Water Productivity Journal

Received: 7 February 2021

Accepted: 23 April 2021

WPJ, Vol. 1, No. 4, Spring 2021

Fog water harvesting investigation as a water supply resource in arid and semi-arid areas

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Abstract

In view of high population growth and water resources deficit in arid and semiarid area and groundwater resources shortage in mountainous area, there is an urgent need to identify the alternative sources of potable water. Fog is one of such sources of water. Although fog water yielding potential is largely ignored by water authorities, it was used extensively in ancient times and promoted the water productivity. The objective of this research is to review the fog collection in Yemen and South Africa. In El Tofo Mountain in Chagungo (Chile), 75 fog collectors were erected. According to the reports, production rates vary from zero on a clear day to maximum of 100000 liter per day. With this arrangement, each of the 330 villagers received about 33 liter of clean water per person per day. Geographical and climate characteristics, droplets distribution, and fog density need to be evaluated and are crucial factors for success of fog water harvesting project. Chemical and microbial studies of fog water harvesting show that the water quality is safe for human consumption. Thus, it can be considered as an alternative source of water in arid and semi-arid regions that dense fog could be available.

Keywords: Fog Water; Traditional Water System; Water Harvesting; Water Productivity; Water Resources Management

INTRODUCTION

Water is an important part of the human life. Sustainable management of water is a major component of the Sustainable Development Goal 6, United Nations. Many residents of the middle and low economic countries are not adequately supplied with this important commodity. However, information is scanty about the specifics of the state of drinking water in many relatively small urban areas (Eludoyin, 2020).

Water scarcity is the first and most challenging crisis worldwide. By growing the world's population, it is inevitable to find the alternative water resources to provide demanding water. Atmospheric water also known as air humidity is one of the most accessible resources and therefore could be used as a sustainable resource for water harvesting (Maleki *et al*., 2021).

Fresh water sustains human life and is vital for human health. It is estimated that about 800 million people worldwide lack basic access to drinking water. About 2.2 billion people (nearly one-third of the global population) do not have access to a safe water supply, free of contamination. Also, over 2 billion people live in countries experiencing high water stress. Current supply of fresh water needs to be supplemented to meet future needs. Living

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nature has evolved the species which can survive in the most arid regions of the world by water collection from fog and condensation at night. Before the collected water evaporates, species have the mechanisms to transport water for storage or consumption. These species possess the unique chemistry and structures on or within the body for collection and transport of water. An overview of arid desert conditions, water sources and plants and animals, lessons from nature for water harvesting, and water harvesting data from fog and condensation were presented. Consumer, emergency and fence applications are discussed and various designs of water harvesting towers and projections for water collection are presented (Bhushan, 2020).

Large portions of the world present the severe freshwater scarcity, with more than 785 million people having no access to drinking water (WHO, 2020). This situation is worsened by population growth, intensive agricultural and industrial activities, poor water management, contamination, and changes in the rainfall regime due to climate change (Gupta *et al*., 2012; Trenberth, 2011). Alternative freshwater production ranges from energy-intensive systems such as water desalination and wastewater reuse to low energy systems such as the passive collection of rainwater, dew, and fog. Fog water harvesting is an exciting alternative as a freshwater resource in arid or semi-arid climate areas (Carvajal *et al*., 2018; Kaseke and Wang, 2018), serving in agriculture, reforestation, and human consumption (Valiente *et al*., 2011).

Some arid regions in the world lack adequate safe drinking water. Figure 1 shows the proportion of population with access to safe drinking water in 2015 (WWAP, 2019; WHO/UNICEF, 2017). over 75% of population in 181 countries had access to safe drinking water. It is estimated that about 800 million people worldwide lack basic access to drinking water (WHO/UNICEF, 2017). This means that they cannot reach a protected source of drinking water within a total walking distance of 30 minutes. About 2.2 billion people, representing nearly one-third of the world population, do not have access to a safe water supply. It meansthat there is no drinking water free of contamination and with easy access in their own property. Almost half of the people drink water from unprotected sources live in sub-Saharan Africa. Women and girls regularly experience discrimination and inequalities in the rights to safe drinking water. Ethnic and other minorities, disability, age and health status are also the factors.

