ADAMA SCIENCE AND TECHNOLOGY UNIVERSITY

SCHOOL OF MECHANICAL, CHEMICAL AND MATERIALS ENGINEERING

MSc. Project

on

Windmill Water Pump for Small-Scale Irrigation and Domestic Use

By

WANDATIR GIZAW AYANA

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Advisor:-N. Ramesh Babu (Asso.Prof.)

Department of Mechanical and Vehicle Engineering

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Approved by board of examiners

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Chairman, department graduate committee	**Signature**	**Date**
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Internal examiner	**Signature**	**Date**
______________________________	__________	__________
External examiner	**Signature**	**Date**
______________________________	__________	__________
Advisor	**Signature**	**Date**

DECLARATION

I hereby declare that this thesis project entitled “Windmill Water Pump for Small-Scale Irrigation and Domestic Use” in partial fulfillment of the requirements for the award of the degree of Master of Science in automotive Technology Teacher Education is the result of my own research except as cited in references. The work carried out from September to February 2016 under the supervision of N. Ramesh Babu (Associate Professor) Department of Mechanical and Vehicle Engineering, Adama Science and Technology University. The matter embodied in thesis project has not been accepted for any degree and is not submitted in candidature of any other degree or diploma.

Name	Signature	Date
Wandatir Gizaw	________________	______________________

I hereby declare I have read this project and in my opinion this thesis project is sufficient in terms of scope and quality. This thesis project has been submitted for examination with my approval.

N. Ramesh Babu (Associate Professor)	________________	________________
(Advisor)	Signature	Date

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ABSTRACT

Ethiopian economy which is mostly agricultural based is suffering due to variation in seasonal rains, drought conditions and lace of well-developed irrigation system. The project work employment is building a windmill water pump. The objective was to build a windmill driven water pump for small-scale irrigation. The project method was selecting project area which is based on the wind speed and availability of underground water, constructing, selecting water pump type and test it. The intention is that supporting a local farmers to have productive throughout the year. However, the windmill drives a pump that pumps water from a well or river to a tank for further use in irrigation. Calculations have been made on the energy available in the wind and an energy analysis was then performed to see what wind speed is required for the system to work. Prototype is built for carried out test for the analysis of actual project output. A project is designed to pump 50 cubic water per day. The tests that have been performed during the circumstances at the time showed that the performance of the windmill is sufficient to feed a 5 hectare of cereal grains in all season throughout the year. Finally concluded that a project result obtained is so far encourage.

Key word: - *Windmill, Water pump, Irrigation, Wind energy*

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LIST OF SYMBOLS AND ABBREVIATIONS

$	US Dollar Sin
RPM	revolution per mint
SNNP	south nation nationality
C_P	Power Coefficient
KE	Kinetic Energy
TSR	Tip Speed Ratio
CAD	Computer Aided Design
3D	Three Dimension
NACA	National Advisory Committee for Aeronautics
MOE	minister of Education

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1. INTRODUCTION

1.1Background of the Study

Many Ethiopians live in the rural areas of the country, making their livelihood as small-scale farmers. The crops they produce are mostly for their own family consumption. But if there is appropriate irrigation system surplus crops can be produced and farmers get benefitted. Rural Ethiopia is in many ways underdeveloped. The infrastructure is poor; roads are in bad shape there is no electricity or running water, and waste management is inadequate.The lack of water is a problem many farmers wrestle with. Even those who live close to a water source, such as a lake or a river are lacking running water in their homes. It is usually the women and children of the household to walk long ways to bring home water. The time they spend on fetching water could be better spent doing something else. Children could go to school, and women could work more in the home or perhaps take a Part-time job to increase the family in-come. Another consequence of lack of water is that it is difficult for farmers to provide the crops with enough water during the dry season (November to May). This means that farmers can only grow crops that will withstand water shortage for a period of time, or perhaps even last through drought.

Only a few kinds of crops can survive in these conditions. Growing the same crops every season can deplete the soil of its nutrients which may lead to an unbalanced diet with not enough vital nutrients and vitamins. Because of the hard living conditions in rural Ethiopia, a common attitude to work and life is to live day by day and earn money just to survive the day. There is almost no long-term planning for the future. Even if its rate is different in different locality the rapid growth of the population is still go rapidly.

But this growth need full supply of fruit, vegetable and other crops. In the developing country the growth doing by waiting of vegetable and crop is the season like summer. But it may not enough to feed the whole nation in country. So extra technic is needed which was used previously in the developed country early such technic is called irrigation. The water pump was developed early First World War. And it pump the water in to the storage tank. The storage water is distributed to the well irrigated field, but the consumption of fuel to fill the desired tank may be huge. This affects the economy of farmer, and the country has to import the fuel from the other fuel producing countries and in addition to that the environment pollution increases. A benefit of using wind energy to power agricultural water pump system is that increase in water requirements for livestock and irrigation tend to coincide with the seasonal increase in wind energy. When properly designed, these wind driven water pump systems can also result in significant long – term cost saving and a smaller environmental foot print compared to conventional systems.

1.2 Statement of the Problem

Obviously it is clear that Ethiopia economic development is leading by agriculture. Hence irrigation is one way of agriculture in which the farmers use the reserved or flooding water to cultivate vegetables and other seeds. The reserved water is pumped and distributed on the farm land by different types of water pumps operated by conventional fuels. But the economics of the local farmers are unable to buy fuel and engine operated water pump. Due to this it is essential to search another alternative mechanism which is renewable powered pump system

This project work is prepared to implement windmill water pump which is renewable and low initial cost and operation cost. The main issue to prepare this project is to;

- To build wind mill water pump for irrigation purpose
- Add some value on green environment development (reduce environmental pollution)
- Use the abundant wind energy

1.3 Objectives

1.3.1 General objective

The general objective of this project is to construct wind power water pump for small scale irrigation.

