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Design of a Plastic Waste Clean-up Array System for Bolgoda Lake

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Abstract— The harmful effects of plastic in waterbodies are well established. Its effects extend to animals in higher trophic levels. This paper presents a reliable and cost-effective waste clean-up device capable of removing floating and partially buoyant waste from freshwater bodies. The device described is a passive clean up system which consists of three main phases, namely, catching, concentration, and collection phase. The catching phase traps the waste and directs it towards a collection cage. The collection cage retains the captured waste, and a conveyor belt extracts it. Finally, the waste trapped is transferred to an exit tray which slides the waste into a bin on the riverbank. A prototype of the device was fabricated and tested in Weras Ganga. The majority of the waste extracted was plastic packaging. However, small quantities of organic substances were extracted as well.

***Keywords*: plastic pollution, trash collector, conveyor belt, rivers**

I. INTRODUCTION

Plastic is a synthetic substance made from hydrocarbons which can be moulded into solid items of nearly all shapes and sizes (Azmy, 2002). It has become the biggest contributor to the degradation of water quality due to its buoyancy, resilience, and toxicant sorption properties (Ericksen et al. 2014). The factors driving the amount of plastics entering rivers include, population growth, urbanization and industrialization patterns within catchment areas, rainfall rates and the presence of structural barriers such as weirs and dams (Ericksen et al. 2014).

Natural degradation of plastic occurs due to photo-degradation followed by thermo-oxidative degradation (Webb et al. 2013). UV rays provide activation energy to initiate the introduction of oxygen atoms into the polymer. This allows the plastics to become porous and split into smaller fragments before the polymer chains achieve a sufficiently low molecular weight for the microorganisms to metabolize them (Webb et al. 2013). These microbes either transform carbon into carbon dioxide in the polymer chains or integrate it into biomolecules (Webb et al. 2013). This process takes 50 or more years to completely degrade the plastics (Webb et al. 2013).

The fragmentation of plastic results in a high surface to volume ratio and they continue to accumulate in the form of environmental contaminants such as Persistent Organic Pollutants (POPs). The adsorption of POPs onto plastic can be transferred into tissues and organs of animals through ingestion and magnified through the food web as shown in Fig. 1. By bioaccumulation and bio-concentration, they impact higher trophic levels.

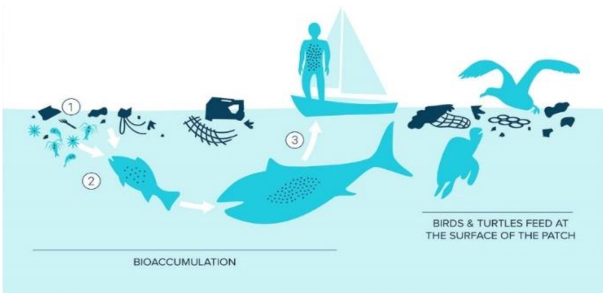

Figure 1. Impact of plastic debris

The global resin and fibre production has increased by 99% from 1950 to 2015, surpassing most other man made materials (Geyer, Jambeck and Law, 2017). In 2015, the volume of plastic entering the ocean annually was 4.8 to 12.7 million metric tons from 192 coastal countries. This approximately accounts for 1.7 to 4.6% of the total plastic waste produced (Jambeck et al. 2015). In 2014 a study revealed that 5 trillion plastic pieces weighing over 250,000 tons were afloat at the sea (Ericksen et al. 2014). If the current consumption patterns continues, the pieces of plastic in the ocean will surpass the number of fish by 2050 (United Nations Environment Programme, 2018).

A. Classification of plastic in the water column

As shown in Table 1 plastic can be classified into three main types based on size, namely macro plastics, meso plastics and micro plastics. The detection and removal methods for each type needs to be addressed separately as they differ in shape, size, material, composition, and abundance. The device described in this paper is designed to extract macro plastics from freshwater bodies, thus, preventing it from entering the ocean.

