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DYNAMICAL ASSESSMENT OF FOG HARVESTING BASED ON FRACTAL THEORY

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ABSTRACT
The limitation of water sources in most places all over the world, especially in arid and semi-arid lands is an important Issue for those who live in these areas. Many governments have dedicated their efforts toward finding new water resources to obtain water.

Fog and cap clouds harvesting are one of the candidate methods to produce pure water. Many countries including Chile, Peru, Ecuador, Canada, Namibia and Nepal Have yet invested on fog harvesting. On the other hand, no significant calculation studies have been yet carried out on quantifying fog harvesting.

In this work, we examined the Physical and dynamic relationship between cloud physics and atmosphere humidity; factors such as distribution of particle amounts, collection efficiency, water including base cloud and vapour flux were all considered. We also presented a new method to estimate fog harvesting, based on fractal theory and concerning the characteristics of collecting devices.
Finally, we successfully evaluated the theories for fractal dimension of particle distribution, using the real data of fog harvesting. The incremental fractal dimension reliability was found to be 83% acceptable.

KEY WORDS
Fog, fractal theory, Cap cloud, Fog harvesting, Water resources

1. Introduction

Water is a vital necessity for human being and water sources are of most frequencies of natural sources all over the world. Interestingly, despite the huge amount of water available on earth, only 3% of the water is pure; of which, only 1% is available and the rest is almost unavailable. This fact clarifies that the human being is facing to the limitation of pure water. The pure water is partly saved in glaciers or polar caps or is spread out in the atmosphere as vapour that in most cases is not economical to be used of ([1]).

Today, many parts of desert areas are in danger of shortage of water, however, fog is observed in these areas in many days of the year. Moreover, in some other regions, cap clouds are formed on the heights because of certain earth topography and good conditions. That is why the humidity of atmosphere can be regarded as a good source of pure water.

Many countries such as Chile, Peru, Ecuador, Canada, Namibia and Nepal have yet invested on fog harvesting issue. For instance, fog harvesting was successfully carried out in Chile, leading to daily production of 11,000 cubic meters drinking water.

Different techniques have been used for fog harvesting in different parts of the world based on the area conditions. Dew pounds, air wells, fog fences and fog harvesting can be mentioned as different procedures of gathering fog humidity ([2]).

Historical evidences confirm that the ancient inhabitants of dry regions in Iran were aware of using fog and dew to acquire water. For instance, in foggy areas, farmers designed their lands in a way to be vertical to the fog movement in order to benefit the maximum use of dew.
In 2006, in a project that was carried out on the heights of Mashhad suburb; the amounts of fog harvesting was measured. Data confirms the possibility of producing water through atmosphere humidity. The results of this investigation were used as measurement data to compare the estimated measurements ([3]).

2. Physic of Fog

Drops in the cloud won't fall down unless they grow and reach to the size of 50 micron in diameters. Normally, they can not drop down affected by the gravity since their diameter does not exceed 40 micron (varies from 1 to 40 micrometers) ([4]). Therefore a procedure is needed to absorb the drops or to make drops grow to the desired diameter. Fog collectors which consist of networks of thin nylon strings could be helpful as they condense fog drops and atmosphere humidity to the water when they are put in contact with them. Some factors which affect the amount of produced water include:

2.1 Size distribution of drops

According to the articles, the number of drops in volume unit of cloud and fog are different and depend on size of the drops ([5]).

In 1948 Marshal and Palmer showed that size distribution of drop particles can be determined from the equation below:

$$n(D_0) = n_0 \exp(-\Lambda D_0) \quad (1)$$

where, D0 is the drop diameter, n (D0) the number of drops with D_0 diameter, $\Lambda = 4.1R^{0.21}mm^{-1}$, R is the amount of humidity flux in surface unit based on mm/h and n_0=8×103

2.2 Collection efficiency

When a drop with a diameter of R drops down from the cloud or fog, washes a cylinder with the diameter of d= 2R on its way. It is supposed that all drops in this cylinder are in contact with the big drop and are absorbed in to it. When opposed to air movement flux, the fog collector nylon string absorbs the water drops and hence fog humidity. But the air movement forms a boundary layer around the string which results in dispersion of drops such that not all the drops on the way of string have contact with it. The process is quite similar to the process of dropping down of a drop from the cloud, mentioned before ([6]).

