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

تحري إمكانية حصاد الضباب في الأجزاء الجبلية الغربية لليمن

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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. This has prompted conducting a fog collection field study 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 m^2 of polypropylene mesh at 19 sites in Hajja, and measuring the daily fogwater amounts collected during the period from 1 January to 31 March, 2003. The results indicated that fog collectors located closest to the red sea with an elevation ranged between 2,000-2,200 meters above sea level 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.

Keywords: *fogwater harvesting, arid and semi arid, mountains, Yemen.*

المستخلص: تقع الجمهورية اليمنية في نطاق المناطق الجافة وشبه الجافة، ويقدر متوسط الهطول السنوي فيها من الإنعدام في المناطق الصحراوية إلي 400 مم في المناطق الجبلية. على مدى الاجيال 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 التي تم تجميعها، يتم جلب المياه من مسافات بعيدة، من قبل النساء والأطفال أساساً، والتي غالبا ما تكون غير صالحة للاستخدام الادمي. 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 يسود فيه الضباب، مما استدعى عمل دراسة حقلية للتحري من إمكانية تزويد المناطق الجبلية بمصدر بديل للمياه من الضباب خلال فترة الجفاف. 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 إلى 13 مارس، 2003. ولقد أشارت نتائج الدراسة إلى أن كمية الضباب المتجمعة من الأجهزة القريبة من سفوح الجبال المحاذية للبحر الاحمر وذات ارتفاع يتراوح بين 2000-2200 متر من منسوب سطح البحر وباتجاه رياح غربية هي الاكثر إنتاجية، حيث وصل معدل تجميعها إلى 4.5 لتر/م2/يوم في مدة ثلاثة أشهر. ولقد خلص هذا البحث إلى إنه برغم من ان هذه التقنية بسيطة وقليلة التكاليف وواعدة، إلا انه ما زالت هناك حاجة لإجراء دراسة للتحقق من تاثير المعاملات الاخرى التي تساهم في عملية تجميع الضباب، مثل الرطوبة النسبية ودرجة الحرارة وايضا تقنيات اجهزة تجميع الضباب.

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

NTRODUCTION

Water scarcity is considered as one of the major threats to humankind in this century. This is especially 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 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.

In general, water harvesting methods can be classified based on the source of the 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 (water in air), 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 fog 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 to collect water for regional agricultural purposes.

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 the needs and conditions. As a result of these successful 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 was 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 that can be achieved during the foggy season. 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.

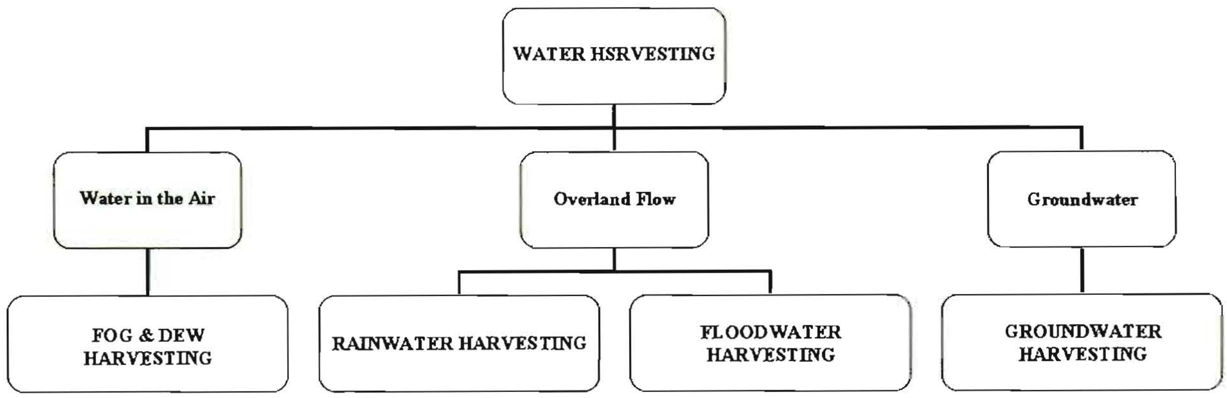

Fig. 1. Water harvesting methods (Prinz, 1996).

