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Water Humidity Collectors; New Methods in Alternative and Sustainable Water Supply

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Abstract

Air humidity is one of the sources of water and one of the components of the hydrological cycle. All the water vapor caused by the radiation of the sun's energy does not turn into precipitation, but a part of it does not turn into precipitation due to its kamali low density and is scattered in the space in a visible or invisible form. The important issue is how to actualize this environmental potential. In order to collect water from the fog, small droplets that cannot rain must fall into the trap. This can be done in different ways, including the use of mesh nets and when the fog passes through them. The materials of these nets, along with environmental factors such as the frequency of fog and wind speed, have a significant effect on the volume of water collected. In this research, two types of fog water collection systems made of metal mesh curtain and polypropylene mesh with dimensions of 1*1 meter and each with three repetitions were designed and installed in the Vishki mountain village of Eshkevarat, Roudsar city, which had many foggy days. A one-year data review recorded 76 fogging incidents. In these events, the average performance of metal mesh and polypropylene mesh collectors was 6.14 and 6.48 (L m^{-2} day^{-1}), respectively, which did not show a significant difference in the type of water absorbing nets. The average water collected for each square meter of metal net collectors was 466 (L $year^{-1}$) and polypropylene net 492 (L $year^{-1}$), which doubles the hope of developing this method in susceptible areas. The highest amount of water collected was in the months of May and August and the lowest was in the months of February and January. The benefit-cost ratio in this project for metal and polypropylene collectors was calculated as 1.77 and 1.96, respectively. Undoubtedly, fog harvesting is useful when access to other sources of water supply, including underground water sources and base water flow, is low and the people of the region feel the need for it.

Key words: Compatibility with Water Scarcity, Eshkevarat, Fog Collectors, Water Supply.

1. Introduction

Along with the many methods of using rainwater, one of the ways to coexist with water shortage in different regions of the country is to try to find new water sources. It is rarely noticed that there are many natural reservoirs of water in the form of water vapor in the world. One aspect of the water cycle in nature that is usually overlooked is fog, which forms a significant part of the hydrology of mountainous regions. Obtaining water and solving its shortage with low maintenance costs and without relying on energy consumption is of great importance in areas where fog is common (Qadir et al., 2018). In cases where the weather conditions are favorable, fog harvesting attention to human and ecosystem needs has long-term economic benefits, but requires a comprehensive approach. In this context, it is necessary to evaluate the efficiency of fog harvesting. Investigating the situation analysis to maximize the potential of collecting water from fog in the field of economic, social, environmental and health changes is inevitable (Korkmaz and Kariper, 2020). The idea of water harvesting from the moisture in the air has occupied the human mind for centuries, perhaps since the beginning of agriculture. Observing the plants that naturally showed moisture in the air in the form of dew on their leaves, or during dense fogs, a streak of water flow could be seen on their trunks, the possibility of making water from fog and humid air was strong in the minds of the people. Nature has provided ample evidence for collecting water from fog as a source of fresh water and has inspired possible designs for man-made fog harvesting systems. For example, Namib Desert beetles have adapted to collecting fog water in an area with 12 mm of annual rainfall (Domen et al, 2014). The beetle's back consists of a hydrophobic surface covered with smooth hydrophilic ridges, which help collect fog water and drain it along channels formed by the ridges into the beetle's mouth. In the forests and gardens of the northern regions of the Iran, the absorption of fog by mosses attached to forest trees and hazelnut trees can be seen.

In the Atacama Desert, water was harvested from air humidity through stone pipes. These pipes were designed in such a way that whenever the fog passed over them, the water from the fog drops was collected and directed downwards into a central tank (Olivier, 2004). In parts of Oman, which is located in the vicinity of the Oman Sea, the project of harvesting water from air humidity in Dhofar region, which has a height of about 900 to 1000 meters, was implemented. The results of this project showed that for a period of three months, the amount of water obtained was about 30 liters per day (Abdul-Wahab and Lea, 2008).

Methods for water harvesting from fog are relatively simple and involve the use of mesh nets attached to a sturdy frame. When the water droplets in the fog hit the mesh, they cause condensation and accumulation, finally a thin stream of water flows through the mesh nets into the gutters that are directed to the collection tank by gravity (Figure 1). The impact and physical collision of fog water droplets with mesh nets due to inertial forces is the main cause of fog water accumulation (Domen et al., 2014). Depending on the fog density and air temperature (especially when the temperature drops and there is no direct sunlight), the fog sticks to the net where the object is colder or less warm, and condensation (density) is created. Obviously, in areas with high humidity, water evaporation is very small and objects have less heat than dry areas. The study of Caldas et al. (2018) shows that mesh collectors are efficient in conditions of high relative humidity and have an efficiency in the range of 3 to 6 liters per square meter per day; But although these collectors are simple and inexpensive systems, premature failure due to wind and storm events may occur during their useful life, requiring immediate replacement.

