1. **Bottled**

   (a) **Upfront Cost** - Considering bubble top systems, the upfront cost includes the down payment for a single 20 liter bottle and the cost of a single dispenser jar.

Item	Price
down payment for bottle	₹130
dispenser jar	₹150
total	₹280

   (b) **Recurring Cost** - Almost all 20 liter containers are sold for ₹60. While, smaller volumes are sold at a variety of prices, they're typically around 20 ₹/liter.

$$\frac{₹60}{20 \text{ liter}} = 3 \text{ ₹/liter}$$

   (c) **Flow Rate** - Once prepacked water is purchased, it can be consumed immediately. Therefore the flow rate is instant.

2. **Reverse Osmosis**

   (a) **Upfront Cost** - According to Kent's product website, the price of a new, typical RO system (Kent Sterling^{TM}) is about ₹18,500.

   (b) **Recurring Cost** - Once installed, the primary recurring cost of an RO system is the price of replacing consumable media. This assumes the price of the water itself and electricity used is negligible. According to a typical user manual, the following items should be replaced once a year. All prices for spare Kent^{TM} parts refer to a merchant's website.

Kent Spare Part Number	Item	Price
20002	RO membrane	₹2,500
20004	ultra filter membrane	₹1,000
20009	activated carbon filter	₹500
20010	sediment filter	₹500
	total	₹4,500

   In order to determine the price per volume this implies, the total volume this RO machine provides to an average family in Bangalore in one year must be determined. According to a 2012 article in *The Hindustan Times*, a single person consumes about 2 liters per day. Also according to ArcGIS, a typical family in Bangalore has about 5 members.

$$\left(\frac{₹4,500}{\text{year}}\right)\left(\frac{1 \text{ year}}{365 \text{ days}}\right)\left(\frac{(1 \text{ person})(1 \text{ day})}{2 \text{ liters}}\right)\left(\frac{1 \text{ family}}{5 \text{ people}}\right) = 1.23 \text{ ₹/liter}$$

   (c) **Flow Rate** - According to the product website, the system can purify 15 liters per hour.

$$\left(\frac{15 \text{ liters}}{\text{hour}}\right)\left(\frac{1 \text{ hour}}{60 \text{ minutes}}\right) = 0.25 \text{ liters/minute}$$

3. **Ultraviolet Irradiation**

   (a) **Upfront Cost** - According to Kent's product website, the price of a new, typical UV system (Kent Maxx^{TM}) is about ₹9,500.

   (b) **Recurring Cost** - Once installed, the recurring cost of a UV system is the price of any consumable media. According to a typical user manual, the following items should be replaced once a year.

Kent Spare Part Number	Item	Price
20003	hollow fibre ultra filter	₹600
20009	activated carbon filter	₹500
20010	sediment filter	₹500
20025	ultraviolet lamp	₹470
	total	₹2,070

   The amount of volume this system provides to a single family in a year is calculated similarly the corresponding RO value.

$$\left(\frac{₹2,070}{\text{year}}\right)\left(\frac{1 \text{ year}}{365 \text{ days}}\right)\left(\frac{(1 \text{ person})(1 \text{ day})}{2 \text{ liters}}\right)\left(\frac{1 \text{ family}}{5 \text{ people}}\right) = 0.57 \, ₹/_{\text{liter}}$$

   (c) **Flow Rate** - According to the product website, the system can purify 1 liter per minute.

4. **Gravity Filters**

   (a) **Upfront Cost** - According to Kent's product website, the price of a new, typical gravity filtration system (Kent Gold^{TM}) is about ₹2,900.

   (b) **Recurring Cost** - The recurring cost of a gravity filter is the price of consumable media. According to a typical user manual, the following items should be replaced according to their respective lifespans.

Item	Unit Price	Lifespan	Price Per Year
sediment filter	₹100	3 months	₹400
activated carbon filter	₹100	6 months	₹200
hollow fibre ultra filter	₹400	12 months	₹400
		total	₹1,000

   The amount of volume this system provides to a single family in a year is calculated similarly the corresponding RO value.

$$\left(\frac{₹1,000}{\text{year}}\right)\left(\frac{1 \text{ year}}{365 \text{ days}}\right)\left(\frac{(1 \text{ person})(1 \text{ day})}{2 \text{ liters}}\right)\left(\frac{1 \text{ family}}{5 \text{ people}}\right) = 0.27 \, ₹/_{\text{liter}}$$

   (c) **Flow Rate** - According to the product website, the system can purify 120 liters per day.

$$\left(\frac{120 \text{ liters}}{\text{day}}\right)\left(\frac{1 \text{ day}}{24 \text{ hours}}\right)\left(\frac{1 \text{ hour}}{60 \text{ minutes}}\right) = 0.08 \, {}^{\text{liters}}/_{\text{minute}}$$

5. **Boiling**

(a) **Upfront Cost** - The upfront cost of treatment by boiling includes the cost of a pot and stove. If it is assumed that a family already has these items for other uses, the upfront cost is essentially zero. However, this cost is quantified for comparison.

