How to Harvest Water from the air? The evidence from Bolivia

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Research Article

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Abstract

The objective of this paper is to analyze how to harvest water from the air in Bolivia. In order to collect water from the air by means of condensation two fog collectors were built in Kañuma, located in La Paz, the capital of Bolivia. Environmental conditions, such as wind direction and velocity, temperature, humidity, barometric pressure, were calculated using a Davis Vantage Pro2 weather station. The formal Quasi-Experimental Research was implemented, determining the cause-effect relation of quantity of water collected and environmental conditions in the lapse of 21 days. Daily controls were performed, analyzing the volume of harvested water regarding evapotranspiration and the psychrometric constant. Our results show that it has been possible to harvest almost 89 ml/day/m^2 in both models, in just 21 days of experimentation. In addition, we want to shed light on sustainable development and public policy implementation on water collection alternatives, especially for high and mountainous areas, where we can locate some of the poorest communities in Bolivia.

1. Introduction

How to collect or harvest water from the air?. Fog collection is achieved by the collision of suspended droplets on a vertical mesh, where they coalesce, after which the water runs down into a collecting drain and a tank or distribution system (Abdul-Wahab 2008).

Fog Collectors were successfully built in south America, for example in Chile, the Project “El tofo” which lasted twelve years and helped to develop the community with their tourism and their crops (Schemenauer 1992), the same happened in the project “Coquimbo”, the use of the water was strictly for human consumption and irrigation; regarding the location of the fog, they denominate it as “Orographic Fog” (Cereceda 2014), because it was located beyond the mountains highest point.

In Peru, the project was located on “Lachay-Lima”, a place where there was not a lack of water problem and the rain rate was really high. In that matter, they have studied the effect of rain rate in the final volume of collected water; and it just affect the 10% of the final volume collected, because there was not dependence between rain rate and the final harvested volume of water (Pinche-Ruiz 1996), this also happened in our project, because we were able to collect water even if there was not a precipitation. The effect of the Psycrometric constant was higher on the days that rained, this indicates that less energy is deployed in the air, so the quantity of water steam will decrease (Urquidi 2022).

And in Puerto Rico located in “The Luquillo”, this project also had only 5 years of duration and it helped to develop the crop quality (Schellekens 1998). Socio-political instability also interferes with the implementation of fog water collection systems, which can prevent external investments and discourages volunteer work (Haiti-Salagnac 2011; FogQuest 2005).

At the beginning of the investigation, we have researched about the existance of a Fog Colector Project located in Bolivia, and there were no results, so that was also another motivation to carry on with this project. Impacts of social change and economic growth on consumption preferences and lifestyles; and, changing climate and rainfall patterns (Falkenmark 1989; White 2014), makes a statement on the importance to develop water collection alternatives.

Gathering atmospheric moisture is far from a new idea: evidence shows that the original inhabits of the Canary Island dug holes under trees with large foliage to collect fog water condensing on leaves (Marzol 2005).

Our results show that among two collectors installed in an area that has not the ideal atmospheric and environmental parameters, it is possible to obtain still some water from the air, that will also have great quality, so it could have many uses, from drinking water to irrigation for crops. It is important to stablish that, to use the collected water for human consumption, some procedures might be needed, such as centrifugation and neutralization of the pH.

Studies have demonstrated that fog collection technology works effectively at a local level when a high sense of ownership has been created by community involvement and sensitization (Fessehaye 2014).

In our research, we will use simple Fog Collectors (two dimensional), located in two different areas and take advantage of humid air that will go through the collector's mesh by means of condensation, that will be directly determined by the Psychrometric constant. In Adition, the present investigation, will be developed based on the needs of economic and efficient alternatives to obtain water, so, they can be applied in indigenous communities of the Bolivian Plateu.

2. Fog Collectors Design

Two different Fog Collectors were designed in our research. Tower "Alfa" (Fig. 1) is 4 meters length by 1,80 meters width, the mesh is located 1 meter above the soil, and tower "Beta" (Fig. 2) that is 1 meter length by 1 meter width, the mesh is also located 1 meter above the surface. Both towers were built in two areas of different environmental conditions. The chosen area is called Kañuma-Achocalla in the city of La Paz Bolivia. The atmospheric conditions in the two areas will be: Atmospheric pressure, Percentage of natural Humidity, Rain rate, Temperature, Wind velocity, Quantity of water collected.
With different dimensions of fog water harvesting research and practice, extensive reviews are available on the history, characteristics, and technical features of fog collection (Maliva 2012; Perez-Diaz 2017; Domen 2014). The world's largest fog water collection and distribution system is in Southwest Morocco, in the Anti-Atlas Mountains near Sidi Ifni. Local non-profit organization Dar Si Hmad operates the system, which has involved a decade's worth of meteorological observation and partnerships with a variety of overseas researchers and engineers (Trautwein 2016; Dar Si Hmad 2016).