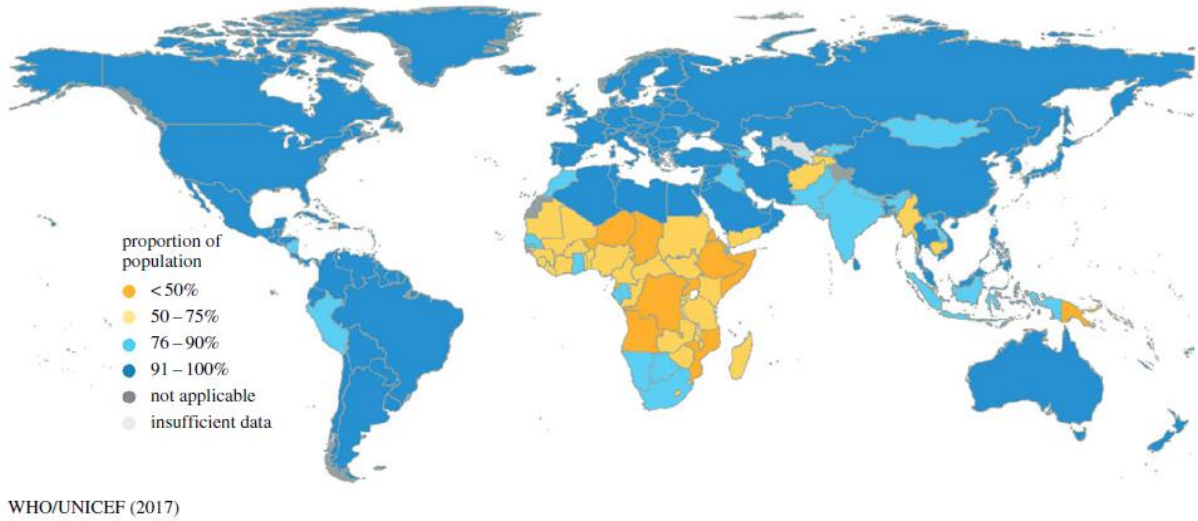

Fig. 1. Proportion of population with an access to basic drinking water services in 2015. One hundred and eighty-one countries had a coverage of over 75% (WHO/UNICEF, 2017)

Because of global warming and an increasing drought, water supply continues to shrink. Figure 2 shows the level of physical water stress around the world, showing percent of total fresh water withdrawn annually. One third of the world populationare experiencing high water stress. In other words, the consumed water resources are not regenerated by rain or purified water reuse (UN, 2018). About 4 billion people experience severe water scarcity during at least one month of the year (WWAP, 2019). Stress levels is increasing as demand for water grows and the effects of climate change are intensified. Most of the people affected by water stress live in North Africa, the Middle East, and South Asia, and the people living in North and South America specifically the southwest USA are also increasingly being affected. Roughly 70% of the Earth's surface is covered by water; however, a vast majority of it exist in the oceans and only 2.5% of it covers the reshwater resources (Brown and Bhushan, 2016).

The objective of this paper is to review the fog water harvesting projects in arid regions in Yemen and Africa, where potable water is a challenge. The fog water quality is further evaluated to find out whether fog water can be considered as an alternative for freshwater resources in arid and semi-arid regions. An approach for locating a fog water harvesting project is also introduced.

MATERIALS AND METHODS

Identification of Potential Fog Water Harvesting Site

The principal areas of interest are typically in desert areas with dense fog, since they often lack conventional water sources. Islands and mountainous areas are also of interest as they often have limited groundwater potential. Conditions for fogwater harvesting are best where there are persistent winds from one direction to transport the low-level cloud and advective fog. Coldness warm and moist air mass through the passing on the cold surface is advective fog (Wiin-Nielsen, 1973). Figure 3 shows the east-west cross section of an idealized case for west coast, such as Chile-Peru, California or Namibia. This is a very simplistic explanation; fog in these desert areas can be caused by much more complex atmospheric and oceanic interactions.

