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Investigation of the Potential of Fogwater Harvesting in the Western Mountainous Parts of Yemen

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Abstract: The Republic of Yemen is located in an arid to semi-arid region. Rainfall rates range from none at certain parts of the country to about 400 mm/yr in its mountainous parts. Rainfall has been harvested and collected in cisterns existed in the mountainous region for generations. In the dry season (October - February), and after the stored water is consumed, people, mainly women and children, have to travel long distances down wadis to fetch water from the nearest water source, which is often not suitable for human consumption. This is the case in the western mountainous region, namely Hajja Governorate, which heavily depends on rainwater for drinking, animal watering, domestic uses and irrigation. However, during the dry season this region experiences foggy conditions. A fog collection field study was carried out in this region to investigate the potential of providing an alternative source for water supply during the dry season. The study consisted of installing 26 standard fog collectors (SFC) of one m² of polypropylene mesh at 19 sites in Hajja, and measuring the daily fogwater amounts collected during the period from 1 January 2003 to 31 March 2003. The results indicated that fog collectors located closest to the red sea with an elevation ranged between 2000-2200 m.a.s.l. and winds from the west direction have produced the highest water output, reaching a maximum of about 4.5 liters per square meter of mesh per day over the three winter months period. The conclusion drawn is that though this technique is cheap, simple and promising, more investigations are still needed on the various parameters contributing to fog collection, such as, relative humidity, temperature, and SFCs technologies.

Key words: *fogwater harvesting, arid and semi arid, mountains, Yemen*

تحري إمكانية حصاد الضباب في الأجزاء الجبلية الغربية لليمن

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المستخلص: تقع الجمهورية اليمنية في نطاق المناطق الجافة وشبه الجافة ويقدر متوسط الهطول السنوي فيها من الصفر في المناطق الصحراوية إلى 400 مم في المناطق الجبلية. على مدى الأجيال يتم حصاد وتجميع مياه الأمطار في البرك والخزانات لأستخدامها للشرب وللأغراض المنزلية الأخرى وخاصة في المناطق الجبلية. وفي مواسم الجفاف (أكتوبر – فبراير)، وبعد نفاد المياه المجمعة، يتم جلب المياه من مسافات بعيدة، من قبل النساء والأطفال أساساً، والتي غالبا ما تكون غير صالة للأستخدام الآدمي. وتنطبق هذه الحالة على منطقة الدراسة بمحافظة حجة الواقعة في الجبال الغربية من اليمن، والتي تعتمد على مياه الامطار للشرب وسقي المواشي والاستخدامات المنزلية والري. إلا انه خلال فترة الجفاف تتسم هذه المنطقة بموسم ضبابي، مما استدعى عمل دراسة حقلية للتحري من إمكانية تزويد المناطق الجبلية بمصدر بديل للمياه من الضباب. أشتملت هذه الدراسة على تركيب 26 جهاز قياسي لتجميع الضباب بمساحة واحد متر مربع لشبكة من مادة البوليبروبيلين في 19 موقعا مختلفا في منطقة حجة، وقياس كمية مياه الضباب المجمعة اليومية خلال الفترة من 1 يناير 2003 - 31 مارس 2003. ولقد أشارت نتائج الدراسة إلى أن كمية الضباب المتجمعة من الأجهزة القريبة من سفوح الجبال المحاذية للبحر الأحمر وذات ارتفاع يتراوح بين 2000-2200 متر من منسوب سطح البحر وباتجاه رياح غربية هي الأكثر إنتاجية، حيث وصل معدل تجميعها إلى 4.5 لتر/م^2/يوم في مدة ثلاثة أشهر. ولقد خلص هذا البحث إلى أنه برغم أن هذه التقنية بسيطة ورخيصة وواعدة، إلا أنه ما زالت هناك حاجة لإجراء دراسة للتحقق من تاثير المعاملات الأخرى التي تساهم في عملية تجميع الضباب، مثل الرطوبة النسبية ودرجة الحرارة وايضا تقنيات أجهزة تجميع الضباب.