1.3.2 Specific objectives

- To select area of the project.
- To select type of water pump used for local farmers .
- To buld prototype of windmill water pump.

1.4 Scope of the project

This project going to touch the overall operation of the windmill, water pump, drive mechanisms and the geographical selection of the project which is based on average annual wind speed weather casting of Ethiopia and where there is underground water or river for small scale irrigation.

1.5 Limitation of the study

Due to the unpopularity of the project in Ethiopia especially in the project area; unavailability of the references, the time and budget also limit the study. The other challenge of this project is that I am lone to do it.

1.6 Significance of the Study

The main contribution of this project is to improve and modify the conventional water pump used for irrigation in to wind energy operated water pump. This project helps to;

- Minimize the consumption of conventional fuel.
- Maximize agricultural productivities.
- Create jobs for micro and small enterprises.
- Introduce modified and localized technology.

2. LITERATURE REVIEW

2.1 Introduction

In order to complete this work, literature review has been made from various sources like journal, books, article and others. This chapter includes all important studies which have been done previously by other research work. It is importance to do the literature review before doing the research because the related information greatly helps in the thesis. What to be done in the research has to be understood clearly by reviewing the literature before starting the thesis study. Reviewing literature one can gain knowledge to make sure that the subject is understood fully and can complete the research. A review of the article was performed to identify studies that relevant to the topic. The material that related to the topic is categorized as windmill, water pump, and other components

2.2 Theoretical / Conceptual Framework

2.2.1 Wind

Wind primarily occurs because of temperature differences in the air caused by sun radiation. When air is heated it becomes less dense and therefore rises. The pressure at ground at level decreases, and because air always flows form high pressure to low pressure, thermal circulation is then developed. One example of this thermal circulation is the sea breeze; a local wind found coastal areas or at large lakes. It occurs on relatively clear days when the sun heats the land more than these, causing the air above the land to rise and flow out over the water. The air cools off, sinks, and flows back in over land. The sea breeze can occur all year round in the tropics, and can reach a speed of 5-10 m/s at ground level. It is most extensive during the afternoons when the sun has heated the ground to a high temperature. The opposite of sea breeze is land breeze. It happens during the night when the land cools off faster than the water, and the process described above is reversed [1].

It is a lot weaker with speed at only about 1 m/s. the wind speed increases with altitude and can be estimated the using the beau fort scale, which is based on observations of the surrounding. In 2007, Anna Håkansson and Petra Nilsson, two students from Halmstad University, visited SCC-ViAFP in Musoma, Tanzania. They conducted a field study [19] that identified several problems that many farmers in the region have; one of them being lack of clean and running water. Håkansson and Nilsson's goal were to develop a product that could solve this problem. Back in Sweden they constructed a windmill prototype that employs wind energy to pump water using a semi-rotary pump. The intention is that local farmers should be able to build their own windmill [20] and pipe system, and thus have running water in their household. However, the windmill has never been built in Tanzania, but SCC-ViAFP wish to implement this solution at their ATC.

2.2.2 Wind power

The kinetic energy in the wind can be converted into different useful energy forms, such as mechanical energy or electricity. This is called wind power. It is a renewable energy resource that is under steady development worldwide. It is also said to be an absolutely clean source of energy, since there are no emissions or direct influences on the environment, except for the aesthetical. It can also produce disturbing noise while running. Wind power technology has come forward since the 12th century when the first windmills were built in Europe for grinding grains into flour. In 19thcentury American, windmills were used for pumping water at farms. Today's wind power stations are very advanced and use complex technology, but the old fashioned type of windmill is still built and used. It is common all over the world, especially in developing countries, but also among famers in America and Australia. One disadvantage with power is that it is unreliable, as the wind cannot be controlled hills and trees can reduce wind to change direction. With a suitable location and with good conditions, wind power is a good energy source. [1].

2.2.2.1 Advantages of Wind Power

- It is the cheapest source of energy. This is because it does not require importation and it is readily available.
- It is environmental friendly i.e. it is a major source of green energy as no greenhouse emissions are released to the atmosphere during its production.
- Require less lab our expenses as maintenance are very minimal and few personnel are required at the site.

2.2.2.2 Disadvantages of Wind Power

Varying wind speeds and directions make it difficult to use wind as a consistent source of power.

Initial investment on construction and installation of wind power machinery is very costly. In the year 2008-2009 the average investment required was $1300 and $1800 for every kW the windmill was to produce (wind energy).

They produce so much noise and are therefore limited to areas away from homes and also away from wildlife reserves [3].

2.3 Power production

1) The kinetic energy of the wind is the source of the driving force of a wind turbine. That kinetic energy can be depicted by the formula

$$E = f m_{spec} v^3 \qquad (1)$$

Where: -E = the kinetic energy

m_{spec} = the specific mass (weight) of air

v = the velocity of the moving air (the wind)

f = a calculating factor without any physical meaning

The power in the wind is proportional to: -

a) The area of windmill being swept by the wind

b) The cube of the wind speed

c) The air density - which varies with altitude.

The formula used for calculating the power in the wind is shown below:

Power = (the product of density of air, swept area and velocity cubed)/2

$$P = ½. \rho (A) (V^3) \qquad (2)$$

Where: -P is power in watts (W)

ρ is the air density in kilograms per cubic meter (kg/m^3)

A is the swept rotor area in square meters (m^2) & V is the wind speed in meters per second (m/s).