Table 1. Categories of marine plastic litter in terms of size

Diameter	Source	Example
Micro (≤ 5mm)	Primary and secondary microplastics	Primary: industrial and domestic products; Secondary: textile, fibres, tyre dust
Meso (5 - 20 mm)	Fragmentation of larger plastic items	Bottle caps, fragments
Macro (> 20mm)	Lost items from maritime activities or from rivers	Plastic bags, food and other packaging, fishing floats, buoys, balloons

Source : Andrady, 2015

Technologies addressing plastic pollution: In Sri Lanka, waste in freshwater bodies is most often removed using excavators or by scooping it out manually. Some water ways contain Bamboo shafts across them to trap waste. In 2020, the ocean strainer, a boom made of polyurethane foam blocks covered in water resistant material was placed across the Dehiwala canal to act as a barrier and prevent plastic waste from entering the ocean (Hoole, 2019). This is similar to placing a bamboo shaft across the river. However, research suggests that foam blocks are more efficient in trapping waste and preventing it from overtopping than bamboo shafts (Ho, 2015).

“Mr. Trash Wheel” and the “The interceptor” are river waste collection devices that are currently implemented. “Mr. Trash Wheel” is implemented in the Baltimore Harbour and “The Interceptor” has been implemented in Indonesia, Malaysia, and the Dominican Republic (Lindquist, 2017). Both systems use renewable power sources. “Mr. Trash Wheel” uses a water wheel as the main power source and solar panels as a backup power source (Lindquist, 2017). “The interceptor” solely runs on solar power.

“The Interceptor” uses a fixed barrier to divert waste towards the collection system while “Mr Trash Wheel” uses a flexible boom to divert waste to the collection system (Lindquist, 2017; How it works - The Interceptor, no date). However, they are both costly to be implemented (Goodwin et al. no date).

The novel features of the device described in this paper are that it is much more economical, the waste collected is transferred to land hence less manpower is required, the device requires very little power as the conveyor belt does not run throughout the day and the size of plastic collected is only limited by the mesh size of the skirt.

This paper consists of three main sections, the methodology which consists of design details of the system and the methods used to test the device. The results contain key insights observed during testing. The next two sections contain the advantages, limitations, and further improvements that can be done.

II. METHODOLOGY

The first step in the deign process was to select a suitable location. The system was designed based on the flow rate and dimensions of the selected waterway. Finally, a prototype of the device was fabricated and tested to ensure it works as required.

A. Site selection

Tides, wind, flow velocity, previous waste clean-up measures taken, and the rate of pollution were the factors considered in this regard.

Based on the rate of pollution, locations short listed include the Dehiwala Canal, Lunawa Canal and Weras Ganga (Fig. 2). After careful consideration of factors such as accessibility, ease of installation and previous clean-up measures taken, Weras Ganga, a tributary of Bolgoda Lake was selected. A prototype of the device was tested at Meda Ela, which is a tributary of Weras Ganga (Fig. 2).

Figure 2. Locations considered and selected testing location

Meda Ela was selected because its easily accessible, the flood walls and bridge eases installation, has an average flow rate and floating plastic waste was observed.

The flow rate of Meda Ela was experimentally found by measuring the time taken for a floater to reach a known distance. The experiment was conducted multiple times and an average value of 0.44 ms^{-1} was obtained.

B. Tides

The water level of Meda Ela was measured on two consecutive days to assess the rise and fall of it during high and low tides. The high tide and low tide times were obtained from tide tables (Fig. 3). The depth obtained was 1 m. A significant variation was not observed during high and low tides.

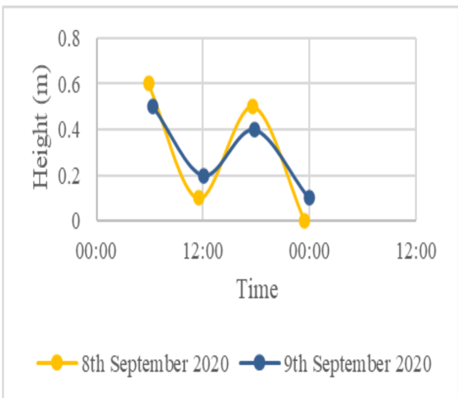

Figure 3. Tide tables for the 8th and 9th of September

C. Designing the device

This concept consists of a floating barrier (boom), where buoyant plastic particles can be caught, while neutrally buoyant aquatic animals can swim underneath (Fig. 4).