كلمات مدخلية: *حصاد الضباب, مناطق جافة وشبه جافة, جبال, اليمن.*

Introduction

Water scarcity is considered as one of the major threats to humankind in this century. This is specially true in the arid regions of the world, where it is expected that available water resources in streams, rivers and groundwater in most of these regions will not be sufficient to meet the future ever-increasing needs of agriculture and urban areas. Therefore, there is a need to reassess ~~certain (the word certain is not needed)~~ indigenous irrigation methods to find their potential value to alleviate future water scarcity (Prinz, 1996). These methods, if associated with water saving techniques, modern hydrological and technological tools, may supplement other water sources and help in securing future water supply.

Commented [wkz1]: Should not we say here “water harvesting methods” instead of irrigation methods, since harvesting will include water use for irrigation and domestic needs, please check the reference again and suggest. May be we can go with irrigation methods but to add water harvesting

In general, water harvesting methods can be classified based on the source of harvested water (Figure 1), which can be water in air, overland flow, or groundwater (Prinz, 1996; FAO, 1997). Of particular interest to this study are the methods of fogwater collection, which were developed in areas without permanent rivers, and where people have to rely on rainfall, dew and fog. These methods are based on the principle that water can be collected from fogs under favorable climatic conditions to provide water for small rural communities in arid and semi-arid regions. This innovative, non-classical water harvesting method has the advantages of being simple, can be applied without large investments, and can be maintained and managed by the users themselves, and hence offers good prospects for future development (FAO, 1997). However, the challenge in implementing these methods effectively is to identify suitable communities and favorable environmental conditions, and ensure that the system meets user demand sustainability, and to develop an efficient system ~~that is efficient~~ to collect water for regional agricultural purposes.

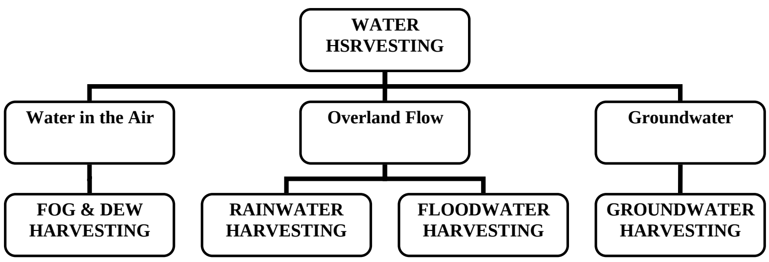

Fig. 1. Water harvesting methods (Prinz, 1996)

Literature indicate that the modern era of fog collection has started in 1987 with the construction of a pilot project of 50 fog collectors at El Tofo district, located in the mountainous region of Chile (Schemenauer and Cereceda, 1994a). In 1992, water from these collectors was taken to the village of Chungungo. In the following years, the number of fog collectors on the mountains of El Tofo district was increased to 100, and the average fogwater production reached about 15,000 liters per day during a year. Since then, the number of fog collectors has varied somewhat depending on need and circumstances. As a result of these projects, other fog collection projects have been initiated in other parts of Chile, as well as in other countries such as Peru, Ecuador, South Africa and the Canary Island of Spain (Canto, 1998). In addition, several evaluation studies have been carried out in many countries, such as Mexico (Schemenauer and Cereceda, 1994b) and Sultanate of Oman (Alesh, 2003; Hildebrandt *et al*., 2005).

The objective of this study is to investigate the potential applicability of fogwater harvesting in the mountainous region of Yemen, and to get sufficient data for making reliable estimates of the daily yield in the different climatic seasons through out the year. Furthermore, an analysis of the relationship between the collected amounts and seasonality, best placement and orientation of the collectors is made to help in the future design process to ensure the best performance at an affordable cost.

Study Area

The Governorate of Hajja, located in the western mountainous region of Yemen, was selected for the fogwater harvesting field experiment (Figure 2). Hajja Governorate is located northwest of the capital city of Sana'a, Yemen, and inland from the red sea, with an altitude range of 1,650 to 2480 meters above sea level. Many people in Hajja depend heavily on rainwater for drinking, animal watering, domestic uses and irrigation. In Hajja, precipitation occurs in two periods, between the months of March and May, and between the months of July and September. During the dry season (October-February), Hajja becomes a foggy region, and hence it was chosen for the study.

