Pedal Bicycle Powered Water Purification System

Level 2 Feasibility Report

HBIM4 Group 8

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1 Executive Summary

In 2015, the number of people worldwide without access to safely managed water services reached 2.1 billion.[1] It is predicted half the world's population will live in water stressed areas by 2025.[2] This project aims to produce a portable pedal powered system to purify water so it is fit for human consumption. There are currently no majorly successful products that achieves this. Research of current products and prototypes, as well as analysis of the intended market, has shaped the User Requirement Specification(URS). The product has been designed to sustainably meet the URS, and comply with the relevant international and British standards. The product will meet the needs of consumers and will be accessible due to its intended price of around £1000.

2 Introduction

2.1 Aim

This project aims to produce a lightweight, portable and robust pedal powered system capable of purifying water suitable for human consumption. The product will meter the volume and test the quality of the water. The main competitor is the Cycloclean produced by the Nippon Basic Co. Ltd.[3] A major drawback of this product is its cost, so our aim is to design a product with comparable performance at a reduced cost. This is important because the targeted consumers are charities and humanitarian aid organisations.

2.2 Baseline specification (BLS) - Cycloclean

BLS	Description	Value/Item
BLS1	Cost	$6600 USD (approx. £5160)
BLS2	Water filtration capacity	5 litres/minute (dependant on pedal power)
BLS3	Product lifespan	2 years
BLS4	Mass	50kg
BLS5	Dimensions	W 0.580 x L 1.780 x H 1.100 m
BLS6	Filtration capability	Dirt, bacteria, smells
BLS7	Purifiable water sources	Natural sources, pools, tanks

Table 1 - Cycloclean specification

2.3 User Requirement Specification (URS)

URS	Description	Importance	Value/Item	Regulation/Baseline
URS1	Cost	High	£1000	BLS1
URS2	Water filtration capacity	Medium	2 litres/min	BLS2
URS3	Product lifespan	High	5 years	BLS3, ISO 14040:2006
URS4	Mass	Medium	15kg (assume 1 person can lift 15kg with ease)	BS EN ISO 11243:2016 BLS4
URS5	Purifiable water sources	Low	Filters from natural sources, pools, tanks	BLS7
URS6	Filtration capability	High	Removes dirt, bacteria, smells	BLS6, COUNCIL DIRECTIVE 98/83/EC[4]
URS7	Dimensions	Low	W 0.50 x L 1.80 x H 1.20 m	BLS5
URS8	Ergonomic design	Medium	URS4, URS7, URS9 combined	BLS4
URS9	Easily attachable	Medium	Basic tool set required	ISO 225:2010 ISO 13920
URS10	Check water purity	High	Suitable for human consumption	COUNCIL DIRECTIVE 98/83/EC
URS11	Meter volume of water purified	Medium	Volume of purified water	BLS2

Table 2- User Requirement Specification

2.4 Budget
The proposed budget is £13,600. This covers the cost of 1200 working hours (£12,000), estimated parts (£625) and manufacturing costs to produce a prototype (£975). The product would cost £1000, covering production costs and generating a small profit.

3 Design Concepts
3.1 Testing of filtered water
3.1.1 TDS sensor
TDS sensors give a measurement of the total dissolved solids- an important factor in testing the water. The TDS sensor is cost effective and can easily be interfaced with and powered by an Arduino Microprocessor.[5]

3.1.2 pH detector
Using a pH detector is a good indicator for hazardous compounds in the water, but they are more expensive than TDS sensors and require large pH probes. The probes pose a risk of breaking and are difficult and expensive to replace. A broken pH sensor would leak its reference liquid into the water, which would be unhealthy to consume. The probes are also incompatible with a microcontroller and have a higher operating voltage of 5V.[6]

3.2 Metering volume of filtered water
Other concepts, such as visual gauging, were considered but discarded due to inaccuracy and imprecision.

3.2.1 Moisture Detector
Moisture detection is cheap but would not give a useful output for calculating the volume of water purified. The researched sensors are too small to give a useful measurement as they cannot measure the full depth of the tank.[7]

3.2.2 Infrared Level Detection
Infrared level detection gives an accurate reading of the water level, but will require further calculations to find the output of purified water. This method is expensive but sensors are small and would be easy to implement.[8]

3.2.3 eTape Liquid Level Sensor
An eTape level sensor would give an accurate reading of the water level, but would require alignment with the bottom of the tank and is the most expensive solution. However, it gives an accurate output based on the pressure of the liquid.[9]

3.3 Microcontroller
An appropriate microcontroller will help meet the metering and purity testing requirements of the URS, which will be displayed on an LCD display board module.

3.3.1 MBED LPC1768
The MBED LPC1768 requires a low operating voltage which reduce energy requirements. However it is expensive at £50, with the Arduino mentioned next costing £20.[10]

3.3.2 Arduino UNO REV3
The Arduino UNO REV3 is cheaper than the MBED LPC1768 and the parts selected for level sensing and purity testing are designed for interfacing with an Arduino microcontroller. However, this requires a greater operating voltage between 7-12V compared to 2.4-3.6V for the MBED. [11]

3.4 Power Supply
3.4.1 Rubber belt
Connecting the pump to the pedals using a rubber flat belt is a cheap solution to harness power (roughly £2).[12] It's efficient due to its thin cross-section meaning there is low bending loss. However, there are high losses from slip and friction. It also wears down quickly and misalignment can shorten its lifespan, meaning it would need replacing often.[13]