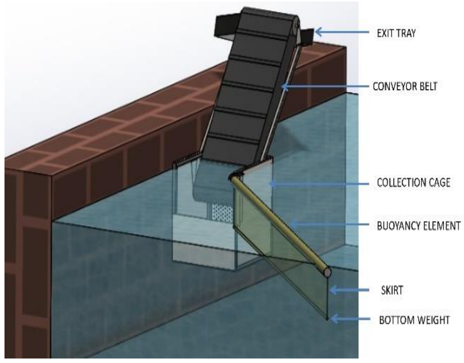

Figure 4. Initial draft of the device

The system removes plastic waste in three phases. Initially, waste is caught in front of the floating boom, the boom acts as a barrier and prevents waste from flowing downstream. Next, the accumulated particles slowly progress along the boom towards the collection cage and new particles are continuously added to this stream. Finally, the stream of waste enters the collection cage and forms a point of high concentration, from which waste is extracted using a conveyor belt. The waste extracted is transferred to an exit tray which slides it into a bin located on the riverbank. The relevant local authorities can empty the bin as and when required.

The Catching Phase: The boom consists of three main parts, namely, a buoyancy element, skirt, and a bottom weight (Fig. 4). The design requirements of the boom are buoyancy, its ability to transport plastic, bending stiffness, skirt orientation and axial stiffness.

The buoyancy element keeps the boom afloat while preventing trapped waste from overtopping. In addition, it compensates for the deadweight of the structure as well as the external forces acting on it. Moreover, it aids in guiding plastic towards the collection cage. For the prototype, a 3 m PVC pipe with an outer diameter of 90 mm and wall thickness of 5 mm was sealed at both ends and was used as the floater (Fig. 5).

Figure 5. Boom used in the prototype

The buoyancy element was fixed to the collection cage using a specially designed hinge capable of moving up, down, in and out (Fig. 6). The hinge was designed to be able to withstand the changes in water level and flow direction.

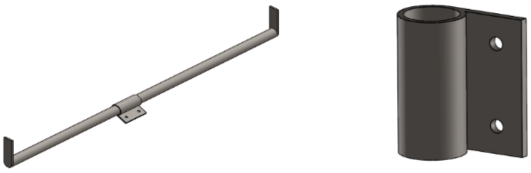

Figure 6. Boom Hinge

The skirt captures partially submerged debris and directs it towards the collection cage. It spans the entire length of the buoyancy element. For the prototype, a 2.54 mm x 2.54 mm diamond polyester mesh with a thickness of 0.78 mm and a width of 420 mm was used (Fig. 5).

To maximize the skirts efficiency, vertical orientation must be maintained (Sivasubramanian et al. 2014). Hence, a bottom weight was needed. As per the calculations, the bottom weight required was 2 kg.

1) The Concentration Phase: The boom was placed at an angle with respect to the riverbank, with the opening against the flow. This angle allows the current to transport the debris towards the collection cage and form a high concentration area, from which debris can be easily removed. The maximum deployment angle of the boom at a speed of 0.5 ms^{-1} should be 45 degrees (Shahryar, 2017). This angle should decrease as the flow rate increases.

2) The Collection Phase: Plastics that get accumulated in the collection cage is removed by a mesh conveyor belt. The conveyor belt system was designed to remove 30 kg of waste per day. The linear and rotational speed (rpm) of the conveyor to remove this quantity of waste in 15 min, 30 min and 60 min were considered. The roller rpm and belt speed were found using Equation 1.

$$M = \rho_{belt} \times K \times (0.9B - 0.05)^2 \times V_{belt} \qquad (1)$$

After careful consideration, the conveyor operation time was selected as 60 minutes. The calculated speed and rpm were 0.263 ms^{-1} and 83.71 respectively. Purchasing a stainless-steel mesh conveyor with cleats for the prototype was not economically feasible. Therefore, a conveyor belt was fabricated. The materials used were lashing belts, a plastic mesh for the conveyor, and pieces of Galvanized Iron mesh for the cleats.