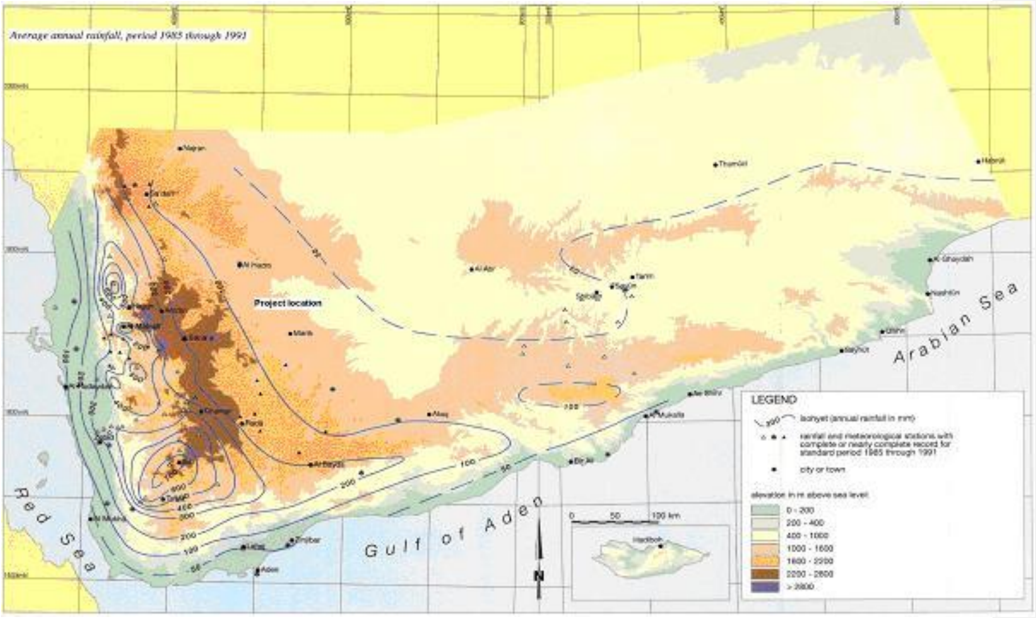

Fig. 2. Location of the Pilot study area in Yemen and rainfall contour map (Jan van der Gun and Abdelaziz ahmed, 1995). ~~The old map is better than this one!! The boundary of yemn is not shown here clearly!~~

Materials and Methods

Twenty-six Standard Fog Collectors (SFCs), with an area of 1 m^2, were constructed with locally available materials and local workmanship, except for the mesh which was imported. These SFCs were installed in December 2002 and January 2003 at chosen 19 different sites. The data of the amounts of the fogwater collection were measured in the period from 1st of January 2003 to 31st of March 2003.

The Standard Fog Collector (SFC) was designed by Schemenauer and Creceda (1994a). The collector is relatively simple and flat; rectangular nets (mesh) of nylon supported by a post at either end ?or? are? set perpendicular to the direction of the prevailing wind. The one used in this study consisted of a

1 m^2 panel of mesh, located 2 m above the ground by a supporting structure (Figure 3). The collection of fog or cloud is achieved by the collision of suspended droplets on a mesh. The droplets coalesce on the mesh and run down into a collecting drain and then into a tank or distribution system. Fog collection can be thought of as an aerial spring; the piping and delivery system is similar to a standard spring-fed gravity water supply (FAO, 1997).

