HARVESTING OF ATMOSPHERIC WATER: A PROMISING LOW-COST TECHNOLOGY

Mohan Bahadur Karkee

Department of Water Supply and Sewerage, Panipokhari, Kathmandu, Nepal
P.O.Box 21096, Tel: 977-1-4443652 Fax: 977-1-4445833
E-mail: mbk_mike68@hotmail.com

Abstract

A research study conducted in eastern part of Nepal to assess the possibility of harvesting two atmospheric water sources, namely fog and rain, has indicated that it is a promising new technology. It is an integrated, community manageable and sustainable water collection system. The system collected 2.5 m^3/m^2 of mesh area per year of fog water and 1.2 m^3/m^2 of roof area per year of rainwater. The water quality was safe enough for drinking, and did not deteriorate during long time storage (4-6 months) in closed containers. This system would deliver 1000 L of water at a cost of US$ 2.80.

Key words: Fog, Rainwater, Harvesting, and Integrated

INTRODUCTION

Of all the earth's resources, water is the most fundamental to life. Being one of the world's poorest countries, Nepal obviously suffers many setbacks in developing the infrastructures. One of the basic needs is the safe drinking water facility. By the end of Ninth Plan (1997 – 2002), only 71.6% of the total population (23.1 million: National Census 2001) had access to safe drinking water and only 20% have had sanitation facilities. The country has planned to provide 100% of the population with safe drinking water facilities by the end of 2017. Department of Water Supply and Sewerage (DWSS), being the lead agency among other sector stakeholders, shares the formidable challenge to achieve the national goal. DWSS has already completed over 5000 water supply schemes and about 1000 ongoing schemes that mostly includes surface water gravity flow systems and ground water systems, but few rainwater collection systems.

However, national NGO Nepal Water for Health (NEWAH) and the local communities have successfully implemented 2 pioneering fog water collection systems for drinking water. It seems impossible that without harnessing every possible source, the full water supply coverage could not be attained. Hence, it enforces to make exploitation of every possible technology and adopt integrated water resources approach in sectoral planning. Fog and rain water has been used for irrigation, horticulture, floriculture, drinking, and ground water recharging etc.

1. Overview

Increasing population has put tremendous pressure on the natural resources. Depleting water sources, deforestation, ever increasing water demand, source disputes and increasing cost of water has urged to explore new sources of water and adoption of indigenous technologies. About 12 million people live in the hilly regions (Statistical Pocket Book Nepal 2002) where other conventional water sources like spring, stream and ground water are inadequate and not available at right places. Changes in climate over few decades have demonstrated that the area is becoming arid and the rain occurrence has been erratic. People have to fetch water from far distances that usually cost them more than two hours a day. Traveling was very difficult because of steep slopes. Plagued by this problem, some villagers had even hired strong men to carry a can of 15 liters of water for US$ 0.5. For a single day they had to spend US$ 1.50. Such hardships initiated the endeavor to harness other atmospheric sources like fog and rainwater since it could be collected right at their house premises.

2. Background

The aim of this paper is to reveal the possibility of harnessing the less provoked non-conventional water resources for drinking water supply. Recent experiments with fog and rainwater harvesting technologies indicate that it is a potential source for drinking water at places where rain and persistent moving fog prevails. Therefore, a first ever research study (UNICEF and WHO Offices, Nepal provided the financial support) was initiated at a fog collection site in Dhankuta district of Nepal. The study site is located at an elevation of 1980 m from mean sea level, and co-ordinates of N 26°42' W 87°24'. It lies on a ridge top frequently covered with advected orographic clouds[1]. The average annual rainfall was 1492 mm in 2000, and the temperature ranged between 5^0C to 30^0C. Humidity varied between 57% in March to 93% in October. There is near persistent north east light breeze with speed up to 4 in Beaufort scale. Some times storms also hit this area during March.