To minimize the energy requirement, the belt was designed to run for one hour daily. The conveyor belt transferred the waste to an exit tray which slides the waste into a bin located on the riverbank (Fig. 4). A bin made of wire mesh was used to remove any trapped water within the trash.

D. Material selection

The materials selected for the system and prototype are included in Table 2.

Table 2. Materials selected for the device and materials used for the prototype.

Component	**Selected Materials**	**Materials used for the Prototype**
Frame	Stainless Steel Box Bar	Mild Steel Box Bar
Shafts	Stainless Steel	Mild Steel
Bearing Support	Stainless Steel Plate	Mild Steel Plate
Floater	PVC pipe	PVC pipe
Conveyor	Stainless steel mesh conveyor	Lashing belts, Plastic Mesh, GI Mesh
Skirt	Wire Mesh	Plastic Mesh
Side Panels - Conveyor Belt	Aluminium Sheet	Alloy Coated Steel Sheets
Side panels - Collection Cage		
Exit Tray		
Power transfer mechanism	Gear Drive	Chain Drive

E. Testing

To ensure that the device functions as required a prototype of it was fabricated and tested for a period of three days. The prototype designed was scaled down by 0.8. On day one, the device was installed and observed for around 5 hours. The drawbacks were noted, the system was removed, and modifications were made and re-installed on the next day.

Three cases were observed during testing:

- The flow of waste along the boom
- The retention of waste in the collection cage
- The ability of the conveyor belt to extract the retained waste.

The results obtained for each of these cases are discussed in the following section.

III. RESULTS AND DISCUSSION

A. Types of waste collected

Majority of waste collected was plastic. Plastic packaging items such as PET bottles, beverage packets, cigarette packets were prevalent (Fig. 7). This shows that plastic packaging is one of the largest aquatic plastic polluters. Moreover, the device removed organic materials such as small aquatic-plants and wood as well.

Small aquatic plants did not affect the system. They flowed along the boom, got retained in the collection cage, and got extracted by the conveyor belt. In contrast, larger plants obstructed the boom and prevented waste from flowing towards the collection cage. Extraction of plastic entangled with these plants was not possible.

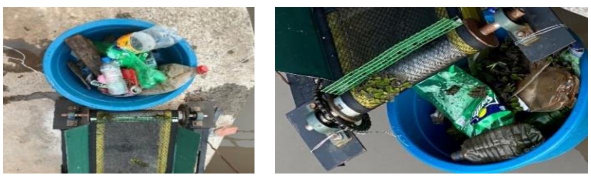

Figure 7. Waste collected by the prototype

During testing, large aquatic plants were removed ~~by~~ manually by increasing the angle of the boom. This was not an efficient way to manage the plants. It resulted in a certain amount of waste entrapped by the boom to escape along with the plants. Placing a barrier on the opposite end of the bridge to trap large plants without affecting the flow solved this issue.

B. Boom

1) *Angle of the Boom*: The flow of waste along the boom was monitored by adjusting the angle of the boom with respect to the collection cage. Initially, the angle of the boom was set at approximately 170 degrees. At this angle, some waste moved along the boom towards the collection cage, but some did not. Next, the angle of the boom was adjusted to approximately 150 degrees. Here, the amount of waste that moved along the boom increased.

The minimum deployment angle of the boom during testing was only 60 degrees. This was less than the recommended angle. However, decreasing the angle further would have increased the space between the retention wall and the end of the boom. This change would have caused waste to escape from that gap.

2) *Skirt Material*: The entanglement of waste with the skirt material and the formation of a barrier decreased the amount of waste that reached the collection cage. In Fig. 8, waste inside the yellow rectangle was stuck due to the piece of wood not moving into the collection cage. Waste is encircled in red to show the two different aspects.