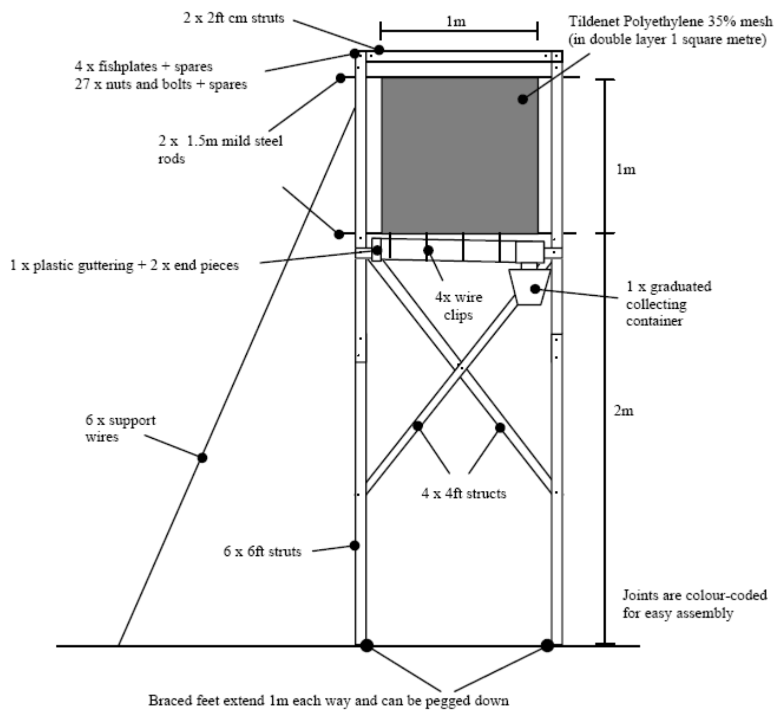

Fig. 3. Diagram of Standard Fog Collector (SFC) used in the study area (Schemenauer and Cereceda, 1994a)

The variables required to quantify the magnitude and reliability of supply and the orientation and sturdiness (Schemenauer and Cereceda, 1994b) required by Fog Collection Units (FCU), include:

- Fog-water yield (m^3 m^{-2} day^{-1})
- Annual variation and seasonality of yield
- Rainfall (mm day^{-1})
- Wind speed (m s^{-1})
- Wind direction during fog events

In order to get a comprehensive assessment of the fog harvesting potential, it is necessary to make daily measurements for the whole year. However, if the study area location has a known fog season, such as the monsoonal fog of Oman (Alesh, 1998), then the study period may be shortened to that season. In this study measurements were made for the foggy season (i.e., Janurary-March).

PARAMETERS INFLUENCING FOG COLLECTIONS

Wind patterns
Conditions for fogwater harvesting are considered best where there are persistent winds in one direction to transport low-level cloud and fog. Figure 4 shows a schematic west-east cross section of an idealized case for the Tihama coastal plain, in Yemen and Saudi Arabia (Furey, 1998). However, this is a very simplistic explanation, and fog in these desert areas can be caused by much more complex atmospheric and oceanic interactions that are not properly understood.

Mountain range
The topographic relief must intercept the cloud. In the case of low-level coastal fog the interception can be made by isolated hills or dunes. For higher clouds, larger mountains are needed. In the latter case the cloud can be pre-existing or orographically induced (Schemenauer and Cereceda, 1994a).

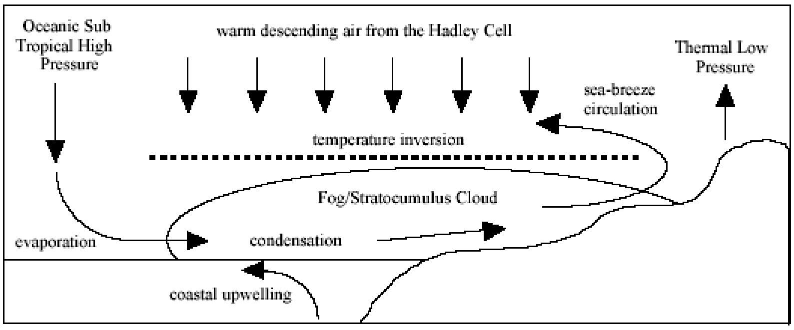

Fig. 4. Mechanisms of the formation of the West Coast advection fog (Furey, 1998)