It is well known, that the fog collectors are very effective in mountain zones where the concentration of the fog is really heavy, thus, we are interested in finding out, what happens if we build the towers in a sector where the atmospheric and environmental conditions are not the optimal ones. However, Kañuma, has an important thermal gradient, given that it is located between El Alto city (4150 meters above sea level) and La Paz city (3625 meters above sea level). Exactly, Kañuma is located at 3600 meters above sea level, and we could appreciate an interesting percentage of Fog as we can see in Fig. 3. Environmental and atmospheric parameters were obtained in the two zones were Tower Alfa and Beta are being operated, with a Davis Vantage Pro2 weather station. The materials and tools needed to build the towers, were provided by a funding of an agreement that Bolivian Private University and the University of Illinois gave. Both institutions were interested in finding out what the results might been. We decided to quantify the final volume of water obtained in the two towers in a lapse of 21 days. This results were registered in a field notepad, that also contains environmental and atmospheric parameters, that helped us to analyze how does the harvest works or develops. We also performed a few tests of water quality, pH, Iron content, hardness and Chloride content. Which resulted better than was expected, resulting in a lightly acid water that could be easily threated, low chloride and iron content, and no hardness at all.

3. Materials And Methods

Atmospheric and environmental parameters such as wind velocity, natural humidity, barometric pressure and temperature in the two areas, were measured with the Vantage Pro2 weather station in different stages during the 21 days of the experiment between the months of March and April, as this period represents, the dry season in the selected area. Because both fog catchers use the same design, materials (raschel mesh and principal poles), there was not a relevant difference of altitude, and the results obtained of evapotranspiration and the psychrometric constant were almost the same, it is demonstrated a high correlation between Fog Collectors (Schemenauer 2008).

To quantify the collected water, daily inspections were performed and the harvested water that was drained into the collection system (Figs. 4 and 5) was measured with the help of test tubes. To calculate evapotranspiration which is a key parameter in the hydrological balance, we have used the Hargreaves method (2003), to dismiss the possibility that the precipitation could affect the final volume of water obtained, just as in the project of “El Tofo” in Chile (Cereceda-Schemenauer 1995), where the monthly fog variation was inversely proportional to the rain rate, precipitation could only contribute an 8% of the final harvested volume (Burger 2018), also a value of evapotranspiration between 3 and 4 shows us that the rain rate will be captured by the vegetation (Sanchez San Roman 2019). We have obtained in all the days of experimentation an average value of 3 mm/day of evapotranspiration.

For the psychrometric constant that is going to be the factor that will let us know how many energy is being scattered into the towers area, so we have an idea of how evaporation is developing, we have used Samani’s method, also using the table of solar radiation created by Allen et al (2003).

All the data obtained was homogenized, to analyze the relationship between the water obtained, parameters calculated and atmospheric variables.

All this results were daily registered in a field note pad for both towers alfa and beta, that contained a photograph of the tower’s collection system, and another of the measurement of the collected water in a test tube. It also contains the date, atmospheric pressure, temperature, percentage of natural humidity, rain rate and wind velocity. With all the data mentioned before, we also performed a two-dimensional statistical analysis between barometric pressure and relative humidity, that in all cases had showed a direct dependence. We also have divided the day in two stages, the first between 7 am to 5 pm, and the second from 7 pm to 5 am, to calculate the standard deviation and average values, so we can also calculate a confidence interval for both parameters Barometric pressure and relative humidity, this is how, all results were validated.

4. Results And Discussion

All the atmospheric and environmental data were obtained, to estimate the evapotranspiration and psychrometric constant in the study area, so afterwards, we could analyze all the date and relate or not, these parameters to the volume of water obtained. We will present a summary of all the obtained data in Tables 1 and 2 for tower Alfa and Beta respectively, also in Figs. 6 and 7 we could observe the evolution of water obtained in both towers.