3.4.2 Roller chain
A roller chain is the most efficient way to convert pedal power to mechanical and, combined with gears, it could provide a high output. However, this is hard to manufacture and costly. Chains are prone to rusting and whilst lubrication can extend their lifespan, this requires careful user maintenance. To overcome this, stainless steel can be used but this is expensive and has a lower load carrying capacity than carbon steel.[14]

3.4.3 Shaft connected to the back wheel
The shaft is connected to the wheel so has no risk of catching on the cyclist's legs. Being a small part, high quality material such as stainless steel N60 alloy can be afforded, which will increase durability.[15]

3.4.4 Dynamo and battery combination
The dynamo can be manufactured through 3D printing which would reduce shipping costs. It's fitted directly on the wheel so there's no risk of catching on the customer's legs. A basic dynamo supplies 6W of power at 12V so multiple dynamos would be needed.[16] If more power is required, a cache battery like the Busch & Muller USB-Werk could be

connected to a hub dynamo permanently on the front wheel, which charges whilst cycling and its power used during purification.[17] However, it would limit the use of the system to the lifetime of the battery.

3.4.5 Water turbine generator

A water turbine is convenient since water will already flow through the pump. However it is heavy so the device will be less portable and may hinder the balance and steering of the bike, hence increasing risk.[18]

3.5 Water purification methods

3.5.1 Chlorination

Chlorination kills microbes and bacteria in water by mixing in chlorine gas or chlorine compounds. This is efficient and low-cost.[19] Chlorine is toxic so overexposure can be harmful to users and the environment. Chlorine can react with numerous chemicals and can travel far when released into the environment.[20]

3.5.2 Ozonation

Ozone gas is bubbled through water, reacting with unwanted molecules so they are no longer harmful.[21] Ozone kills bacteria efficiently and only requires a small exposure time but monitoring and running the treatment is expensive.[22] Ozone is toxic in large concentrations and should not be released into the environment. Current research shows ozonation by-products are possibly carcinogenic.[23]

3.5.3 Germicidal Irradiation

Germicidal irradiation is the process of killing or stopping reproduction of microorganisms and viruses, using Ultraviolet (UV) light. UV radiation exposure can cause eye and skin damage.[24] It can break chemical bonds in polymers, like plastics and rubbers, and can produce ozone. To avoid this, the lamp can be adjusted so radiation of wavelength less than 254 nm is not emitted.[25] For maximum purification, the system should use a pre-filter to improve turbidity and remove organic matter.

3.5.4 Reverse-Osmosis Filter

High pressure water passes through a partially permeable membrane which removes ions in the water.[26] This requires simple maintenance but is expensive because it requires lots of energy to produce high pressure.[27]

3.5.5 Activated Carbon (AC) filter

When water flows through an AC filter, organic matter and chemicals cannot pass through the filter block, as they are absorbed by porous charcoals.[28] The filter also removes bad odours and taste. These filters are popular amongst households and are low-cost.[29]

3.6 Attachment to Bicycle

To allow the device to attach to a range of bicycles a standard bicycle was chosen for modelling the attachments. This has a 16” frame and 26” wheels, the recommended size for a person of average height. The bicycle is a hybrid design so has clipless pedals and a regular frame and handlebars. For use when the bicycle is stationary, a stand is needed to support the rear wheel. The two most feasible attachment types are considered below.

3.6.1 Pannier Rack

The water storage tanks, pump and purification systems are attached using a metal rig. The rack is attached to the bike through a series of screw fastening locking mechanisms. The water would be stored in a dirty water tank above the back wheel and splits into two tanks on either side of the wheel. This is compact but expensive because 2 filtration systems and an extra water tank is needed.

3.6.2 Trailer

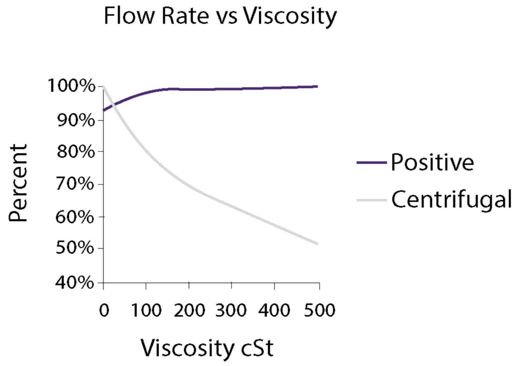
The tanks, pumps and purification systems are held in a trailer behind the bike. This allows for easier attachment to the bike as it requires fewer fastenings and everything fits into the trailer. This option, however, requires a suspension system to protect the delicate purification system and would be wider than the bike itself.

3.7 Pumping method

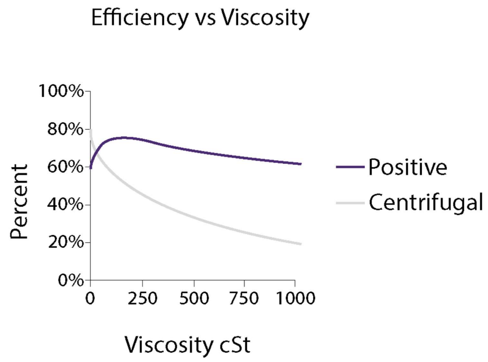
Due to the low power output from the cyclist (approximately 200-300W for 45 minutes), the pump choice is important so maximum efficiency is achieved.[30]

3.7.1 Types of pumps

Two types of pumps were considered; centrifugal pumps and positive displacement pumps. For low viscosity fluids the centrifugal pump is widely used. Positive displacement pumps, such as piston pumps, are used for fluids containing solids or with a large viscosity because they are less susceptible to blockages. The graphs in Figure 1 compare efficiencies and flow of the pumps.



