PROJECT REPORT

ON

WARKA WATER TOWER : AN INNOVATIVE WATER HARVESTING TECHNIQUE FROM THIN AIR

Submitted in partial fulfilment of the requirements for

the degree of

BACHELOR'S DEGREE IN CIVIL ENGINEERING

Conferred by

UNIVERSITY OF MUMBAI

Submitted

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DECLARATION

I declare that this written submission represents my ideas in my own words and where other's ideas or words have been included, I have adequately cited and referenced the original sources. I also declare that I have adhered to all principles of academic honesty and integrity and have not misrepresented or fabricated or falsified any idea/data/fact/source in my submission. I understand that any violation of the above will be cause for disciplinary action by the Institute and can also evoke penal action from the sources which have thus not been properly cited or from whom proper permission has not been taken when needed.

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ABSTRACT

Semi-arid region is a region where the rainfall varies from 250 mm to 650 mm per year. Because of less rainfall , high evapo-transpiration , surface and ground water availability is very less in these regions. It leads to water scarcity and drought conditions. Conventional water harvesting structures are not suitable in these regions. Hence there is need to go for alternative solution such as water harvesting from thin air. The aim of this research work is to find alternative method of water harvesting from thin air to overcome drinking water problems in semi-arid regions. The objective of this study is two fold , firstly to carryout comparative analysis of different water harvesting structures from thin air and secondly to carryout feasibility and cost analysis of Warka Water Tower in semi-arid region. In this research work , different water harvesting structures from thin air were studied and Warka Water Tower was found to be most economical and convenient because of its low initial cost , zero energy requirement and less maintenance cost and easy availability of construction material. The rate of discharge of a Warka Water Tower is 100 lit per day , however its efficiency can be increased with suitable conditions. Hence Warka water tower can be effectively used for drinking water purpose in semi-arid regions. In this study, feasibility analysis of Warka Water Tower was carried out and it was found that the structure is suitable at temperature 40 degree Celsius and relative humidity 50 -70 %. Cost analysis shows that the cost of a single Warka tower is 33,000 rupees.

Keywords- Semi-arid region , Warka Water Tower , thin air , water harvesting , drinking water supply

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Introduction

1.1 General

Although water is Nature's most abundant substance, only 3% of the world's water is fresh. Less than 1% of the fresh water is accessible, in rivers, lakes, and underground reservoirs; the rest is suspended in the atmosphere or trapped in glaciers and the polar ice caps. There is an urgent need to develop technological solutions that can provide enough water to serve rural which are normally isolated from conventional supply systems. Rainfall is a major component of the water cycle and is responsible for depositing most of the fresh water on the Earth. It provides suitable conditions for many types of ecosystems, as well as water for hydroelectric power plants, crop irrigation and domestic requirements.

The major cause of rain production is moisture moving along three-dimensional zones of temperature and moisture contrasts known as weather fronts. If enough moisture and upward motion is present, precipitation falls from convective clouds (those with strong upward vertical motion) such as cumulonimbus (thunder clouds) which can organize into narrow rain bands. In mountainous areas, heavy precipitation is possible where upslope flow is maximized within windward sides of the terrain at elevation which forces moist air to condense and fall out as rainfall along the sides of mountains. On the leeward side of mountains, desert climates can exist due to the dry air caused by down slope flow which causes heating and drying of the air mass leading to below normal precipitation which causes water scarcity

1.2 Water scarcity and drought

Water scarcity in varying degrees affects one in three people on every continent of the globe, as needs for water rise along with the population growth, urbanization and increase in household and industrial uses. Water stress is the symptomatic consequence of scarcity which may manifest itself as increasing conflict over sector usage, a decline in service levels, crop failure and food insecurity. Droughts result from water stress and periods of drought can have significant environmental, agricultural, health, economic and social consequences.

Drought is a climatic anomaly, characterized by deficient supply of moisture resulting either from inadequate rainfall, erratic rainfall distribution, higher water need or a combination of all these factors. The escalating impacts of drought includes widespread crop failure, unreplenished ground water resources, depletion of water level in lakes/ reservoirs, leading to shortage of drinking water, reduced food and fodder availability etc.

1.3 Impact of water scarcity

Water scarcity and drought produces wide range of impacts that span many sectors of the society, including economy and may reach well beyond the area experiencing a drought. Of all the 20th century natural hazards, droughts have had the greatest detrimental impact. In recent years, large scale intensive droughts have been observed on all continents, affecting large areas in Europe, Africa, Asia, Australia, South America, Central America, and North America and high economic and social costs have led to increasing attention to droughts.

India is amongst the most vulnerable drought-prone countries in the world; a drought has been reported at least once in every three years in the last five decades. In India, 68% of the country is subjected to different degrees of water stress and drought conditions. Of the entire area, 35% of the area which receives rainfall between 750 mm – 1125 mm is considered drought prone while another 33%, which receives rainfall between 750 mm – 1125 mm is considered chronically drought prone. Since the mid-nineties, prolonged and widespread droughts have occurred in consecutive years, while the frequency of droughts has also increased in recent times. Drought Vulnerability of India may be attributed to the following reasons.

- High average annual rainfall of around 1150 mm; no other country has such an high annual average, however there is considerable annual variation.
- Even though India receives abundant rain as a whole, disparity in its distribution over different parts of the state is so great that some parts suffer from perennial dryness. In other parts, however, the rain is so excessive that only a small fraction can be utilized. The availability of rainfall as compared to Long Term Average exceeds 30% in large areas of the country and over 40-50% in parts of drought prone Saurashtra, Kutch and Rajasthan and Marathwada.
- About 73% of the total annual rainfall is received in less than 100 days during the southwest monsoon and the geographic spread is uneven particularly in tropical wet-dry regions like Marathwada.

1.4 Water Harvesting

It means capturing rain where it falls or capturing the run off in your own village or town. And taking measures to keep that water clean by not allowing polluting activities to take place in the catchment.

In general, water harvesting is the activity of direct collection of rainwater. The rainwater collected can be stored for direct use or can be recharged into the groundwater. Rain is the first form of water that we know in the hydrological cycle, hence is a primary source of water for us. Rivers, lakes and groundwater are all secondary sources of water. In present times, we depend entirely on such secondary sources of water. In the process, it is forgotten that rain is the ultimate source that feeds all these secondary sources and remain ignorant of its value. Water harvesting means to understand the value of rain, and to make optimum use of the rainwater at the place where it falls.
Therefore, water harvesting can be undertaken through a variety of ways

- Capturing runoff from rooftops

- Capturing runoff from local catchments
- Capturing seasonal floodwaters from local streams
- Conserving water through watershed management

Fig. 1.1 shows classification of different water harvesting techniques.

1.4.1 Necessity of water Harvesting

These techniques can serve the following purposes:

- Provide drinking water
- Provide irrigation water
- Increase groundwater recharge
- Reduce storm water discharges, urban floods and overloading of sewage treatment plants
- Reduce seawater ingress in coastal areas.