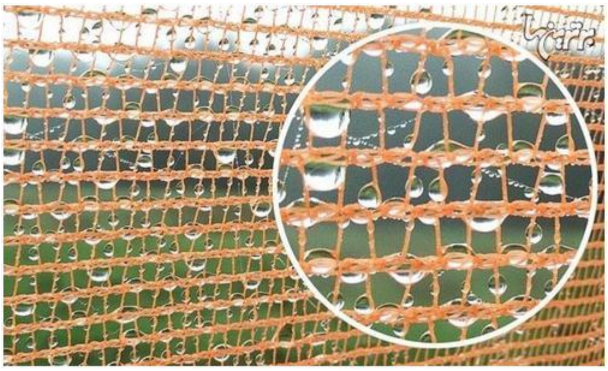

Fig. 1. A view of condensation and accumulation of fog and creation of a thin flow of water in the fog collecting net system

Mousavi Baygi and Shabanzadeh (2008) designed and built four types of collectors, including single-walled conical, double-walled conical, multi-walled conical and curtain collectors with different dimensions and sizes, in order to realize the feasibility of water harvesting from fog in the heights of Razavi Khorasan province. The results showed that according to the direct effect of the number of layers on the harvested water, if the number of curtain collectors increases to 20, the harvested water from such a collector can reach 40 liters per day on average in dry days. The results of the study of Davtalab et al., (2013) in order to water harvesting from air humidity in hot and coastal areas in southern Iran showed that the southern coastal areas of Iran due to the proximity to the humidity of the Persian Gulf and the Oman Sea, as well as high temperature and high humidity capacity for absorption, they have a very good potential to water harvesting from air humidity. The fog collector system in laboratory size was designed by Gharibreza (1999) and registered as an innovation in the Iran's patent system. In this project, the effectiveness of different materials for water absorbing was tested and finally the hood filter with the highest efficiency was identified. Also, its water absorbing part was designed in a rotating shape to compensate for the changes in the direction of the wind carrying the fog. This design can also be used at home-base.

The use of three-dimensional and vertical curtain-shaped collectors has a significant effect on improving their efficiency and increasing their performance in collecting a significant volume of water. Because it is much easier to make them and can make these collectors with any number of layers. Multi-layer collectors significantly increase the efficiency of fog collection (Tiedemann and Lummerich, 2010). The efficiency and performance of fog water collecting systems have been improved and increased by considering two points including space filling (i.e. using three-dimensional collectors) and the construction of vertical collectors. Paying attention to the mentioned points caused Tiedemann and Lummerich (2010) in their studies to design five fog collection systems of cone type with vertical collecting strips, cone with diagonal collecting strips, cube, star and double-wall curtain system, and finally the vertical curtain system suitable and recommendable (Figure 2). Examining the projects implemented in different countries shows that a significant amount of water is collected from this method. By using air moisture harvesting systems, it is possible to supply up to 15,000 liters of drinking water per day from each unit (50 collectors) in coastal areas (International Development Research Center, 2003).

E D C B A

Fig. 2. Design and construction of mist harvesting systems (Tiedemann and Lummerich, 2010) from right to left, respectively: A: Cone-shaped system with vertical collector strips, B: Cone-shaped system with diagonal collector strips, C: Cube-shaped system, D: Star-shaped system, E: Double-wall curtain system with dimensions of 4x8x0.3 meters with a metal frame and with 10 additional bars in between and with best performance

Currently, these activities are being carried out with good growth in various countries in the world such as the West Coast of South Africa, Peru, Oman, Yemen, Haiti, Chile, Namibia, Ecuador, Guatemala, Eritrea, Nepal and Canada (Qadir et al., 2021). For example, in 1992, an average of 11,000 liters of water was produced in the dry coastal areas of northern Chile by using the fog water extraction system. This project, which has been implemented as the largest water harvesting project from air humidity; it was done in a mountain range on the central coast of northern Chile.

Table 1. Summary of fog water harvesting potential for selected locations in the world

Location	References (Domen et al, 2014)	Average performance of 40 square meter collectors (liters/day)	Number of foggy events per year	Average performance)liter/square meter/day(
South Africa	Olivier and de Rautenbach (2002)	184	80	4.6
Nepal	Karkee (2005)	272	192	6.8
Chile	Schemenauer and Cereceda (1994b)	120	365	3
Peru	Schemenauer and Cereceda (1994b)	360	210	9
Oman	Abdul-Wahab et al. (2007a)	800	77	20
Canary Islands	Marzol (2008)	380	230	9.5
Namibia	Shanyengana et al. (2002)	96	120	2.4
Arabia	Gandhidasan and Abualhamayel (2012)	160	45	4
Morocco	Marzol and Megı´a (2008)	284	141	7.1

Table 2. Areas of implementation and performance of water collection systems from fog (Qadir et al., 2021)

Country	Technical aspects and characteristics of stakeholders	Characteristics of the place of execution
Guatemala	A total of 1640 square meters of fog collection system was installed, which collects 8.5 cubic meters of water on average daily. The joint effort between the stakeholders has led to the success of this project.	Small villages located at an altitude of 3300 meters above mean sea level and on top of Kochomatans mountain.
Eritrea	In Arborobue, the average daily fog water collection was 3.1 liters per square meter and in Nefasit is 1.4 liters per square meter. Trained members of these villages have formed committees to manage the fog collection systems.	The small settlement of Arborobue with 827 inhabitants at an altitude of 2085 meters and Nefasit with 3990 inhabitants at an altitude of 1725 meters above sea level.
Chile	This project has 14 large mist collectors, piping network and water storage with an average daily collection of one cubic meter. The project was supported by several stakeholders.	Falda Verde area, which is located in 5 kilometers of the north of Chañaral and 1.5 kilometers from the coast of Chile. This area is located at an altitude of 600 meters above sea level with an average annual rainfall of 30 mm.
Peru	This project collects 300-400 liters of water per collector per day in suitable fog conditions. A non-governmental organization and the people of the society are its main beneficiaries.	This project is located in a village on the outskirts of Lima at an altitude of 294 meters above sea level. At least 35% of the people in this village do not have access to water.
Morocco	Multi-organizational cooperation leads to the development of the most extensive fog collection system with daily water supply of up to 22 liters per square meter.	Aït Baamrane region in the southwest of Morocco, above the Boutmezguida mountain, at an altitude of 1225 meters above sea level.