(a)



(b)

Figure 1- (a) Flow rate vs Viscosity for positive displacement pump and centrifugal pump (b) Efficiency vs viscosity for positive displacement pump and centrifugal pump [31]

3.7.2 Impeller Material

The impeller would be fabricated out of a durable and chemically resistant material that is cheap to meet the URS. Potential materials include High Density Polyethylene (HDPE) and Stainless Steel 316. HDPE is cheaper but not always BPA free which is unacceptable when pumping drinking water.[32 33]

3.7.3 Impeller Design

Three impeller designs were considered; open, closed and semi-open. The important requirements are a high efficiency and a low risk of blockages from salts and precipitates. The closed impeller is the most efficient because it has the smallest clearance between the impeller blades and the pump wall but is prone to blockages. The open impeller is least susceptible to blockages but is inefficient. The semi-open impeller will be used as it is a balance between the two. [34]

4 Final Design

4.1 Selected Components

Category	Selected Component	Reason
Water testing method	TDS Testing	Provides a cheaper alternative and is more compatible with microcontrollers.
Water metering method	Infrared Level detection	More accurate method for level detection, lightweight and easy to use, clear data output.
Microcontroller	Arduino UNO REV3	Less expensive, electronic sensors designed for Arduino compatibility.
Power supply	Dynamo (4 bolted onto the back wheel; either side of the chain and seat stays)	Lightest, cheapest and most reliable solution. One to power the UV lights connected in series and the remaining will power the electronics and pump. This removes the need for an additional battery and to connect anything to the pedals, making it low risk.
Water purification methods	Activated Carbon Filter paired with UV-C Germicidal Irradiation Mercury vapour Lamp	Safe solution with fewer potential safety issues. Selecting two options for better purity.
Attachment to bicycle	Pannier rack	Increases durability of the system by using bicycle suspension.
Pumping method	Centrifugal Pump	The most efficient pump design and the stainless steel is chemically resistant meaning it will not pollute the water when wetted.
Pump Impeller material	Stainless Steel 316	Stainless Steel 316 is highly resistant to alkalis, salts, acids, cheap (£2.88/kg), heat resistant and has a life expectancy of around 15-20 years.

Pump Impeller design	Semi-open	Has a high efficiency and is more durable than an open impeller.[34] Due to only having one side closed off it is less susceptible to blockages than a closed impeller.
Bicycle stand	See Figure 14, Appendix 7.5.3	A wide base will provide stability to the bicycle and will be out of the way of the purification system.

Table 3- Selected components summary

4.2 Initial Modelling and Design

An initial CAD model of the design is shown in Figure 2, showing the structure of the design over the back wheel (the rest of the bike would be situated to the left), not including the dynamo and electronic components. The dirty water is stored on top, it flows through the pump and into the activated carbon (AC) filter. After the AC filter the flow splits in two, for improved weight distribution, and flows through the box containing the UV light for germicidal irradiation. Finally, it is stored in clean containers. The system is supported by a pannier rack attachment with supports for the dirty water container, UV boxes and clean water containers.

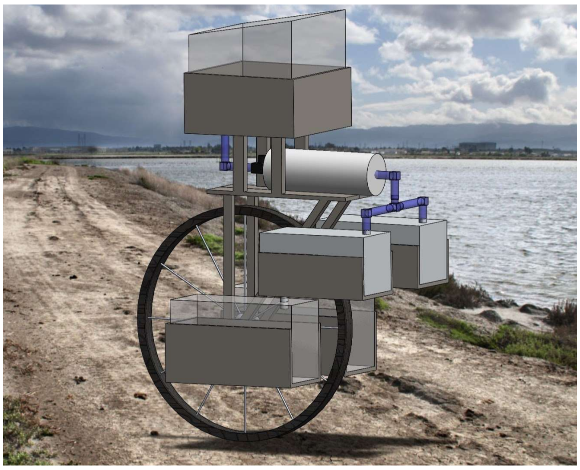


Figure 2 - CAD design of proposed solution

4.3 Cost breakdown

Item	Description	Cost (£)	Quantity	Total Cost (£)
RS Pro Long Life Brushless Pump [36]	A micropump capable of pumping 2.6L/min. Pump life of around 10,000 Hours	89.60 ex VAT	1	89.60
UV water Treatment System [37]	6W Lamp (with casing), 4.5L/min maximum flow rate. Bulb life of 9000 hours	99.99	2	199.98
10L plastic water container [38]	A container to store the clean water.	11.30	2	22.60
20L plastic water container [39]	A container to store the dirty water.	13.50	1	13.50
Custom built pannier rack with attachments	A pannier rack similar to Axiom Streamliner Disc Deluxe Rear Rack.[40]	80.00	1	80.00
RS Dynamo Motorised Friction Head Rear Light S5G5 [41]	Dynamo to produce the required electrical power output.	7.47	4	29.88
MDPE Pipe 20mm diameter, 25m [42]	Pipe to carry water through the system.	21.45	1	21.45
MDPE Tee 90 [43]	T-junction for the pipes.	6.48	1	6.48