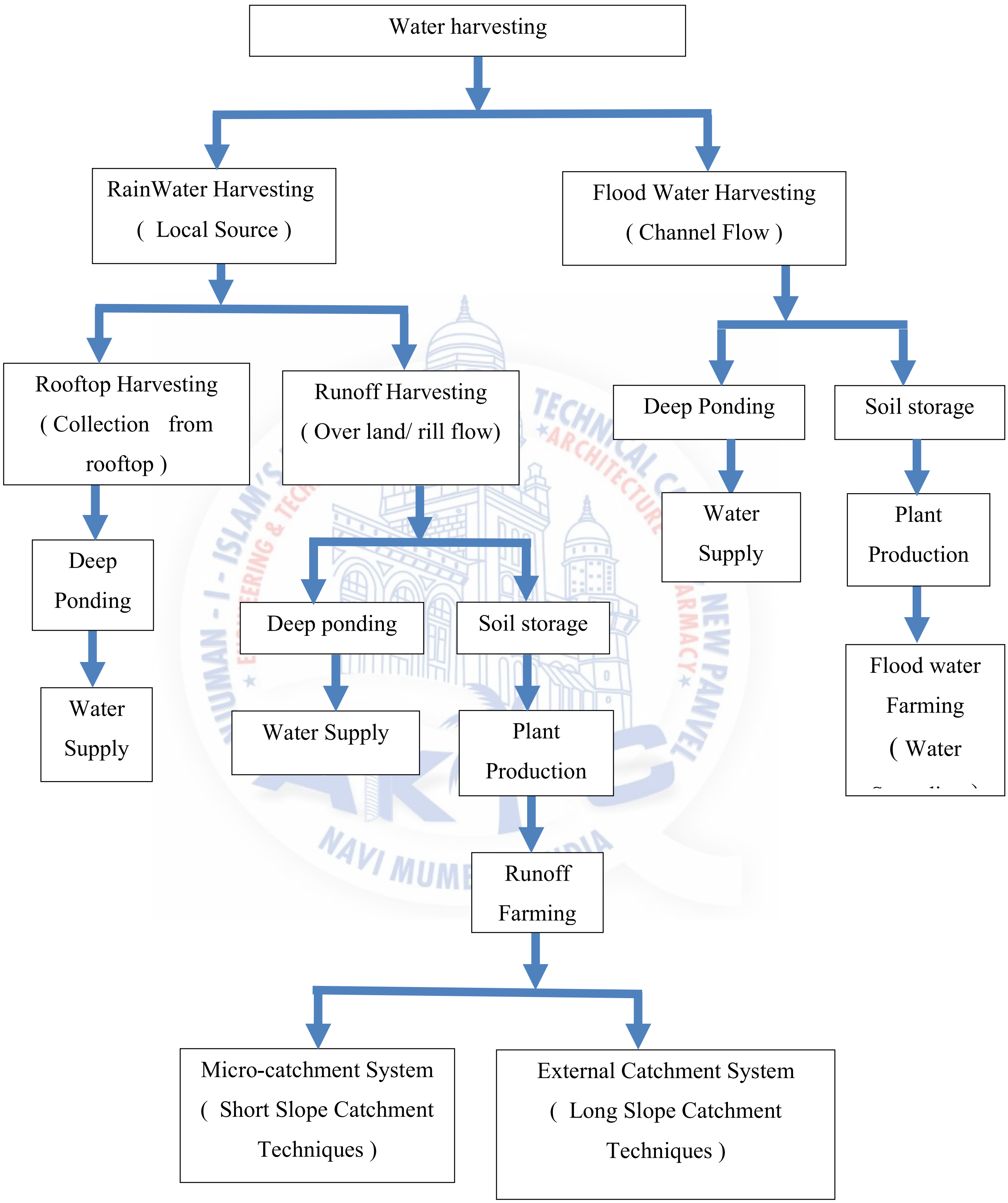

Fig 1.1 Classification of water harvesting techniques

1.5 Need of study

Semi-arid region is a region where the rainfall varies from 250 mm to 650 mm per year. Because of less rainfall , high evapo-transpiration , surface and ground water availability is very less in these regions. It leads to water scarcity and drought conditions. Conventional water harvesting structures are not suitable in these regions. Hence there is need to go for alternative solution such as water harvesting from thin air.

1.6 Aim of research work

This study is aimed of finding the alternate techniques for water harvesting other than rainfall to overcome the drinking water problems, such as thin air.

1.7 Objective of research work

1. To carry out a comparative analysis of different methods of water harvesting from thin air and other sources.
2. To carryout feasibility analysis and cost analysis of Warka Water Tower.

1.8 Scope of research work

This study will be helpful to solve the drinking water scarcity problem in semi-arid region where rainfall is very scare and conventional water harvesting structures are not helpful.

1.9 Organization of project report

The study carried out is organized in this report as below:

Chapter 1: Introduction

This chapter gives brief introduction about the water scarcity in India and drinking water problems in semi-arid region. It also introduces the research objectives and necessity of study.

Chapter 2: Literature review

This chapter presents review of literature referred for the study. The chapter includes background of the study focusing on why the study is necessary. Also review of comparative study of different water harvesting structure over the world are presented in the chapter.

Chapter 3: Study area and methodology

This chapter introduces the study area for which the study is carried out. Also the data and methodology used for the study are included.

Chapter 4: Results and discussion

All results obtained are presented in this chapter and are discussed.

Chapter 5: Summary and conclusion

Based on the results of study appropriate conclusions are presented in this chapter and project work is summarized.

Chapter 2

Literature Review

2.1 General

This chapter explains about the different water harvesting techniques and their advantages and disadvantages. These are the different water harvesting technique found all over the world which is implemented in different region in different country around the world having different suitable climatic condition some of them are listed below.

2.1.1 List of different water harvesting techniques:

- Water maker
- Aerial well
- Fog collector/harvesting
- Sky well
- Warka water tower

2.2 Water Maker

Water maker was first installed in 2007 at small village (Jalimudi, Andhra Pradesh) of India. It is a device, atmospheric water generator (AWG) which is working on dehumidification techniques. This unique technology uses optimized dehumidification techniques to extract and condense moisture in the air to produce healthy, purified drinking water (Fig. 2.1).

As the technology is climate dependent, Water Makers require average temperatures between 25°C - 32°C and an average RH of 70% - 75% to produce water as per their capacity.Since It is working on electricity, it requires energy about of 2.2- 2.5 kW per day which is again a major problems for rural region. The initial cost of device is about 4 lakh rupees in Indian currency which gives the discharge of 120 lit per day .

Fig. 2.1 Water Maker
(www.watermakerindia.com)

2.3 Aerial well / air well

An air well or aerial well is a structure or device that collects water by promoting the condensation of moisture from air. Designs for air wells are many and varied, but the simplest designs are completely passive, require no external energy source and have few, if any, moving parts (Fig. 2.2).

High-mass air wells: used in the early 20th century, but the approach failed. The high-mass air well design attempts to cool a large mass of masonry with cool night time air entering the structure due to breezes or natural convection. In the day, the warmth of the sun results in increased atmospheric humidity. When moist daytime air enters the air well, it condenses on the presumably cool masonry. None of the high-mass collectors performed well.

Fig. 2.2 Airwell structure
(https://en.wikipedia.org/wiki/Air_well_(condenser)

2.4 Fog harvesting

Fog, a cloud that touches the ground, is made of tiny droplets of water-each cubic meter of fog contains .05 to .5 grams (half the weight of a paper clip) of water. Fog collectors are nets slung between two poles, but they are made of a polypropylene or polyethylene mesh that is especially efficient at capturing water droplets. When the fog rolls in, the tiny droplets of water cling to the mesh, and as more and more cluster together, they drip into a gutter below that channels the water to a water tank (Fig. 2.3).

Fog harvesting is particularly suitable for mountainous areas .Fog harvesting technologies depend on a water source that is not always reliable, because the occurrence of fogs is uncertain. Small fog collectors cost $200 each to build. Large 40-m² fog collectors cost between $1,000 and $1,500 and can last for up to ten years

.

Persistent winds from one direction are ideal for fog collection:

- A field of dunes or a mountain range that rises high enough is necessary to intercept clouds of fog that are advanced in to the region.
- The region of the stratocumulus cloud, which normally has the highest liquid content, is between 400 m to the direction of the wind bringing cloud and fog from the ocean.
- One should try and work as close to the coast as possible, ideally within 5 km but possibilities exist up to at lest 25 km inland.
- It is very important that there be no major obstacle to the wind within a few kilometers of the site.
- An upwind ridgeline that there is no major obstacle to the wind within a few kilometers of the site.
- The presence of an inland depression or basin that will heat up during the day will cause a local low-pressure area. This will enhance the sea breeze and increase the wind speed with which marine cloud decks flow over the terrain.

Fig 2.3 Fog harvesting structure
(http://www.climatetechwiki.org/content/fog-harvesting)

2.5 Skywell

Skywell**,** is pitching atmospheric water-generator systems, which extract water out of the air with its advanced water generators. The technology is relatively simple, and works similarly to a dehumidifier. Air is forced over a cooled coil, which causes the water to condense. Each Skywell unit takes about 24 hours to generate five gallons of water by consume about five to 8 kilowatt electricity per day.(Fig. 2.4) and Its mechanical device costs around 4 lakhs rupees($6300).

Fig 2.4 Skywell device (http://losangeles.cbslocal.com/2015/06/10/dodger-stadium-battles-drought-with-cutting-edge-skywell-de-humidifier/)

2.6 Warka water tower

The Warka water harvesting technique and construction system are inspired by several sources. Many plants and animals have developed unique micro- and nano-scale structural features on their surfaces that enable them to collect water from the air and survive in hostile environments. By studying the Namib beetle's shell, lotus flower leaves, spider web threads and the integrated fog collection system in cactus, we are identified several specific materials and coatings that can enhance dew condensation and water flow and storage capabilities of the mesh.