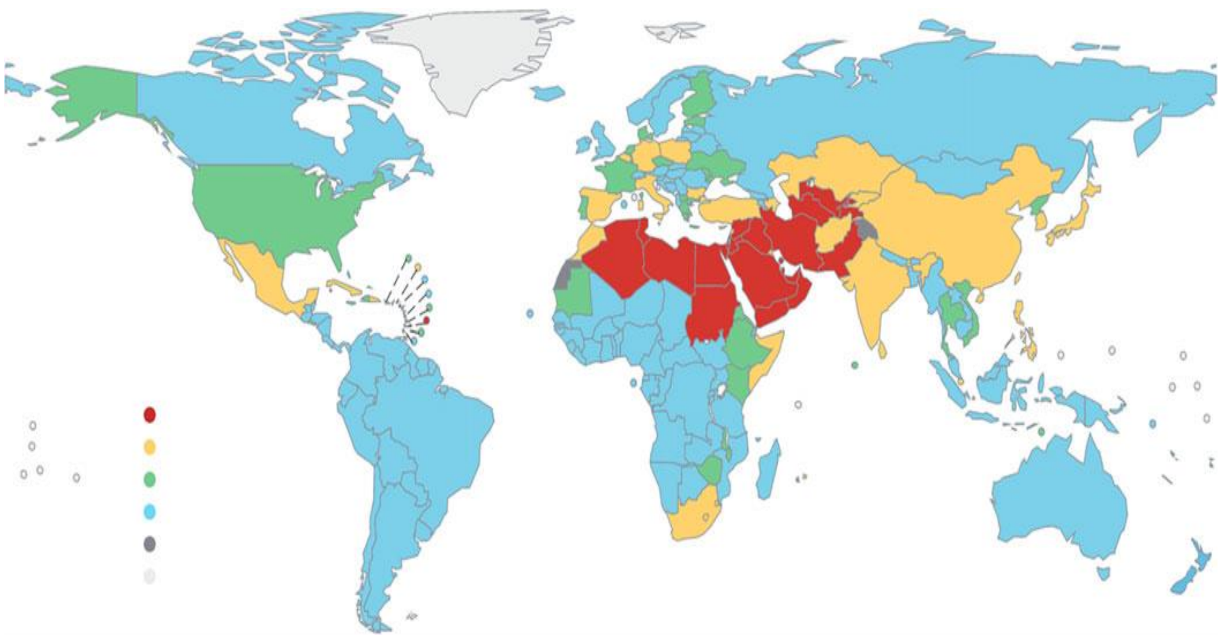

Fig. 2. Level of physical water stress (UN, 2018)

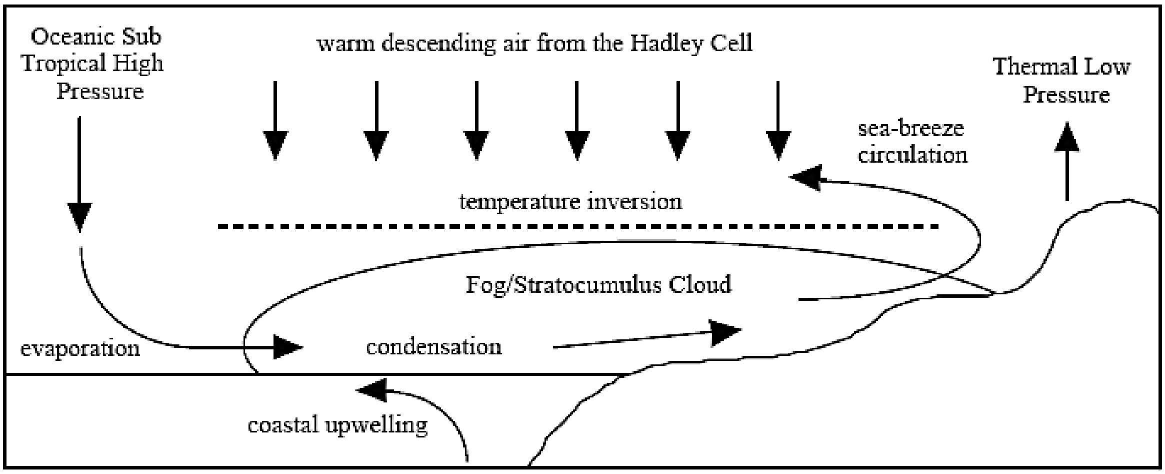

Fig. 3. West coast advection fog (Furey, 1998)

In the Namib, this coastal fog gives only moderate yield and has lower wind speeds than the so-called "high fog" which is in fact the cloud intercepted further inland. The key factor is the temperature inversion caused by the subsiding subtropical air that prevents vertical development of the cloud that would produce rain. Instead, the cloud and fog moves inland until ground heating causes the moisture to evaporate.

The topographic relief must intercept the cloud. With low-level coastal fog this can be isolated hills or dunes. For higher cloud, larger mountains are needed. In this latter case the cloud can be pre-existing or orographically induced. Orographic cloud is most clearly seen on islands, such as Hawaii and Cape Verd.

Marine cloud and fog decks generally dissipate further inland due to evaporation. It is often therefore desirable to have the collectors located within 5 km of the coast and usually not more than 25 km. This distance must be balanced against topography in relation to the cloud deck. Observation and experiment are needed to determine optimum location. In high elevation areas, cloud is intercepted or induced by the topography; the distance to the coast is irrelevant.