MDPE Elbow 90 [44]	90 degree bend for pipes.	3.83	4	15.32
Granular AC Filter [45]	10” filter, max flow rate 4-5L/min, 6 month life.	4.50	10	45.00
Arduino UNO REV3	A microcontroller.	20.00	1	20.00
Digital TDS meter	Device to measure TDS in water.	4.10	2	8.20
SST Liquid Level Sensor	Device to meter the water quantity.	19.76	2	39.52
Arduino LCD display board module	Digital display to show quantity and quality of water.	2.99	1	2.99
Harsh environment wire, 30m	To connect up the electronic components.	10.60	1	10.60
Bike Stand	Stand to prop up the back wheel so the system can be used when bike is stationary.	20.00	1	20.00
			Total Cost (£)	**625.12**

Table 4- Bill of Materials

4.4 Sustainability

Aluminium 6061 from the pannier attachment and HDPE used for the pipes and tanks are widely recycled. With an increased worldwide access to recycling facilities, the likelihood of parts being disposed of in landfill is low.
The electronic components contain precious and toxic metals like silver and cadmium. However as they are encased in steel it is highly unlikely that they will leak out.
Activated carbon will be hazardous waste if it absorbs toxic chemicals but since it will only be filtering drinking water it is unlikely to become toxic.

4.5 Manufacture

The pannier is easily manufactured by casting the individual struts and then welding them together. The plastic tanks and other plastic components can also be cast and moulded into the desired shape. They are designed to be detachable from the pannier to reduce total weight and make replacing parts easier. Their shape is simple so it would be easy to mould.
The electronics, filtration system, dynamo and pump are pre-manufactured so they would be incorporated during the assembly stage and are designed to be able to be taken on and off the pannier frame.

5 Conclusions

Our output capacity needs to be modified; the UV germicidal light has a minimum exposure time which restricts the rate water can flow through the system. In addition, the pump has a maximum pumping capacity of 2.6L per minute.
The proposed solution offers a significantly cheaper solution to the main competition, costing £1000. An activated carbon filter used in conjunction with UV germicidal lamp means water produced will be safe to drink and will meet purity standards. The overall design is compact and lightweight, weighing around 15 kg when empty and measuring 1m high by 0.5m wide. With provision for a 5 year lifespan the design will meet relevant URS points.

6 Project Plan

We plan on fully defining the design, including detailed CAD modelling, a comprehensive bill of materials and details of the manufacturing process specified, by mid-February. Monitoring our progress shall be done using a Gantt chart, shown in Appendix F, (Figure 15). The approximate timescale of each task is set with an assigned person responsible for the respective task. The chart has some flexibility regarding how long is needed to complete each task and contingency allows for unforeseen obstacles.

7 Appendices

7.1 Appendix A: Risk Assessment

Severity Level	Severity Description	Likelihood Level	Likelihood Description
1	Damage to product. Chance of non-immobilising injury but no hospital treatment required.	1	Highly unlikely
2	Damage to product. Chance of non-immobilising injury requiring hospital treatment.	2	Unlikely
3	Chance of immobilising injury requiring hospital treatment.	3	Possible
4	Chance of injury/trauma requiring urgent hospital treatment.	4	Likely
5	Chance of very severe life-threatening event.	5	Highly likely

Table 5- Risk Assessment definitions

Hazard	Risk	Severity level	Likelihood level	Precautions
Electric shock from dynamo	Injury from sudden electric discharge.	1	3	No wires or electrical components to be exposed.
AC filter does not remove all organic matter and sediment	Poor turbidity of water, hence germicidal irradiation will be less effective and water will not meet health standards.	3	3	Replace AC filter every six months.
Water exposure time to UV too short, hence not fully purified	Higher chance of contracting diseases such as cholera and typhoid.	5	2	Water testing included in design and flow rate will be regulated to ensure a sufficient exposure time.
UV breaks down molecules in materials such as plastics and rubbers	Environment and user exposed to UV radiation. Can cause eye and skin damage.	3	2	Keep lamp in sealed container with automatic safety switch if the container opened. Line the container with aluminium.
Not completing the project and going over-budget	Not meeting the expectations of the stakeholders	1	2	Produce a bill of materials and cost estimation to be aware of the costs involved.
Balance/ weight distribution going wrong	The bike could tip backwards causing the user to fall off it.	2	2	Limit the size of the water containers to reduce the maximum weight of the system.
Weight of water causing pannier to fracture	The pannier system breaking could cause the tanks to detach from the bike.	3	2	Apply a factor of safety when calculating the maximum stress and choosing a material with a high yield stress.
UV Bulb breaking	Water flowing through will no longer be safe to drink. Broken glass can cause cuts.	4	3	Attach above bicycle suspension, advise good maintenance and safety checks.

Table 6- Risk Assessment

7.2 Appendix B: Calculations

7.2.1 Frictional Head Loss exiting pump

Assuming nozzle length L= 15 mm, nozzle diameter d = 6 mm, surface roughness k = 0.045 mm

$$U_m = \frac{\bar{Q}}{A} = \frac{2.6*10^{-3}}{60\pi\left(\frac{(6*10^{-3})^2}{4}\right)} = 1.533\ ms^{-1}$$

$$R_e = \frac{U_m*d*\rho}{\mu} = \frac{1.533*6*10^{-3}*1000}{8.9*10^{-4}} = 10335$$

$$\frac{k}{d} = 0.0075$$

$$\textit{Through use of a Moody diagram}: f = 0.0403$$

$$h_f = 4f\frac{L}{D}\frac{U_m^2}{2g} = 0.0483\ m$$

7.2.2 Minor Losses due to pipe expansion

Assuming pipe 1 has diameter of 6mm, pipe 2 has internal diameter of 15.2mm (20mm pipe)