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 between 1,650 and 2,480 meters above sea level (masl). 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 experiences foggy conditions, and hence it was chosen for the study.

MATERIALS AND METHODS

Twenty-six Standard Fog Collectors (SFCs) were constructed with locally available materials and local workmanship, except for the mesh that was imported. These SFCs were installed in December 2002 and January 2003 at 19 different sites that were chosen for the field study. 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 both ends arranged perpendicular to the direction of the prevailing wind. The SFC 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).

The complete system can be easily build or assembled on site. The installation and connection of the panels is quick and simple, and the assembly is not labor intensive and requires little skill. No energy is needed to operate the system or transport the water, capital investment is low, and maintenance and repair are minimal (IDRC, 1997).

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

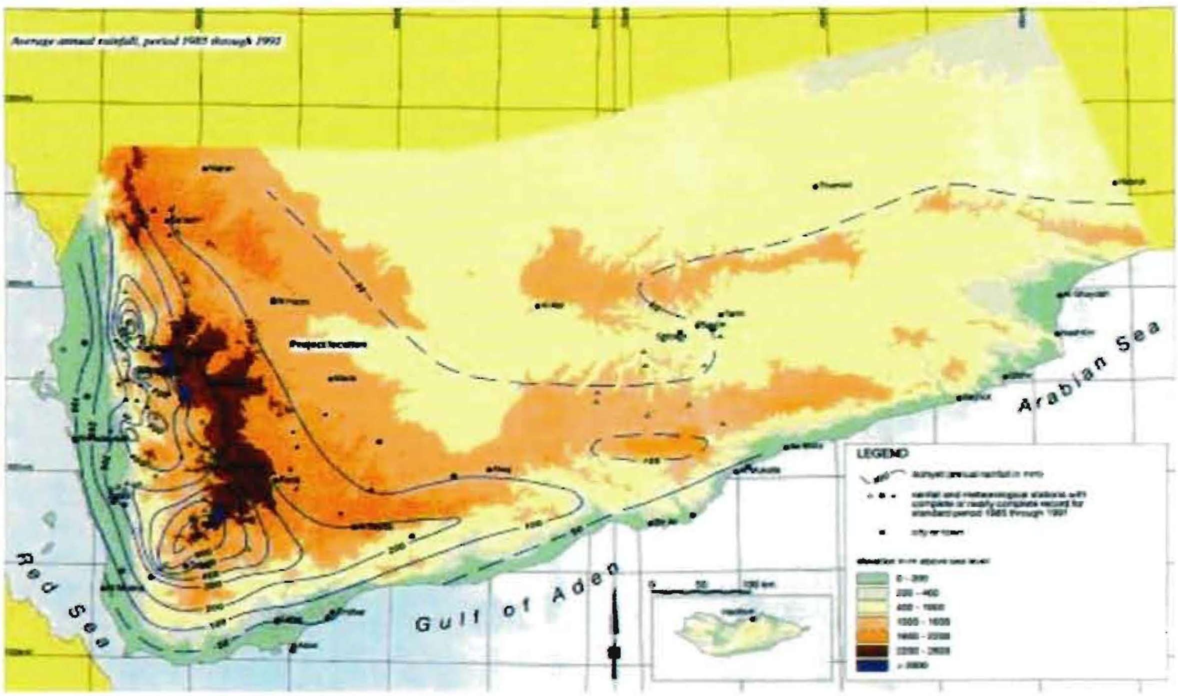

Fig. 2. Location of the Pilot study area in Yemen and rainfall contour map (Van Der Gun and Ahmed, 1995).