Table 1

Summary of parameters Alfa 2022

Date	Harvest (ml)	ml/day/m2	Rain Rate mm	Psychrometric K (hPa/°c)	Wind Velocity (m/s)
21/03/2022	0	0,00	2,5	77,13	1
22/03/2022	160	33,33	2,5	79,59	0,9
23/03/2022	150	31,25	0	76,06	0,4
24/03/2022	0	0,00	0	76,06	0,3
25/03/2022	210	43,75	0,9	86,56	0,6
26/03/2022	0	0,00	0	85,18	0,2
27/03/2022	0	0,00	0	84,73	0,3
28/03/2022	700	145,83	0,4	81,39	0,7
29/03/2022	0	0,00	0	71,26	0,6
30/03/2022	0	0,00	0	71,47	0,6
31/03/2022	180	37,50	0	72,09	1
01/04/2022	0	0,00	0	72,63	1,8
02/04/2022	0	0,00	1,78	92,53	1,3
03/04/2022	0	0,00	0,25	93,04	2,2
04/04/2022	1210	252,08	1,2	77,25	2,2
05/04/2022	0	0,00	0	60,27	0,3
06/04/2022	105	21,88	0	66,38	0,4
07/04/2022	0	0,00	0	79,88	0,4
08/04/2022	135	28,13	0	87,31	0,4
09/04/2022	0	0,00	0,65	97,38	0,9
10/04/2022	415	86,46	0	85,89	1,3
Total	**3265**				

Table 2

Summary of parameters Beta Tower (own elaboration 2022)

Date	Harvest (ml)	ml/day/m2	Rain Rate mm	Psychrometric K (hPa/°c)	Wind Velocity (m/s)
21/03/2022	0	0,00	3,1	80,52	1,8
22/03/2022	0	0,00	3,1	83,13	1,3
23/03/2022	0	0,00	0	79,32	0,5
24/03/2022	0	0,00	0	79,3	0,9
25/03/2022	70	70,00	1,3	86,04	0,6
26/03/2022	0	0,00	0	89,84	0,4
27/03/2022	0	0,00	0	88,9	0,6
28/03/2022	220	220,00	0,52	84,95	0,9
29/03/2022	0	0,00	0	74	0,9
30/03/2022	0	0,00	0	73,92	0,9
31/03/2022	70	70,00	0	74,85	1,1
01/04/2022	0	0,00	0	75,5	2,2
02/04/2022	0	0,00	2,54	96,97	1,8
03/04/2022	0	0,00	0,51	97,6	2,7
04/04/2022	610	610,00	1,78	80,42	2,7
05/04/2022	0	0,00	0	62,16	0,8
06/04/2022	40	40,00	0	68,65	0,9
07/04/2022	0	0,00	0	83,26	0,9
08/04/2022	43	43,00	0	91,4	0,9
09/04/2022	0	0,00	1,02	102,42	0,4
10/04/2022	135	135,00	0	89,83	1,8
Total	**1188**				

With all the data collected, we found out that, from 3 am, the values of air pressure and humidity are higher during the day, and they will remain almost constant until 9 am. So, the most efficient lapse of time for harvesting was between 3 and 5 am, period in which the psychrometric constant will be at it is lowest. In fact, the days that we have registered a lower value of psychrometric constant, we listed a record in harvested water, given that, when energy is removed from the air, this gets colder, generating a thermal gradient which will benefit the dew point, so the state of water will go above the curve of saturation as an advantage, condensing most of the water steam in the air.

It is important also take in consideration to control the volume of water collected, before 6 am, for the reason that after this hour, with the temperature increasing, the natural humidity will decrease and the psychrometric constant will increase, whereas, there could result in a loss of 10 percent of the harvested water. Another key parameter is the wind velocity, being the wind, the main agent of water steam carriage through the tower's mesh, that is why, before the towers were built, it is necessary to perform tests of wind direction.

The quantity of water collected relies on the rectangular geometry of the fog collectors, given that in this rectangular collectors, the drained water wont accumulates and drop out of the recollection system and generate losses [23]. That is why, we have built a rectangular model (tower Alfa) and a square one (tower Beta). We have determined the rate of water collected in terms of milliliters/day/m^2. During the 21 days of experimentation, in the Alfa tower, we have collected 3 liters and 265 mililiters in average 32 milliliters/day/m^2, with a rain rate of 0,48 mm, average psychrometric constant 79 (hPa/c°) and an average wind velocity of 0,85 (m/s). On the other hand, for Beta tower, we have collected in total 1 liter and 188 mililiters, in average 56,67 milliliters/day/m^2, with a rain rate of 0,66 mm, average psychrometric constant 83 (hPa/c°) and an average wind velocity of 1,19 (m/s).