$$k = \left(1 - \frac{d_1^2}{d_2^2}\right) = \left(1 - \frac{6^2}{15.2^2}\right) = 0.844$$

$$h_{l,1} = k\frac{u_1^2}{2g} = 0.844\frac{1.533^2}{2g} = 0.101\ m$$

7.2.3 Minor Losses due to pipe contraction leaving pump

Assuming $\frac{d2}{d1} \to 0$ due to pump diameter being significantly larger than the exit pipe diameter

$$h_{l,2} = k\frac{u_2^2}{2g} = \frac{1}{2} * \frac{1.533^2}{2g} = 0.0599\ m$$

$$h_{l\ total} = h_f + h_{l,1} + h_{l,2}$$

$$= h_f + h_{l,1} + h_{l,2} = 0.0483 + 0.101 + 0.0599 = 0.209\ m$$

7.2.4 Pump Efficiency

$$\eta = \frac{HP_{Water}}{HP_{Pump}} = \frac{W_{Water}}{W_{Pump}}$$

Where η is efficiency, W represents work and HP represents work in horsepower

$$HP_{Water} = \frac{\bar{Q}(H+h_{l\ total})}{3960}$$ [46]

$H + h_{l\ total}$ represents the theoretical maximum head if there were no losses

The maximum output pressure is 0.386mBar which is 3.94m after converting maximum pressure to head using the formula:

$$P = 0.0981 * H * SG$$ [47]

where SG is the specific gravity

Conversion of flow rate and total head into imperial units which after further conversion produced:

HP_{Water} = 1.76 W

$$\eta = \frac{1.76}{6} = 0.293$$

The pump is 29.3% efficient when running at max capacity when ignoring effects of fluid head loss due to friction and minor losses such as sudden expansion

7.2.5 Flow Rate in the System

If we assume that the pump will operate at 75% capacity then the flow rate leaving the pump will be:

$$Q = 0.75(2.6) = 1.95L/min = 3.25 \times 10^{-5}\ m^3/s$$

Applying mass flow continuity across the system, from the pipe on exit at the pump through the T-junction to the two separate but identical pipes entering the UV container:

$$Q_1 = Q_2 + Q_3,\ as\ Q_2 = Q_3\ then\ Q_1 = 2Q_2$$

$$Q_2 = 0.5 \times 3.25 \times 10^{-5} = 1.625 \times 10^{-5}\ m^3/s = 0.975L/min$$

As this is less than the maximum flow rate for the UV purification, the exposure time will be long enough and a full tank of dirty water will take 10 minutes to purify.

7.2.6 Buckling Analysis for Struts supporting dirty water container

Assuming the struts are 25mm diameter, 2mm thickness, 150mm length, made of 6061 Aluminium Alloy, a common material for pannier racks, then:

$$I = \frac{\pi}{4}(R_{outer}{}^4 - R_{inner}{}^4) = \frac{\pi}{4}(10^4 - 8^4) = 4637\ mm^2$$

$$E = 68.9GPa = 68.9 \times 10^3\ Nmm^{-2}$$

$$Critical\ Load = P_{cr} = \frac{\pi^2 EI}{L^2} = \frac{\pi^2(68.9\times10^3)(4637)}{150^2} = 140\ kN$$

The struts support a 20L water container and base of assumed mass 5kg so the full assumed mass is 25kg. Assuming the load is evenly split between the four struts, and applying a factor of safety of two:

$$P = 2 \times \frac{25}{4}g = 123\ N$$

As $P << P_{cr}$ the struts will not buckle.

7.2.7 Stress in the frame

Assuming the struts are 25mm diameter, 2mm thickness, made of 6061 Aluminium Alloy, a common material for pannier racks, then:

$$A = \frac{\pi}{4}\left(d_{outer}^2 - d_{inner}^2\right) = 75.39mm^2$$

$$\sigma_{yield} = 170\ MPa = 170\ Nmm^{-2}$$

$$F_{yield} = \sigma_{yield} A = 170 * 75.39 = 12816.3\ N$$

Assuming under the same load conditions and distribution as for buckling and applying a factor of safety of two:

$$F = 2 \times \frac{25}{4} g = 123\ N$$

As $F << F_{yield}$ the struts will not buckle.

7.3 Appendix C: Pugh Matrices

7.3.1 Water Pumping Methods Pugh Matrix

			Centrifugal Pump	Positive Displacement Pump
Criteria	Explanation	Weight	Score	Score
Cost	Cheap so charities and . less developed areas can afford it.	7	9	7
Efficiency	Needs to be high due to low and inconsistent input power.	9	8	5
Lifespan/ Durability	System has to function for at least the lifespan of 5 years.	6	6	8
Pumping Power	Pump power needs to exceed specification.	5	5	7
Simplicity of Design	A simpler design means it is easier to clean and results in a more reliable pump.	8	8	6
		Total score	260	225

Table 7- Water pumping methods Pugh matrix

7.3.2 Microcontroller Concepts Pugh Matrix

			MBED LPC1768	Arduino UNO REV3
Criteria	Explanation	Weight	Score	Score
Cost	Cheap so charities and less developed areas can afford it.	9	4	9
Maintenance	System must be easy to fix with limited tools, as it is intended for use in areas with limited maintenance facilities.	6	6	6
Lifespan/ Durability	System has to function for at least the lifespan of 5 years.	9	6	6
Weight	Lightweight for portability preferable.	2	5	3
Size	Small for ease of application preferable.	2	6	3
Power Required	Should require little power due to limited power from cyclist.	8	9	8
Dangers/ risk	Design must not expose user to unnecessary dangers.	2	9	9
		Total Score	238	265