Wind turbines are machines that extract energy from the wind by leveraging the aerodynamic principals of lift and drag. Lift and drag forces move the turbine blades which convert kinetic wind energy to rotational energy. The rotational energy can then be transformed into electrical energy. The rate of energy extracted from the wind is governed by Equation (3), where P is the power, T is the torque, and ω is the angular velocity of the turbine blades [8].

$$P = T\omega \tag{3}$$

2.3.1 Drag and lift force

When a wind machine interacts with the wind, the force of the wind is transferred to the wind machine. Depending on the design of the wind turbine, power from wind may be extracted as drag force or lift force or the combination of both. The drag force is the component of the wind force on the turbine blade which is in the direction of the upstream wind. Lift force is the component of the wind force perpendicular to the wind stream. The lift force is responsible for twisting and turning of the object interacting with the wind.

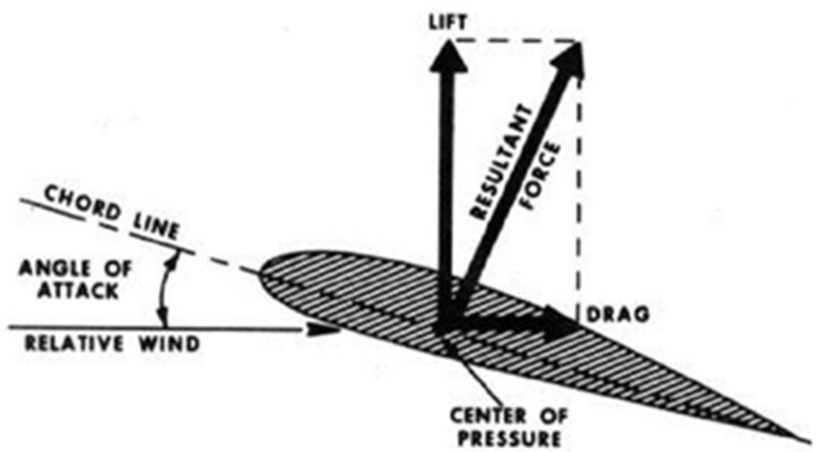

Figure 1: Illustration of drag and lift forces on an aero-foil of a wind turbine

Accordingly, wind machines can also be classified as drag or lift machines depending on their design for the extraction of the drag or lift force from the wind. Wind machines that extract the lift force are more efficient and can run at speed much higher than the upstream wind from which they extract the power. The maximum speed a drag machine attains is the speed of the upstream wind. Lift and drag forces are measured experimentally in a wind tunnel for air foils as a function of the angle of attack, α [4].

The angle of attack is defined as the angle between the chord line c of the air foil and the direction of the wind, as shown in Figure 10. For aircraft wing design, it is generally ideal to choose the airfoil that has the greatest lift-to-drag ratio, since there will be the least amount of thrust required to maintain altitude The objective of turbine blade design is also to maximize the lift force on the blade and reduce drag so that the force on the blade that acts in the tangential direction is maximized. Lift acts in the direction normal to the fluid flow, which is not necessarily acting in the tangential direction once the turbine blades begin to spin. In most wind turbine designs, only the lift force on a blade creates a tangential force in the correct direction, while the drag force creates a small tangential force in the opposite direction. Other than the tangential force, another force, called thrust, is also comprised of lift and drag and acts normal to the plane of rotation. In air turbine design, it is crucial to reduce the thrust on the turbine blades because it wastes energy and it requires a stronger blade to withstand its loading

Wind is often used as an energy source to operate pumps and supply water to livestock. Because of the large amount of water needed for crops, wind power is rarely used for irrigation.

As larger and/or more efficient wind turbines are developed, groups of these wind turbines (or single wind turbines) are expected to be able pump water to be used for irrigation projects a windmill consists of a very large fan with 15 to 40 steel or galvanized blades gear box mechanism driven by the blades. This mechanism converts the rotary motion of the blades to an up-and-down motion

A piston pump, which is driven by the up and-down motion produced by the link mechanism. A pump rod that descends from the windmill to the well

The propeller must have many blades to develop a high starting torque, which is needed to start the piston pump. Generally windmills begin when the wind speeds exceed 7mph water near the well bottom and is drive by the pump rod [4].

2.4 Types and Component of Wind Turbines

2.4.1 Windmills

The windmill features a very robust design composed of simple and inexpensive components. The system is easy to operate and requires minimum repair and maintenance. The greatest advantage of a wind wheel is In comparison to a conventional wind turbine with a few slender blades rotating at high speeds, a windmill starts more easily because the rotor blades cover far larger share of the swept area. The windmill is an effective device for pumping water because a lot of water is required to get it running.

A wind turbine is a device that converts the kinetic energy of the wind into mechanical energy.

This mechanical energy can be used for specific tasks (such as grinding grain or pumping water) or for driving a generator that converts the mechanical energy into electricity that is supplied to the power grid or individual users.

The earliest recorded (traditional) windmill dates from the year 1191 in Suffolk, England. The popularity of the windmill grew as a replacement for animal power for grinding grain. With the introduction of iron components in the 19th century, the traditional windmill reached its summit and was a common sight in towns and villages.

2.4.2 Types of wind turbine

Type of wind turbines are determined by their constructional geometry and the aerodynamics of the wind passing around the blades. Wind turbines can, however, be broadly categorized as vertical axis or horizontal axis. Vertical axis turbines have their axis of rotation perpendicular to the direction of the upstream wind while horizontal axis turbines have their axis of rotation parallel tote direction of the wind.