In this place, 50 large air moisture collectors have been installed, each of which has a double layer of polypropylene fiber network with an area of 48 square meters (International Development Research Center, 2003). Table (1) summarizes the water harvesting potential from fog for selected locations in the world (Domen et al, 2014). Table (2) also refers to the characteristics of implementation areas and technical aspects of fog harvesting collection systems in several countries (Qadir et al., 2021). The noteworthy point in this table is the establishment of fog collection systems in the mountainous and less developed regions of these countries.

Mahmoudi et al. (2016) in the study of the feasibility of water harvesting from air humidity in the south of Sistan and

Baluchistan province, first collected the data of water vapor pressure, relative humidity and precipitation of Chabahar station for a period of 20 years. The amount of water extracted from the humidity of the air was also designed and implemented by a curtain collector with dimensions of 1 x 1 meter. The amount of water extracted from this collector was recorded daily for 365 days. The results of the theoretical calculations showed that the southeast coast of Iran is susceptible to the implementation of the water extraction plan due to the high average relative humidity. Also, the results of this study showed that the average water content in one cubic meter of air in the studied area is 29 grams in the wettest state and 1.8 grams in the driest state.

But due to the fact that water harvesting is dependent on different conditions and even in the best conditions it is not possible to collect all the moisture in the atmosphere, during the test field and checking the available statistics, it was found that about 20% of the water in the air can be collected in this exploited area. Therefore, based on this threshold, the highest amount of extracted water is related to the month of June with 8.6 liters per square meter per day and the lowest amount is related to the month of February with 1.1 liters per square meter per day. In general, the result of this study showed that in the southeast of Iran, due to the relative humidity above 70% in most days of the year and the constant blowing of the wind, there are suitable conditions for water harvesting from air humidity. In the mountainous heights of the northeast of the Iran, in North Khorasan province, the capability of water harvesting systems from fog has been evaluated (Mousavi-baygi, 2008). According to the results of this research, this system was able to extract water between 0.5 and 3.3 liters per square meter daily. In this research, the use of this system and its cheapness and various installation plans have been emphasized to increase its efficiency.

Rahimi (2012) has emphasized the possibility of water harvesting from fog by examining 115 synoptic stations in Iran in a 40-year period (1960 to 2005). But in this research, he pointed out the trend of decreasing the number of foggy days in mountainous areas compared to increasing the number of foggy days in coastal areas. In Iran, Astara with 220 days and Kish Island with 213 days with fog have the longest fog season. In Gilan province and in the mountainous areas of Ashkorat of Rudsar city, the existence of areas with more than 50 days of fog has provided a good opportunity to collect it for drinking and horticultural purposes.

In this research, collecting water from air humidity in these areas was done with the aim of investigating the possibility of water harvesting from fog and increasing the resilience of its residents in the face of the water shortage crisis. In these areas, which are known as the development hub of hazelnuts and medicinal plants in the country, the necessity of providing water for supplemental irrigation in critical months as well as providing drinking water is twofold. In many mountainous and high areas of Ashkorat, due to physiographic and topographic features, it is not possible to access underground water sources (wells and natural springs) and surface water of rivers. Residents of these areas use all available environmental capacities in order to supply water needed for domestic use, drinking and irrigation of their gardens and fields. Extraction of rainwater from the roof of construction buildings, small water catchment surfaces, creation of micro-catchment at the foot of trees and construction of water reservoirs are examples of these cases.

The main hypothesis in this research is to measure the feasibility of using the humidity in the air (fog) to supply the water needed by rural users and combining it with other systems of rain catchment surfaces in order to be used for various purposes such as supplementary irrigation of gardens and fields or drinking purposes of villagers. This research seeks to take advantage of all environmental capacities and provide suitable conditions for the use of resources and energies in nature, in order to convert air humidity into accessible water, for multi-purpose use, in the deprived villages of Ashkorat region of Rudsar city. In general, it can be said that considering the great potential of fog and humidity in some regions of the world, especially in the northern regions of Iran, and the need of local communities for it, water harvesting from this source is an important step in providing good quality water for irrigation, drinking and other needs.

2. Material and Methods

2.1.Case Study

Ashkur is a mountain and summer resort located along the Alborz mountain range. The place of implementation of the project is also located in Vishki village of Rahim Abad district of Rudsar city in Gilan province, Iran. Vishki village was located in Ashkur-Olya and Siarstaq Yilaghi districts and according to the census of Iran Statistics Center in 2015, its population was 134 people (56 households). The area under hazelnut cultivation in this village is more than 110 hectares and its people are engaged in animal husbandry in addition to agriculture. Table (3) shows the geographical location and Figure (3) shows a view of the research area in the country, province and city.