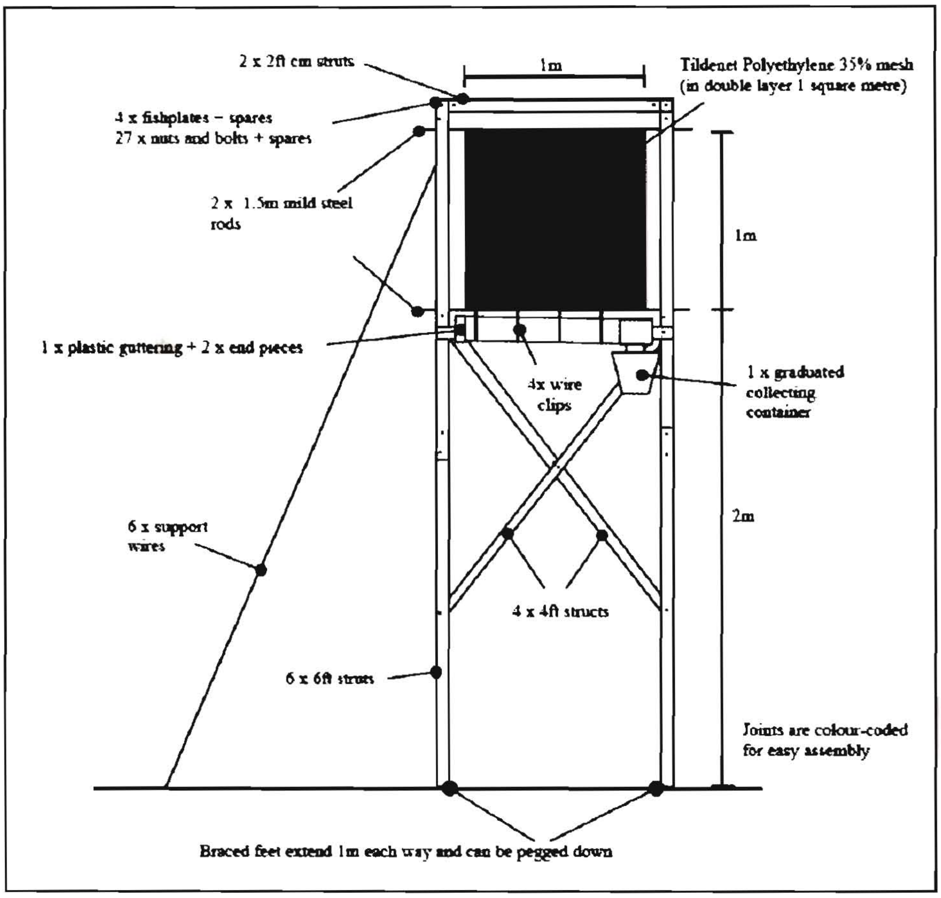

Fig. 3. Diagram of Standard Fog Collector (SFC) used in the study area (Schemenauer and Cereceda, 1994a).

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 only during the foggy season (i.e., January-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 need further investigation understanding.

Distance to the coastline

Marine clouds and fog decks generally dissipate further inland due to evaporation. It is often

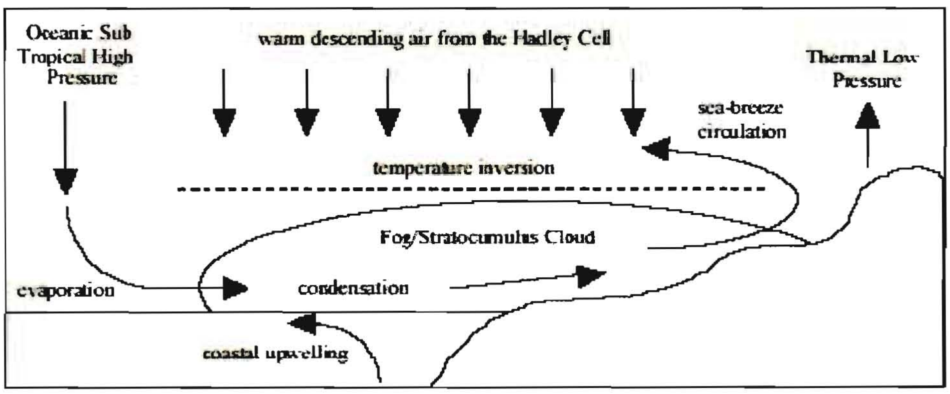

Fig. 4. Mechanisms of the formation of the West Coast advection fog (Furey, 1998).

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 ridgelines and through passes, with the fog often dissipating on the downwind side. If the orientation of the SFCs is not directly facing the fog movement 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 mechanism influence is most noticeable in the west of the country; this mechanism is active from March to May and to some extent during autumn (i.e., October-November). The latter mechanism 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).