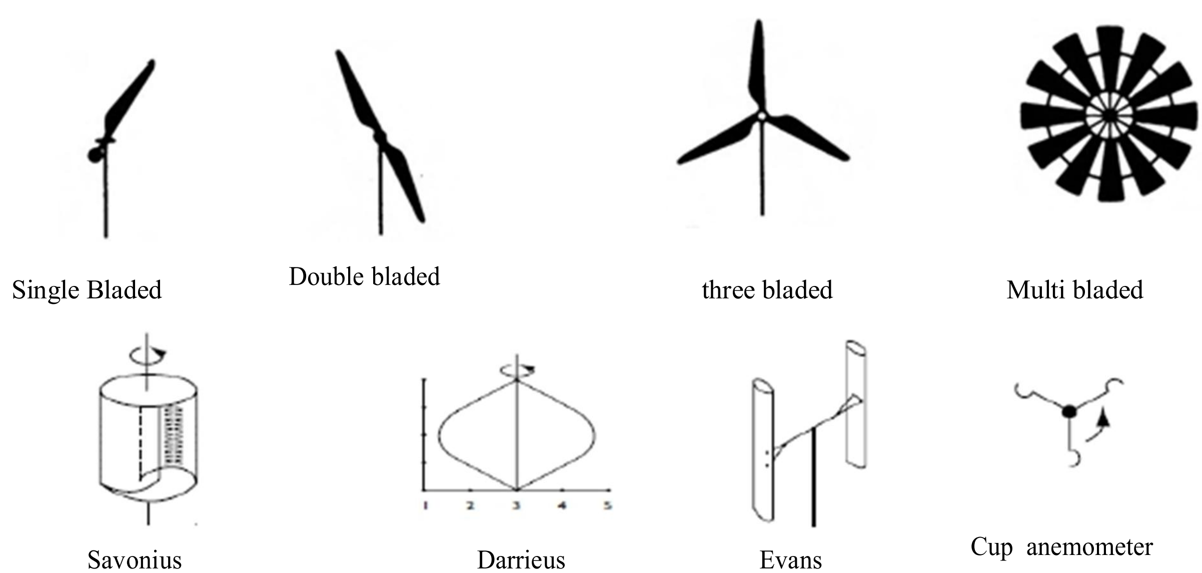

Figure 2: Classification of wind turbines [9]

2.4.3 Components of a wind turbine

The components of a wind turbine vary depending on the type of the turbine, its purpose and sophistication. The basic elements of a wind turbine system includes the blade, hub, axis, orientation system (tale steer), gear box, nacelle, generator, and tower. The picture blow depicts the different components of a wind turbine system.

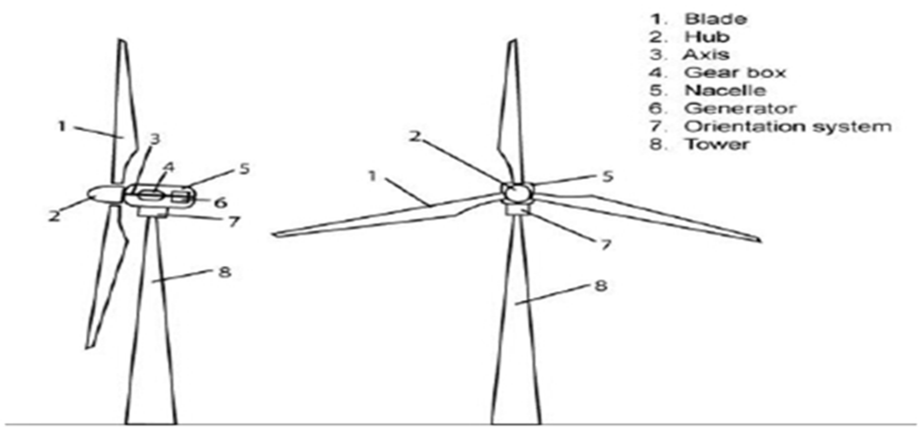

Figure 3: Basic components of a wind turbine Blade [15]

The blade of a wind turbine is the airo-foil which interacts with the wind force to turn it into a rotary motion. A wind turbine, depending on the design, may have one or more blades. The number of blades a wind turbine has determines the speed at which it rotates. Wind turbines with lower number of blades rotate faster while those with several blades rotate slower. The rotational speed of a wind turbine also determines the purpose they are used for. Wind turbines for higher torque applications for mechanical shaft drives such as direct mechanical coupling with water pumps tend to have more number of blades. Wind turbines used for electrical applications have fast rotating turbines and their number of blades is smaller.

2.4.3.2 Hub

The hub of a wind turbine is the center of the rotor where the blades are mounted on. It is the element of the machine the supports the axis of rotation.

2.4.3.3 Axis

The line around which the blades of a wind turbine rotate is called the axis of a wind turbine. Wind turbines can be designed as vertical or horizontal axis turbines.

2.4.3.4 Orientation system (tale steer)

Orientation system is the component of a wind turbine that makes the rotor chase the direction of the wind for maximum interception. The orientation system can be electrically controlled. Mechanically controlled orientation system is referred to as the tale of the wind turbine.

2.4.3.5 Gear box

A gear box in a wind turbine helps to change the speed or the direction of rotation of a wind turbine. Gear boxes can be used in wind turbines for either electrical or mechanical applications.

2.4.3.6 Nacelle

It is a cover housing that enclosed all of the generation or gear box components of a wind turbine.

2.4.3.7 Generator

It is a component that converts mechanical rotation into electrical energy in an electric wind turbines system.

2.4.3.8 Tower

It is a support structure for the wind rotor/ turbine, the gear box and the generator. The tower also helps to keep the hub at the required height from the ground for interception of higher wind speed. [9].

2.4.4 Rotor solidity and tip speed ratio

Rotor solidity refers to the density of the blades in the wind intercepting areas of the rotor. It is the proportion of the area of the rotor that intercept the wind. High solidity turbines have greater number of turbine blades in the rotor while low solidity wind turbines have only fewer number of blades.