Table 3. Geographical location of the installation area of fog water harvesting systems

Vilage	Latitude)UTM(	Longitude)UTM(	Height above sea level (m)	province	City	the part
Vishki	4067508	440431	1720	Gilan	Rudsar	Rahimabad

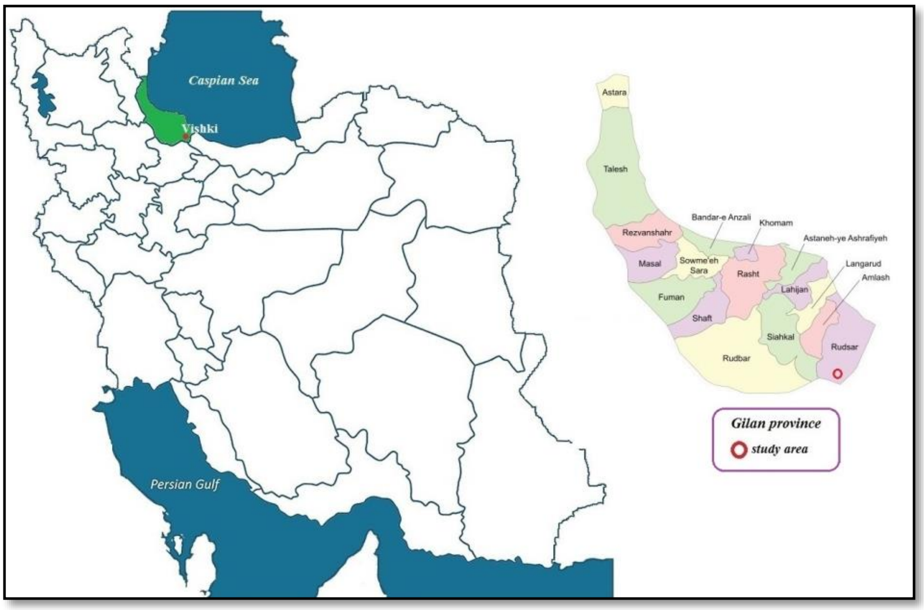

Fig. 3. A view of the research area in Iran, Gilan province and Rudsar city

2.2.Requirements for choosing the location of the project

By potential measurement, the location of fog harvesting systems were selected. The best method for choosing places prone to extracting water from fog is to use maps and meteorological data, which can determine the location of air moisture collection systems by extracting the number of cloudy days in the studied area. Knowing the direction of the prevailing wind has a significant impact on the success of the project. Due to the importance of using meteorological data in selecting areas prone to project implementation, there is no meteorological station except one rain gauge station at an altitude of 480 meters in Ziyaz village. However, from the total of 12 synoptic weather stations located in Gilan province, Dillman weather station is closer to Ashkorat region due to its location in the mountainous area at an altitude of about 1500 meters. Therefore, the information of this station was used.

Examining the data of this station during the statistical period of 2006-2018 (equivalent to 4180 days) showed that the values of minimum, maximum and average temperature parameters were 6.8, 16.7 and 11.7 degrees Celsius respectively, maximum 24-hour rainfall or maximum rainfall in one day is 51 mm, the number of sunny hours is 5.8 hours per day, the average wind speed is 2.4 meters per second, and the minimum, maximum and average relative humidity are 49.1, 79.8 and 63.7%, respectively. Examining the average relative humidity in this station (more than 60%), shows that this parameter is high in high mountain areas, including the research area in Ashkorat. Rahimi (2012) introduced these areas with more than 50 days of fog. In addition to using meteorological data from Dillman station, taking advantage of local knowledge, experiences of leading farmers and operators in the region and paying attention to their observations helped to establish the systems properly. In general, to choose the location of the project, one should pay attention to the technical and social requirements of the location of the systems. The technical requirements include the frequency of fog and the presence of areas with more than 50 days of fog per year, the presence of suitable topography and access to the area, the presence of windy environment and knowledge of the direction and speed of the wind in the areas where the systems are installed. The social requirements also include the need of the people of the region for water for agricultural and drinking purposes, paying attention to the ownership of the lands where the systems are installed (implementation of the project in the lands of the exceptions of individuals) and the participation of local beneficiaries and operators in the implementation of the project, monitoring and protection of the installed equipment and systems.

2.3.Construction and operation of the system

In order to design and build curtain collecting systems of metal mesh and polypropylene mesh with dimensions of 1 x 1 meter, as well as to transfer and water storage, the necessary tools including 2.5 inch galvanized pipe, metal mesh, polypropylene mesh and PVC gutters were prepared. The construction of fog water collection systems with dimensions of 1 x 1 m was done in the workshop of the technical service department of the Soil Conservation and Watershed Management Research Institute. A mist collector system is simply a net with fine holes and devices that keep it in an upright position. The collector consists of two vertical poles placed in a hole on the ground and fixed with stone or cement. The net is installed between these two vertical beams (Figure 4).