Distance to the coastline
Marine cloud and fog decks generally dissipate further inland due to evaporation. It is often therefore desirable to have collectors located within 5 km of the coast and usually not more than 25 km (Furey,1998). This distance must be balanced against topography in relation to the cloud deck. Observations and experiments are needed to determine the optimum location. In high elevation areas where cloud is intercepted or induced by the topography, the distance to the coast becomes irrelevant (Furey, 1998)

Orientation of the topographic features
It is important that the longitudinal axis of the mountain range, hills, or dune system be approximately perpendicular to the direction of the wind bringing the clouds from the ocean. The clouds will flow over the ridge lines and through passes, with the fog often dissipating on the downwind side. If the orientation of the SFCs is not directly into the fog then the yield is likely to be underestimated. In Namibia, the use of a bi-directional fog collector was suggested to provide more accurate information for choosing the best orientation for the large collectors (Furey, 1998).

Rainfall seasonality

Rainfall in Yemen depends on two main mechanisms, the Red Sea Convergence and the Monsoonal Inter-tropical Convergence Zone. The former influence is most noticeable in the west of the country; this mechanism is active from March to May and to some extent in autumn (i.e., October-November) (Abdullah: indicate the months of automun), while the latter reaches the country in July-September, moving north and then south again, so that its influence lasts longer in the south. Seaward exposed escarpments such as the western and southern slopes receive more rainfall than the zones facing the interior (Meteorological Service, 2000). this info has no relevance here, suggest to delete it The average temperature decreases more or less linearly with the latitude

FIELD WORK AND MEASUREMENTS

Planning for the fieldwork began in November 2002, and subsequently 26 SFCs were constructed in nineteen different sites in Hajja region. Table 1 shows the locations, orientations and the elevations of the SFCs in the study area.

The SFCs were preferentially sited on ridges and saddle points in positions where experience has shown that there will be strong enough winds to push the fog through the mesh of the collectors. The SFCs were located facing the south and west directions depending on the local topography based on the prevailing wind direction during the months of December, January, February and March, which are from the south and sometimes west (meteorological Service, 2000).

The harvested fogwater was measured on a daily basis; measurements were made during the period from the first of January to the 31st of March, 2003. These are the dry months in winter when rainfall is virtually non-existent and the need for water is very high.

Table 1. SFCs details in the study area.

Area name	Site Number	SFC Number	Location UTM E N	Orientation	Elevation (m.a.s.l)
Schiraqi	1	1	352061 - 1729727	180	2260
Schiraqi	1	2	352061 - 1729727	270	2260
Schiraqi	2	3	352530 - 1730131	170	2450
Schiraqi	2	4	352530 - 1730131	270	2450
Schiraqi	3	5	352662 - 1730058	240	2450
Schiraqi	4	6	352887 - 1730132	180	2450
Schiraqi	5	7	352312 - 1729695	190	2300
Mabyan	1	8	346743 - 1739771	230	2020
Mabyan	2	9	346622 - 1739871	215	2030
Mabyan	3	13	347000 - 1739300	270	2000
Mabyan	4	10	347416 - 1737470	200	1650
Hajja City (Antenna)	1	11	350366 - 1735330	225	1820
Hajja City (MOA)	2	12	350114 - 1734950	180	1750
Humlan	1	14	351331 - 1733100	230	1775
Humlan	2	16	351420 - 1732770	270	1835
Humlan	3	15	351520 - 1732080	250	1890
Aschmur	1	17	366230 - 1735710	270	2840
Aschmur	1	18	366230 - 1735710	180	2840
Aschmur	1	19	366230 - 1735710	0	2840
Maswar Bait Sheim	1	20	357050 - 1728100	180	2640
Maswar Bait Sheim	1	21	357050 - 1728100	250	2640
Maswar Bait Sheim	2	22	357220 - 1728100	0	2660

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Maswar Bait Saad Salah	3	23	355000 - 1727600	0	2440
Maswar Bait Saad Salah	3	24	355000 - 1727600	270	2440
Maswar Bait Saad Salah	4	25	355000 - 1727350	180	2485
Maswar Bait Saad Salah	4	26	355000 - 1727350	270	2485

It is not clear how there is 19 sites out of the 26, clarify! I have counted them in the second column and they do not add to 19!