High Solidity Wind Turbine

Low Solidity Wind Turbine

Figure 4: High and low solidity wind turbines/ rotors

Wind turbines for mechanical shaft drive are of high solidity rotor (have more blades) than those used for electricity generation.

In high solidity wind turbines, the interaction of the wind with the blades is greater than the casein low solidity turbines. The power in the wind can be expressed in terms of high torque-low speed or low torque-high speed. High solidity turbines have low speed and high torque while low solidity turbines have high speed but low torque. Hence, high solidity wind turbines start easily with large initial torque, but soon reach maximum power at small rotational speed. Low solidity wind machines may require higher wind speed to start as they intercept with smaller portion of the air mass but reach maximum power only at faster rotational speed. Thus, high solidity machines are mainly used for mechanical shaft power such as water pumping and start operation even at lower wind speeds. Low solidity turbines are mainly used for electricity generation as higher shaft rotational speed is required for electricity generation.

Even though the number of blades and the solidity of the turbines determine the extent of the rotor's power extraction from the wind, the rate at which the rotor rotates at a given wind speed also plays an important role in intercepting the airstream. The concept of tip-speed-ratio is introduced to determine the combined effect of rotor's solidity and its speed of rotation in relation to the speed of the airstream.

Tip-speed-ratio is the ratio of the speed of the tip of the blades to the speed of the upstream wind.

It is the most important parameter of a wind turbine as it relates the intercepting area of the rotor, the wind speed, and the rotor frequency.

If wind turbines are too slow they lose much of the wind passing through them, and if they rotate too fast it is as though they act as a wall. In both cases, there is degradation in the rate of power extraction. For this reason, optimum rotor solidity and tip speed ratio are very important for efficiency.

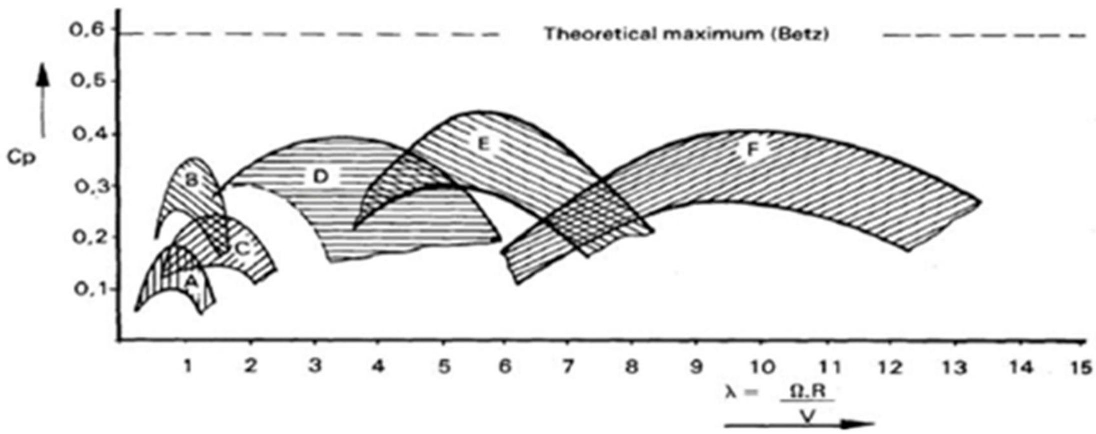

Figure 5: Comparison of different turbine rotor. [6]

Rotors:

A Savonius: Chinese panamone

B American multi blade

C Cretan sail rotor

D Four-bladed, curved steel plat

E 1 Three-bladed, air foil

E 2 Darrieus air foil

F Two-bladed air foil

Table 1: Wind turbine advantages disadvantages

No	Name of wind turbine	Advantages	Disadvantages
1	Vertical-axis wind turbine (VAWT).	✓ Easy installation and servicing ✓ Allowing for placement or replacement of heavy equipment. ✓ Simple design	✓ It cannot start moving by itself, ✓ Winds are lower near ground level hence less power output ✓ Do not require large amounts of power
2	Horizontal axis wind turbine (HAWT)	✓ Blades are to the side of the turbine's center of gravity, helping stability ✓ The turbine collects the maximum amount of wind energy by allowing the angle of attack to be remotely adjusted. ✓ The ability to pitch the rotor blades in a storm so that damage is minimized ✓ The tall tower allows the access to Stronger wind in sites with wind shear and placement on uneven land or in offshore locations.	✓ It has difficulties operating near the ground ✓ The tall towers and long blades are hard to transport from one from one place to another and they need a special installation procedure. ✓ They can cause a navigation problem when placed offshore

2.5 Water Pump System Components

Water is the most common fluid handled by pumps. Virtually, the reforest all types of pumps used with wind- powered pumping systems are generally found to be of three types: reciprocating, rotary and diaphragm. Both reciprocating and rotary pumps of are of the positive displacement type. A positive displacement type of pump is that in which a measured quantity of water is an entrapped in a space its pressure is raised and then it is delivered. A Wind water pump can be a mechanically or an electrically driven water pump where the mechanical shaft power by the rotor of a wind turbine. In a wind pump system a stream of air interacts with the blades of a rotor to convert the wind force into rotational motion. The rotational motion can be directly transferred through a shaft or gear system to drive mechanical pumps such as vertical displacement pumps or centrifugal pumps. The available wind speed and the size of the rotor that intercepts the wind determine the power output from a wind turbine. The in a wind water pumping system the rotors sized to meet the pumping power requirements. Due to intermittent nature of wind, a wind turbine system needs an appropriate size of water storage to ensure availability of water when needed. Optimum system performance is ensured by matching the components of the system (rotor diameter vs. Motor/pump vs. Controller/inverter).Optimum sizing also ensures economically viable operation for the system. PV water pumping systems are relatively simple systems with three basic components:

2.5.1 Mechanical Wind Pumping System

- Power source (Wind turbine/rotor)
- Gear system or simple shaft
- Mechanical steering guide
- pump assembly
- Storage tank

2.5.2 Uses of Pumps

Pumps are used extensively on construction projects for:

1. Removing water from pits, tunnels, and other excavations.
2. Dewatering cofferdams.
3. Furnishing water for jetting and sluicing.
4. Furnishing water for many types of utility services.
5. Lowering the water table for excavations.
6. Foundation grouting.