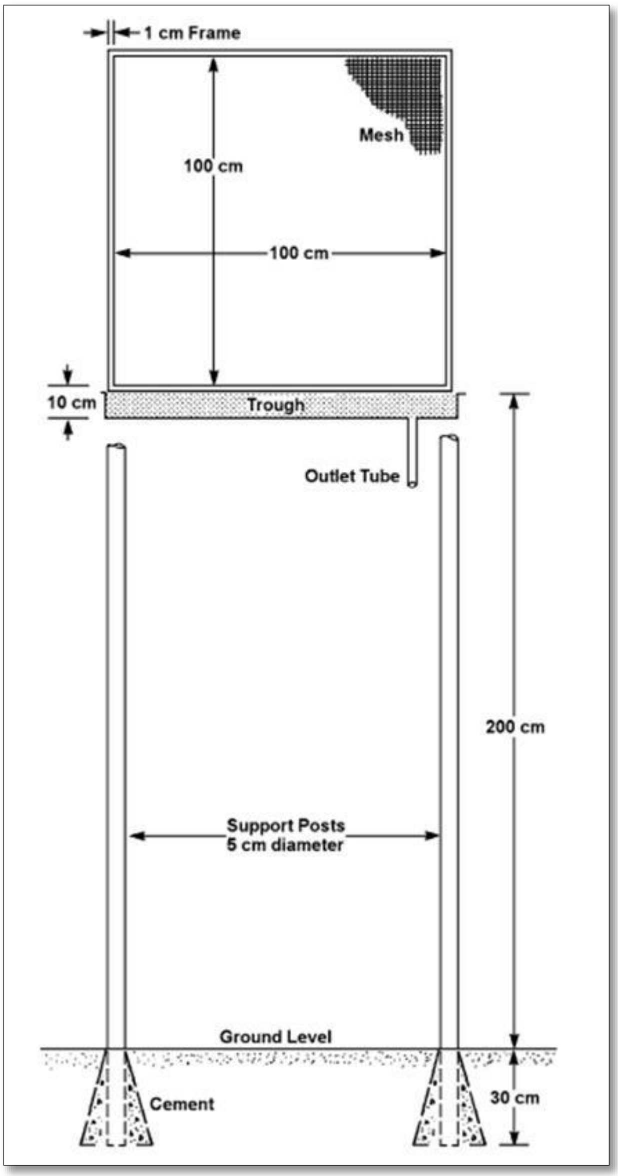

Fig. 4. Schematic view of the curtain collector system design in this research

The material of the net is usually galvanized metal or polypropylene plastic, and usually it should be of a type that has already been approved by researchers (Korkmaz and Kariper, 2020; Caldas et al., 2018; Domain et al., 2014). The change in the mesh distance, size and wettability of the fibers in the meshes affects the amount of water that can be collected. So that changing the mesh fibers also improves the performance of the meshes. Therefore, it was tried to carry out the research by preparing propylene mesh fabric with a diameter of 1 mm and preparing domestically made propylene fibers and other fibers with the ability to absorb moisture.

Of course, all efficient nets are within a certain range of 1mm ≤ h ≤ 2mm mesh, so that the use of propylene or polyethylene nets in catching fog is efficient, durable enough against wind, sun, ultraviolet radiation and rain and can drain water quickly (Klemm et al. 2012). Then, in order to direct the water collected from the nets to the tank, a PVC gutter was installed from under the lower cable connected to the net. Pipes were also installed to transfer water from the gutter to the tank or water source at the end of this collector. Figure (5) shows the construction of fog water harvesting systems in the workshop of the technical services department of the Soil Protection and Watershed Research Institute with dimensions of 1 x 1 m.

Fig. 5. Construction of the system in the Research Institute of Soil Protection and Watershed Management with dimensions of 1 x 1 square meter

Fig. 6. A view of the systems installed in Vishki village

Generally, mesh collectors are divided into two main groups, standard mist collectors and large mist collectors, according to the mesh surface area (Klemm et al. 2012). The typical size in standard fog collectors is 1 x 1 m, while large fog collectors can be wider in size and are usually rectangular due to aerodynamic requirements. After construction, these systems were moved to the project site. Figure (6) shows the systems installed to collect water from the fog in the area of the research implementation.

2.4. Collecting and monitoring the rate of conversion of air humidity into water and determining the volume of water

By installing water collection tanks, the volume of water stored in each of the metal mesh and polypropylene mesh collectors was measured with a calibrated beaker. Monitoring was done at 17:00 every day and in case of fog, the amount of water collected in the tank was measured. It should be mentioned that the executive operation of installing the systems was done on June 25, 2021 and data collection started with the first occurrence of May on July 1, 2021 and continued for one year until the end of June 2022.

2.5. Comparison of adders and analysis of results

In this research, two metal mesh and polypropylene mesh collectors were used, each with three repetitions. During the one-year monitoring period, the volume of water collected in each fog event was recorded by mentioning the number of fog hours and their comparison was done using SPSS 20 statistical software. By examining the benefit-cost ratio of the collectors, management strategies for the development of this method as a small water source in the mountainous areas of Ashkorat were considered.

3. Results and Discussion

In this research, curtain vertical collector systems designed by the Soil and Watershed Protection Research Institute were used due to their lower cost and ease of construction. In studies of Tiedemann and Lummerich (2010) also introduced the vertical curtain system as suitable and recommendable compared to five fog collection systems. Mousavi Baygi and Shabanzadeh (2008) also recommended a curtain collector due to its better and more convenient use and much lower construction cost compared to conical collectors. In this research, with continuous observation and monitoring of the collected data, while knowing the number of foggy days, the amount of water extracted from each one square meter surface was measured. Examining the data from the measurement showed the collection of different amounts of water on foggy days. So that the amount of fog and dew water collected varied from 0.02 liters on a foggy day with 3 hours of fog to a maximum of 30 liters with 24 hours of continuous fog. Table (4) shows the total amount of water collected for each square meter of metal mesh and polypropylene mesh collectors during the one-year monitoring period and in different iterations. Examining this table shows that each metal net collector has extracted 466 liters per square meter per year and polypropylene net 492 liters per square meter per year. According to this table, the highest amount of water collected (liters per square meter) was in the months of May and August, and the lowest amount of water was collected in the months of February and January.