APPROACH AND METHODOLOGY

This study was based on field level observations made at the project site. The project was jointly implemented by NEWAH and local communities with technical and financial assistance from Canada. Booking of hydro-meteorological observations were made from August to September. However, at least a full one year data was required to make the project design analysis. Therefore, the fog and rain collection data provided by NEWAH was used for analysis. Water quality parameters were examined during the site visit, and all the water quality analyses were completed in the laboratory at Institute of Engineering, Lalitpur, Nepal.

[1] Department of Meteorology and Hydrology

1. Understanding the Technology

The fog water collection technology is very simple, and demand less operation and maintenance works. A fog collector screen made up of polypropylene mesh is mounted vertically on two or more posts. The screen is placed perpendicular to the direction of wind where the tiny water droplets present in the fog are trapped. Several droplets combine to form a large drop that fall by gravity into the storage tank through a trough placed horizontally at the bottom of the screen. From the storage tank, the water is fed into the distribution system.

The water drops in the atmosphere interact with terrain and obstacles in different ways. Due to the presence of water droplets in air, the horizontal visibility decreases and the formation of cloud takes place. When the base of cloud lies near or at the surface of ground, then it is called fog. The relative size and fall velocities of water drops are given in the Table 2.1.

Table 2.1: Comparative drop sizes of rain, drizzle and fog

0.5mm to 5mm	40 μm to 0.5mm	1 μm to 40 μm	
			Fall velocity m/s
			2 to 9
		..:	0.05 to 2
			0.01 to 0.05
Rain	Drizzle	Fog	

Source: R.Schemenauer and P.Cereceda, 1994 (Natural Resources Forum)

Since all of these fall velocities are quite low, the angle of fall of the drops will be influenced by horizontal winds of even few meters per second. Even the largest rain drops will normally fall at an angle. In the case of fog droplets, the fall speeds are almost horizontal. Therefore, the appropriate position of collector for fog droplets is a vertical, or near vertical surface.

For initial assessment of fog water yield, a Standard Fog Collector (SFC) of 1m^2 mesh area (Figure 2-1) along with some accessories is used. The SFC is usually kept at site for about a year. When the yield is promising, the Long Fog Collectors (LFC) is used for actual extraction of water. The width of LFC is generally 4m and the length varies up to 20m depending upon the space available on the ground. To capture more water, number of LFC is increased.

Figure 2-1: Actual SFC unit
Photo: Keith Mac Quarrie

Trees can also be good fog collectors depending on their height and leaf structure. The amount of liquid water present in a cubic meter of cloudy air varies tremendously, from 0.05 g/m^3 in wispy clouds to 3 g/m^3 or more in thunderstorms. At coastal fog collection sites, values such as 0.2 g/m^3 would be typical[2]. Fog water was collected through double layered Coresa (Chilean) mesh, and water was collected through Corrugated Galvanized Iron sheet roof catchments.

2. Replication in other Countries

A major fog collection experiment was undertaken in the Sultanate of Oman during 1989 and 1990. The project was funded initially by UNDP, WMO and the government of Oman. The maximum duration of monsoon is from mid-June to mid-September and it is often some weeks shorter. Data were collected with both standard 1 m^2 collector and larger collectors. In the upper elevations, from 900 to 1000 m, average collection rates of 30 L/m^2/d were obtained for three month period.

The largest fog collection project to date has taken place on a ridgeline (at 780 m) above the fishing village of Chungungo (29^o 27' S and 72^o 18' W) on the north central coast of Chile for 330 villagers. Experimental projects conducted in Chile indicate that it is possible to harvest between 5.3 L/m^2/day and 13.4 L/m^2/day depending on the location, season, and type of collection system used.

In Nepal, two fog collection schemes have successfully been completed at Danda Bazar in Dhankuta and Megma in Ilam districts. Rain water harvesting technology has been practiced for last ten years. Both of these technologies have been implemented independently. But the integrated technologies initiated by this study have never been tried before.