2.5.3 The Water Pump Classification of Pump

Water pumps are generally classified into rotor-dynamic (centrifugal) and positive displacement pumps. A centrifugal pump consists of an impeller within a casing as shown in the figure below.

Water flows axially towards the impeller and the impeller accelerates the water in the radial direction building pressure. Positive displacement pumps have rotating or reciprocating parts that push water in an enclosed volume moving the water up to the discharge point.

The pumps commonly used on construction projects may be classified as:

A. Displacement

1. End section centrifugal pump
2. Split case
3. Special effect pump

B. Dynamic pump

1. Reciprocating

a. Diaphragm

b. Piston

2. Rotary

2.5.4 Positive Displacement Pumps

Positive displacement pumps operate with low and high speeds. They are therefore suitable for wind water pumping applications because they can pump water even during low speed periods.

The main drawback of positive displacement pumps is their relatively high torque requirement to start from inertia (what is called the "breakaway torque"). In low wind regimes mechanical wind turbines with positive displacement pumps are more suitable as the initial torque could be high enough to start pumping. Positive displacement pumps are self-priming and are most suitable alternatives for

- Pumping high viscosity liquid
- Gentle movement of liquids
- Low flow, high pressure applications

2.5.4.1 Reciprocating Pumps:

In this type of pump, a piston or a plunger moves inside a closed cylinder. On the intake stroke, the suction valve remains open and allows water to come into the cylinder. The delivery valve remains closed during intake stroke. On the discharge stroke, the suction valve is closed and water is forced in delivery pipe through delivery pipe through delivery valve which opens during discharge stroke

The reciprocating pumps may be single acting or double acting. In the former type water is discharged only on the forward stroke of the piston and in the latter type, water is discharged on forward and return strokes of the piston. This type of pump is quite suitable for greater discharge under high head of water. Force required to work a reciprocating pump is

$$P = w \times a \times 1 \qquad (4)$$

Where, ‘P’ is the force required to lift the piston in kg, ‘a’ is area of cylinder in m^2, ‘l’ is the length of stroke in m and ‘w’ is the specific weight of water is 1000 kg m^{-3}.

Work done in one upstroke is w × a ×1 × h, where ‘h’ is the total height through which the water is raised, m

2.5.5 Progressive Cavity Pumps (Screw Pumps)

In progressive cavity pumps water is transported by volumetric displacement due to rotation of the pump (see 6 figure). The pump consists of stationary hollow cylinder (stator) and a steel rotor (impeller) enclosed within the cylinder. Water enclosed in the cavity between the stator and the enclosing cylinder is moved upwards and outwards during rotation of the stator. In comparison with that of a centrifugal pump, the performance curve of a progressive cavity pump is much steeper. This gives the advantage of higher efficiency in combination with better resistance to abrasive material entrained in the pumped medium [11].

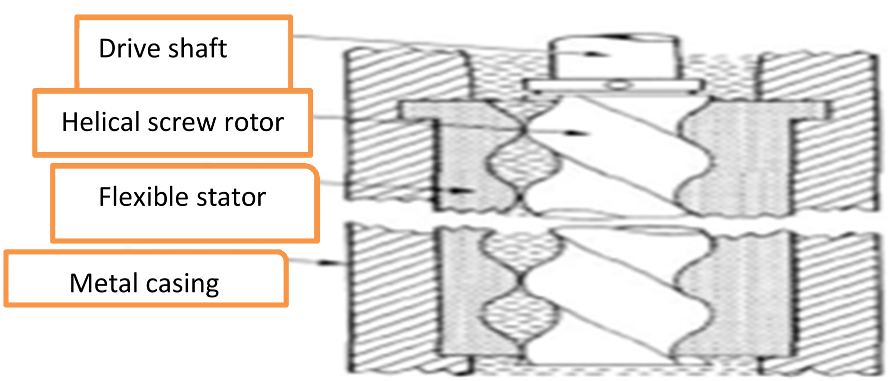

Figure 6: Progressive cavity pumps [31]

2.5.5.1 Piston Pumps

Piston pumps are desirable particularly for high head pumping. In piston pumps the head the water is pumped to is independent (or nearly) on the speed of operation of the pump. The pumping rate depends on the number of strokes of the pump/piston. Since piston pumps practically do not have minimum operating limits (speeds), they can pump water at low wind speeds (in contrast to centrifugal pumps which have minimum speeds below which they cannot perform). However, similar to progressive cavity pumps, piston pumps as show the (figure 7) also have requirements for brief bursts of power at start up making mechanical wind pumps more preferable to electric wind pumps.

