Deriving a Method to Calculate My Household Carbon Footprint based on Water Consumption

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Personal Engineering Project (Part 2)

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Topic: Household Carbon Footprint Audit

Research Questions:

1. How and why should we try to reduce our carbon footprints?
2. What are the sources of carbon emissions generated at my house solely based on water consumption?

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1 Introduction

1.1: Background

71% of the world is covered by water. 96% of this is saltwater which is not usable while less than 1% of it is available for human consumption[1] out of the 3.5% fresh water supply. Clearly, water is a very precious commodity essential for human survival but unfortunately it is being wasted and contaminated every day. Case in point, "4.9 million people in Bangladesh still do not have clean water close to home" while "one in two people in urban areas use contaminated water[2]". The technology involved in sanitizing water through extraction and purification is quite expensive. As a result, minimizing water wastage is essential for the growth of the economy.

1.2: Rationale

I am conducting an investigation of my personal and household water consumption to assess the extent to which I contribute to water consumption relative to different categories of people within my country. The following investigation is intended to inspire youth to conduct similar explorative assessments of their own to further their knowledge regarding water consumption. By doing so, the next generation of decision makers will be equipped with the necessary knowledge to preserve our most essential resources and thus create a more sustainable world. Not to mention, by having the necessary knowledge to predict their water bill, youth can actively intervene within the home to reduce unnecessary water consumption and minimize expenditure for their parents.

1.3: Methodology

1. Conduct literature review of the current water consumption rates within Bangladesh in relation to high income vs low income demographics.
2. Estimate average water consumption, averaged over three consecutive months of data to reduce random errors.
3. Conduct a field survey of the water pumps within my home to derive relevant quantitative estimations using a water pump chart and map out each pump in diagram format.

[1] : "Water Facts - Worldwide Water Supply | ARWEC| CCAO | Area Offices." 11 Apr. 2020, https://www.usbr.gov/mp/arwec/water-facts-ww-water-sup.html. Accessed 9 September 2021.
[2] "Bangladesh - Facts and Statistics - WaterAid." https://www.wateraid.org/bd/bangladesh-facts-and-statistics. Accessed 9 September 2021.

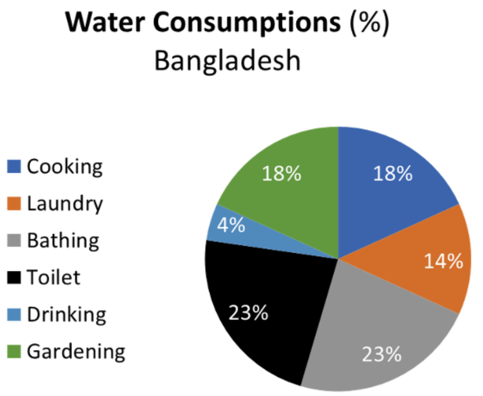
2. Discussion of Results

2.1: Analysing Water Bill and Estimating Household Contributions using Secondary Data

Table 2.1 is a summary of the average water consumption at my house. The price of water in Bangladesh is given by a unit rate of BDT/m^3. For reference, 1 Litre=1m^3.

Table 2.1: Household Water Consumption Bill Data

Months	Water Bill BDT (w/o surcharge)	Water Consumption (L)	Water Consumption (m^3)	Estimated Unit Rate (BDT/m^3)
March	5887.00	360000.00	360.00	16.35
April	4307.00	258000.00	258.00	16.69
May	5704.00	343000.00	343.00	16.63
Average Monthly Water Consumption (L)	320333.33			
Average Monthly Water Consumption (m^3)	320.33			
Average Bill (BDT)	5299.33			
Average Unit Rate (BDT/m^3)	16.56			



Per Capita Water Consumptions (Liter/capita/day) Bangladesh

Type of Consumption	Amount Liter/capita/day
Cooking	20
Laundry	15
Bathing	25
Toilet	50
Drinking	5
Gardening	20
Total	**135**

Waste Concern: 2018

Figure 2.1: Water Consumption Composition by Waste Concern at BRAC Learning Center, Savar Campus