[2] Natural Resources Forum, 1997, Volume 18, Number 2

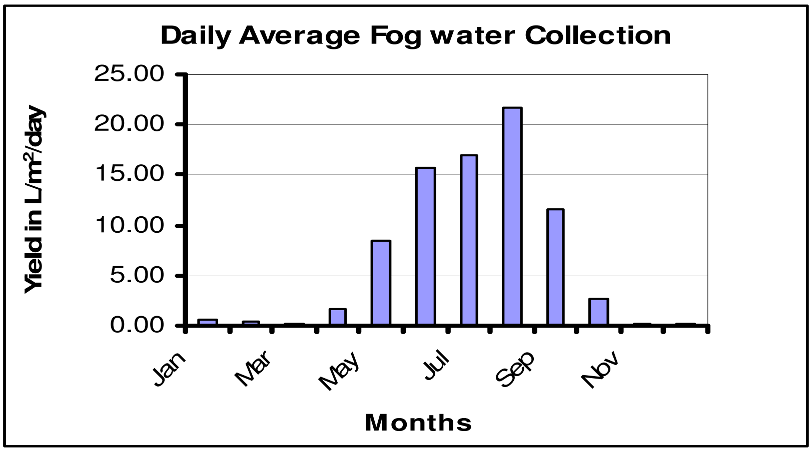
In the Arabian Peninsula, the fog collection technology has been used recently in Yemen (Shamsan, Saada and Hajja Governorates), Sultanate of Oman (Dhofar regions). Recently, the fog collection projects have been successfully implemented in South Africa, Guatemala, Peru, Bolivia, Colombia, and Namibia. Besides, the other countries like Sudan, India, Pakistan, Venezuela, Canary Islands, Kenya, Angola, Morocco, Arabian Peninsular regions, Hindu-kush regions, China are also the potential areas for this technology replications.

Rain water harvesting is almost 4000 years old, when desert dwellers smoothed hillsides to increase rainwater runoff. They built ditches to collect water, and conveyed it to lower lying fields. This practice permitted agricultural civilizations to develop in regions with an average of rainfall about 100 mm. Rain water could provide a clean, convenient, and relatively reliable water supply in areas lacking good alternative water resources.

3. System Design and Analysis

The research study was focused to adopt an integrated water collection technology and to develop a sustainable, cost-effective model to suit the need of a 7 member family for a design period of 10 years. The daily average fog water collection in different months is shown in Figure 2-2.

Figure 2-2: Daily Average Fog water Collection



Source: NEWAH, Kathmandu 2000

The National Drinking Water Guidelines of Nepal prescribes the average daily water demand for rural community to be 25-45 liter per capita per day (lpcd) from conventional sources. However, a community level survey at the site revealed that 14 Lpcd was just enough. Hence, a combined demand of 15 Lpcd was adopted. Out of 15 liters, 9 liters were tapped from fog and the remaining 6 liters from rain sources. The calculations of mesh area, roof area, and storage capacity, were based on the need of a single family system. The average daily fog yield of 6.75 L/m^2/day was observed and used for calculation.

Mesh area calculation[3]

Theoretical mesh area (S_t) required is based on the water demand, and the actual required area (S_a) corresponds to the amount of water effectively captured by physically available mesh in a given moment. The mesh areas were calculated by using Equations (1 – 4).

$$S_t = (N \times C_p) / V_c \quad \text{.......... (1)}$$

$$S_a = S_t / (DF \times E) \quad \text{.......... (2)}$$

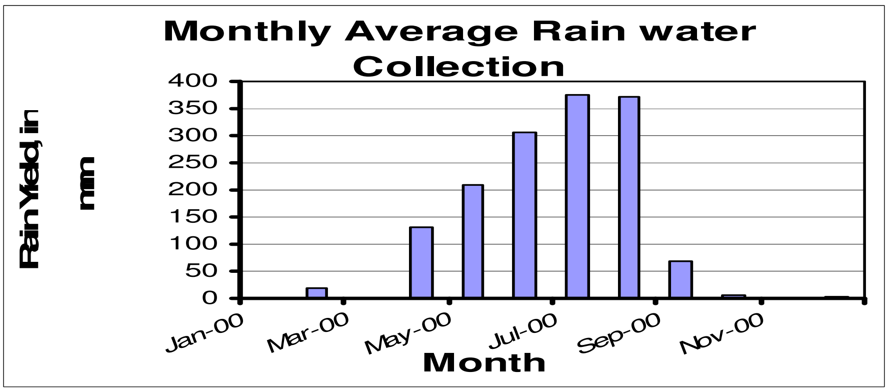
$$DF = (1 - C_m / C_t) \times 100 \quad \text{.......... (3)}$$