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

Table 1. SFCs details in the study area

Area name	Site Number	SFC Number	Location UTM E N	Orientation	Elevation (masl)
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
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

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 1st 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.

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 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 was excellent. The data also show that some of 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 one 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 the west winds are the most productive. Humid air comes from the Red Sea, with Mabian being the first mountain range encountered in its movement inland. Examination of the data of sites 9 and 8, which have the best collection rates, indicates that these sites are well exposed to winds coming from the west up a major wadi. Site 13 is 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 might be proved to be productive.

Figure 7 shows the variation of fogwater collection with different wind speeds. In Hajja governorate, fog occurs under low wind speed conditions. 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. the results indicate good collection amounts between elevations of approximately 2,000 and 2,500 masl. 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 masl would be potentially good productive sites and need to be evaluated.

CONCLUSION AND RECOMMENDATIONS

The field study on fogwater collection in the western mountainous areas of Yemen indicated that, in principle, fogwater could 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 afforestation.

The field study results indicated that fog collectors located closest to the red sea with an altitude range between 2,000-2,200 masl 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 decrease the cost and space requirements.

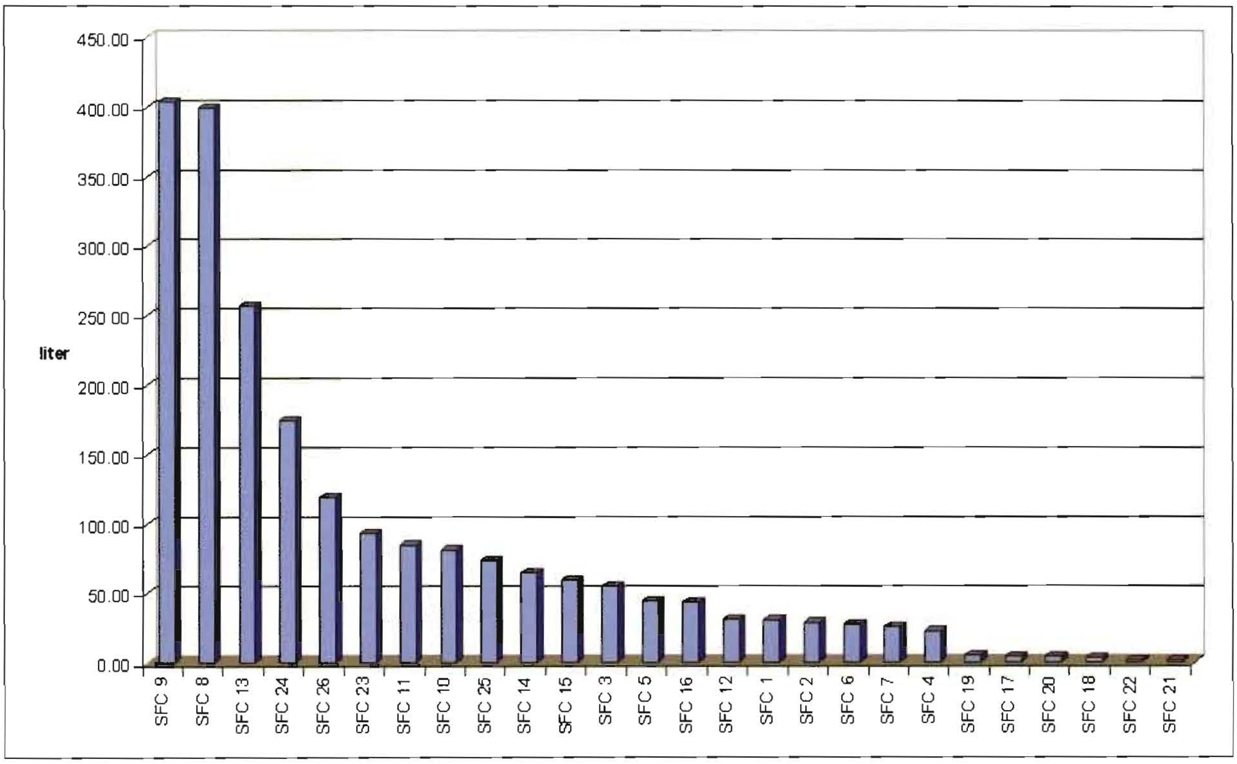

Fig. 5. Total fogwater collection amounts in the project area for the period 1 January - 31 March 2007.