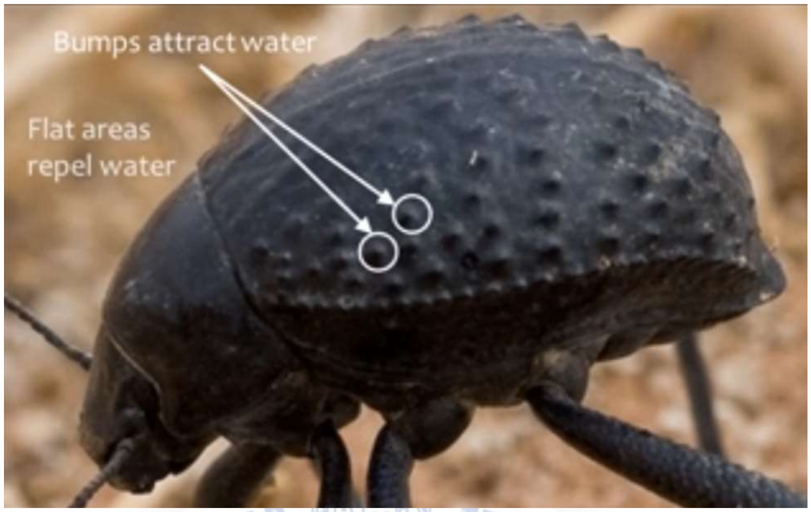

Fig 2.5 Namib beetle
(http://reducedplanckconstant.wordpress.com/tag/namibian-desert-beetles/)

The termite hives have influenced the design of Warka's outer shell, its airflow, shape and geometry. Also the local cultures and vernacular architecture, were used for incorporating traditional Ethiopian basket-weaving techniques in Warka's design.

Fig 2.6 Warka tree
(http://www.warkawater.org/project/)

The name of the project 'Warka' comes from the Warka Tree, which is a giant wild fig tree native to Ethiopia. It constitutes a very important part of the local culture and ecosystem by providing its fruit and a gathering place for the community.

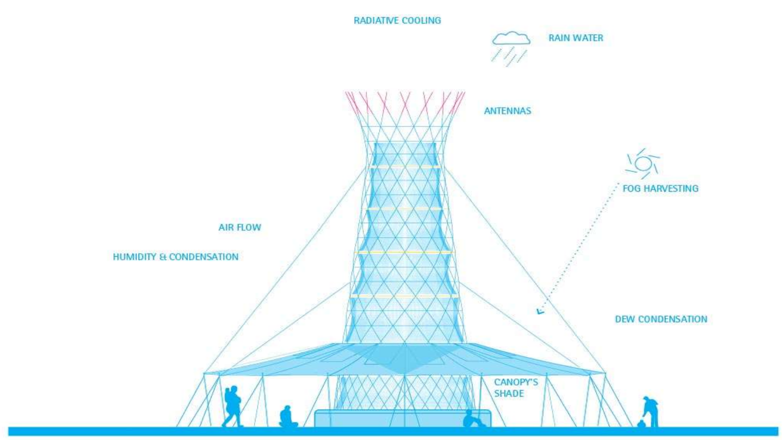

Fig 2.7 Warka water tower

(https://www.dezeen.com/2016/11/10/video-interview-arturo-vittori-warka-water-tower-ethiopia-sustainable-clean-drinking-water-movie/)

Warka Water relies only on natural phenomena such us gravity, condensation & evaporation and doesn't require electrical power.(Fig. 2.7) It is a vertical structure designed to harvest potable water from the atmosphere (it collects rain, harvests fog and dew). Warka Water is designed to be owned and operated by the villagers, a key factor that will facilitate the success of the project. The tower not only provides a fundamental resource for life – water – but also creates a social place for the community, where people can gather under the shade of its canopy for education and public meetings.

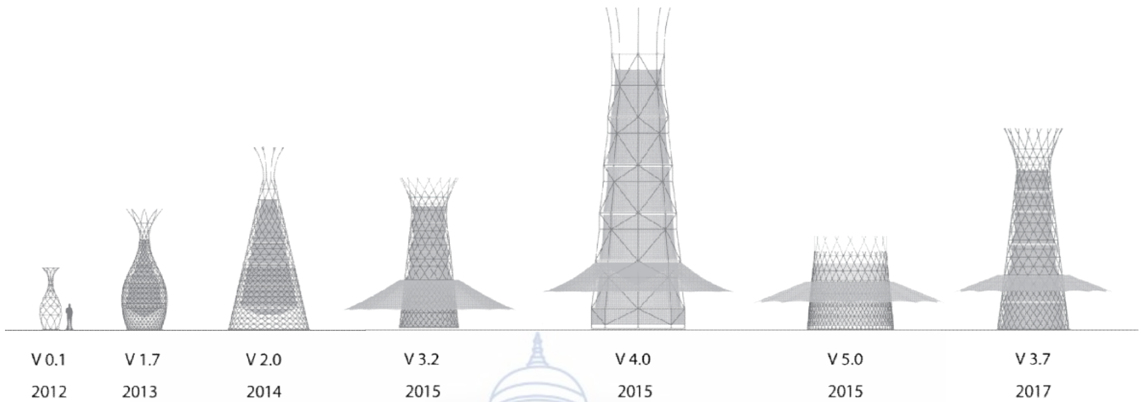

Fig. 2.8 Development stages of warka water tower
(http://www.warkawater.org/project/)

Warka water(WW) design and development activities have been mainly conducted at the Architecture and Vision labs, in Italy. Since the beginning of the warka water tower, severeal full scale prototype were made and several experiment were conducted.

A number of 12 prototypes have been constructed to date and WW has been assembled and constructed for test, demonstration, exhibition in several countries such as: Italy, France, Germany, Ethiopia, Brazil and Lebanon.(Fig. 2.8)

2.6.1 Materials

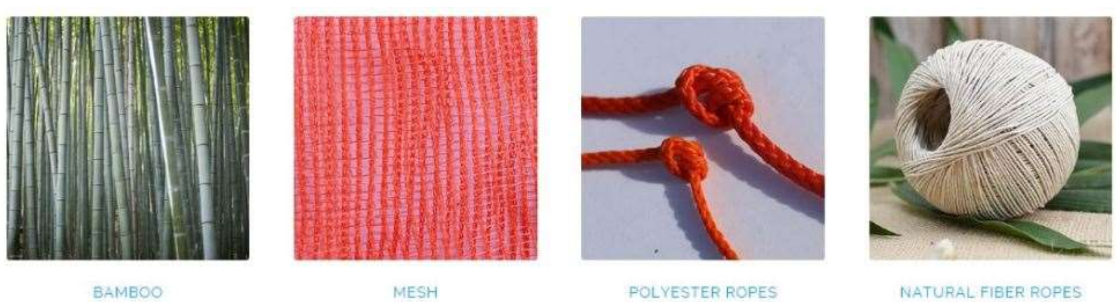

Fig. 2.9 Materials required to construct warka water tower
(http://www.warkawater.org/project/)

Warka Water mainly uses local natural and biodegradable materials (Fig. 2.9). It is a temporary structure designed to not leave traces on the environment after removal and therefore doesn't require excavation or ground modification works for set-up. The Warka doesn't extract water from the ground. In addition to drinking water, the water generated by the Warka tower can be used for irrigation, reforestation, and ecosystem regeneration.

From the literature review, it is clear that warka water tower is more advantageous than other structures and hence can be used effectively in semi-arid regions. A detailed methodology for construction of warka water tower is explained in chapter 3.

Chapter 3

Methodology

3.1 General

This chapter deals with the description of the study area that is selected for this project work, the methodology to be adopted for feasibility analysis and cost analysis of warka water tower.

3.2 Study area

Maharashtra state has a geographical area of 3,07,713 sq.km . The State has 35 districts and 353 talukas. Administratively, the State has six divisions with Headquarters at Konkan (New Bombay), Pune, Nasik, Aurangabad, Amravati and Nagpur. The population of the State is 112.3 million as per 2011 Census out of which 41 million is urban and 55.7 million rural. Out of total area of the State, 73 %, i.e., 2.25 lakhs, sq. km of area is cultivable and 17.6 % is under forest.