In fact, the collection efficiency can be calculated from the equation below:

$$E(R,r) = \frac{y_c}{(R+r)^2} \quad (2)$$

where R is the ray of nylon string and r is the ray of the drops contacting the string. y_c is the maximum horizontal deviation of water drops in response to air flux.

Collection efficiency for cloud drops with the ray below 3.2 µm is zero and for upper rays is obtained as follow:

$$E = 0.4\log(r) + 1 \qquad r \le 0.6mm$$
$$E = 0.9 \qquad r > 0.6mm \quad (3)$$

2.3 Liquid water content

Liquid water content (LWC) is calculated based on Equation (4) ([7]):

$$r = \left[\left(\frac{3\times LWC}{4\pi N}\times 10^4\right)\right]\times 10^4 \quad (4)$$

r is the radius of the droplet and N is the number of droplets in surface unit.

2.4 Vapour flux

When direct wind component on collector network as well as the wind speed is determined, the amount of Vapour flux from the network collector is calculated.

Since the number of particles with different diameters in volume unit is obtained from equation (1) ([8]), the drops flux from surface unit can be obtained from following equation:

$$F_v = \sum\left(\frac{4\times \pi N r^3}{3\times A\times t}\right) \quad (5)$$

N indicates the number of drops with r ray, and A is the surface of collector section, t is the time.

3. Fractal theory

In a width slice of a cloud, water drops with different rays are arranged in a circular pattern. Then, if a fog collector network is settled in this area, the regions where drops hit the string shows the number of water drops which are in contact with the string. Therefore, the amount of produced water can be estimated regarding the number of water drops and with respect to collection efficiency. The number of contacts depends on density of collector network and three dimensional orientations of the drops ([9]).

In fractal environments, the general pattern of irregularities on the surface depends on resolution degree that the object is seen through; and is determined from the formula (6) ([10]):

$$N_2 = N_1 \times G^D \quad (6)$$

G, is the resolution degree, N_1, is the number of irregularities before scaling, N_2 is the number of irregularities after scaling, and D is fractal dimension. For example in calculating the shadow surface of clouds that is studied two dimensional, the surface of cloud is well set with perimeter of cloud square 1.48. So, the fractal dimension of cloud in this condition is 1.35([11]). On this basis we can estimate the number of drops hitting the network if the collector network density is presumed to be the factor of resolution. This means, the more collector network density we achieve, the more resolution we have. As a result, more contacts with the network take place.

4. Material and methods

The Information on 37 time intervals of harvesting process -used as primary data- is shown in table (1).

The characteristics of grid collectors (square frame 100cm*100cm), one layer cone(big circle diameter of 21cm, small circle diameter of 12 cm and the height of 37cm) and a two layer cone (big circle diameter of 25cm, small circle diameter of 20 cm and the height of 46 cm) with different scales are shown in table (2).

LWC was required in order to calculate the amount of produced water. Since no such data was available, the fractal theory of distribution of cloud drops was examined based on two different hypotheses as follows: First, we assumed that the produced water is in relationship with the network density with a fractal dimension of 1.35. In the second hypothesis we examined incremental fractal dimension (D= 2 - 1.35) ([10]).

Table 1
Volume of water harvested from collectors ([3])

Collectors	Grid	One-layer	Two-layers
	Harvested water (L/m^3)		
1	0.040	0.044	0.056
2	0.276	0.442	0.500
3	0.103	0.077	0.227
4	0.345	1.443	1.455
5	0.276	1.340	1.273
6	0.345	1.985	3.227
7	0.414	1.443	1.455
8	1.897	1.649	2.227
9	0.052	0.041	0.091
10	0.250	0.258	0.500
11	0.052	0.077	0.136
12	0.095	0.103	0.182
13	0.069	0.072	0.136
14	0.164	0.155	0.318
15	0.103	0.077	0.227
16	0.086	0.052	0.182
17	0.672	0.670	1.364
18	0.190	0.206	0.409
19	0.147	0.103	0.308
20	0.103	0.129	0.273
21	0.405	0.258	0.909
22	0.517	0.619	1.364
23	0.474	0.412	1.045
24	0.431	0.309	0.909
25	0.448	0.335	0.909
26	0.052	0.041	0.091
27	0.250	0.258	0.500
28	0.672	0.670	1.364
29	0.190	0.206	0.409
30	0.147	0.103	0.318
31	0.164	0.155	0.318
32	0.103	0.077	0.227
33	0.086	0.052	0.182
34	0.293	0.232	0.364
35	0.095	0.077	0.182
36	0.362	0.021	0.500
37	0.086	0.052	0.182