$$E = (1 - \text{Dev.std.} / V_c) \times 100 \quad \text{.......... (4)}$$

where,

- N = population that the project should supply
- C_p = daily water demand in L/capita/day
- DF = physical availability (%), corresponds to actual daily available mesh area actually capturing
- C_m = collectors in daily maintenance program
- C_t = total number of collectors
- E = efficiency of the system in %. It is the percentage of variation of the standard deviation, with respect to the median of the average volume of water V_c in L/m^2/net/day collected in the area under study. The monthly average rainfall collection is shown in Figure 2-3.

Figure 2-3: Monthly Average Rainfall



Source: NEWAH, Kathmandu 2000

[3] Based on the work by A. Cruzart 1998

Roof area Calculation
Similarly, the monthly rain collection was calculated using rational formula (5).

$$Q_s = 0.992*C*I*A \qquad \text{………..} \quad (5)$$

where,

Q_s = monthly amount of water collected from roof catchments in liter
C = coefficient of runoff. For CGI roof counting the minor losses through evaporation, leakage from gutter and dispersion (C = 0.85 adopted)
I = monthly average rainfall in mm.
A = area of roof catchments in m^2

Storage size calculation
The calculation of storage capacity was determined by using the following expression.

$$V = MCS + MCD - (TS - TD) \qquad \text{………..} \quad (6)$$

where,

V = Volume of storage tank in liter.
MCS = Maximum Cumulative Surplus in liter.
MCD = Maximum Cumulative Demand in liter.
TS = Total Supply in liter.
TD = Total Demand in liter.

It was so designed that there was no surplus supply and no demand deficit in total cycle. The final storage required per house was 17000 L. The corresponding required mesh area and roof area were 12 m^2 and 12 m^2 respectively to cater daily demand of 15 Lpcd. However, the storage capacity reduced to 3000 L when seasonal storage (for 7 months) was provided, other factors remained the same.

4. Cost of the System

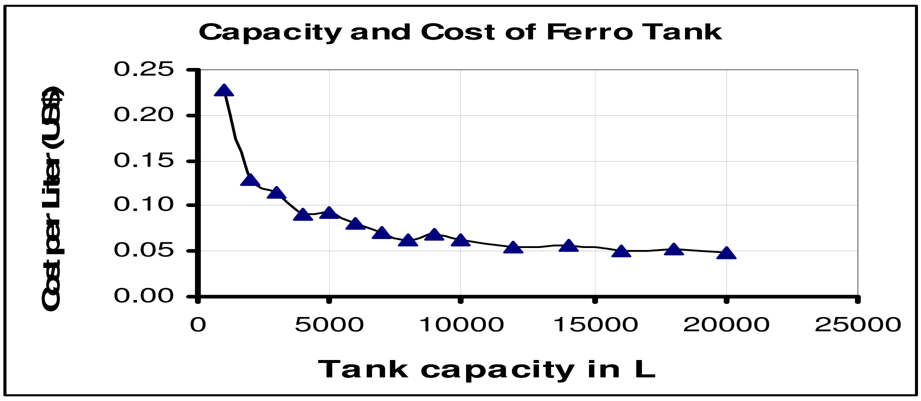
For the analysis purpose, mesh screen with all necessary pole mounting accessories, complete roof structure, gravity spring intake Type-IA with protection, and the required storage were considered because they are the major cost bearing and cost varying components. Therefore, only the costs of these components were used for cost analysis. The costs of different supply systems are shown in Table 2-1.