There were no environmental impacts of using a mesh as the skirt material. When the skirt was removed there were no fish, aquatic plants, or other animals caught on it. However, since the testing period was short, the long-term impact of using a mesh is unknown.

Figure 8. Waste Getting Stuck on the Boom

3) *The orientation of the skirt*: The skirt retaining its vertical orientation was one of the main requirements of the system. Initially, due to the bottom weight being insufficient (0.6 kg) the skirt did not retain its position. As a solution to this, the bottom weight was increased by removing the end caps of the GI pipe that was used as the bottom

weight (1.03 kg). This solution worked to a certain extent but did not retain its vertical orientation fully. However, as per calculations, the bottom weight has to be 2 kg for the skirt to retain its vertical position.

C. Environmental conditions

The effects on the system due to tides and an increase in flow velocity were observed.

During testing, the flow velocity did not significantly increase therefore overtopping of waste was not observed. Also, large fluctuations in the water level during high and low tides were not observed.

Environmental conditions during testing were relatively constant. Therefore, the durability of the device in extreme weather conditions is unknown.

D. Collection Mechanism

1) Effectiveness of the Collection Cage in Retaining Waste: As shown in Fig. 9, the collection cage was able to effectively retain waste. However, the capacity of waste it was capable of retaining was limited to its size. Since the prototype was a scaled-down (1:0.8) version of the device

the amount of waste that the collection cage is capable of retaining is much higher.

Figure 9. Waste Entrapped in the Collection Cage

2) Efficiency of the Conveyor Belt: The conveyor belt was able to extract all waste retained by the collection cage including large PET bottles. However, during the initial testing period, flat waste particles got trapped between the cleats and the belt. This waste got dislodged at locations where it was not been collected. Therefore, such waste entered back into the water.

Fig. 10 shows a plastic bottle (which is circled in red) getting trapped between the conveyor belt and a cleat. It results in the overthrowing of the beverage packet shown inside the yellow rectangle. The trapped bottle got dislodged when it was under the conveyor and entered back into the water stream. This trapped bottle destabilized the bucket used to collect waste and caused some of the waste to enter back into the water stream (the waste in the yellow rectangle). This was caused by the cleats being fastened at the two ends only. As a solution to this, the cleats were fastened to the conveyor from the centre as well. This prevented waste from sliding between the cleats and conveyor.

The length of the conveyor belt did not reach the top of the retention wall therefore, as the design description states an exit tray that transfers the waste into a bin on the riverbank could not be fixed. As a solution, an easily removable bucket with holes drilled, was attached to the end of the conveyor to extract waste falling from it. However, this limited the amount of waste that could be removed by the conveyor belt in a single cycle. The bucket had to be removed, emptied, and replaced a few times during extraction.

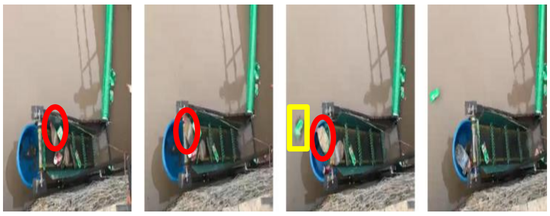

Figure 10. Waste Getting Trapped Between the Conveyor Belt and a Cleat

Due to the complexity in obtaining grid electricity for the device, a vehicle battery was used to power the motor. The motor used for the prototype was a 12 V brushed DC motor. Drawbacks of the motor were, when the tension of the belt increased the motor overheated, and the load-carrying capacity of the belt was limited by the power of the motor. However, large quantities of waste were not extracted by the conveyor belt at once, hence the motor performed as expected during testing.

E. Financial feasibility of the system

The cost incurred to design, fabricate, and implement the prototype was approximately Rs. 30,000. Despite the low cost of fabrication and testing of the prototype the actual cost of the final device would approximately be around Rs.72,000 ($ 373.35). This is due to the use of materials that would increase the durability of the device.