Item	**Price**
kerosene stove	₹400
10 liter pot	₹300
total	₹700

(b) **Recurring Cost** - The recurring cost for boiling is the cost of the fuel used for heat. For simplicity, this source is assumed to be kerosene. According to an MSR article, about 1.6 liters of water can be boiled with 1 liquid ounce of kerosene. Also, according to a *Times of India* article, low income residents can expect to pay about ₹15 per liter of kerosene after any subsidies.

$$\left(\frac{₹15}{\text{liter of kerosene}}\right)\left(\frac{1 \text{ liter of kerosene}}{33.814 \text{ ounces of kerosene}}\right)\left(\frac{1 \text{ ounce of kerosene}}{1.6 \text{ liter of water}}\right) = 0.28\ {}^{₹}/_{\text{liter}}$$

(c) **Flow Rate** - According to an online article, the EPA recommends bringing water to a boil and keeping it at that temperature for at least one minute in order to kill all biological pathogens. To facilitate estimation, it is assumed that the one minute is negligible compared to the time required to bring the water from room temperature to a boil. This assumption lends to a generous estimate of the boiling method's flow rate given that the times of rolling boil and cooling are ignored.

i. Setup

$$\begin{aligned}
\text{total heat is product of heat absorption rate and time:} \quad & Q = \dot{Q}t \\
\text{total heat needed to change water's temperature:} \quad & mc\Delta T = \dot{Q}t \\
\text{temperature difference is between room and boiling:} \quad & mc\,(T_b - T_r) = \dot{Q}t \\
\text{water's mass is product of its density and volume:} \quad & (\rho V)c\,(T_b - T_r) = \dot{Q}t \\
\text{isolating rate of volume per time:} \quad & \text{flow rate} = \frac{V}{t} = \frac{\dot{Q}}{\rho c\,(T_b - T_r)}
\end{aligned}$$

Where

- Q is the total heat required to complete the treatment;
- $\dot{Q}$ is the rate of heat absorbed per time by the water from a kerosene stove;
- t is the time required to complete the treatment;
- m is the mass of the water treated;
- c is the specific heat capacity of the water treated;
- ΔT is the change of the water's temperature;
- T_b is the water's final temperature as it begins to boil;

- T_r is the water initial temperature, room temperature;
- ρ is the density of the water being treated;
- V is the volume of water being treated;
- F_{boil} is the rate of volume of water boiled per time on a typical kerosene stove.

ii. Data

Property	Quantity	Source	Conversion
ρ	$\frac{1\ g}{cm^3}$	USGS article	$\frac{1000\ g}{L}$
c	$\frac{4.184\ J}{(g)(°C)}$	USGS article	-
T_{boil}	$100°C$	Engineering Toolbox	-
T_{room}	$21°C$	BBC article	-
$\dot{Q}$	$\frac{950\ kCal}{hr}$	Classic Enterprise Industries	$\frac{66246.7\ J}{min}$

iii. Calculation

$$\text{flow rate} = \frac{\left(\frac{66246.7\ J}{1\ min}\right)}{\left(\frac{1000\ g}{1\ L}\right)\left(\frac{4.184\ J}{(g)\,(°C)}\right)(100°C - 21°C)} = 0.20\ {}^{\text{liters}}/_{\text{minute}}$$

6. Water ATMs

(a) **Upfront Cost** - Besides the price of acquiring a loadable card for routine use, Water ATMs offer no upfront cost to the end beneficiary.

(b) **Recurring Cost** - After several field interviews, a typical water ATMs price can fall anywhere between ₹5 and ₹10 per 20 liters dispensed. That is, the recurring cost is about ₹0.5 per liter.

(c) **Flow Rate** - Customers can drink water from one of these installations as soon as its dispensed. That is, the flow rate is instant.