In contrast with bigger projects such as Atiquipa in Peru (Cereceda 2014), where the quantity of water harvested was between 3 and 15 liters/day/m^2, but, there were built towers of 48 square meters, or the case of the community Majada Blanca in Coquimbo Chile (Hernandez 2014), with 2,5 liters/day/m^2, with collectors of 153 square meters, we can consider that both towers Alfa and Beta have worked properly, given that the atmospheric and environmental conditions were not most appropriate, and the density of the fog was not very heavy.

Whereas some might believe that a rectangular model works better, I personally think that a square model can perform as good as the others. It is necessary to control the integrity of the structure of the towers, given that the wind may damage the mesh or the poles. In the 21 days of experimentation, we could identify an interesting behavior regarding the water harvesting cycle, for the reason that there was trend in the days of null water recollection, that would be between two or three days, so the next day we would harvest water in both towers. This also happened in various previous projects, such as in Coquimbo Chile (Leiva-Rivera 2014) were the null days of collection were between 1 to 15, reaching a maximum value of recollection of 14 liters/day/m^2

Regarding tower Beta, despite being the smaller one, it could harvest and important average rate of water collected, so we can say that it is really important to have advantageous climate and atmospheric values, such as, high wind velocity, high and dense fog, low psychrometric constan, high relative humidity.

Subsequently, about water quality, we have tested 3 samples of each tower (one of every week) obtaining the following results, presented in Tables 3 and 4.

Table 3
Summary of quality parameters Alfa Tower 2022

Date	Sample	pH	Iron (mg/L)	Hardness CaCO3 (mg/L)	Chloride (mg/L)
21/04/2022	1	5,97	0,02	0	20
21/04/2022	2	6,15	0,17	0	20
21/04/2022	3	6,95	0,09	0	20

Table 4
Summary of quality parameters Beta Tower (own elaboration 2022)

Date	Sample	pH	Iron (mg/L)	Hardness CaCO3 (mg/L)	Chloride (mg/L)
21/04/2022	**1**	6,25	0,08	0	20
21/04/2022	**2**	6,28	0,24	0	20
21/04/2022	**3**	3,86	0,11	0	20

All the tests were performed with the help of a photometer and a pHmeter. The color of the harvested water in the tower Beta was green, on the other hand, the water collected in the tower Alfa was more crystalline as we can see in Figs. 8 and 9.
The water color is developed from organic matter, or by the presences of some metals such as iron, that it is dissolved or in suspension. With all the results, we can assure that, if we want to use the harvested water for human consumption, given the acid pH, we have to perform first a neutralization. In all the samples, we have a low iron and chloride content, values that are accepted by the Bolivian standard law for drinking water. Also to eliminate the color or turbidity, it will be necessary to perform a water spin process. The harvested water is completely useful for irrigation; we just have to be careful with the susceptible soils to water acidity.

For human consumption, according to the analysis performed in “El Tofo” Chile (Cereceda-Schemenauer 1992), it has been determined that the parameters were acceptable regarding the water quality law (NCH 409), except for the pH, which values were far too acid. It also happened with the measurements (Amaro 2008), resulting in values of 3,3 of pH, in contrast of what the World Health Organization (WHO) demands, values of pH between 6,5 and 8,5. Finally regarding the value for hardness in all the samples were null, therefore the quality of the water harvested from the fog it is acceptable. In urban areas, smog (a mixture of smoke and fog in the air) is emerging as a significant air quality challenge, impacting respiratory systems and overall human and animal health, and threatening human lives by increasing the chance of vehicle accidents due to low visibility (Zhou 2017).

4. Conclusions

Due to the effects of climate change, a water crisis is generated worldwide. In our analysis we have investigated the performance of two fog collector on unfavorable conditions. Alfa Tower was projected to be the most successful regarding its geometry and extension, but Beta tower also performed well. In the course of the 21 days of the investigation, we have been able to collect in Alfa Tower a rate 32milliliters/day/m^2, and in Beta Tower in average 56,67 milliliters/day/m^2. The investigation shows that we can still collect a good rate of water with a small Fog Collector, if you have on favour the atmospheric and environmental conditions, such as wind velocity, percentage of natural humidity, barometric pressure, and more important lower values of Psychrometric Constant, which will determine how much water steam will be captured.