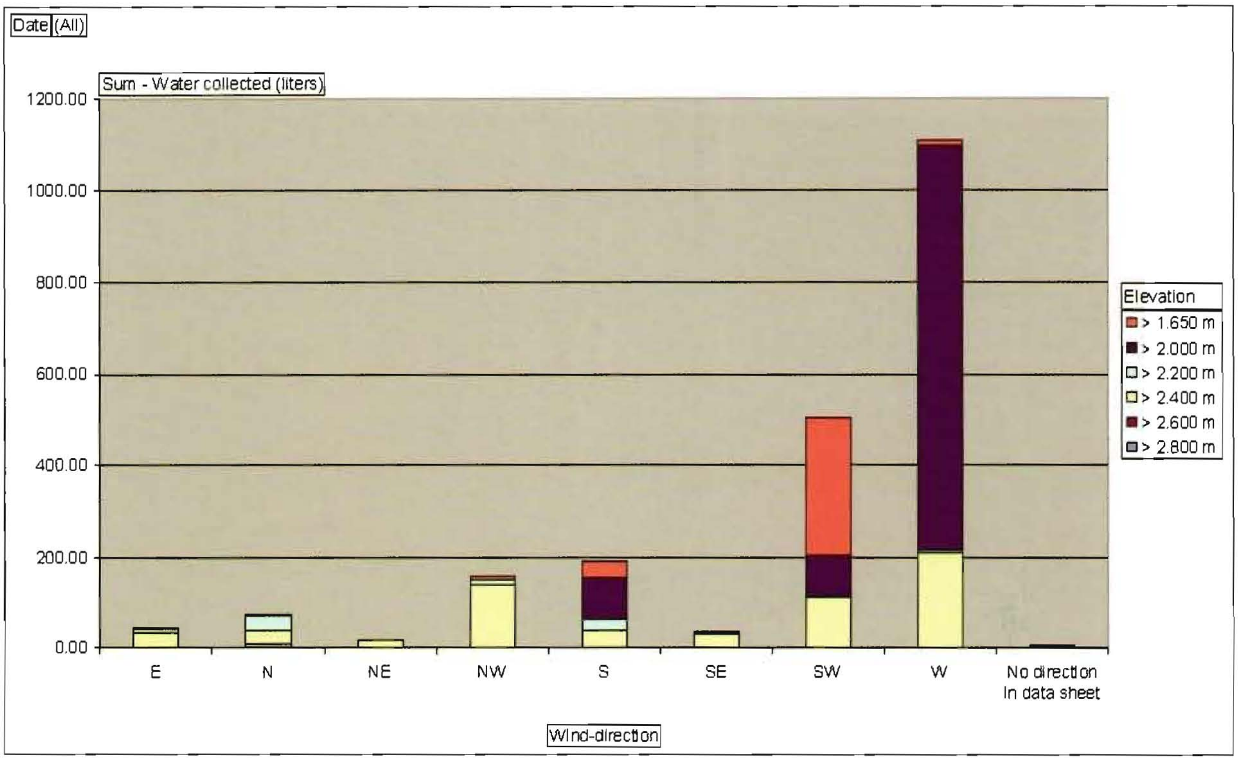

Fig. 6. Variation of fogwater collection with wind direction.