Fog water harvesting is not restricted to hyper-arid areas. There is potential application in highland tropical areas, such as the Chiapas of Mexico or the Philippines. The rainfall in these areas, though generally very high, is often very seasonal and there may be application for fog collection as dry season water supply. In the Cape Verd Islands, the dominant trade winds bring most air that produces no rain, but the short monsoon season brings 600-1000 mm at the high elevations.

Fog Collection Evaluation and Operational Projects in the Hajja Governorate, Yemen

This is the region bordering on the Red Sea located to the northwest of the capital Sanaa. The people in the rural areas of the Yemen have a major need for clean drinking water in the winter months of December to March. This period is outside the yearly rain season, which extends from April to August. A fog collection protocols and instrumentation that have been developed in Chile was installed and evaluated .Table 1 shows the results of this evaluation. The field data quantified the fogwater collection potential in northern Yemen. The rates are very good, especially fog collectors 8, 9, 13, 23, 24 and 26 with averages above 1 liter a day during dry seasons. The best sites, fog collectors 8 and 9, averaged 4.5 L/m^2.d. The collection rates are the highest for sites between elevations of approximately 2000 and 2500 m above sea level in Mabiyan and Maswar districts. This rate of altitudes was used as starting point to continue the testing fog collection in Yemen, since the many villages are located at these altitudes. West winds are most productive. They generate 80% of the total fog collection. This humid air comes from the Red Sea and Mabiyan. In examining the data site by site, sites 8 and 9, with the best collection rates, were well exposed to the winds coming from the west up a major valley. Site 13 was in the same area but had the lower collection rates as the exposure to the west winds was not as good. The two sites in Hajja City (11 and 12) did not produce the high enough collection rates to justify the construction of large fog collectors at this time. An examination of the amount of fogwater collected as a function of wind speed shows that the fog is normally present with low wind speeds. Almost 50 % of the collection occurred when the wind speed was in interval of 2 of the Beaufort wind scale (Schemenauer *et al.*, 2004). One of the ways of measuring the wind is use of the Beaufort Table that Admiral Francis Beaufort in 1905 designed it for thw navigators. In the latter years it was used inland. Zero in this scale shows no wind condition and the maximum of it is 12 that shows hurricane.

Fogwater Harvesting along the West Coast of South Africa

The West Coast of South Africa is one of the most arid parts of the country with the annual rainfall rarely exceeding 250 mm. Only three perennial rivers traverse the area with the flow in the other smaller rivers varying seasonally and usually having drying beds in summer. Although a few communities make use of river water either through direct extraction or via pipelines or canals, the main source of water is groundwater through boreholes, wells and fountains. This is, unfortunately, not always available in sufficient quantities and is often contaminated with naturally occurring salts or heavy metals. There was

Table 1. Results obtained in Yemen (Average water production in liters per square meter per day)

Station	Average	Collector No.	UTM	Angle	Altitude (m)
Schiraqi	0.34	1	352061-1729727	180	2260
Schiraqi	0.32	2	352061-1729727	270	2260
Schiraqi	0.61	3	352530-1730131	170	2450
Schiraqi	0.25	4	352530-1730131	270	2450
Schiraqi	0.49	5	352662-1730058	240	2450
Schiraqi	0.30	6	352887-1730132	180	2450
Schiraqi	0.33	7	352312-1729695	190	2300
Mabyan	4.49	8	346743-1739771	230	2020
Mabyan	4.54	9	346622-1739871	215	2030
Mabyan	2.92	13	347000-1739300	270	2000
Mabyan	0.93	10	347416-1737470	200	1650
Hajja City (Antenna)	0.98	11	350366-1735330	225	1820
Hajja City (MOA)	0.36	12	350114-1734950	180	1750
Humlan	0.77	14	351331-1733100	230	1775
Humlan	0.52	16	351420-1732770	270	1835
Humlan	0.71	15	351520-1732080	250	1890
Aschmur	0.05	17	366230-1735710	270	2840
Aschmur	0.04	18	366230-1735710	180	2840
Aschmur	0.06	19	366230-1735710	0	2840
Maswar Bait Sheim	0.05	20	357050-1728100	180	2640
Maswar Bait Sheim	0.02	21	357050-1728100	250	2640
Maswar Bait Sheim	0.02	22	357220-1728100	0	2640
Maswar Bait Saad Salah	1.12	23	355000-1727600	0	2440
Maswar Bait Saad Salah	2.08	24	355000-1727600	270	2440
Maswar Bait Saad Salah	0.88	25	355000-1727350	180	2485
Maswar Bait Saad Salah	1.42	26	355000-1727350	270	2485

an urgent need to identify alternative sources of potable water such as fog water due to high population growth and the expected boom in west coast tourism. Figure 3 indicates that, in general, the annual fog incidence decreases with increasing latitude and longitude. The mean annual fog day frequency increases from 66 d per year at Dassen Island to 111 d at Cape Colombine, to 148 d at Port Noloth. Longitudinally, the zone with highest fog day frequencies abuts the coast, decreasing with distance from the sea this accords with the observations for the Namib and other west coast deserts. In this area the highest rate of collected water was reported at Cape Colombine.