Also, in this research and during the one-year measurement period, 76 fogging incidents were recorded (Table 5 and Figure 7). On average, each foggy event in the day and night has 8 hours of abundance with different moisture content. Rahimi (2012) has also reported the area of implementation of the current research among the areas with more than 50 days of fog by examining 115 weather synoptic stations in Iran. Table (5) also shows the average performance of metal and polypropylene nets during foggy events in terms of (liters/m^2/day).

Table 4. The total amount of water collected in liters for each square meter of metal mesh and polypropylene mesh collectors with three replications during one-year monitoring.

Month	Metal mesh treatment (liter)			Polypropylene net treatment (liter)		
	Iteration 1	Iteration 2	Iteration 3	Iteration 1	Iteration 2	Iteration 3
Oct	13.6	13.45	21.1	12.5	18.2	20.4
Nov	60	60	69	63	72	70
Dec	9	12	15	12	15	17
Jan	7.5	8.5	16.5	8.5	10.5	12
Feb	2.5	2.5	3.3	3	3.5	2.5
Mar	28	27.5	25	26	27	28
Apr	26	26	26	28	26	25.5
May	114.5	110.5	115.5	108.5	109.5	131.5
Jun	15.5	18.5	18.5	16.5	16.5	18.5
Jul	46.7	53.5	78.6	50.5	67.9	65.9
Aug	76.3	83.2	127.3	86.2	109.9	117.4
Sep	21	21	26	20	27	30
Sum	420.6	436.65	541.8	434.7	503.0	538.7

Table 5. Water harvesting potential from fog in the study area during one year

Month	Sep	Aug	Jul	Jun	May	Apr	Mar	Feb	Jan	Dec	Nov	Oct
Number of foggy events (items)	6	7	13	4	16	4	4	2	5	1	5	9
Average mesh collector performance metal (liter/square meter/day)	3.8	13.7	4.6	4.4	7.1	6.5	6.7	1.4	2.2	12.0	12.6	1.8
The average performance of the polypropylene mesh collector (liters/square meter/day)	4.3	14.9	4.7	4.3	7.3	6.6	6.8	1.5	2.1	14.7	13.7	1.9

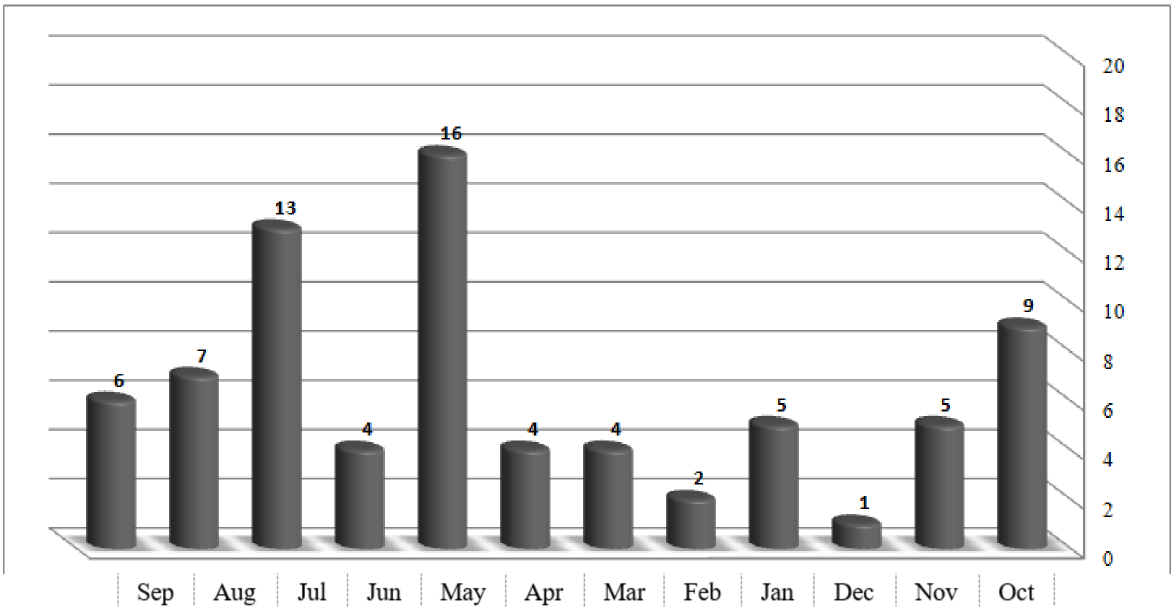

Fig. 7. The number of foggy events recorded in each month during the one-year measurement period