Our results show that that our collected water has great quality conditions. It is possible to harvest water from the air under special conditions. The collected water could have many uses, from drinking to irrigation for crops. However, using collected water for human consumption will require, some procedures, such as centrifugation and neutralization of the pH.

While funding organizations are needed for the initial investment and continuous monitoring of activities and financial aspects, direct user's actions and commitment can help make projects sustainable over time (Correggiari 2017). Bolivia has not developed enough research on fog exploitation, there are no existing projects of Fog Collectors around the country, that is why, it is very important to continue investigation, testing and building different models of fog collectors in Bolivia, placed in areas where the fog is dense, such as La Cumbre in La Paz City. If this way of obtaining water were all the actions are well projected and applied, it could cover the water needs of communities of up to 4000 people. A fog collector, should also generate new opportunities, improve life quality, especially among poor Bolivian communities (Czarnecki 2019).

As well, in addition to low operational and maintenance costs in providing water that meets drinking quality standards, fog water collection is an environmentally friendly intervention that does not rely on energy consumption; i.e., fog water harvesting is a green technology. Such water collection options provide ecosystem services as well (Vanham 2016).

Based on results from our analysis for future Fog Collectors they must be built in mountainous areas, where the wind velocity is high (with values around 30 (m/s)) and low psychrometric constant. However, a fog collector installed in a wooded area it is not recommended, because evapotranspiration will be high and hydrological balance could be affected, generating a lower performance of the fog.

Statements And Declarations

Ethical Approval

Not applicable, the research has not human or animal participants involved

Consent to Participate

Not applicable, the research has not human or animal participants involved

Consent to Publish

Not applicable, the research has not human or animal participants involved

Author Contributions

Ariel Urquidi Rodriguez contributed to conceptualization, data curation, formal analysis, funding acquisition, investigation, validation. The first draft of the manuscript was written by Ariel Urquidi Rodriguez and both authors commented on previous versions of the manuscript. Both authors read and approved the final manuscript.

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Competing Interests

The authors have no relevant financial or non-financial interests to disclose.

Availability of data and materials

All data generated or analysed during this study are included in this published article.