Marathwada Region, which is mainly located in the main drainage of Godavari River is facing severe drought several year. Drought caused by climate change is leading to reductions in the availability of fresh water supplies in some regions. Actually, the region is facing the recurrent droughts with constant variations of rains and prolonged gaps. However, the water scarcity this year, especially in Jalna, Aurangabad, Beed and Osmanabad districts is altogether different from the famine of 1972 because we have indiscriminately siphoned the ground water and made no efforts to recharge it.

Fig 3.1 Map of study area(Jalna district)
(https://www.skymetweather.com/content/weather-news-and-analysis/why-marathwada-is-the-most-drought-affected-region/)

3.3 Metrological conditions

3.3.1 Climatic condition

Marathwada has the typical tropical hot and dry climate. The average day temperature ranges from 27.7 - 38.0°C while it falls from 26.9 - 20.0°C during night. Similarly winter and summer temperature also varies greatly. Summer (March to May) is very hot with maximum temperature as high as 46.0°C in the Nanded district. Winter (November to January) is pleasant with temperature falling as low as 2.2°C in Beed district. Relative humidity is extremely low for major part of the year ranging from 35 to 50 percent and reaching over 85 percent during monsoon.

The rainy season is considered from middle of June to the end of September, which is followed a sultry period from about the end of September to the middle of November. The winter season commences from the middle of November and ends in January, which is followed by a dry hot summer from February to middle of the June. Generally, summers are full of gusty winds.

3.3.2 Temperature

Another related ecological factor is temperature or heat, which is the result of quality and quantity of light. The temperature denotes the heat energy available from solar radiation. It is the critical atmospheric variable and the major catalyst for climatic conditions. It comes from the sun as short wave radiations and the reflected long waves from the earth. The temperature at a particular place is largely determined by its distance from the equator. Temperature affects wind velocity, evaporation and rainfall, sea currents, soil formation from rocks and other vital activities viz., morphology, physiology, biochemistry and distribution of the plants. The environmental temperature where they live affects all forms of life.

Temperature variations are the most important of all ecological factors together with rainfall to determine the biomes distribution. It is influenced by time, slope, latitude direction etc. It varies during the day and night times, in sun and shade, at different depths of water bodies and during the whole year with the change of climate. Due to variation in temperature, soil temperatures also vary from place to place. Clouds, winds, water, soil etc., also affect the temperature of a place. Thermometers are usually used to measure temperature and expressed in terms of degree Celsius.

3.3.3 Precipitation

Water during rainfall is directly of little use to the organisms. It is used only after reaching the soil. Precipitation is the result of gravitational pull on the vapour in atmosphere. Atmospheric moisture reduces the intensity of light falling on plants. Precipitation occurs in various forms such as drizzle, rain, snow, dew and frost, sleet and hail.

All he above forms of precipitation, rain is the most important. It is the source of soil water and also affects humidity of atmosphere. Rains in India are caused by monsoons. About 45 % of the water available during annual precipitation flows into rivers, 20 % percolates into the ground and the remaining 35 % is lost by evaporation.

3.3.4 Relative humidity in air

Atmospheric moisture in the form of invisible vapour is known as humidity. It is one of the different forms of water in nature. The moisture content and its form in the atmosphere affects the amount of solar radiation received and reflected by earth. It is "the amount of moisture in air as percentage of the amount which the air can hold at saturation at the existing temperature". Humidity is greatly influenced by intensity of solar radiation, temperature, altitude, wind, exposure, cover and water status of soil. High temperature increases the capacity of the air to retain moisture and cause lower relative humidity. Low temperature cause higher relative humidity by decreasing the capacity of air for moisture.

Daily variations in relative humidity values depend upon the type of habitat conditions. Of the other factors of aerial environment, humidity plays an important role in life of plants and animals. Processes as transpiration, absorption of water etc., are much influenced by atmospheric humidity. Humidity affects the life of plants in various ways. Effects of moist air on plants are more or less similar to those of reduced light intensity. Relative humidity (RH) is measured by the instrument called Psychrometer or by paper strip hygrometer or a thermo-hydrograph and expressed in terms of relative humidity.

3.3.5 Cloud cover

Cloud cover (also known as cloudiness, cloud age, or cloud amount) refers to the fraction of the sky obscured by clouds when observed from a particular location. Okta is the usual unit of measurement of the cloud cover. The cloud cover is correlated to the sunshine duration as the least cloudy locales are the sunniest ones while the cloudiest areas are the least sunny places. The global cloud cover averages around 0.68 when analyzing clouds with optical depth larger than 0.1. This value is lower (0.56) when considering clouds with an optical depth larger than 2, and higher when counting sub visible cirrus clouds.

3.3.6 Vapour pressure

The vapour pressure that a single component in a mixture contributes to the total pressure in the system is called partial pressure. For example, air at sea level, and saturated with water vapour at 20 °C, has partial pressures of about 2.3 KPa of water, 78 KPa of nitrogen, 21 KPa of oxygen and 0.9 KPa of argon, totalling 102.2 KPa.

3.4 Methodology

As discussed in literature review, Warka water tower is the most suitable water harvesting structure from thin air and can be used in semi-arid regions. The adopted methodology for this study is explained in the flow chart (Fig 3.2).

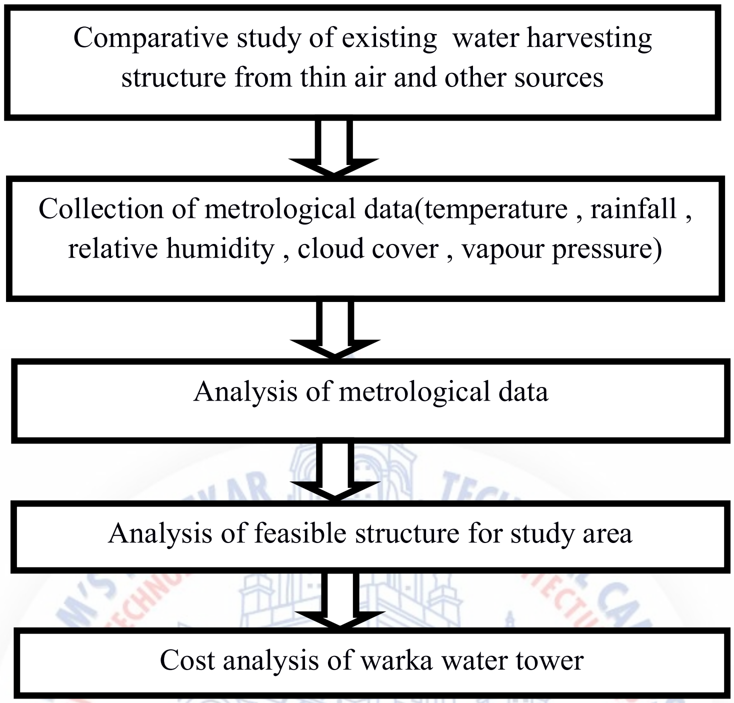

Fig. 3.2 Flowchart of methodology

3.4.1 Working principle of warka water tower

Warka Water relies only on natural phenomena such us gravity, condensation & evaporation and doesn't require electrical power. It is a vertical structure designed to harvest potable water from the atmosphere (it collects rain, harvests fog and dew).

3.4.2 Feasibility analysis of warka water tower

Monthly meteorological data viz. rainfall, maximum and minimum temperature, cloud cover, vapour pressure etc. were analyzed for a period of 102 years (1901-2002) in this study to check whether this structure is feasible or not in the study area.