Due to variability of the fog over short distances, the determination of spatial fog patterns is neither straightforward nor easy. In South Africa, this is exacerbated by the paucity of fog recording stations especially in the more sparsely populated parts of the country. The interpolation of the fog incidence between stations is therefore extremely difficult and a map resulting from this method is not ideal and cannot be regarded as detailed or accurate. Notwithstanding these limitations, a fog incidence map (Figure 4) was compiled which illustrates, to some extent, the spatial patterns of fog incidence along the West Coast.

Fogwater Quality

Quality of the collected fogwater in South Africa and some other areas are discussed in this section.. The results of the chemical and microbial analyses of two water samples that were collected from Cape Colombine on 24 August 1997 and on 18 May 1998 are given in Table 2.

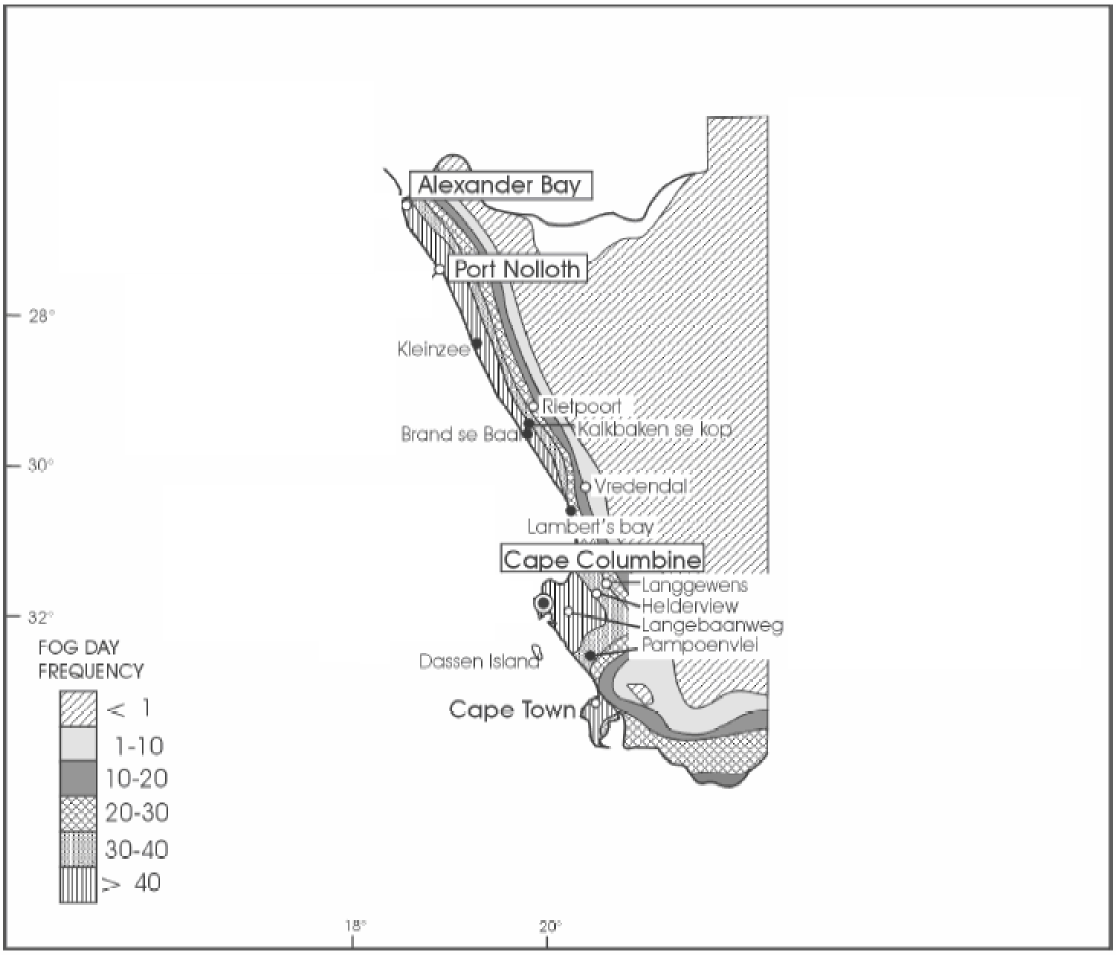

Fig. 4. Fog day frequency west coast (Olivier, 2002)