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Figures

Figure 1

“Alfa” tower 2022

Figure 2

“Beta” tower 2022

Figure 3

Fog in Kañuma Achocalla 2022

Figure 4

Water Collection system 2022

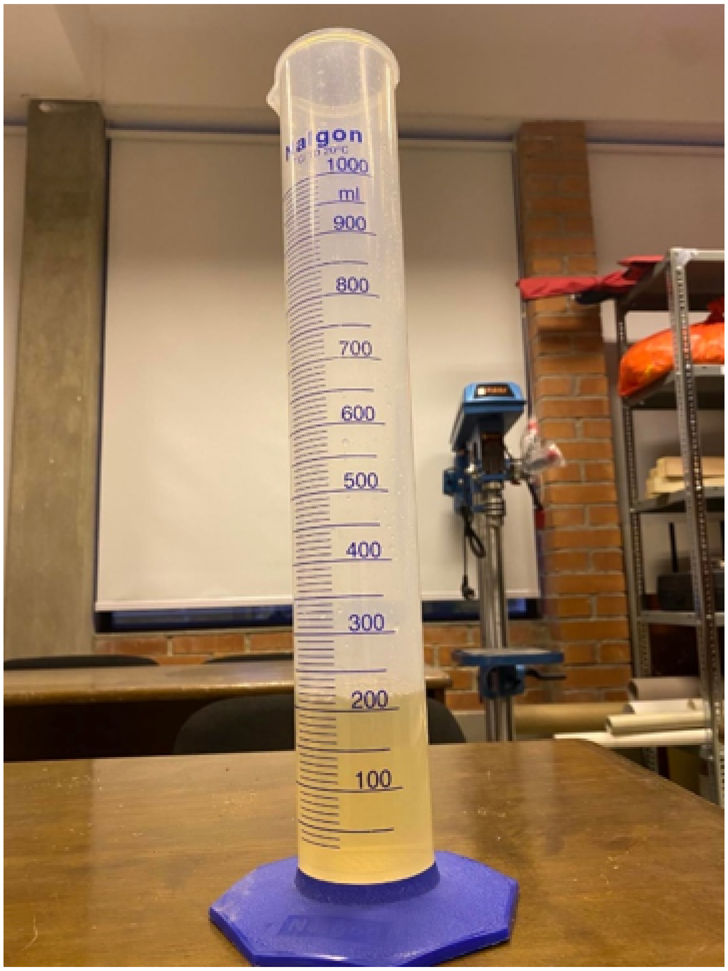

Figure 5

Quantification of harvested water in test tubes 2022

