and increased public knowledge regarding waste disposal. In 2020, the installation of the PRCT resulted in an increased flow rate of drainage compared to the installation of the Mesh Type Wall Trap in 2008. The results are derived from the quantitative analysis of the amount of waste captured by the respective traps. The findings indicate that the Mesh type wall trap exhibited a higher accumulation of rubbish compared to the PRCT. Therefore, the flow rate decreased as the amount of waste increased, as indicated by the table above.

4. Conclusion

In conclusion, the installation and manufacture of this PRCT are straightforward, manually constructed, and user-friendly. The materials required for constructing this trap, including PVC pipe, green net, cable ties, glue, and a cutter, can be readily obtained from local hardware stores or even sourced from construction site waste. Nevertheless, the PRCT provides limited durability due to its composition of PVC and green netting. Enhancements can be implemented for the material by employing more resilient and long-lasting pipe options, such as MDPE pipe or similar alternatives. The implementation of a portable waste containment device has resulted in heightened awareness within residential communities on appropriate waste disposal practises, including the avoidance of using drainage systems as dumping sites. The amount of rubbish is significant, although it has decreased compared to the prior quantity of waste gathered by the Mesh Type Wall Trap. With a gross pollutant retention rate beyond 90%, the subject in question meets the criteria for categorization as a Best Management Practise Facility, stated in the MSMA. The flow rate of the Mesh Type Wall Trap was seen to be higher compared to PRCT, with average flow rates of 7.43 mm^3/s and 39.2 mm^3/s, respectively. The issue of effluent overflow can be disregarded as the problems related to clogging were resolved prior to the implementation of the PRCT.

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