Table 2-1: Supply System Cost Matrix

Type of Supply System	Cost in US$
Coresa mesh with mounting	8.50/m^2
26 Gauge CGI Sheet Roof	2.00/ m^2
Gravity Spring Type-IA Intake	773.00/ unit

Comparison of storage capacity from 1 m^3 to 20 m^3 and the per liter cost are shown in Figure 2-4.

Figure 2-4: Cost per Liter of Ferro Tank



WATER QUALITY

Rain water has very low mineral contents. Generally, even if the collected water contain particulates from a roof surface, its quality is often better than that of turbid surface water. In rural areas, for example, the quality of rain water collected from metallic roofs is often regarded as pristine. A case study on the water quality of stored rain water conducted during the implementation of a rain water jar construction program in Thailand has pointed out that rainwater is potentially the safest and most economical source of drinking water (Wirojanagud and Mungamdee, 1989). Examination of some water quality parameters for both fog and rainwater indicated that the collected water can be used for drinking. Many studies, in Nepal, on the stored rainwater quality confirmed that it is safe. Moreover, this study also ensures that fog and rainwater are safe to drink and the community has accepted as well. The water quality parameters are presented in Tables 3-1 and 3-2.

Table 3-1: Observed Quality of Fog water

Parameter	**Value**
Water temperature ^{O}C	15.25
Conductivity, µS/cm	278
pH	5.55
Color	clear
Taste	palatable
Turbidity, NTU	<5
Chlorides, mg/l	none
Total hardness, mg/l	24
Alkalinity, mg/l	26 (HCO_3^-
Relative humidity, %	78
TDS, mg/l	178

Table 3-2: Observed Quality of Rainwater

Parameter	**Value**
Water temperature ^{O}C	21
pH	6.8
Color	clear
Taste	palatable
Turbidity, NTU	<5
Free chlorine, mg/l	10 -12
Total hardness, mg/l (as CaCO3)	12 -14
Alkalinity, mg/l (as CaCO3)	14 -16

Quality of stored rainwater changes depending upon the construction materials used in storage tank, quality of construction works, sanitation practice of consumers and water treatment processes. The physical parameters like odor and turbidity reduces by the process of self-purification and plain sedimentation after a long storage period. Leaching property of concrete tank also helps to improve taste of water. Increase in chemical parameter (pH, hardness and alkalinity) may be the result of minerals leached out from the tank. If acidic water is stored in tank, it is neutralized after reacting with calcium leached from the cement used in tank construction.

CONCLUSION AND RECOMMENDATIONS

From the technical and cost analysis of different water supply options, it was the combined fog and rainwater harvesting that costs the least (US$ 968) compared to others. Tables 4-1 and 4-2 represent the total costs of four different technology options.

Table 4-1: System costs for Fog, Rain Collection

Fog Collection		**Rain Collection**	
Item	Cost, USD$	Item	Cost, USD$
Mesh $16m^2$	136	Mesh	-
Roof	-	Roof $32m^2$	64
Storage $19m^3$	970	Storage $20m^3$	981
Total	1106	Total	1045

Table 4-2: System costs for Gravity, Combined Collection

Combined Collection		**Gravity Collection**	
Item	Cost, USD$	Item	Cost, USD$
Mesh $12m^2$	102	Intake,TP-IA	773
Roof $12m^2$	24	Roof	-
Storage $17m^3$	842	Storage $1m^3$	224
Total	968	Total	997

Analysis showed that fog water yield per m^2 at the site is double than the rain water (i.e. 2.5 m^3/m^2/year and 1.2 m^3/m^2/year respectively). Observed fog period was about 192 days, and a maximum daily fog water collection up to 118 $L/m^2/d$ was observed. Therefore, in terms of quantity, quality, and cost the proposed model as shown in Figure 4-1 is an appropriate alternative technology solution that could be managed and maintained by rural communities having similar site conditions. Use of bleaching powder is also suggested to keep off contamination.

It is worth investigating whether rain, fog or dew collection technology has ever been used by the community or in the region. This will ease understanding, acceptance and the exploration for suitable sites. It may also help further the management and development of fog water harvesting technology.