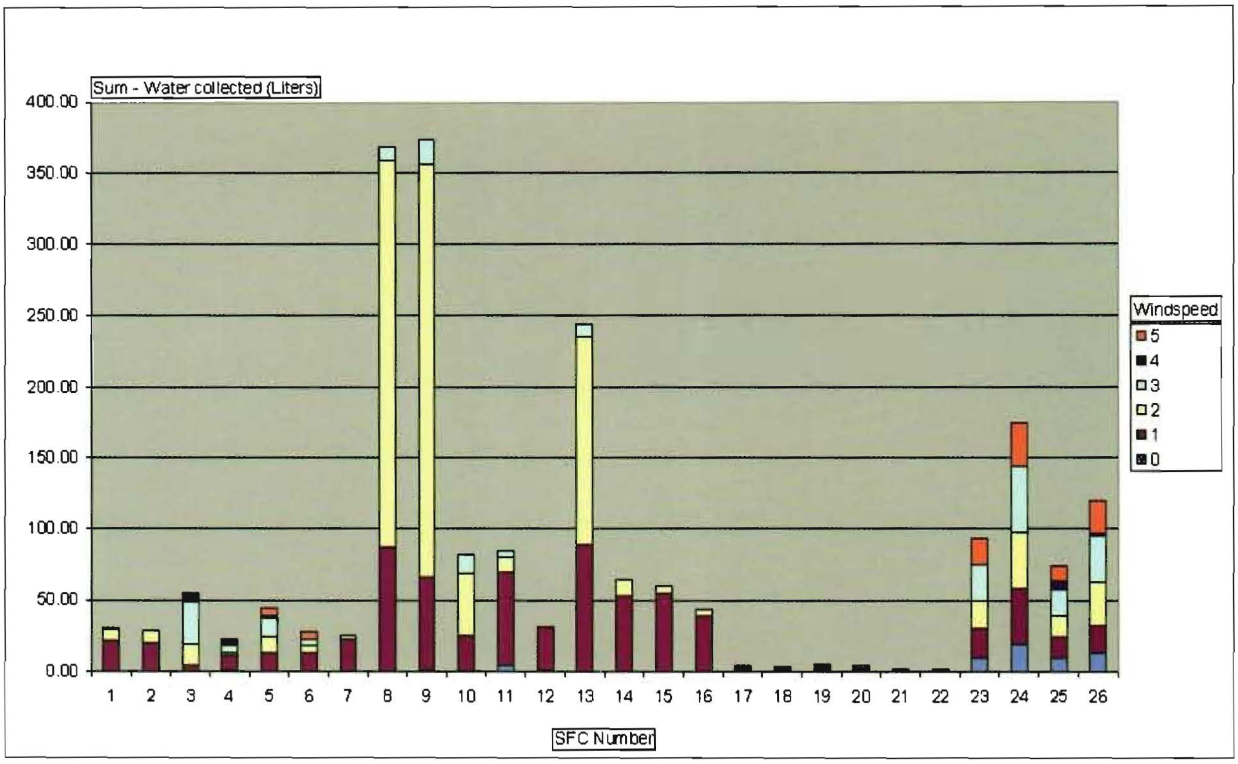

Fig. 7. Variation of Fogwater collection with wind speed.