3.4.3 Design considerations of warka water tower

The warka water tower consists of four major parts such as stability structure, canopy's shade, Ropes and Mesh. (Fig. 3.3)

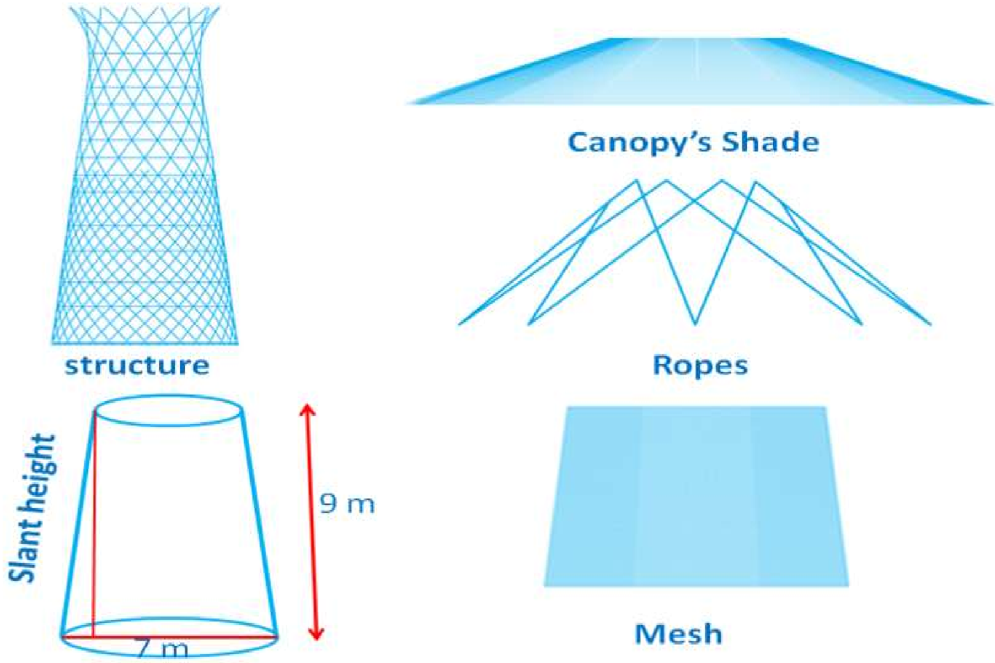

Fig.3.3 Parts of warka water tower

Height of warka water tower = 9.0 m

Footprint diameter = (7,3) m

Diameter of canopy = 10 m

Slope of stability = 1 in 2.2

Slant height of tower = $\sqrt{(9*9+4*4)}$

= 9.85 m

Average perimeter of tower c/s = $\pi(D1+D2)/2$

= 3.14*(7+3)/2

=15.71 m

Pitch height = 4.5 m (one spiral binding of splitter bamboos of complete one peripheral)

The above methodology is adopted and the results were calculated and discussed in chapter-4.

Chapter 4

Results and Discussion

4.1 General

This chapter deals with comparative analysis of different water harvesting devices from thin air, fog and other resources. Results of feasibility analysis, design and cost analysis of warka water tower are also discussed in this chapter.

4.2 Comparative study of different water harvesting devices

As discussed earlier in chapter 2 and 3, there are 5 major water harvesting devices being used in different countries of world with their own advantages and disadvantages. A comparative analysis of the structures is summarized in table 4.1

Table no 4.1 Comparative study of different water harvesting devices

characteristics	**Water maker**	**Airwell**	**Fog harvesting**	**Skywell**	**Warka water tower**
Initial cost	$6000	$2000	$200	$6000	$250
Suitable condition	Any where RH(50-80) TEMP(0-40 ^{0}C)	Any where RH(50-80) TEMP(<50 ^{0}F)	High altitude with fog condition	Any where RH(50-70) TEMP (0-40)^{0}C	Any where RH(50-70) TEMP(0-40) ^{0}C
Installation	Skill labour require to install and maintain it	No Skill labour require to install and maintain it	No skill labour is require	Skill labour require to install and maintain it	No skill labour is require
Principle	Device of dehumidification process	Structure and device is used for dehumidification process	Formation of water droplet	Device of dehumidification process	Formation of water droplet
Rate of discharge	110 lit/day	50-100 lit/day	100 gallon/day	50-100 lit/day	50-100 lit/day
Maintenance cost	$(0.2-0.3) per gallon	Less than $0.1 per gallon	Less than $0.1 per gallon	$0.3 per gallon	Less than $0.1 per gallon
Energy require to run	2.2-2.5kW /day	-	-	7-9 kW / day	-

From study of different water harvesting structures available all over the world which having its own advantages and disadvantages, it is evident that warka water tower is most suitable because its having less initial cost up to Rs 33,000 per tower, no external energy is required and less maintenance cost and rate of discharge is up to 100 lit per day and it can be increased with suitable conditions.

4.3 Analysis of metrological data

Monthly and yearly metrological data (Temperature, Rainfall, Wet day frequency, Cloud cover and Vapour pressure) of Jalna district was analyzed from 1901 to 2002 and the results are explained using graphs.

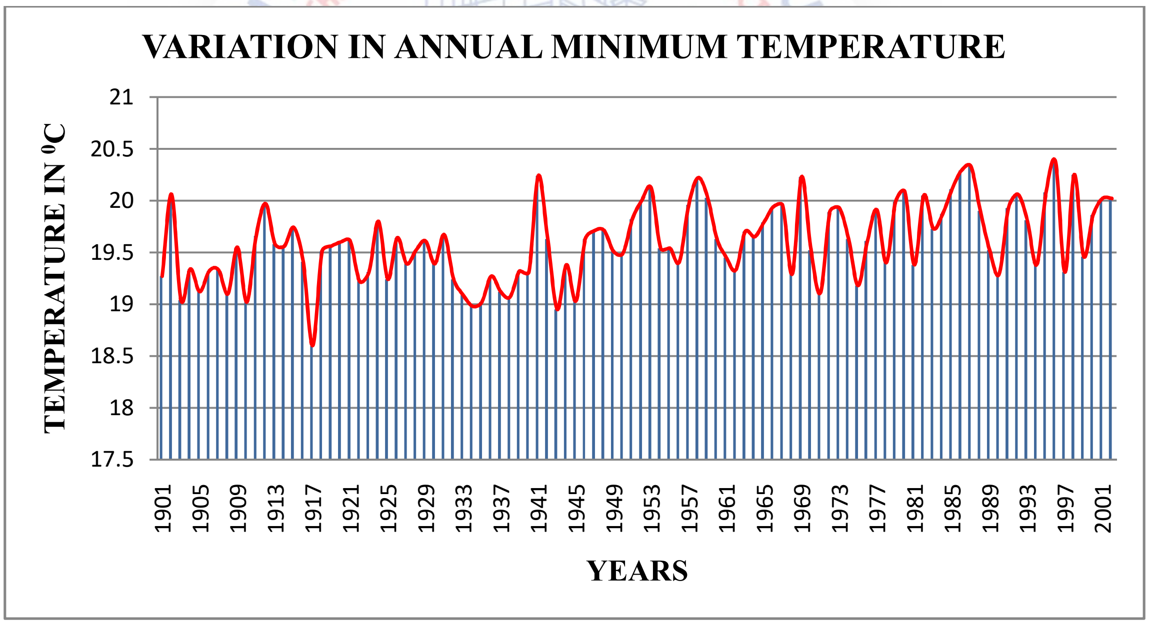

Fig. 4.1 Variation of Annual average minimum Temperature

From the average annual temperature bar chart, it was also observed that the maximum average minimum temperature was found in the year of 1996 i.e. 20.37 ^oC, throughout the year. It was also found that the average annual minimum temperature was 18.60 ^oC. It was observed that 51 numbers of years received less than average temperature and 50 number of years equal and above the average yearly temperature out of total years under observation.

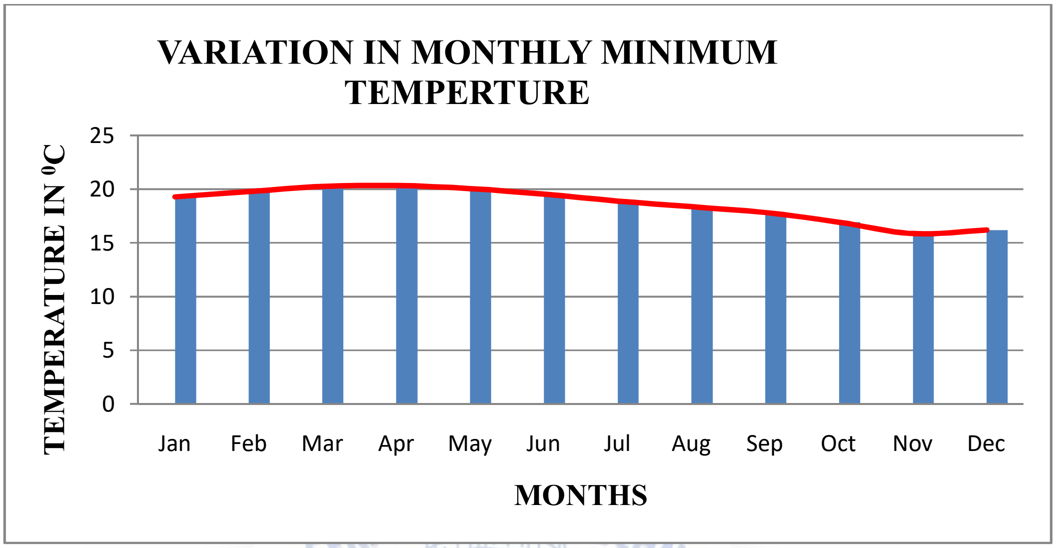

Fig. 4.2 Variation of monthly average minimum Temperature

From the minimum average monthly temperature bar chart, it was observed that the Jalna district had received maximum average minimum temperature in the month of April i.e. 20.32 °C, and had received average minimum temperature in the month of November i.e. 15.85 °C out of total years under observation.