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RESULTS AND DISCUSSION

Analysis of the data of the harvested fogwater during the study period (1 January - 31 March 2003) indicates that fogwater collection rates observed in the majority of the collectors were not acceptable according to Schemenauer and Cereceda (1994a), while the collection rates in collectors numbers 9, 8, 13, 24, 26 and 23 were moderate averaging about 1 liter per day (Figure 5). In general, Mabyan area collection sites collected the highest water output (9, 8, and 13), with site 9, the closest site to the to the red sea, producing the highest measured rate (a total of 400 liters). Furthermore, analysis of the data trends during the study period have shown that the period from mid-January to the end of February is a dry period with lower water production, while during the month of March water production rate is excellent. The data also shows that the collectors on the highest altitude sites did not produce a significant amount of water. It is worth noting that as the climate may vary from a year to another, and therefore, determining the daily, weekly, monthly and annual climatic parameters variations is important in order to determine both the water availability and the water storage requirements.

Figure 6 shows the variation of fog collection with wind direction, which indicates that the west winds are the most productive. Humid air comes from the Red Sea, with Mabian the first mountain range encountered in its way inland. Examinations of the data of sites 9 and 8, which have the best collection rates, were well exposed to winds coming from the west up a major wadi. Site 13 was in the same area but had lower collection rates, as the exposure to the west winds was not as good as the others. However, in light of the observations that collection rates were also high with southwest winds, it would be valuable to examine several new sites to the north of the city, which may be proved to be productive.

Figure 7 shows the variation of fogwater collection with different wind speeds. In Hajja governorate the fog is present with low wind speeds. Almost 50% of the water collection occurred when the wind speed was around 2 of the Beaufort wind speed.

The variation of the fogwater collection with elevation is illustrated in Figure 8, and it shows good collection amounts between elevations of approximately 2000 and 2500 m above sea level. The collection rates for these sites are from 1.12 to 4.5 liters per square meter of mesh per day in the Mabian and Maswar districts. This range of altitudes is a good starting point to continue testing fog collection in Yemen, especially since many villages are located at these altitudes. In general, all the ridges and mountain chains located from the north to the south that are above 2000 m would be potentially good productive sites and need to be evaluated.

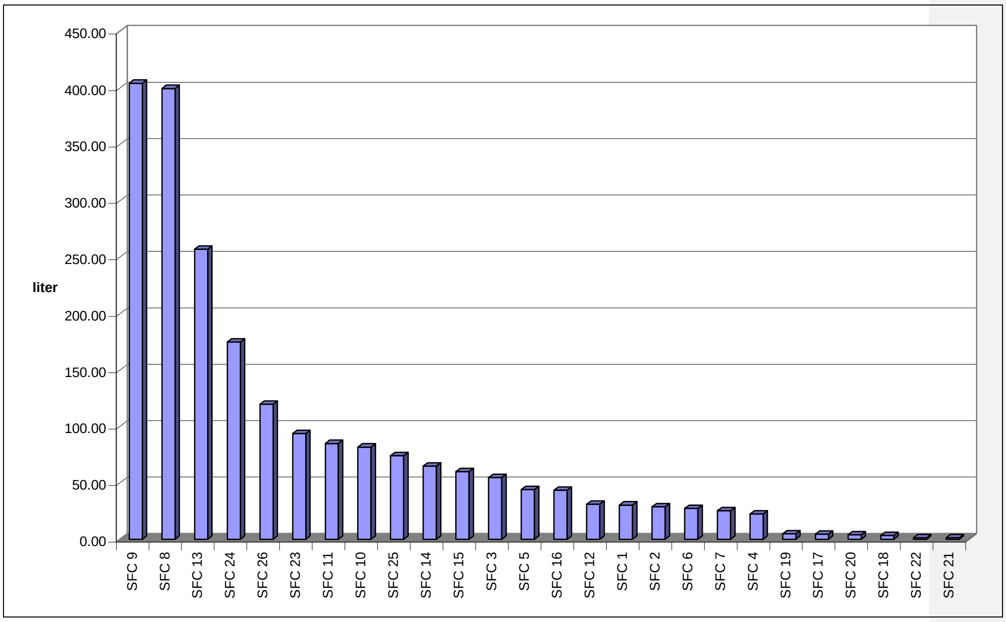

Fig. 5. Total fogwater collection amounts in the project area for the period 1 January - 31 March 2007.