Table 2. Chemical and microbial analyses of Cape Columbine fog water

Chemical Analysis	**Date: 24/8/97**	**Date: 18/5/98**
Potassium as K (mg/l)	89.3	1.9
Sodium as Na (mg/l)	2522.0	44.0
Calcium as Ca (mg/l)	151.0	33.0
Magnesium as Mg (mg/l)	308.0	5.7
Ammonia as N (mg/l)	3.0	0.3
Sulphate as SO4 (mg/l)	674.0	17.0
Chloride as Cl (mg/l)	4692.0	77.0
Alkalinity as CaCO3 (mg/l)	56.0	177.0
Nitrate as N (mg/l)	13.2	0.4
Conductivity (mS/m) (Lab)	1400.0	45
pH (Lab)	6.5	7.3
Saturation pH (pHs 20°C)	7.8	8.0
Total dissolved solids (calc) (mg/l)	8960.0	288.0
Total hardness as CaCO3 (mg/l)	1648.0	106.0
% Difference	2.29	1.86
Cations meq/l	145.14	4.81
Anions meq/l	148.46	4.89
Microbial Analysis		
Heterotrophic P/C po 1 ml at 35°C	± 450000	
Total coliforms per 100 ml	0	
Faecal coliforms per 100 ml	0	-

A most important finding was that the water was free from any disease-causing organisms (E. coli) and, thus cannot cause a health hazard. The high counts of heterotrophic organisms are not significant since there is no specified maximum allowable limit. Moreover, these organisms can be removed using a simple sand filter. The microbial characteristics of potable water are determined, with existing or non-existing E. coli bacteria in samples. These bacteria that grow in the digestive system of human and animals are the contaminant or clean water indicates. In normal rate of these bacteria in 0.1 liter of sample, there is no coliform, evenly, one coliform.

The sodium chloride content was extremely high in the first sample. As this might have been due to contamination by wind-blown salt deposited on the collector during dry conditions, the collector was washed before collecting second sample. The second sample thus a true reflection of the quality of the water collected on the fog collector. The difference in water quality is marked. The total dissolved solids (TDS) have been decreased from 9000 mg/l to 288 mg/l. if the criterion alone is taken into account, water from the second sample has indeed water quality (TDS conc. < 450 mg/l (WHO, 2020)). However, it is not necessarily the TDS level but the concentration of specific ions that is determined to health. Fortunately, the concentrations of all ions are considerably less in the second sample. The sodium ion concentration having decreased from 2522 mg/l to only 44 mg/l. the calcium present in the water is probably the residue of the tap of water used to wash down the screen. Analysis of the second sample thus indicates that the water collected on the fog screens is potable and fit for human consumption. As wind-blown salt deposition clearly occurs on the collectors located close to the sea, it is assumed that this problem will not be experienced when the site is the further inland. In an operational system, some mechanism will have to be introduced to allow the first water collected during a wet event to be discarded.

Fog Chamber

The fog density and droplet distribution are two important factors to choose a suitable site for fog collection project. The fog droplet size determines the volume of the dissolved ions. The intensity of fog is one of the most important characteristics since it determines the visibility. The degree of visibility depends on the opacity of the air, resulting from the number of particles held in suspension. It is defined as “the greatest distance at which a dark object can be seen and identified for what it is against the horizon”.

1n 1999, laboratory of Clermont-Ferrand in charge of research on safety of roads invented a system that could measure these parameters. Fog characteristics are determined by means of a transmissiometer measuring the transmission factor related to the extinction coefficient, K. It allows the meteorological visibility range, MVR, to be determined by using the Koshmieder low as:

$$MVR = 3 / K \quad (1)$$

The extinction coefficient is directly connected to the fog granulometery; that is to say droplet diameter and concentration. In order to characterize these physical parameters, an optical granulometer is used (Colomb *et al*., 2004).

RESULTS AND DISCUSSION

Table 3 shows the results from the various fog chemistry studies around the world. Values in bold are those exceeding the WHO guidelines. The high levels of As, Pb and Se in Chile are associated with first flush and the preceding quality is closer to the lower values presented. The high level of heavy metals in India is attributed to the heavy industries such as iron smelting, aluminum production and burning pyrite-rich coal.