The site observed 250 $m^3/100m^2$ of mesh area per year of fog water and 125 $m^3/100m^2$ of roof area per year of rainwater. Therefore, an extra supply of 375 m^3 water could be trapped from 200 m^2 of collection area per year at a mere cost of US$ 2.80/m^3. It is a low cost sustainable approach of supply augmentation. This dual system has an advantage that it could be expanded in future in line with the increasing demand.

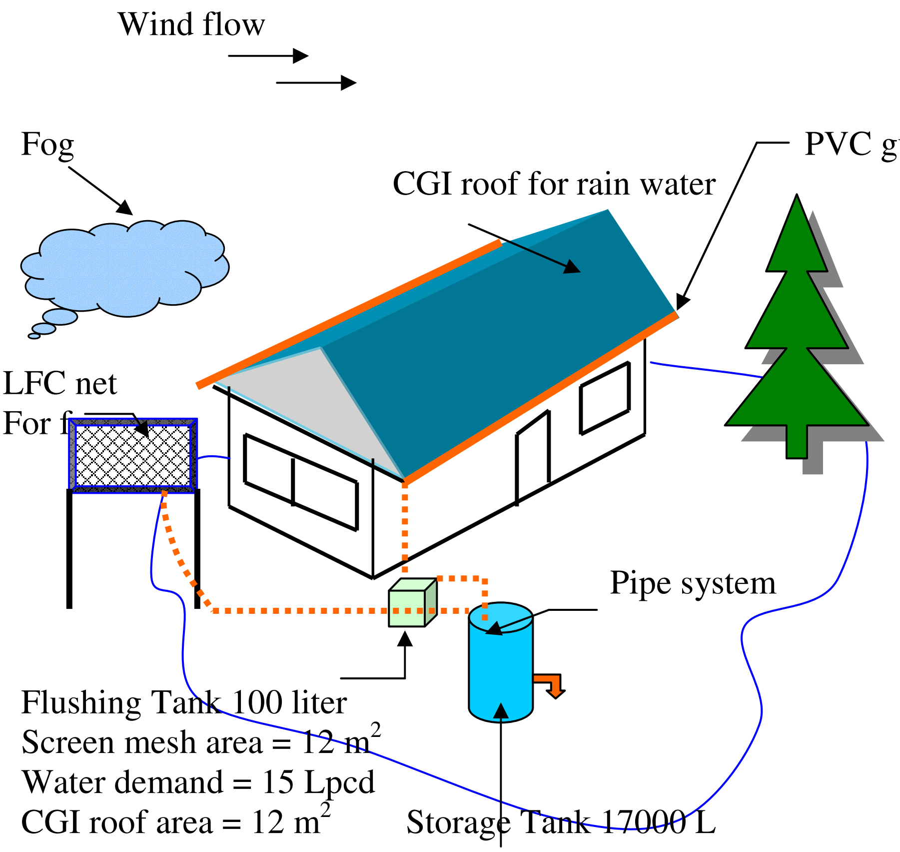


Figure 4: A Typical Rural Model House with Fog and Rain Water Collection

1. Advantages

However, the fog and rain water collection system has the following advantages.

- Quick and simple design and construction.
- Modular system that can grow in line with demand or available funds
- Passive collection system requiring no energy input to operate
- Cheap and easy to maintain and repair
- Multiple use of water for domestic, irrigation, livestock, reforestation
- Water quality is generally good in non-industrial areas, though pH is low

2. Disadvantages

The disadvantages of the fog collection system are mentioned here.

- Technology requires very specific climatic and topographic conditions.
- Yield is difficult to predict.
- Yield is very sensitive with changes in climate.
- It requires full community participation.

This research finding might provoke the need for adopting new approaches in integrated water resources management and planning. Generally, rain is scarce and conventional water sources are fast depleting in Arabian Peninsula. Meanwhile, fog harvesting has been in practice for some time in Dhofar region, Oman and Hajja in Yemen. This model could be adopted as a backup supply and ground water recharging systems especially in arid Arab regions.

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