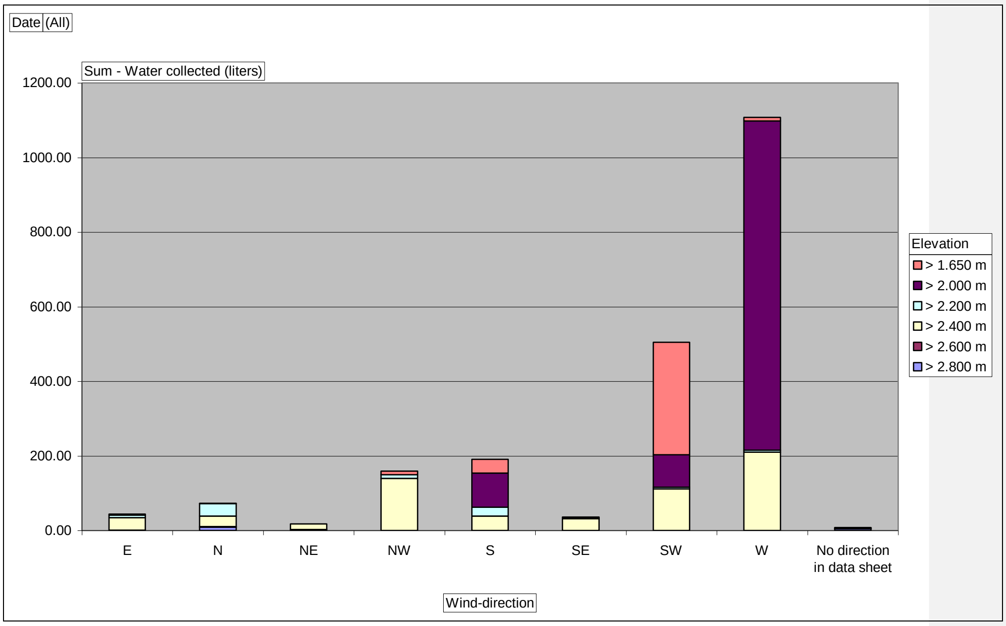

Fig. 6. Variation of fogwater collection with wind direction.