Concentrations of dissolved ions are greatly influenced by droplet size; comparison of different droplet fraction has shown a higher concentrations in smaller fog droplets. Studing the fog-droplet sizes needs specialized equipment. In Paposo (Chile) fog water did not meet the WHO standards for chlorine and nitrate. However, as the Table 3 shows, other studies have found the chlorine and nitrate levels to be well within the WHO limits, expect in rural France which is probably due to high levels of nitrate usage in agriculture.

One of the most notable characteristics of fog water is the low pH. The majority of fog water chemistry studies presented at the 1998 Vancouver Conference (Canada) reported typical values of between 3 - 5 (Schemenauer and Bridgman, 1998).

CONCLUSION

The fact that the highest yields were measured at Cape Colombine in the South Africa emphasizes the fact that the high fog incidence does not necessarily imply that high volumes of water can be collected. The origin of the fog, wind speed during fog events and elevation are the major determinants in the volume of water that can be collected. Indeed,

Table 3. The results of analyses the fog water around the world

France	Taiwan	India	Namibia	Oman	Chile	WHO	Chemical characteristic *(mg/l)*
3.94	4.08	0.4-6.5	6.2	7.4	4.7	6-8.5	pH
0.67	-	0.29-0.96	-	<0.06	<0.05-0.21	0.3	Fe
0.27	-	0.05-0.96	-	0.014	0.002-0.283	0.3	Mn
123.0	5.4	16.1-31.9	3.4	4.7	1.6	45	NO_3
<0.05	17.0	21.1-110.5	3.2	3.4	12.3	400	SO_4
-	-	0.5-2.4	-	0.02	-	1.5	F^-
49.4	28.2	12.2-35.4	4.8	44.1	8.7	250	Cl^-
-	-	-	-	<0.001	0.012-0.073	0.05	As
0.006	-	-	-	<0.0005	<0.5-0.006	0.005	Cd
<0.02	-	-	-	<0.005	<0.001-0.003	0.05	Cr
0.21	-	0.10-3.90	-	<0.005	<0.003-0.218	1.0	Cu
0.142	-	0.09-0.10	-	<0.0005	0.001-0.181	0.05	Pb
-	-	-0.019-0.125	-	-	-	0.001	Hg
-	-	-	-	<0.005-0.008	<0.005-0.016	0.01	Se
1.4-65.4	1.9	12.2-35.4	1.2	15.1	0.1	200	Ca
-	1.5	1.6-6.2	0.4	2.9	0.7	125	Mg

selection of a suitable site is vital to the success of a fog water harvesting project. Pipe costs from the collectors to the point of use are the major infrastructure costs. Thus, it is important to minimize the pipe length. Not only is cost an issue, but also the hydraulics must work. Thus, the collectors must be high enough above the users for sufficient pressure for water delivery. According to the reports following Yemen project, in terms of more widespread application in the region, all of the ridges and mountain chain above 2000m, from the north (Saudi Arabia) to the south (Aden), would potentially be good productive sites and should be evaluated for their fog collection potential. Persian Golf's Islands in Iran have the similar characteristics. So that, the evaluation of the potential of these islands for fog collecting is considerable. The chemical and microbial studies on fog water have shown that the collected water in most area is suitable as drinking water. Once the yield and quality have been determined, the unit cost of water produced should be calculated. A decision must be made as to what the fog water will be used for. The collected water can be used in reforestation, domestic water supply, agricultural water productivity, and energy production for driving small turbines. In Table 4, advantages and disadvantages of a fog water project are discussed. One of the most disadvantages of project is that the pilot project for estimating the yield is necessary.

ACKNOWLEDGMENT

We sincerely thank Dr. Ali Akbar Alemrajabi and Dr. Ahmad Sedaghat, the professor and the associate professor of the Department of Mechanical Engineering of Isfahan University of Technology for their information and guidance about fog chamber.

REFERENCES

Bhushan, B. (2020). Design of water harvesting towers and projections for water collection from fog and condensation. Philosophical Transactions of the Royal Society A, 378(2167), p. 20190440.