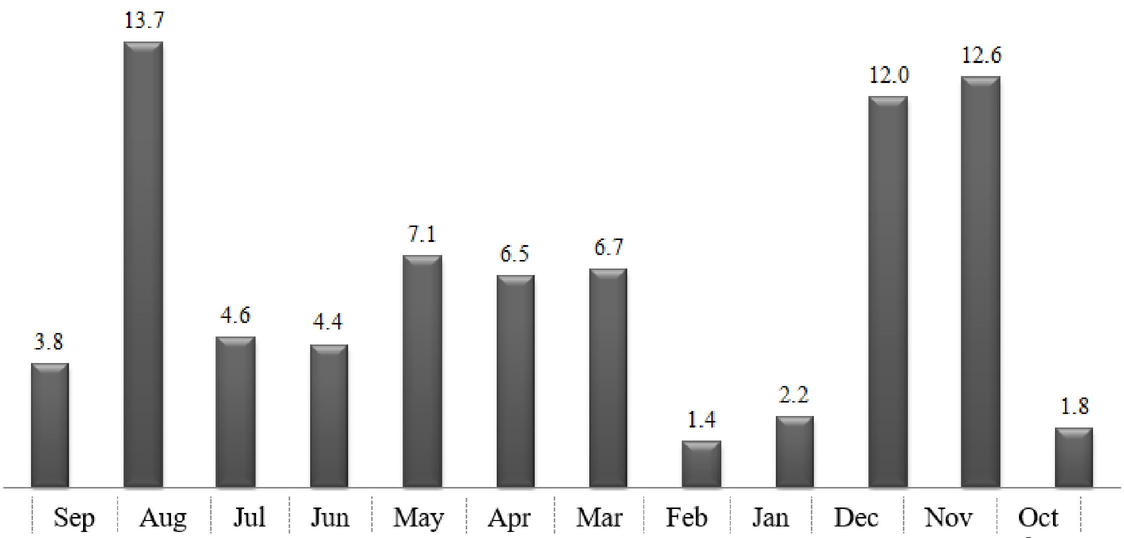

Fig. 8. The average water extracted from the metal curtain collecting system (liters/m^2/day)

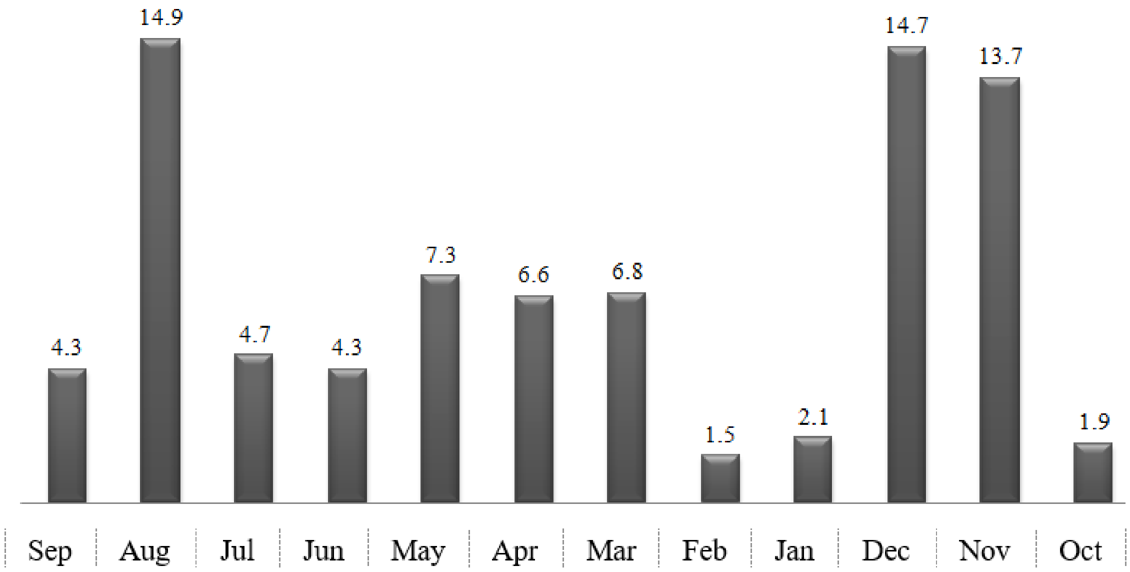

Fig. 9. The average amount of water extracted from the polypropylene curtain collection system (liters/m^2/day)

Evaluation this table and figures (8) and (9) shows that the maximum amount of monthly withdrawal from metal mesh and polypropylene mesh collectors in August is 13.7 and 14.9 (liters/m^2/day), respectively, and the minimum is about 1.4 and 1.5 (liter/m^2/day) in February. Also, the data analysis showed that the total water collected in the critical months of July and August is 18.3 and 19.6 (liters/m^2/day), respectively. This amount of water harvesting from fog in these months doubles the hope of developing this method in order to compensate for the lack of water in the critical months and adapt to the lack of water in this region.

3.1.Comparison the types of collectors

Examining the recorded data showed that the average performance of metal mesh and polypropylene mesh collectors with 76 fogging events was 6.14 and 6.48 liters per square meter per day, respectively (Table 6). The average yield of water harvesting from fog in terms of (liters/square meters/day) in South Africa (4.6), Chile (3), Namibia (2.4) and Saudi Arabia (4), which was lower than the values recorded in this research. And in Nepal (8.6), Peru (9), Oman (20), Canary Islands (5.9) and Morocco (1.7), more than these values have been reported (Domen et al, 2014). Mousavi Baygi and Shabanzadeh (2008) also reported the performance of fog water collection systems between 0.5 and 3.3 liters per square meter per day.

Mahmoudi et al. (2016) also reported the highest amount of extracted water as 8.6 liters per square meter per day and the lowest amount as 1.1 liters per square meter per day. Also, the examination of the results in the research area did not show a significant difference at the level of 1 and 5% in the type of water-absorbing nets (metal net and polypropylene net) (Table 7). It seems that the proper installation of the systems in the direction of the wind flow and at the appropriate height has a greater effect than the type of water-absorbing mesh nets in the average performance of these systems. Mousavi Baygi and Shabanzadeh (2008) also found the amount of air humidity, wind speed and height of the installation site to be effective in the amount of extracted water.