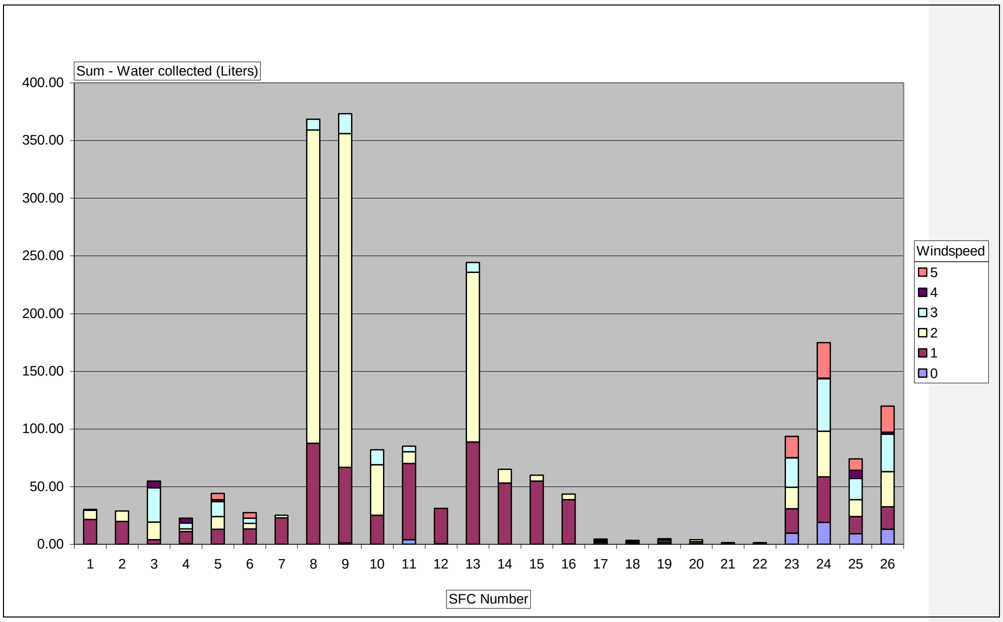

Fig. 7. Variation of Fogwater collection with wind speed.

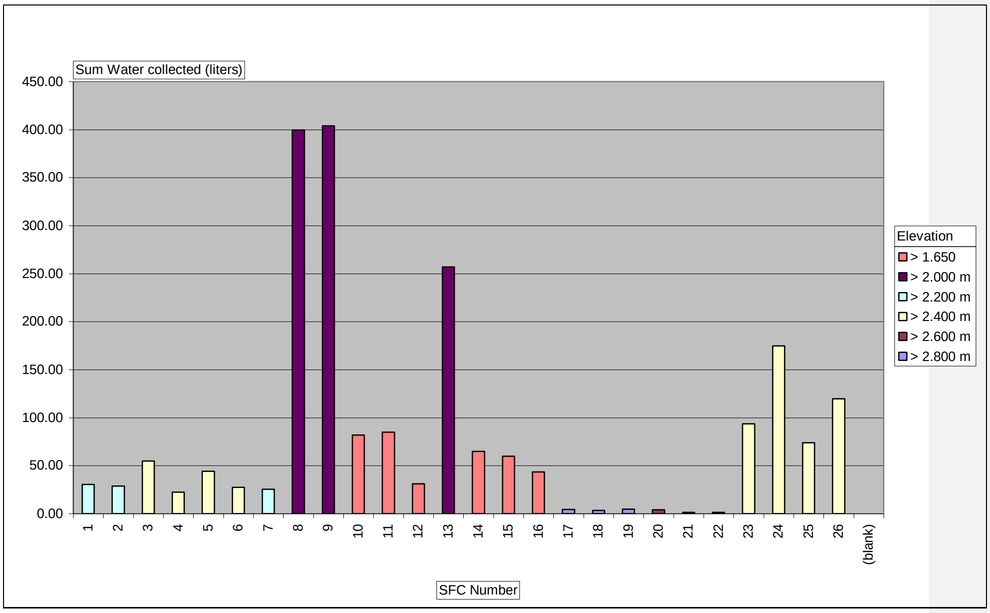

Fig. 8. Variation of fogwater collection with altitude.

CONCLUSION AND RECOMMENDATIONS

The field study on fogwater collection in the western mountainous areas of Yemen indicated that fogwater can represent an important water resource for the inhabitants with maximum water amounts occurring in the dry winter months of January to March. Fogwater harvesting might be an appropriate technological solution that can be built, managed and maintained by rural communities to be used for watering plants and a forestation.

The field study results indicated that fog collectors located closest to the red sea with an altitude range between 2000-2200 meters above sea level and westerly winds have produced the highest water output, reaching a maximum of about 4.5 liters per square meter of mesh per day over the three winter months period. It is recommended that more investigation is made on the relationship and impact of various climatic parameters contributing to the fog collection, such as relative humidity, temperature, and the distance from the coastline, as well as SFCs technologies. Operational requirements should be investigated, which include measurement of the volume collected and recording of meteorological data, either manually or by automatic weather station, since changes in weather conditions may change the operational design of the harvesters. Furthermore, more sites should be studied and investigated, either in Hajja or elsewhere in Yemen such as in the eastern parts of the country.

Furthermore, it is recommended that research is made on the dynamics and chemistry of fog in order to optimize quality and yield, and on the design of more efficient meshes needed to increase the yield to keep costs and space requirements down.

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