Table 4. Advantages and disadvantages of a fog water project

Advantages	Disadvantages
1. Quick and simple design and construction and without any need to many time and skill for installation	**1**. Need to very specific climatological and topographic conditions
2. Un patentable technology (except some mesh designs)	**2.** Need to pilot project for estimating yield
3. Modular system that can grow in line with demand or available funds	**3.** Very sensitive yield to changes in climate conditions consequently, necessity of a back-up supply
4. Operation of passive collection without any energy	**4.** Non-attention to regional or national importance of fogwater collection as water supply
5. Cheap and easy to maintain and repair	**5.** Economic and hydraulic problems due to further distance between point of use and collectors
6. Low capital investment and other costs compared to conventional sources of potable water in mountainous and arid areas	**6.** Necessity of existence of a good access for installation, maintenance and monitoring
7. Multiple uses of water for domestic, irrigation, livestock, reforestation	**7.** Security of land tenure problems
8. Potential to improve the quality of life for rural communities in remote desert and mountainous areas	**8.** Abnormal quality in some regions for chlorine, nitrate and some mineral
9. Good quality of water in non- industrial areas, though low pH rarely	**9.** Vulnerability to vandalism
10. beneficial environmental impact of collected water	**10.** Possible secondary environmental degradation through increased human and livestock populations in fragile ecosystems

Brown, P.S. and Bhushan, B. (2016). Bioinspired materials for water supply and management: water collection, water purification and separation of water from oil. Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences, 374(2073), p. 20160135.

Carvajal, D., Minonzio, J.G., Casanga, E., Muñoz, J., Aracena, A., Montecinos, S. and Beysens, D. (2018). Roof-integrated dew water harvesting in Combarbalá, Chile. Journal of Water Supply: Research and Technology—AQUA, 67(4): 357-374.

Colomb, M., Dufour, J., Hirech, M., Lacôte, P., Morange, P. and Boreux, J.J. (2004). Innovative artificial fog production device-A technical facility for research activities.

Eludoyin, A. (2020). Accessibility to Safe Drinking Water in Selected Urban Communities in Southwest Nigeria. Water Productivity Journal, 1(2): 1-10. doi: 10.22034/wpj.2020.248540.1013.

Furey, S. (1998). Fogwater harvesting for community water supply, Doctoral Dissertation, Cranfield University, UK.

Gupta, V.K., Ali, I., Saleh, T.A., Nayak, A. and Agarwal, S. (2012). Chemical treatment technologies for waste-water recycling—an overview. Rsc Advances, 2(16), pp. 6380-6388.

Kaseke, K.F. and Wang, L. (2018). Fog and dew as potable water resources: Maximizing harvesting potential and water quality concerns. GeoHealth, 2(10): 327-332.

Maleki, M., Eslamian, S. and Hamouda, B. (2021). Principles and Applications of Atmospheric Water Harvesting. Handbook of Water Harvesting and Conservation: Basic Concepts and Fundamentals, pp. 243-259.

Olivier, J. (2002). Fog-water harvesting along the West Coast of South Africa: A feasibility study. Water Sa, *28*(4): 349-360.

Schemenauer, R.S. and Bridgman, H. (1998). 1st International Conference on Fog and Fog Collection: proceedings: First International Conference on Fog and Fog Collection, July 19-24, Vancouver, Canada.

Schemenauer, R.S., Osses, P. and Leibbrand, M. (2004). Fog collection evaluation and operational projects in the Hajja Governorate, Yemen. In Proceedings of the Third International Conference on Fog, Fog Collection and Dew, (1115): 11-15 October, Cape Town, South Africa.

Trenberth, K.E. (2011). Changes in precipitation with climate change. Climate Research, 47(1-2): 123-138.

UN. (2018). Sustainable development goal 6: synthesis report 2018 on water sanitation. NewYork, NY: United Nations. See www.unwater.org/app/uploads/2018/07/SDG 6_SR2018_web_v5.pdf.

Valiente, J.A., Estrela, M.J., Corell, D., Fuentes, D., Valdecantos, A. and Baeza, M.J. (2011). Fog water collection and reforestation at a mountain location in a western Mediterranean basin region: Air-mass origins and synoptic analysis. Erdkunde, pp. 277-290.

WHO/UNICEF. (2017). Progress on drinking water, sanitation and hygiene: 2017 update and SDG baselines. Geneva, Switzerland: WHO/UNICEF. See washdata.org/sites/default/files/ documents/reports/2018-01/JMP-2017-report-final.pdf.

WHO (World Health Organization, Drinking-water). (2020). URL https://www.who.int/news-room/fact-sheets/ detail/drinking-water.

Wiin-Nielsen, A. (1973). Compendium of Meteorology for Use by Class I and Class II Meteorological Personnel: pt. 1. General hydrology (Vol. 2, No. 4). Secretariat of the World Meteorological Organization, Geneva, Switzerland.

WWAP. (2019). The United Nations world water development report 2019: leaving no one behind. WWAP (UNESCO World Water Assessment Programme): UNESCO, Paris, France.