Table 8- Microcontroller concepts Pugh Matrix

7.3.3 Purity Testing Methods Pugh Matrix

			TDS Sensor	pH Sensor
Criteria	Explanation	Weight	Score	Score
Cost	Cheap so charities and less developed areas can afford it.	9	9	6
Maintenance	System must be easy to fix with limited tools, as it is intended for use in areas with limited maintenance facilities.	6	9	5
Lifespan/ Durability	System has to function for at least the lifespan of 5 years.	9	8	4
Weight	Design should be portable and not impact ability to ride bike.	4	8	3
Size	System must be portable and attachable to bike.	4	9	4
Power	Should require little power due to limited power from cyclist.	8	9	6
Dangers/ risk	Design must not expose user to increased health and safety risk.	4	9	5
		Total Score	383	216

Table 9- Purity Testing Methods Pugh Matrix

7.3.4 Display Concepts Pugh Matrix

			LCD Display Screen with touch (MBED)	LCD Display Screen (Arduino)	Level Gauge
Criteria	**Explanation**	**Weight**	**Score**	**Score**	**Score**
Cost	Cheap so charities and less developed areas can afford it.	9	8	9	9
Maintenance	System must be easy to fix with few tools, as it will be used in areas with limited maintenance facilities.	6	8	9	9
Lifespan/ Durability	System has to function for at least the lifespan of 5 years.	9	8	8	7
Weight	Should be lightweight for portability.	2	9	6	5
Size	Should be small for ease of use.	1	9	6	6
Power Required	Should require little power due to limited power from cyclist.	8	8	8	9
Dangers/ risk	Should avoid unnecessary risk.	2	5	5	2
Accuracy of readings	Does the option give an accurate and precise reading?	8	9	9	2
		Total Score	**365**	**371**	**306**

Table 10- Display Concepts Pugh Matrix

7.3.5 Level Sensor Methods Pugh Matrix

			Arduino GIKFUN	SST Infrared Level Sensor	eTape Liquid Level Sensor
Criteria	**Explanation**	**Weight**	**Score**	**Score**	**Score**
Cost	Cheap so charities and less developed areas can afford it.	9	8	4	1
Maintenance	System must be easy to fix with limited tools, as it is intended for use in areas with limited maintenance facilities.	8	6	9	9
Lifespan/ Durability	System has to function for at least the lifespan of 5 years.	9	6	9	9
Weight	Lightweight for portability preferable.	6	9	9	5
Size	Small for ease of application preferable.	4	8	9	6
Power	Should require little power due to limited power from cyclist.	9	9	9	8
Dangers/risk	Must not expose user to unnecessary dangers.	4	6	9	9
Quality of data	Data must be able to provide useful and consistent data for water metering.	9	4	9	9
		Total Score	**401**	**477**	**405**

Table 11- Level Sensor Methods Pugh Matrix

7.3.6 Power Supply methods Pugh Matrix

Criteria	Explanation	Weight	Rubber belt Score	Roller chain Score	Shaft connected to back wheel Score	Dynamo Score	Water turbine generator Score
Cost	Cheap so charities and less developed areas can afford it.	8	9	8	6	8	6
Resources	Are replacements easy to find?	6	7	6	4	5	5
Maintenance	Users with little to no experience should be able to maintain it.	7	6	4	3	6	4
Lifespan/ durability	System has to function for at least the lifespan of 5 years	3	3	5	6	6	6
Weight	It should be portable and not hinder performance of the bike.	6	8	7	7	10	3
Size	It should be small so it is not in the way of pedalling.	4	8	8	8	10	3
Power Supplied	High power output is needed to power the pump, electronics and potentially the UV light.	9	5	6	6	4	7
Efficiency	Needs to be high due to low and inconsistent input power.	9	3	6	7	4	4
Dangers/ risk	Should not cause an increased health and safety risk to the user.	8	6	6	8	9	9
		Total Score	**365**	**373**	**366**	**398**	**325**

Table 12- Power Supplied Pugh Matrix

7.3.7 Water Purification Methods Pugh Matrix

Criteria	Explanation	Weight	Chlorination Score	Ozonation Score	Germicidal Irradiation with AC pre-filter Score	Reverse -Osmosis filter Score
Cost	Cheap so charities and less developed areas can afford it.	6	7	4	7	1
Efficiency	Needs to be high due to low and inconsistent input power.	7	6	8	9	4
By-products	By-products shouldn't harm environment, user or water purity.	6	4	2	6	7
Sustainability	Should be sustainable so has minimal impact on environment.	7	3	3	7	9
Durability	Has to function for at least 5 years.	6	6	4	7	6
Safety	The system should not cause danger to the user when in use, the purified water must be fit for human consumption.	9	4	3	5	7
Ease of build/access to resources	Replacing parts should be easy and users with no experience should be able to maintain it.	5	6	5	6	7
		Total Score	**231**	**189**	**307**	**273**