The amount of N_1 in equation (6) -which is determined with LWC-, is assumed as a constant value since the amount of LWC, in each harvest has been fixed in three networks. So, if the diagram log (N/N_1) is drawn for every time of harvest as opposed to log (G), the declivity of diagrams shows the fractal dimension (D).

$$Log(\frac{N}{N1}) = D.Log(G) \quad (7)$$

Therefore, having the amount of produced water through each network and concerning the density of that network, the fractal dimension is estimated. The obtained amounts from 37 series of data were examined with both mentioned hypothesis.

Table 2
Characteristics of collectors and selected scales

Collector type	**Scale**	**Collector area (Cm^2)**	**Number of strings**
Grid	0.058	10000	580
One layer	0.100	1942	200
Two layer	0.240	3231	800

5. Results and Conclusion

In equation (7) changing the amount of N_1 in a series of data which were gathered in equal LWC conditions does not change the declivity but only the intercept. Therefore considering the fact that the fractal dimension equals the declivity of the diagram log (N/N_1) against log (G), the amount of log (G) was used to draw the diagram (Figure 1).

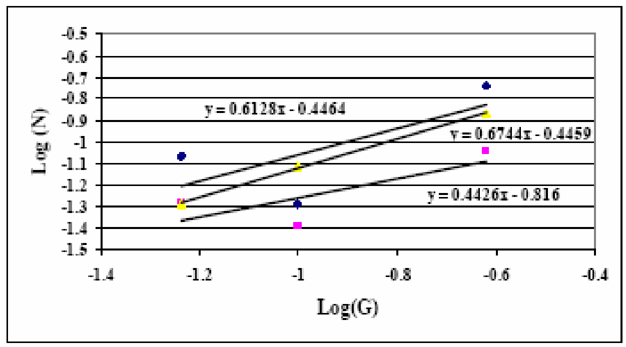

Figure 1. Diagram of log (N/N1) vs. log (G) (Data is shown for 3 series of 37 series data.)

Declivity was determined for all the 37 series and results were undergone statistical analysis. First, the slope was examined with u=1.35. Data analysis rejected the hypothesis of D=1.35. Declivity distribution revealed that the mean=0.58 and standard deviation is 0.22. In the second round of the test, the hypothesis of u=0.65 was tested. With respect to the fractal dimension of 0.64, the mean tests for the declivities were done assuming the mean to be=0.65. Our results revealed that the hypothesis of incremental fractal dimension is 83% reliable (Table 3).

Table 3
Statistic analyses

Hypothesized Value	0.65
Actual Estimate	0.58
Df	36
Std Dev	0.22
t- Test	
Test Statistic	1.37
Prob > |t|	0.17
Prob > t	0.088
Prob < t	0.911

The results of the T-test presented above showed the fact that distribution of the amount of fog particles is a fractal phenomenon which is distributed through incremental fractal dimension. Thus, calculating fog harvesting with collector networks could be carried out with 83% reliability and the volume of water for harvest can be calculated.

Based on our results we shall notify that:

- These results may possibly vary when the experiment is repeated with three similar collectors. (Two of the collectors were not the same). Therefore, more precise research using the same equipment is needed.
- This experiment requires constancy of all environmental parameters such as fog movement flow inside the collector network. So, providing certain similar environmental conditions which differ only in network density, can confirm our results with more reliability. Therefore, researches done in laboratory environment are of extra value.
- Determining LWC value is necessary for evaluating the reliability of the test; hence, the study based on perfect information can help us estimate the fractal dimension.
- In conclusion, it appears that studies on fog harvesting are not sufficient yet. Considering the atmosphere humidity as one of the valuable sources of providing pure water, more complementary researches are required.

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