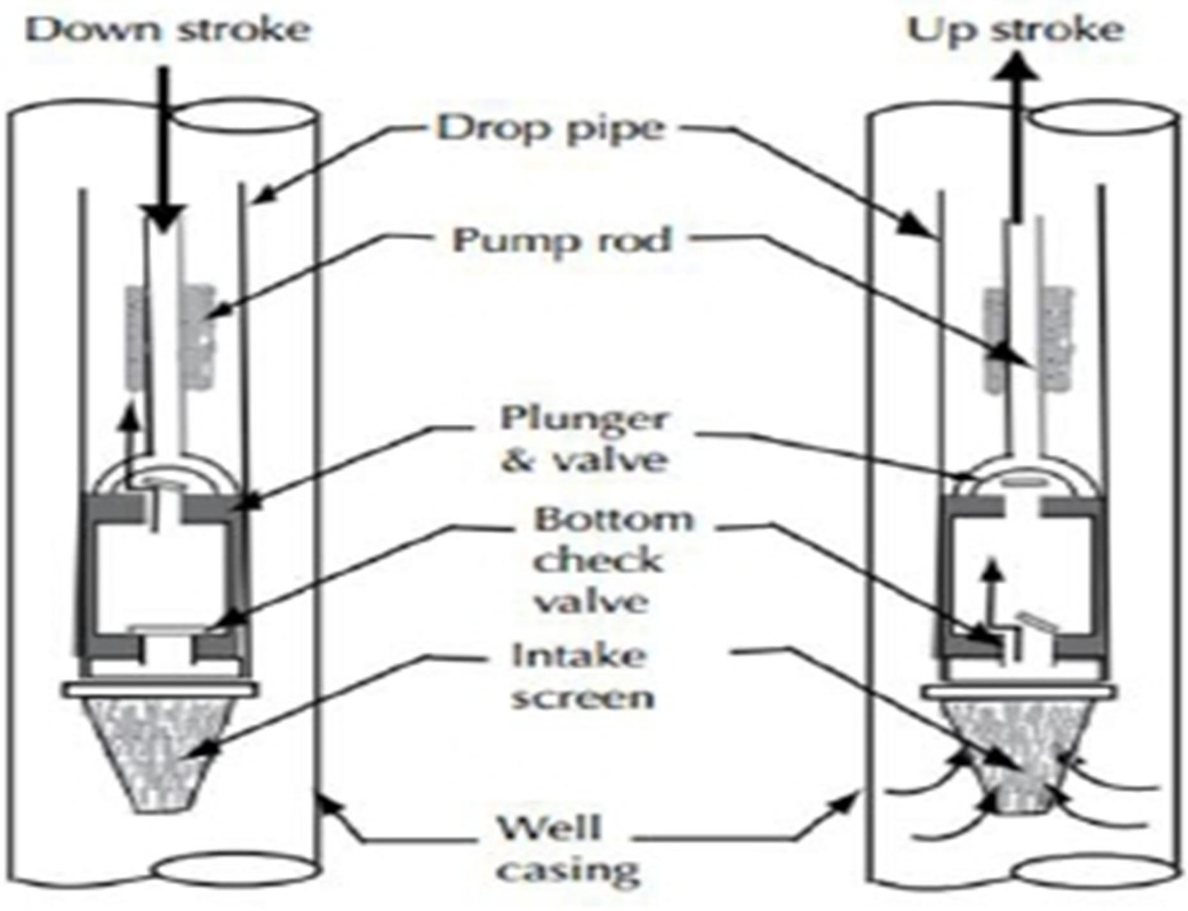

Figure 7: Vertical displacement piston pumps for mechanical wind pump [29]

2.5.5.1.1 Double – Acting Piston Pump.

When the piston is moved in one direction, the water ahead of the piston is forced out of the cylinder. At the same time additional water is drawn into the cylinder behind the piston.

Regardless of the direction of movement of the piston, water is forced out of one end and drawn into the other end of the cylinder

2.5.5.1.2 Single – Acting Piston Pump

This consists of a cylinder with an inlet pipe and valve at the base a leather- sealed piston with an inlet pipe and valve at the base, a leather- sealed piston with a one- way valve and a water outlet at the top, water passing through the pump only on the lifting stroke of the piston. These types of pumps are suitable for medium or high heads with an operating speed of up to 40 strokes per minute. [10].

2.5.5.2 Diaphragm Pumps

Diaphragm pumps use a positive displacement design rather than centrifugal force to move water through the casing. This means that the pump will deliver a specific amount of flow per stroke, **revolution or cycle.**

Engine-powered versions are the most common and typically use the drive shaft to turn an offset connecting rod that is coupled to a flexible diaphragm. The connecting rod alternately rises (expands) and lowers (contracts) the diaphragm at a rate of 60 cycles per minute (RPM).

A vacuum is created inside the pump casing each time the diaphragm is raised (Figure 8). This opens the inlet valve and seals the discharge valve allowing water and air to enter the

The diaphragm pump is composed of the following:

- A chamber used to pump the fluid
- A diaphragm operated by either electric or mechanical means
- Two valve assemblies: a suction valve assembly and a discharge valve assembly

When the diaphragm is pulled back, a vacuum is created in the chamber in front of the diaphragm. This vacuum causes the discharge valve to be forced closed against its seat. The vacuum allows atmospheric pressure to push fluid up against the outside of the suction valve, opening the valve and filling the chamber. When pressure is returned to the diaphragm, forcing it toward the front of the chamber the increased pressure causes the closed and the suction valve to be forced closed and the discharge valve to be forced open. The fluid is pushed out of the chamber and the pumping cycle starts over [7].