As demonstrated in Table 2.1, my household consumes 320333.33 L of water per month. This amount is distributed among 18 occupants. Therefore, our daily overall water consumption per capita is about

$$\frac{320333.33L/month}{30\ days \times 18\ occupants} = 593.21L/day/occupant$$

Although this is over four times greater water consumption than the average litres of water consumed by a Bangladeshi per day, the same percentage breakdown demonstrated above can be applied for my household:

Table 2.2: Composition of Water Consumption at my Household

Type of Consumption	Fraction of Composition	Amount (L/day/person)
Cooking	0.18	106.78
Laundry	0.14	83.05
Bathing	0.23	136.44
Toilet	0.23	136.44
Drinking	0.04	23.73

Gardening	0.18	106.78
Total	**1.00**	**593.21**

I believe that the reason our average consumption is much greater than the national average is due to income. Our household falls within the higher-income category, which is why we are able to afford a significantly higher water consumption bill than the average citizen of Bangladesh. Nonetheless, the Table 2.1 seems believable since the Dhaka Water Supply and Sewerage Authority (WASA) estimates the average daily water demand to be 150 L/capita while households in formal settlements consume 310 L/capita. Furthermore, the BRAC Institute of Governance and Development (BIGD) uncovered that slum use 85 L/capita, while wealthier areas in Dhaka such as Gulshan and Banani have the highest consumption rate of 509 L/capita. Although slightly less than my household consumption of 593.21 L/capita, my estimation appears to be more or less consistent with their study[3].

2.2 Estimating my Contribution to the Monthly Water Using Water Bill

In an attempt to verify the average water consumption per capita, I conducted an investigation to calculate my personal average water consumption per day. The "Rate" column shows the flow rate of water in litres/min for showers, water taps, and the facet for washing dishes. But for toilet water, it shows the litres of water consumed per flush and for laundry, alongside showing the number of litres per load. The limitation of this data is that I did not incorporate the approximate water consumed through cooking as it is a tough estimate based on my discussion with our kitchen staff.

Table 2.3: Estimating Water Bill

Activity	Rate	Time (minutes)	Frequency (times/day)	Litres of Water Used/day	m^3 of Water Used/day	m^3 of Water Used/month	Estimated Water Bill (BDT)
Showers	9.5	5	2	95	0.095	2.85	47.196
Toilet Water	6	0.25	6	36	0.036	1.08	17.8848
Water Taps	7.5	0.33	10	24.75	0.02475	0.7425	12.2958
Washing Dishes	11.4	5	3	171	0.171	5.13	84.9528
Laundry Water	50	60	1	50	0.05	1.5	24.84
Gardening Hose Water	64	20	1	64	0.064	1.92	31.7952
Drinking	1	1	1	4	0.004	0.12	1.9872
Total				**444.75**	**0.44475**		**220.9518**

As shown in Table 2.3, my daily water consumption estimate is 444.75 litres without consideration of the amount of water that goes into cooking as that was difficult to estimate. Although off by about 25% than the average per capita consumption of 593.21L/day, this shows that my method of calculation has a reasonable degree of accuracy. Furthermore, with a projected bill of 220.95 BDT, I contribute to only 4% of my household's average water consumption bill. Since there are 18 occupants in the house, I would be expected to consume 5.55% of the bill on average so the fact that I consume 4% demonstrates that I am relatively more environmentally conscious than the rest of my household.

[3] "Understanding Dhaka's water crisis: What can we do sustain our ...." 24 Oct. 2019, https://www.dhakatribune.com/bangladesh/development/2019/10/24/understanding-dhaka-s-water-crisis-what-can-we-do-sustain-our-water-usage. Accessed 29 Oct. 2021.

Link to calculator:
https://7.ly/aarDk

2.3 Deriving a Way to Estimate Electricity Consumption from Water Pumped Using Primary Data

While measuring my daily water consumption, I realized that water on its own does not carry an emission factor such as electricity, gas, organic waste, etc. Therefore, I understood that my investigation would need to be a little more comprehensive. Since I had already found my daily electricity consumption, I thought why not explore a way to quantify the amount of water being pumped every day in terms of electrical units and then convert it to my CO_2 equivalent emission in tons as I did before? Well, that is exactly what I ended up doing. I started by conducting a baseline survey of the centrifugal pumps situated in my house and then using a **pump performance chart** published by Dr. Stephen Grimmer (Ph.D., MSc, BSc in Geology from Imperial College London)[4] to determine the number of litres pumped by the average pump per minute based on the vertical displacement that it has to pump the water.