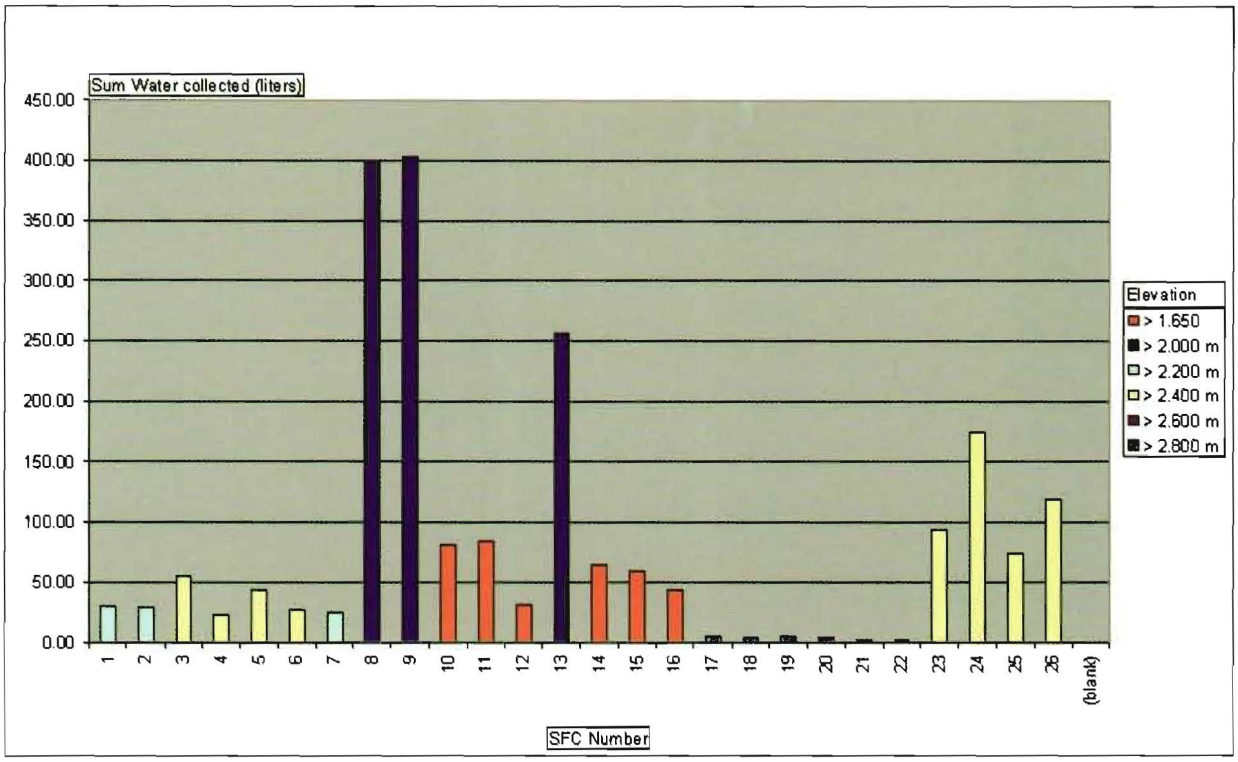

Fig. 8. Variation of fogwater collection with altitude.

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REFERENCES

Alesh, SA (1998) Work done on fog and fog collection (moisture capture) in the Sultanate of Oman. *In: Proceeding of The First International Conference On Fog And Fog Collection,* Vancouver, Canada. July 19-24, 1998. pp 417-420.

Alesh, SA (2003) *An Experimental Study of Fogwater Collection in Salalah Area, Oman:* MSc thesis. Department of Earth Science, College of Science, Sultan Qaboos University, Masqat. (Unpublished).

Canto, W (1998) The Coastal Fog (Camanchaca): A water resource available for the benefit of desert communities. *In: Proceeding of the first International conference on fog and fog collection*, Vancouver, Canada. July 19-24, 1998. pp. 191-193.

FAO, (1997) Irrigation in the Near East Region in Figures. Water Report (9). Available on line at: http//www.fao.un.org

Furey, SG (1998) *Fogwater Harvesting for Community Water Supply.* MSc thesis, Infrastructure Engineering, Silose College, Granfield University.

Hildebrandt, A (2005) *Ecohydrology of a seasonal cloud forest in Dhofar, Sultanate of Oman.* Ph. D. thesis, Massachusetts Institute of Technology, USA, p211.

Hildebrandt, A, Eltahir, E, Amerjeed, M, Shammas, M, and **AlMahari, G** (2004) The hydrology of a semiarid cloud forest in Dhofar (Oman). *Am. Geophysical Union. Eos Transactions*, Joint assembly Suppl. Abstracts **85**(17): 66-67.

IDRC, (1997) *Fogwater Collection System.* International Development Research Center (IDRC), Ottawa, Canada. Available on line at: www.idrc.ca/library/document/096904/index.htm

Van, der, Gun, J, and **Ahmed, A** (1995) Water Resources of Yemen. Report WRY35, TNO, Delft.

Meteorological, Service, (2000) *Annual Metrological Data. Meteorological Service,* Sanaa, Republic of Yemen.

Prinz, D (1996) Water harvesting: history, techniques and trends. *Z. f. Bewässerungswirtschaft*, **31**(1): 64-105.

Schemenauer, RS, and **Cereceda, P (1992)** Monsoon cloud water chemistry on the Arabian Peninsula. *Atmospheric Environment,* **26A**: 1583-1587.

Schemenauer, RS, and **Cereceda, P** (1994a) Fog Collection's Role in Water Planning for Developing Countries. *Natural Resources Forum,* **18**: 91-100.

Schemenauer, RS, and **Cereceda, P** (1994b) A Proposed Standard Fog Collector for Use in High-Elevation Regions. *J. Appl. Meteorol.*, **33**: 1313-1322.

Ref. (2432)
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