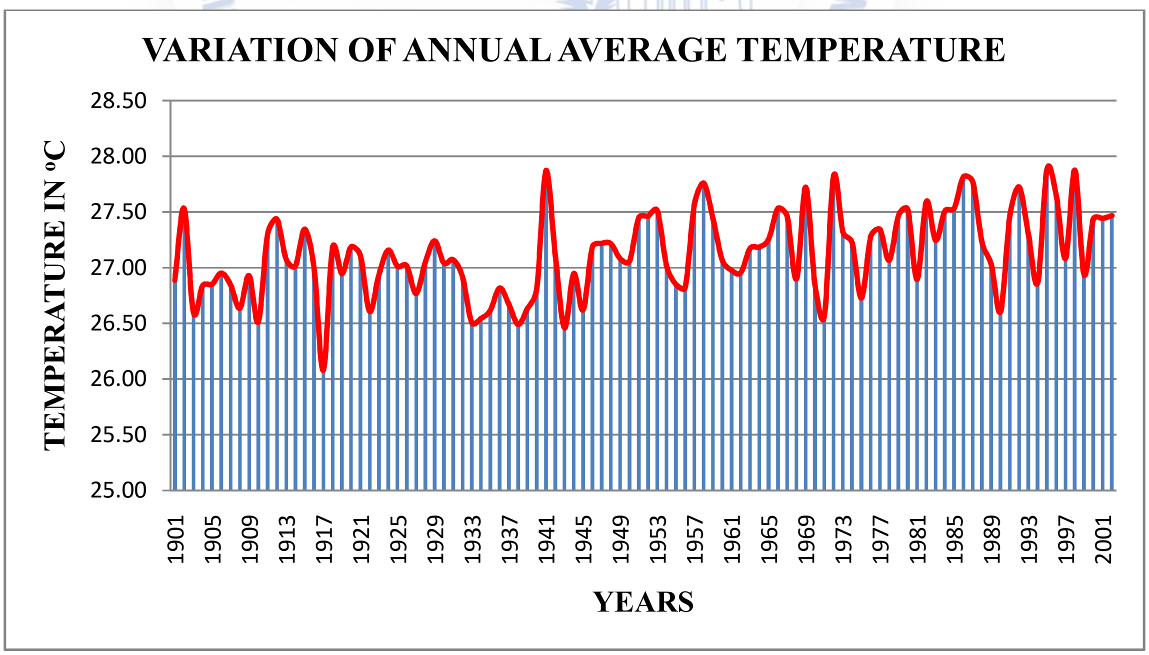

Fig. 4.3 Variation of Annual average Temperature

From the average annual temperature bar chart, it was also observed that the maximum average temperature was found in the year of 1995 i.e. 27.88 ^{o}C throughout the year.It was found that the average yearly temperature was 27.12 ^{o}C. It was also observed that 54 numbers of year received less than average temperature and 48 number of year equal and above the average yearly temperature out of total years under observation.

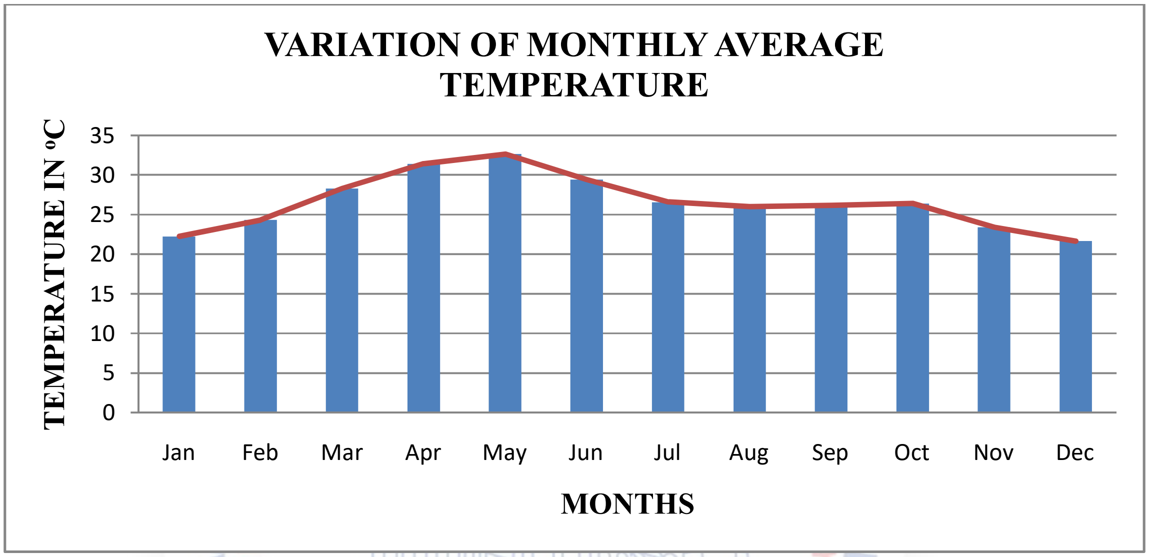

Fig. 4.4 Variation of monthly average Temperature

From the average monthly temperature bar chart, it was observed that the Jalna district had experienced maximum average temperature in the month of May i.e. 32.63 ^{o}C, and had received average minimum temperature in the month of December i.e.21.64 ^{o}C, for the total period under observation.

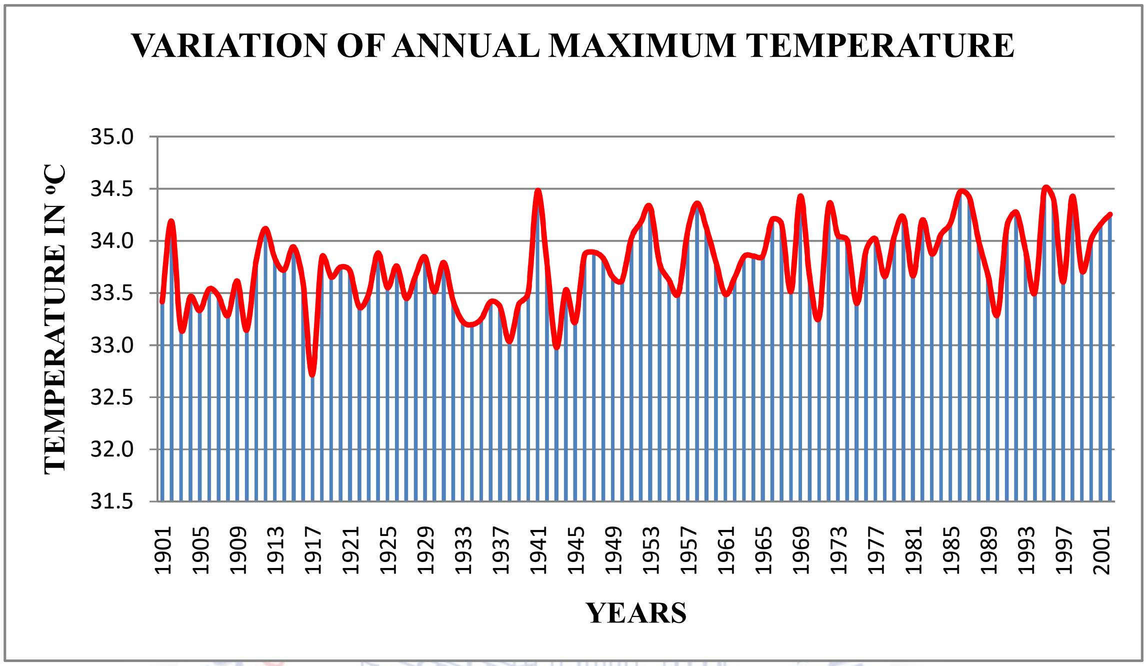

Fig 4.5 Variation of Annual average maximum Temperature

From the average annual temperature bar chart, it was also observed that the maximum average temperature was found in the year of 1917 i.e. 32.71 ^{o}C throughout the year.It was found that the average yearly temperature was 33.76 ^{o}C. It was also observed that 50 numbers of year received less than average temperature and 52 number of year equal and above the average yearly temperature out of total years under observation.