Then, based on a household survey I conducted, I found that there is one 1 horsepower pump that is connected to the main water supply line of the Dhaka Water and Sanitation Authority (DWASA). This 1 horsepower pump is connected to an underground water reservoir that stores water and supplies it when needed (i.e., if there is less water in the overhead tank). This underground water reservoir is connected to a 2-horsepower pump that is situated inside a little house-shaped enclosure. Then, this pump pumps water from the underground reservoir 6 floors (i.e., 60ft) high to the overhead water tank at the roof of my building. This overhead water tank supplies water throughout the house and is re-filled through the 2 HP pump at ground level when more water is needed. The water supplied from the overhead tank does not require any pumps to supply and simply flows to the floors below it with help of gravity.

[4] "How many litres of water can 1 HP pump to the second floor building?." https://www.quora.com/How-many-litres-of-water-can-1-HP-pump-to-the-second-floor-building. Accessed 29 Oct. 2021.

Here is a detailed diagram of the entire water pumping system in my house from a top-view:

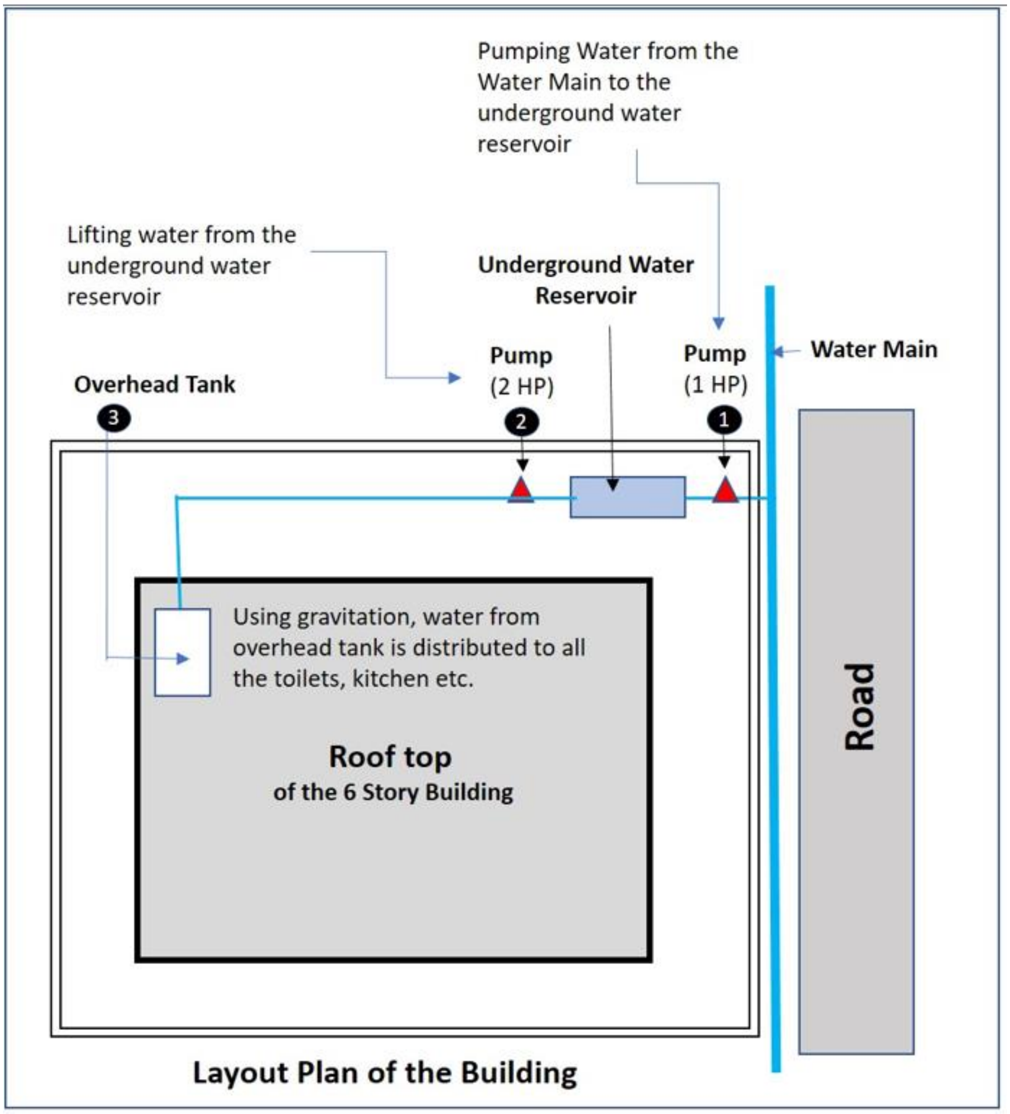


Figure 2.2: Water Pump Network (Aerial View)

Here is a detailed diagram of the entire water pumping system in my house from a side-view:

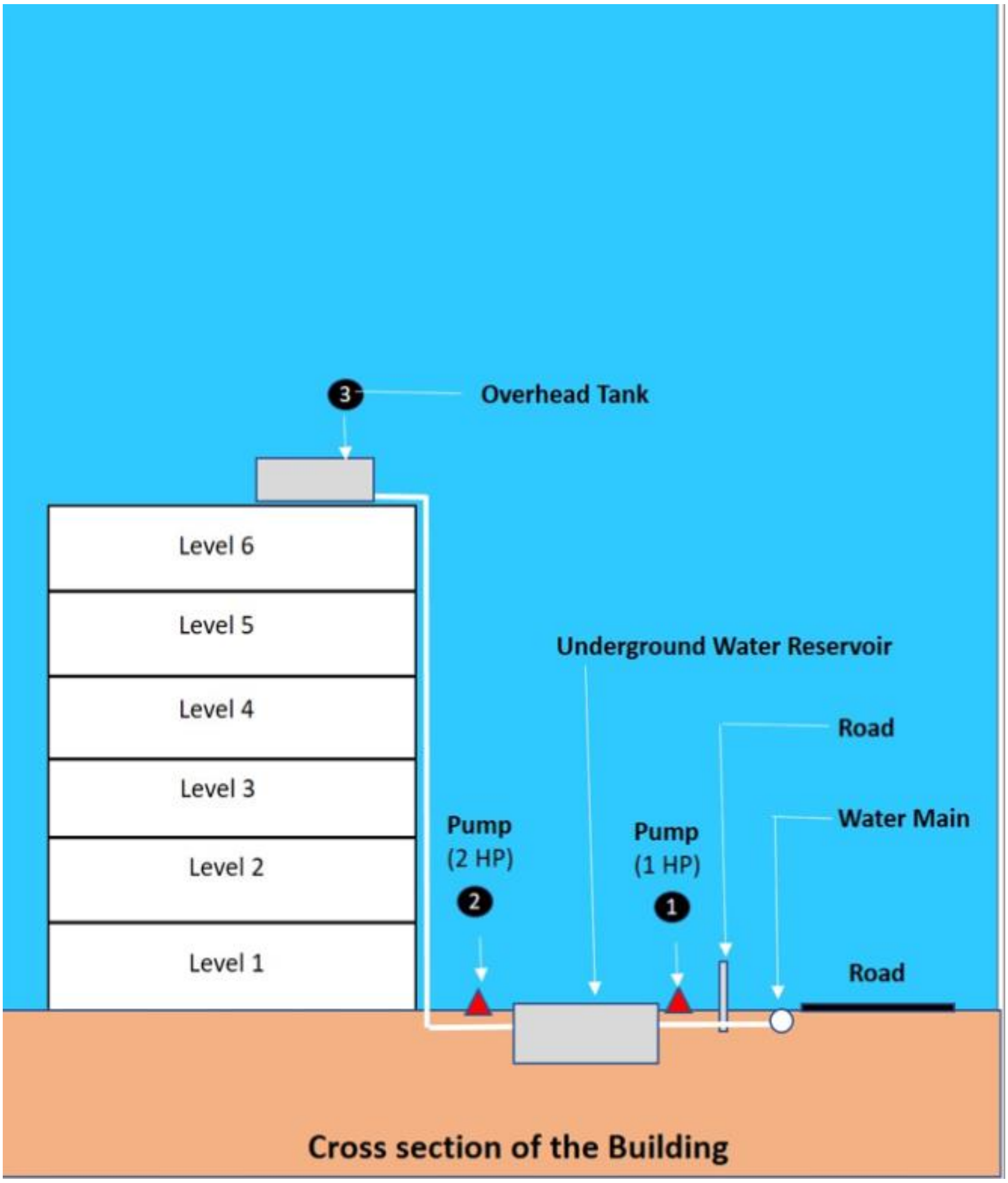


Figure 2.3: Water Pump Network (Lateral View)

Here are how these pumps look in reality at my house:

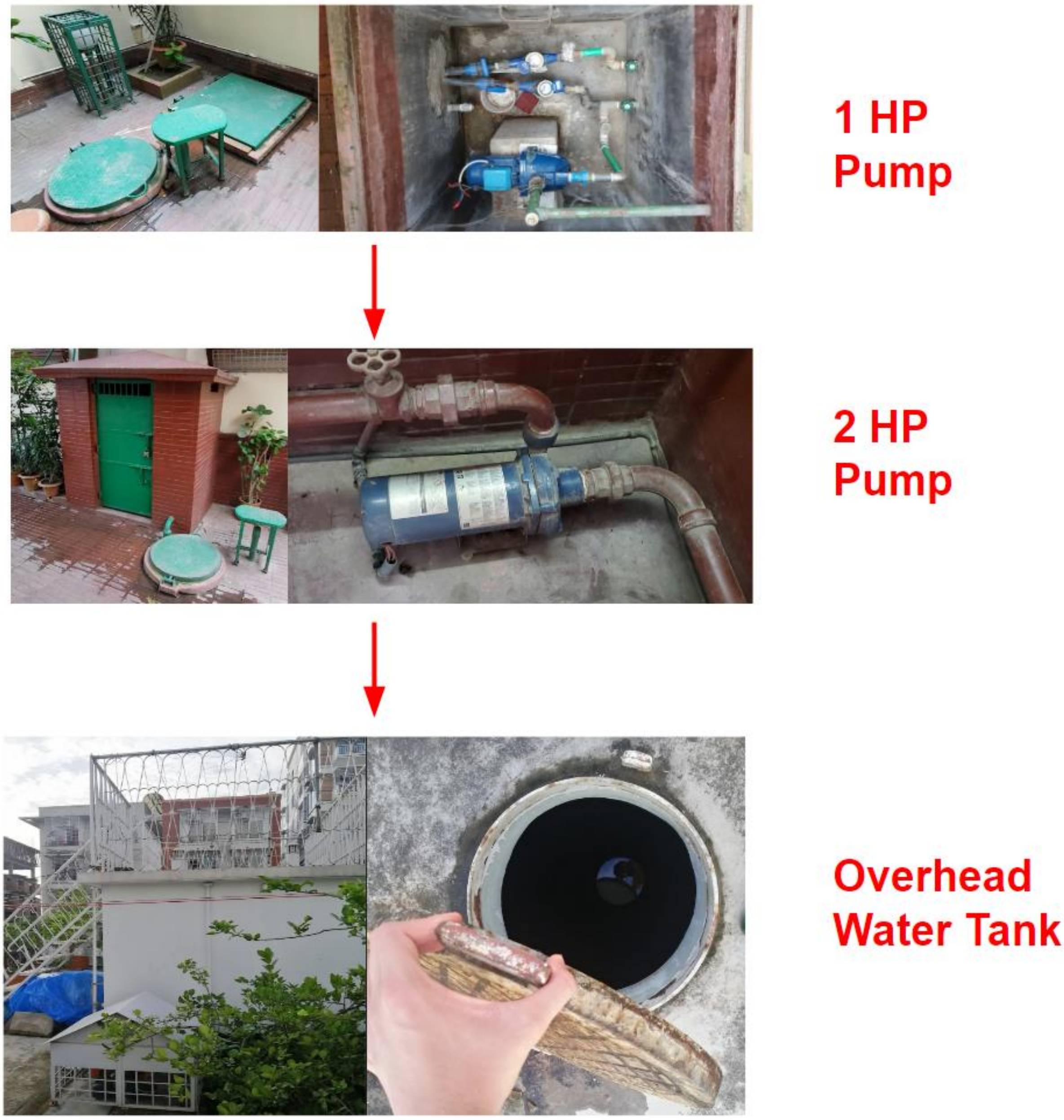
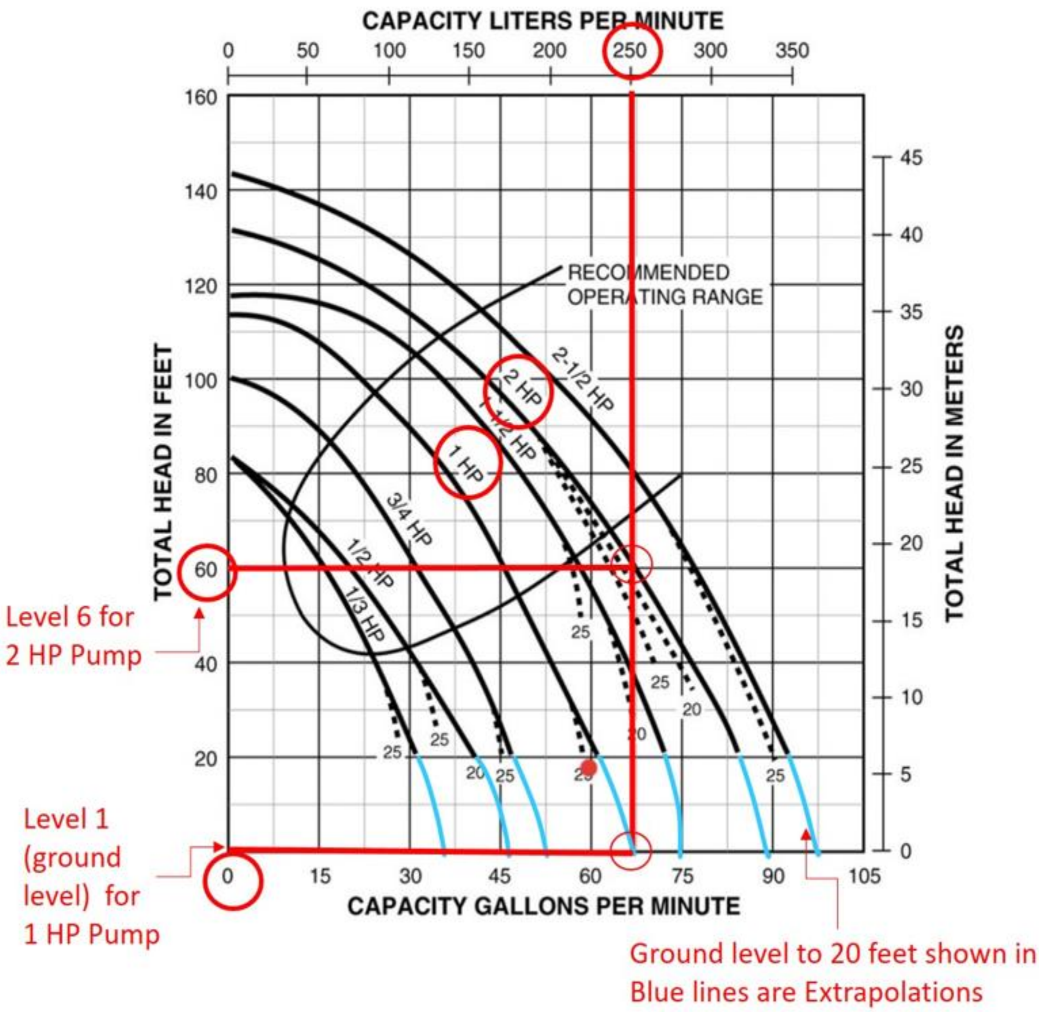


Figure 2.4: Photo showing how water pumps of different capacity sizes are utilized to pump water from the main line to the overhead water tank of house surveyed

Now, with the understanding that the rotational mechanical energy delivered by the shaft of the motor of the pump is equal to 746W (assuming an 80% efficiency and deducting energy loss through friction), as well as the fact that **1 HP hour is equivalent to 746 Watt-hour** (which a foundational concept of electrical and mechanical engineering), I found the daily runtime of the water that is being pumped at my house. This allowed me to employ the unitary method and solve for the daily kWh consumed by each occupant in my house per day and per month.