Table 6. Average water collected from metal and polypropylene nets (liter/square meter/day)

Collector type	N	Mean	Std. Deviation	Std. Error	Minimum	Maximum
Metal mesh	228	6.14	6.67	0.44	0.02	30.00
Polypropylene mesh	228	6.48	6.89	0.46	0.02	30.00
Total	456	6.31	6.78	0.32	0.02	30.00

Table 7. Comparison of the types of nets used in collection systems

		Sum of Squares	df	Mean Square	F	Sig.
Data * Collector type	Between Groups	13.13	1	13.13	0.285	0.594
	Within Groups	20893.65	454	46.02		
	Total	20906.77	455			

3.2.Cost-benefit analysis of collectors

By analyzing the results and examining the cost to the benefit of each of the collectors, management strategies to develop of this method as a small water resource in the mountainous areas of Ashkorat will be recommended. The total cost of raw materials, supplies, equipment, design, construction, and installation of each one square meter collecting system of metal curtain type and polypropylene including galvanized pipes, nets, gutters and storage source is 42 and 40 dollars of initial investment, respectively (Table 8). This investment will be made in the first year of project implementation and will be used for many years (at least ten years). The measured data during one year according to table (4) showed that on average each of the metal collectors collects 466 liters and the polypropylene collector collects 492 liters of water. In the research area, the purchase price of each liter of water for garden irrigation is $0.01. The amount of income in 10 years with a 10% increase in water price for metal and polypropylene collectors was calculated to be $74.3 and $78.4, respectively. In this way, taking into account the cost of 42 and 40 dollars for the construction of each metal and polypropylene collector system, the benefit-cost ratio in this project was 1.77 for the metal collector system and 1.96 for the polypropylene collector system. In this study, if we limit the amount of water collection to two seasons, spring and summer, the amount of water collected from each metal and polypropylene system will be 335 and 352 liters, respectively. In this situation, the benefit-cost ratio for these systems is 1.27 and 1.40, respectively, which shows the economic nature of this method along with other rainwater harvesting methods.

Table 8- The cost of raw materials, supplies, equipment, construction and installation of a one square meter curtain collector system

No	Supplies and equipment	total (dollars)		Unit price (dollars)	Amount required
		Polypropylene system	Metal system		
1	Galvanized pipe	10.8	10.8	0.9	12 kg
2	Metal mesh	0	3.5	3.5	1 m^2
3	Polypropylene mesh	1.5	0	1.5	1 m^2
4	PVC gutter	0.7	0.7	0.7	1 m
5	Polyca tube	0.4	0.4	0.8	0.5 m
6	Polyka and glue	0.8	0.8	0.8	1
7	Storage tanks 20 liter gallon	1.6	1.6	1.6	1
8	Cement	0.8	0.8	0.04	20 kg
9	Sand	0.6	0.6	0.01	60 kg
10	Construction and transfer wages	18.6	18.6	--	
11	Unforeseen expenses	4.2	4.2	--	
12	Total Cost ($)	40.0	42.0	--	

It should be mentioned that providing management solutions and promotion recommendations according to the conditions of the region and the place of construction will provide the possibility of establishing low-cost systems for the users of these areas.

4. Conclusion

In this research, two curtain collecting systems of metal mesh and polypropylene mesh with dimensions of 1 x 1 m and each with three repetitions were used. With continuous annual observation and monitoring, 76 foggy days were recorded in the research area. The total amount of water collected for each square meter from metal net collectors was 466 liters per year on average and for polypropylene net was 492 liters per year. The highest amount of water collected was in the months of May and August and the lowest was in the months of February and January. The average performance of metal mesh and polypropylene collectors showed that the maximum monthly harvest from these collectors in August was 13.7 and 14.9 (liters/m^2/day), respectively, and the minimum was 1.4 and 1.5. (liter/m^2/day) was in February. The comparison of the type of collectors did not show a significant difference in the type of water absorbing nets (metal net and polypropylene net). The benefit-cost ratio in this project for metal and polypropylene collectors was calculated as 1.77 and 1.96, respectively; but if the amount of water collection is limited to the first six months of the year, this ratio will be 1.27 and 1.40. It is important to pay attention to its technical and social requirements in choosing the locations of the project. The frequency of fog occurrence and the presence of areas with more than 50 days of fog pollution per year, wind speed and direction, moisture content of fog, topographic characteristics and access to the area, including technical requirements, and the need of the people of the region for water for agricultural and drinking purposes, the ownership of the land where the systems are installed and the implementation of the project in the exception lands, the participation of local beneficiaries and operators in the implementation of the project in order to monitor and protect the installed equipment and systems are among the social requirements of the project implementation.

It should be noted that the expansion of water harvesting systems from fog in susceptible areas requires the participation of local communities, empowerment of people, government support and active participation of local institutions as key drivers for the development of these systems in the sustainable supply of fresh water. The design and construction of fog collecting systems should also be done in such a way that it is practically possible to deploy and operate it while being simple and low cost. So that improving the efficiency of these systems according to the natural conditions of each region will expand the use of this method in susceptible regions. Therefore, providing appropriate management and promotional solutions to establish low-cost systems to benefit the users of these areas from this environmental capacity can be a suitable solution to deal with the water scarcity crisis in the region. It is recommended to compare and evaluate the value of fog water harvesting systems with other sources of water production from economic, social, environmental and commercial points of view. Undoubtedly, fog harvesting is useful when other sources of water supply in the region are scarce and people feel the need for it. It should be noted that harvesting water from fog can be considered by planners as a sustainable option in supplying part of the water needs of susceptible areas due to the low cost of implementation and maintenance.

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6. Disclosure statement

No potential conflict of interest was reported by the authors

7. References

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