Table 13- Water purification methods Pugh matrix

7.3.8 Full Design Concepts Pugh Matrix (Sketches can be found in Appendix 7.5.2)

				Design Concept						
				Design 1	Design 2	Design 3	Design 4	Design 5	Design 6	Design 7
Design Criteria	Description	Explanation	Weight	Score	Score	Score	Score	Score	Score	Score
Attachability	Is the design easy to attach and detach from a wide range of bicycles?	Device needs to be able to attach to a variety of bikes without any previous expertise required, so all can use it	9	9	4	6	5	7	5	4
Ergonomics	Does the design affect the way a person can use and pedal the bicycle?	The design should not encroach upon the space required for a person to pedal a bike normally	8	8	3	5	4	8	4	5
Flexibility	Can it be used whilst the bicycle is moving as well as stationary?	If the system can purify when in motion, it adds an additional option to the user	2	9	9	9	9	9	9	9
Lightweight	Is the design lightweight and so can be picked up by the majority of people? Will the bicycle be able to be moved when the design is attached?	Part of the design spec, the design should be lightweight to make it easy to move and attach to a bike	7	1	5	5	2	4	4	2
Cost	Are the materials required expensive and will it be cheap to manufacture?	Cost should be kept low where possible but not as a compromise to the safety of the design	3	3	4	6	6	7	6	6
Robustness	Is the design resistant to knocks and will it be hard to cause any damage to it?	To meet a lifespan of 5 years, the design should be knock-resistant	8	6	3	3	3	5	6	4
Reliability	Will the design be easy to maintain, can parts be detached and reattached easily and are replacement parts easily available?	As the system will be sent out globally, parts should be available globally and be fixed with little technical equipment	5	7	2	5	7	7	7	6
Sustainability	Does the design use sustainable materials and have a low carbon footprint?	It is important to have sustainable designs as engineers have a responsibility to promote sustainability	5	7	7	7	7	7	7	7
Safety	Are there any moving parts exposed which could be a danger to people? Are there sharp edges anywhere?	The safety of the customer should be of paramount importance	9	6	4	6	5	7	4	3
Size	Is the design compact and fits easily around the bicycle? Is it small enough to be moved by one person?	The design should be able to be used by one person and so the size of the design should reflect this	5	4	3	7	4	4	7	4
			Total Score	371	245	338	286	387	330	270

Table 14- Full design concepts Pugh Matrix

7.4 Appendix D: Stakeholders

- Distributors: Charities e.g. WaterAid
  - Have lots of power as they have the most money to invest and have power to distribute them to crisis areas where it is most needed
- Inform: Department stakeholders, Ian Mearns and Dr Hamed Bahmani
  - Keep informed to ensure the project stays on track and meets the specification
- Satisfy: Governments and Regulatory Bodies
  - Need to satisfy standards and sustainability to ensure our project can reach those families in need and be used internationally
- Users: Families with no access to clean water
  - Have the highest interest (in terms of their health) since they need clean water most