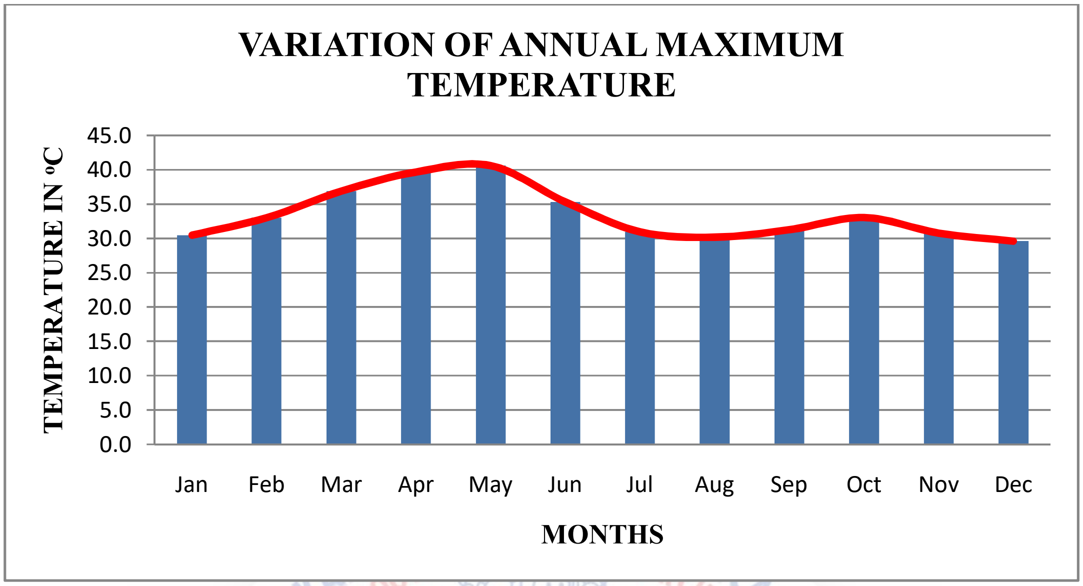

Fig 4.6 Variation of monthly average maximum Temperature

From the average monthly temperature bar chart, it was observed that the Jalna district had experienced maximum temperature in the month of May i.e. 40.6 °C, and had received minimum of maximum temperature in the month of December i.e.29.6 °C, for the total period under observation.

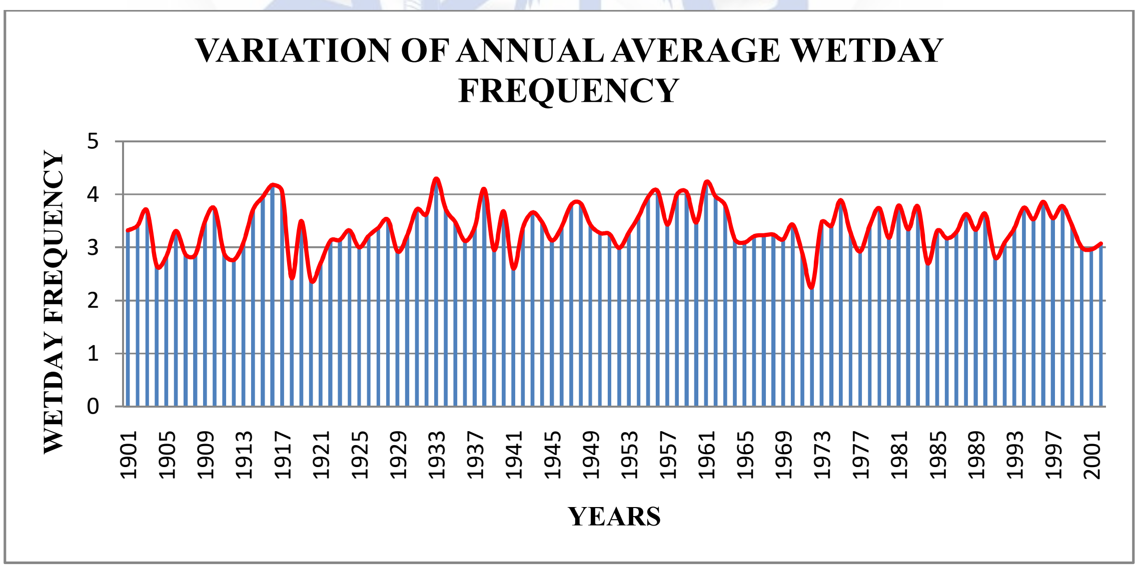

Fig. 4.7 Variation of Annual average Wet day

From the annual average wet day frequency bar chart, it was also observed that the maximum average wet day frequency was found in the year of 1933 i.e. 4.3 days per months throughout the year. It was found that the average yearly wet day frequency was 3.70 days per month. It was observed that 76 numbers of year received less than average wet day frequency and 26 number of year equal and above the average yearly wet day frequency out of total years under observation.

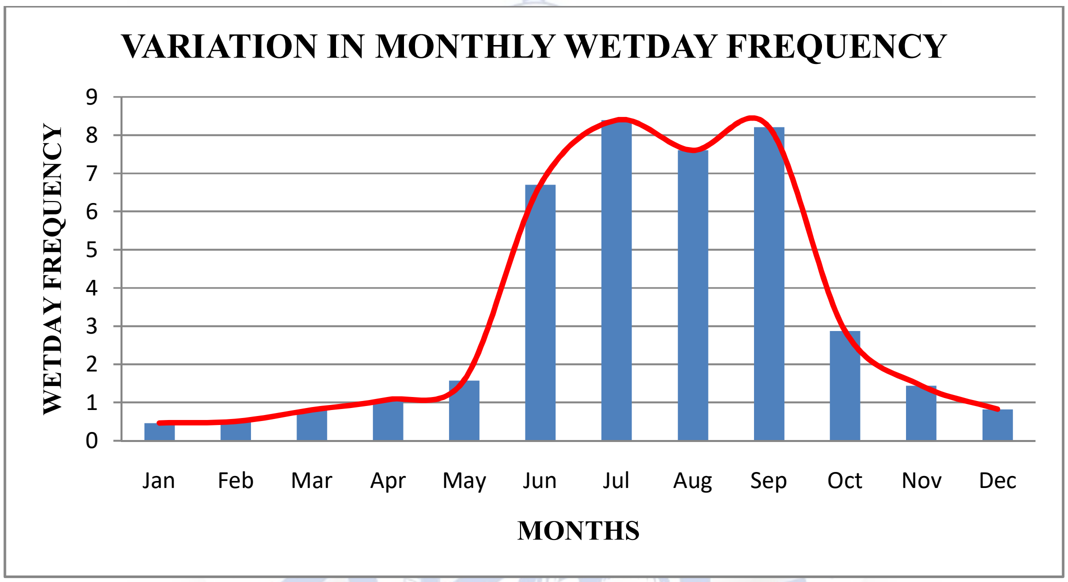

Fig. 4.8 Variation of Monthly average Wet day

From the average monthly wetday frequency bar chart, it was observed that the Jalna district had received maximum average wetday frequency in the month of July i.e. 8.39 days, and had received average minimum wetday frequency in the month of January i.e. 0.46 days out of total years under observation.