The bar chart in Fig 11 compares the cost to implement this device when compared with devices such as “The Interceptor” and “Inner Harbour Water Wheel”. However, these devices have been tested and optimized for many years. Therefore, the cost is justifiable.

"The interceptor" can remove 50,000 kg per day. The operational cost of the proposed device is not known as it is still in the pilot stage. "The inner harbour water wheel" was designed to remove 22,500 kg of waste per day. The operational cost of the device has not been published. The device proposed in this paper can extract 300 kg of waste per hour. The operational cost of the device would increase if it were allowed to run throughout the day as the motor is powered by grid electricity. If solar panels were used instead, the operational cost would reduce but the manufacturing cost would increase.

The cost was converted to USD using the exchange rate given by the central bank ($ 1= Rs. 192.85).

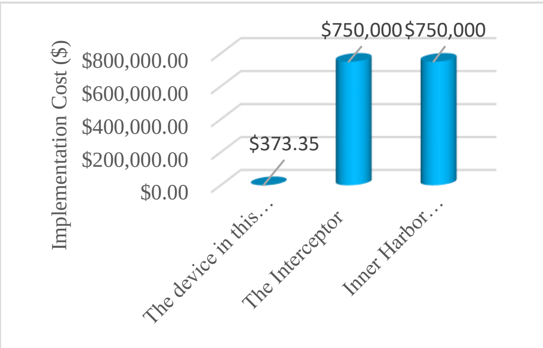

Figure 11. Cost comparison of existing devices with the device introduced in the paper

Further testing is needed in order to establish the total amount of waste that can be extracted by the system, maximum load that can be carried by the plastic mesh conveyor belt used in the prototype, durability of the device in extreme weather conditions, movement of partially submerged waste along the collection cage, effects of biofouling on the system. The system must be tested for a long period in order to obtain reliable results.

IV. CONCLUSION

Manually removing waste from rivers is a tedious process. The device introduced in this paper can trap and extract debris efficiently with little to no human involvement.

There are several novel features of this device in comparison to other commercial devices. The waste collection system is adjacent to the riverbank. Therefore, overhauling it for repairs and maintenance is straightforward. Moreover, collecting the extracted waste is a simple process of emptying a bin.

Systems such as "Inner Harbour Water Wheel" and "The Interceptor" are advanced commercially available products. They can remove large quantities of waste efficiently. However, they are expensive to implement in a developing country like Sri Lanka. In comparison, the cost of fabrication and implementation of this device is much lower.

In order to optimize the amount of waste collected, this device can be operated in locations with low backflow of water, that will increase its waste trapping efficiency.

The results clearly illustrate the device's capability to trap and extract waste in average weather conditions. However, its durability in extreme conditions is unknown. Testing the device for an extended period would validate the results.

To maximize its efficiency in wide rivers, two devices can be placed on either end of the riverbank with a clearance between them for vessels to navigate through. This would increase its capture efficiency. However, implementing two devices would increase the cost by two-fold.

The device can be modified to become more cost-effective and eco-friendlier. The suggested improvements are as follows.

A. Further Improvements

- Using a renewable power source such as solar power or hydropower (water wheel). The use of solar power is easier as Sri Lanka has sunlight throughout the year.
- Fully automating the system by using a timer circuit.
- Fixing a garbage level detection system to the collection bin to remotely monitor the waste collection.
- Adding a tension adjusting system and an auto-cleaning system.
- Exposure of the moving parts of the device could result in waste getting entangled with them. This has to be addressed appropriately.
- To reduce the material cost of the device, recycled materials or anodic protection can be used.

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ACKNOWLEDGMENT

Our utmost appreciation goes towards the Department of Mechanical Engineering of General Sir John Kotelawala Defence University for giving us their support throughout the project. We would like to thank our supervisor, Captain (E) M.C.P. Dissanayake, whose expertise was invaluable. His insightful feedback pushed us to sharpen our thinking and brought our work to a higher level.

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