This is the chart I used to determine the rate at which water is pumped in my house:



- 1 HP Pump supplies 250 Liter/Minutes (ground level to ground level)
- 2 HP Pump lifts 250 Liter/Minutes (ground level to 60 feet level)

Figure 2.5: Centrifugal Pump Performance Chart

By extrapolating for the points on each curve, I was able to estimate the values at which each line would meet the x-axis. The x-axis for the basis of this chart represents 0 feet or ground level. Moreover, assuming a height of 10 ft per floor, it can be assumed that the height of my 6-story house is 60ft (including the roof and staircase leading up to the pipe).

That said, the following calculations can be used to determine the electrical wattage consumed by the water pumps at my house based on retention time:

As demonstrated by Table 2.1, the average monthly water consumption at my house is 320,333.33 L total. The unit rate for water in Bangladesh based on my calculations is approximately 16.56 BDT/m^3

$$Hence, 320{,}333.33\ L\ or\ 320.33m^3$$

with unit rate of 16.56 BDT/m^3
is 5305.33 BDT cost for the average monthly bill.
And $320{,}333.33\ L$/month consumption is the same as:
$320.33m^3/30\ days = 10.67m^3/day$.
Therefore, about $10.67m^3$ water is pumped per day for use within my house.

As demonstrated by my annotation of the chart in Table 2.4, both the 1 HP and 2 HP pump curves at their respective heights yield the same exact number of litres pumped of 250L/min. This means that the number of litters/min a 2 HP pump can pump 6 floors up is the same as a 1 HP pump can pump at ground level.

As mentioned above, **1 HP hour is equivalent to about 746W**. Hence the following can be deduced:

Table 2.4: Conversion from HP hour to W

1 HP Pump	2 HP Pump
10, 670 L pumped/day at a rate of 250 L/min takes 42.68 minutes. A 1 HP pump consumes 746W. Hence: $\frac{746W}{x} = \frac{60\ mins}{42.58\ mins}$ where x=530.65W	10, 670 L pumped/day at a rate of 250 L/min takes 42.68 minutes. A 2 HP pump consumes 1492W. Hence: $\frac{1492W}{x} = \frac{60\ mins}{42.58\ mins}$ where x=1061.31W

Based on the calculations above, a sum total of 1591.96W or 1.59kW of electrical energy is consumed every day in my household. Rounding up 42.58 minutes to 60 minutes or 1 hour retention time per pump, the following calculations can be done:

$$1.59kW \times 2\ hours = 3.18kWh\ consumed\ per\ day$$

Then accounting for 18 occupants in the house, the following calculation can be done to estimate the monthly electricity consumption from water pumping:

$$\frac{3.18kWh}{18\ occupants} = 0.176kWh/person/day\ \times 30\ days\ = 5.28kWh/person/month$$

Despite pumping the same volume of water on average (i.e., 10.67m^3) water, the 1 HP pump is less powerful and takes longer on average to pump water than the 2 HP pump. Although the 1 HP pump is half as powerful, the 2 HP pump has to lift water 6 stories high (i.e., 60ft), which should take more time overall. But as evidenced by the diagram above, the 1 HP pump does not lift water but only pumps along the same ground level height. Coincidentally enough, this yields the same pump time of 42.68 minutes.

In any case, using the emissions factor of 0.644 kgCO_2e/kWh for electricity:
$5.28kWh/person/month \times 0.644\ kgCO_2e/kWh = 3.4kg\ or\ 0.0034 metric\ tons\ of\ CO_2\ emissions$ is released. **This means that water consumption accounts for less than 1% of all emissions produced on the basis of electricity.**

3. Extending the Line of Inquiry

With intent to further extract value from the aims of this investigation, one should measure their waste consumption rate and track their gas bills to evaluate their emissions factor generated from these other sources which contribute to pollution. For further information on the emissions factors for the primary sources of CO_2e emissions, please check Table 1.1 of Part 1 of this report.