7.5 Appendix E: Sketches

7.5.1 Pump Design Sketches

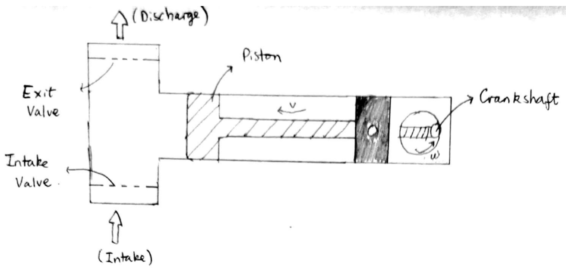


Figure 4- Positive displacement pump

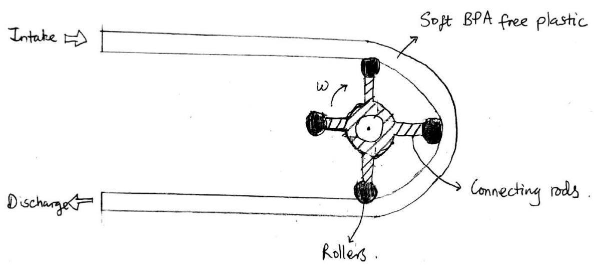


Figure 5- Peristaltic Pump

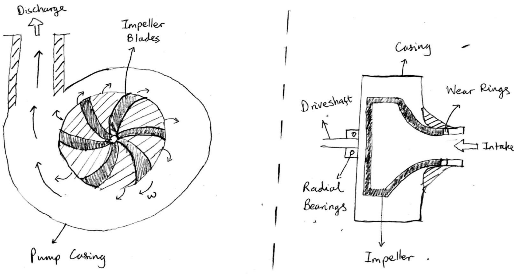


Figure 6- Centrifugal Pump side view and section view

7.5.2 Concept Design Sketches

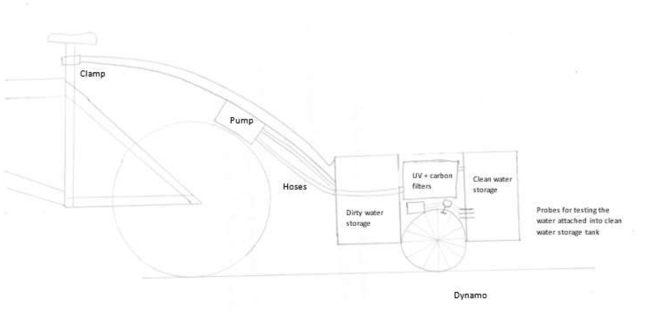


Figure 7- Design 1

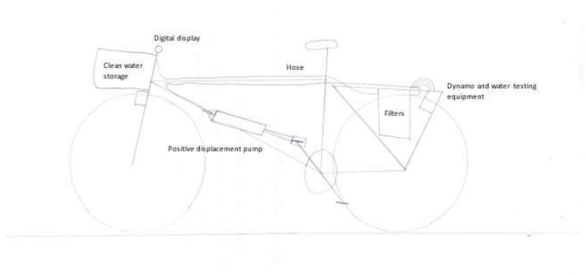


Figure 8- Design 2

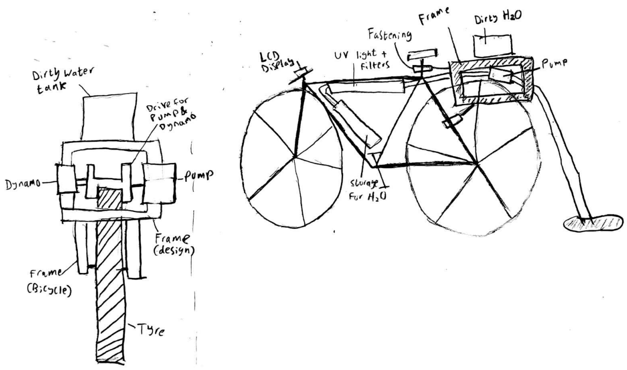


Figure 9- Design 3

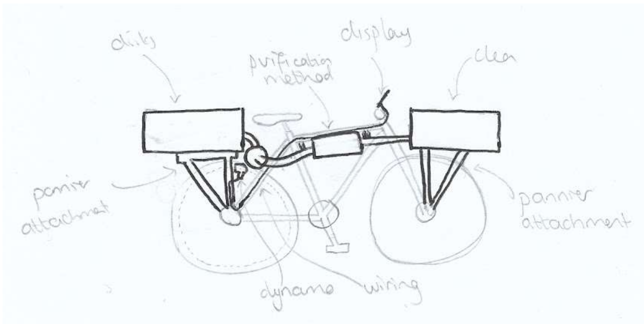


Figure 10 - Design 4

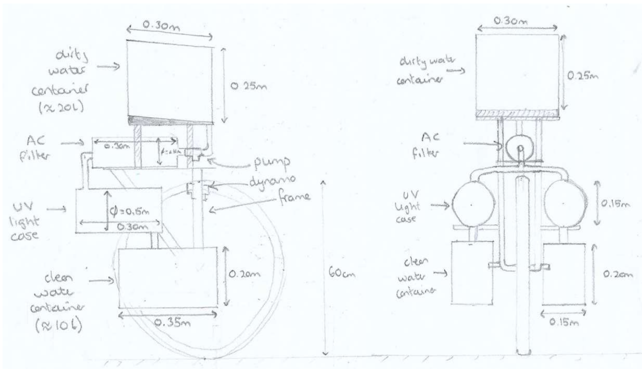


Figure 11- Design 5

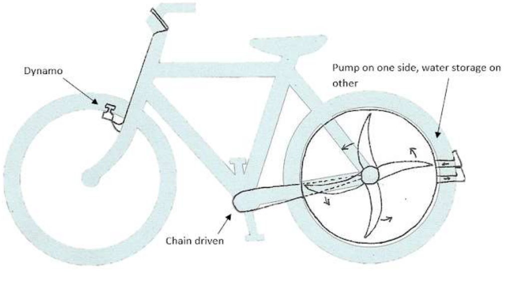


Figure 12- Design 6

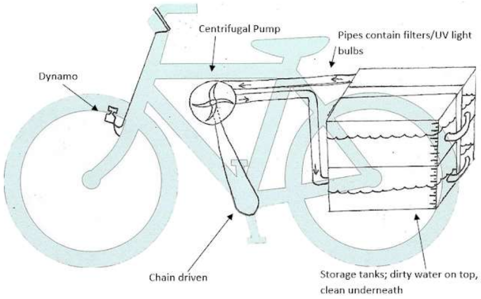
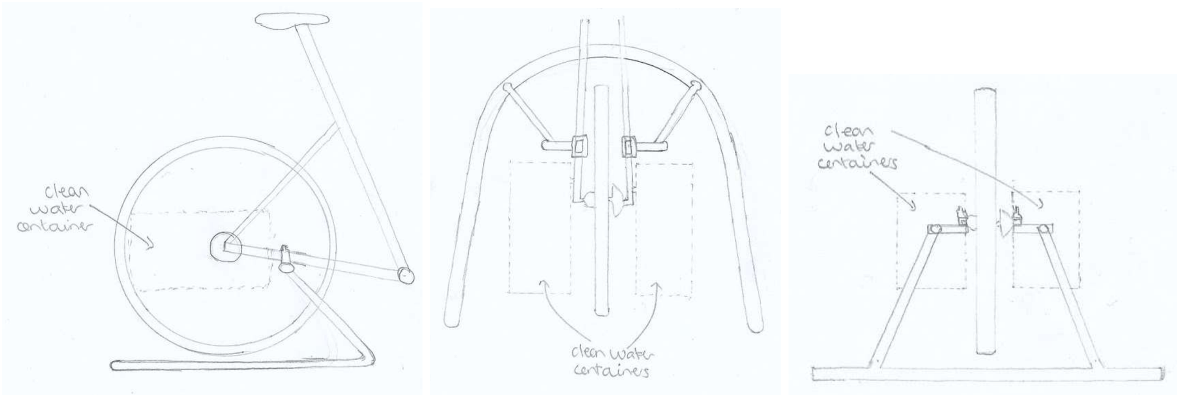


Figure 13- Design 7

7.5.3 Bicycle Stand Sketches



(a) (b) (c)

Figure 14- Bike stand design; (a)side view (b)top view (c)front view

7.6 Appendix F: Gantt chart

Figure 15 - Gantt Chart

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