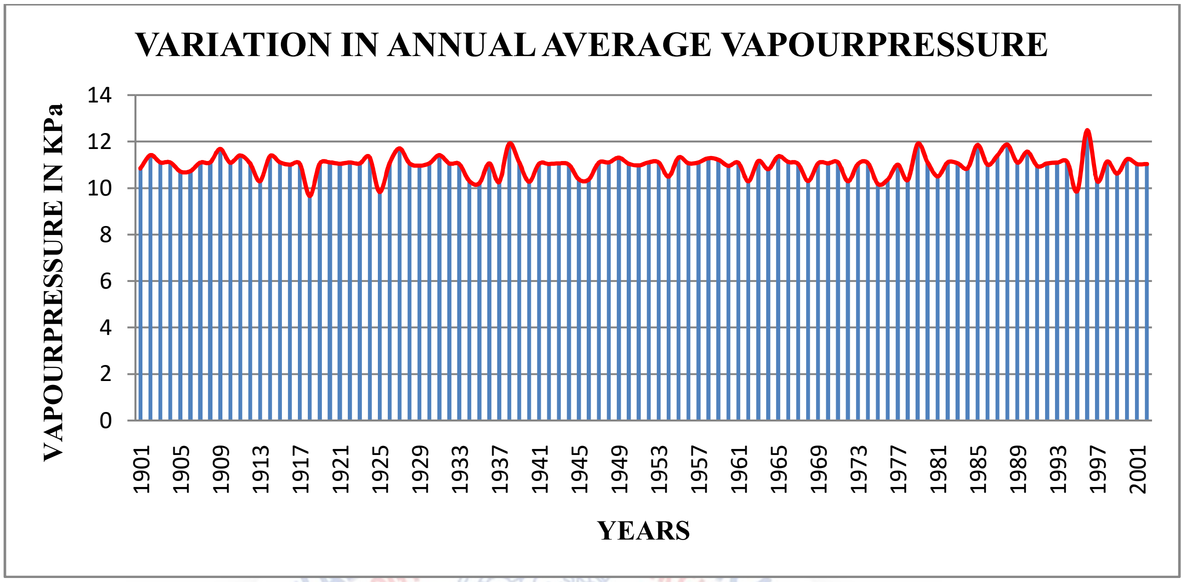

Fig. 4.9 Variation of Annual average vapour pressure

From the annual average vapour pressure bar chart, it was also observed that the maximum average vapour pressure was found in the year of 1996 i.e. 12.48 Kpa throughout the year. It was found that the average yearly vapour pressure was 10.985 Kpa . It was observed that 29 numbers of year received less than average vapour pressure and 73 number of year above the average yearly vapour pressure.

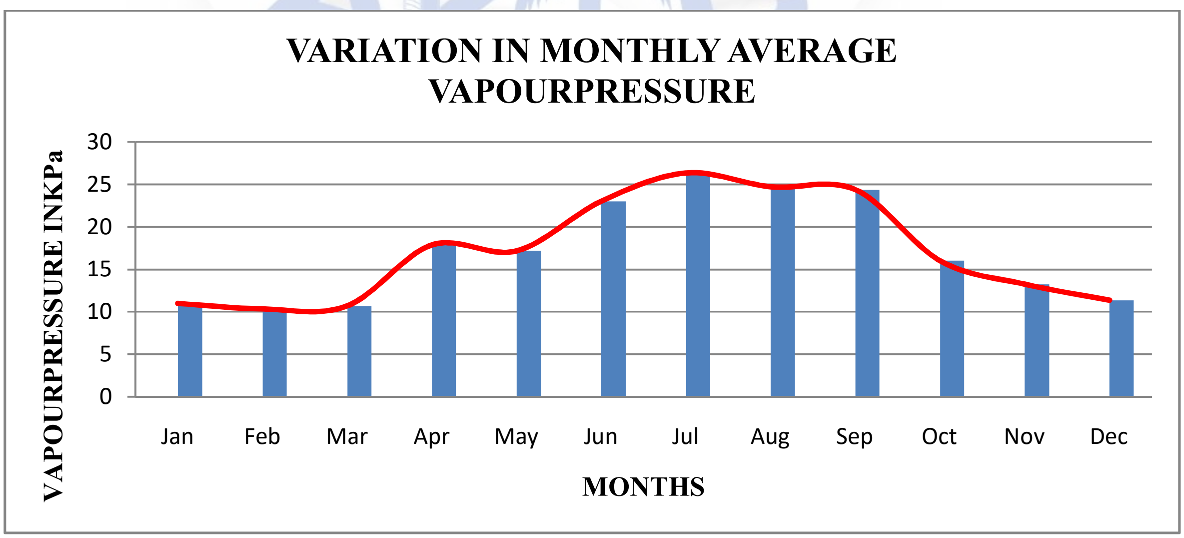

Fig 4.10 Variation of Monthly average vapour pressure

From the average monthly vapour pressure bar chart, it was observed that the Jalna district had received maximum average vapour pressure in the month of July i.e. 26.34 Kpa, and had received average minimum vapour pressure in the month of February i.e. 10.34 Kpa.

From the above analysis it is clear that the temperature in the study area varies from 15.85 to 40.6 ^{o}C . Vapour pressure and cloud cover in the study area varies from 9.66 to 26.34 KPa and 0.46 to 8.39 days in months respectively. It was observed from the other sources that the RH in the study area varies from 30 to 75%. (Source: Indian metrological department and worldweatheronline). Hence warka water tower is feasible in this region.

4.4 Cost analysis of Warka water tower

Based on methodology adopted in 3.4, the design and cost analysis of warka water tower was done.

No. of spiral binding = 2

Length of each spiral binding = $\sqrt{(4.5 * 4.5 + 15.71 * 15.71)}$

= 16.34 m

Total length = 2 x 16.34 = 32.68 m

Perimeter of lower c/s = 22 m

Assuming space between two consecutive spiral = 0.5 m

No of spiral member required = 22/0.5 = 44 No's

Total length of spiral members = 32.68*44

Total length of spiral member = 1437.92 m = 4717.58 Ft

Ht of each bamboos = 5 ft having 6 fraction(splitter

No. of bamboo required = 200

Cost of single bamboo = Rs 100/ Ft

Total cost of bamboo = Rs 20,000 (approx)

Length of natural ropes = $\sqrt{(6 * 6 + 7.5 * 7.5)} * 4$

(Here 6m is the vertical height where rope is attached and 7.5 is the horizontal distance at base) =75 m (approx 5kg)

Rate of cost of natural fibre ropes = 400/kg

Total cost of natural ropes = Rs 2

Total cost of polyester ropes = Rs . 500

Area of mesh = 30 sq m

Rate of mesh = 50/ sq m (approx)

Total cost of mesh = 50*30 =Rs 1500

Area of shade = $\frac{\pi}{4} * (10 * 10 - 5 * 5)$ (at height of 3m from bottom)

= 60 sq m

Total cost of canopy mesh = Rs 3000 (approx)

Cost of tank = Rs 3000 (1000 lit capacity)

Cost of funnel = Rs 3000

Total cost of warka water tower = Rs 33,000

Hence the total cost of warka water tower is around Rs 33,000 for 1000 lit capacity.

The present research work is summarized in chapter 5 and important conclusions are enlisted based on the results and discussion.

Chapter 5

Summary and Conclusions

5.1 Summary

Semi-arid region is a region where the rainfall varies from 250 mm to 650 mm per year. Because of less rainfall , high evapo-transpiration , surface and ground water availability is very less in these regions. It leads to water scarcity and drought conditions. Conventional water harvesting structures are not suitable in these regions. Hence there is need to go for alternative solution such as water harvesting from thin air. The aim of this research work is to find alternative method of water harvesting from thin air to overcome drinking water problems in semi-arid regions. The objective of this study is twofold , firstly to carryout comparative analysis of different water harvesting structures from thin air and secondly to carryout feasibility and cost analysis of Warka Water Tower in semi-arid region. In this research work , different water harvesting structures from thin air were studied and Warka Water Tower was found to be most economical and convenient because of its low initial cost , zero energy requirement and less maintenance cost and easy availability of construction material. The rate of discharge of a Warka Water Tower is 100 lit per day , however its efficiency can be increased with suitable conditions. Hence Warka water tower can be effectively used for drinking water purpose in semi-arid regions. In this study, feasibility analysis of Warka Water Tower was carried out and it was found that the structure is suitable at temperature 40 degree Celsius and relative humidity 50 -70 %. Cost analysis shows that the cost of a single Warka tower is 33,000 rupees

5.2 Conclusions

- Warka water tower is feasible and recommended in semiarid region as a water harvesting device from thin air because of low initial cost , no electric supply required , low maintenance cost , easily available construction materials.
- Proper maintenance and effective metrological condition can increase its efficiency and can be effectively used for drinking water supply in semi-arid regions**.**

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