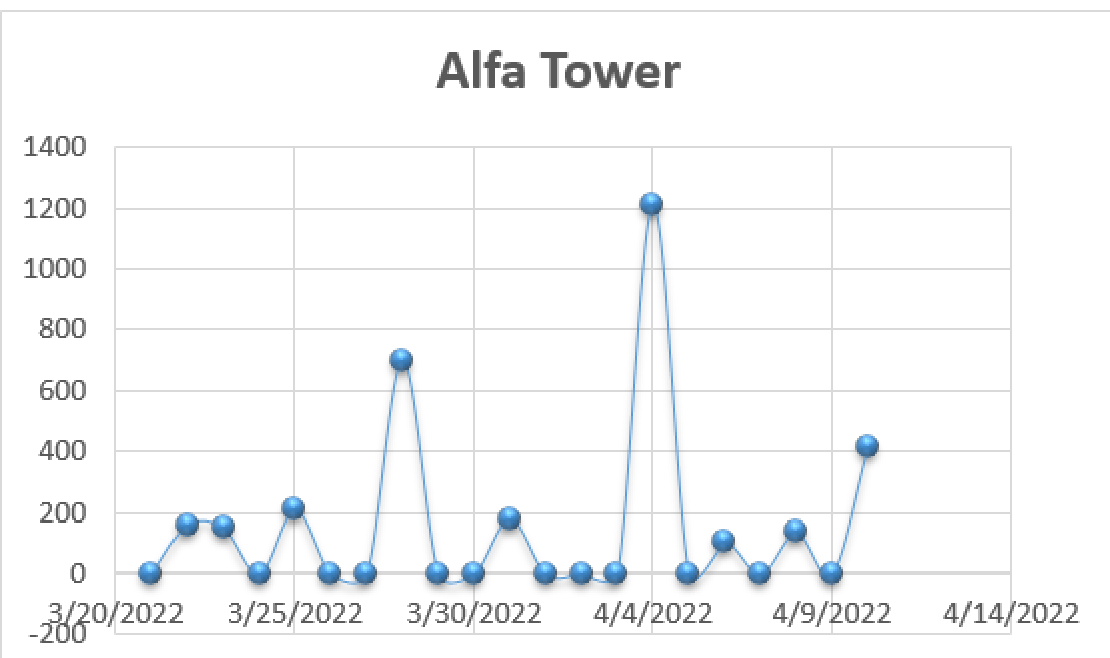

Figure 6

Evolution of water collected Alfa Tower 2022

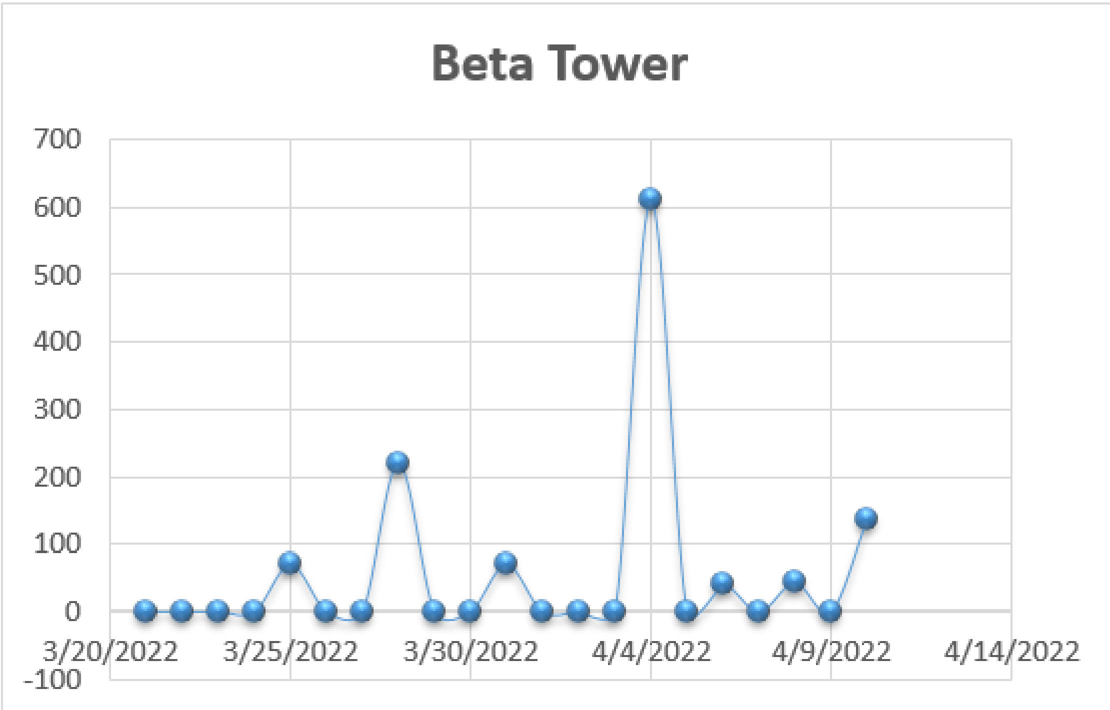

Figure 7

Evolution of water collected Beta Tower (own elaboration 2022)

Figure 8

Samples 1,2,3 from Alfa Tower 2022

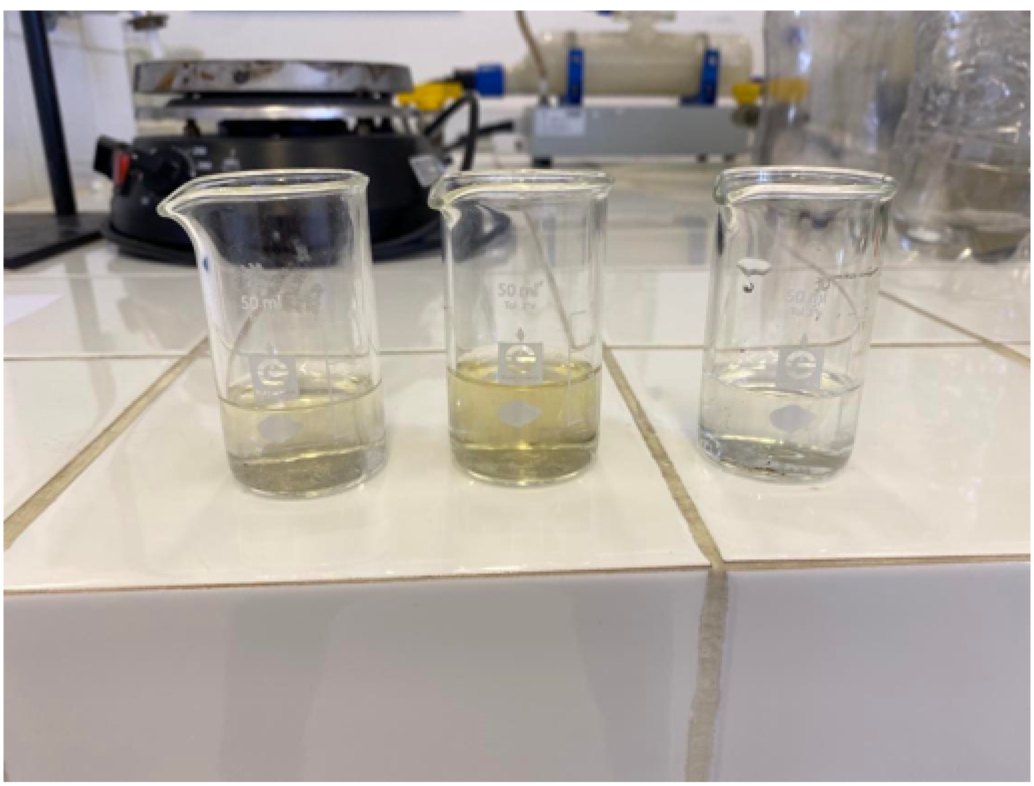

Figure 9

Samples 1,2,3 from Beta Tower 2022