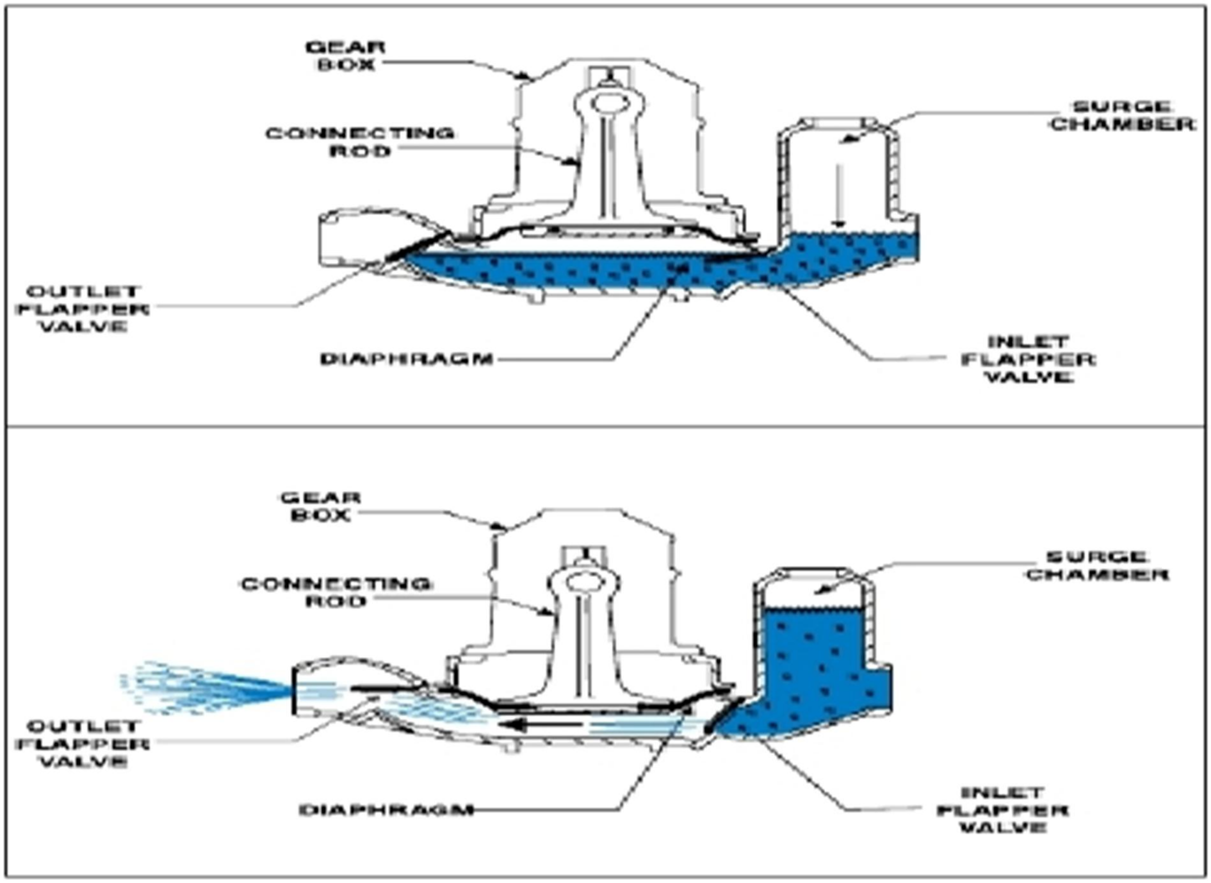

Figure 8: Diaphragm pump suction and discharge stroke [7]

2.5.5.3 Air-lift Pump

Operates by the injection of compressed air directly into the water inside a discharge or educator pipe at a point below the water level in the well. The injection of the air results in a mixture of air bubbles and water. This composite fluid is lighter in weight than water so that the heavier column of water around the pipe displaces the lighter mixture facing it upward and out of the discharge pipe. The piping assembly consists of a vertical discharge pipe called the educator pipe and a smaller air pipe. Airlift pumping is extensively used in the development and preliminary testing and cleaning of tube wells. The advantages of air-lift pumps are simplicity, tube well need not be perfectly straight or vertical, and impure water will not damage the pump. The main disadvantage is its low efficiency about 30 percent. Specific Speed of a pump may be defined as the speed of a geometrically similar pump when delivering one m^3 s-1 of water against a total head on one meter. The value of specific speed is useful in comparing the performance of different pumps [11].

3. METHODS AND MATERIALS

3.1 Introduction

This project concentrates on construction of small wind turbine drive mechanism of water pump for rural irrigation to deliver underground water or river water.

It is very important to follow appropriate methodology to accomplish the task, selection of the required components like windmill turbine, drive mechanism of the pump is very important for the success of the project.

3.2. Materials used to construct the project

3.2.1 Introduction to Materials Selection

Materials were selected by considering the materials' properties that can withstand the environmental conditions as well as the cost.

A wide range of materials are used in wind turbines. There are substantial differences between small and large machines and there are projected changes in designs that will accommodate the introduction of new material technologies and manufacturing methods. To arrive at a total, the material usage is weighted by the estimated market share of the various manufacturers and machines types. In general the materials used for wind turbines are Steel, Aluminum, Copper and Reinforced Plastic

In this project we have used Aluminum sheet metal and aluminum sheets. The following are certain important properties present in the materials selected.

Table 2 Materials used in water pump

No	Machine parts	Selected materials	Selected criteria
1	Cylinder	Hollow steel	b/c it is not corrosion with water
2	Piston	High strength plastic	Light in weight and resist wear
3	Connecting rod	Steel bar	Have high strength

Table 3 Materials usage in savonius wind turbine

No	Machine parts	Selected materials	Selected criteria
1	Shaft	Hollow aluminium	b/c it is less in thickness & light in weight
2	Rotor blade	Aluminum sheet	For easy self-starting
3	Gear	Aluminum	b/c it has less in weight
4	Base	Steel bar	For prevention of collapsing
5	Tower	Steel bar	b/c it helps to increase the tower stability
6	End plate	Aluminum sheet	Due to its light in weight corrosion, résistance, rigidity, & it is easy to construct & low cost

3.3 Methods

Project starts with selection of the location where project is to be implemented. Study of the area is necessary to identify the availability of water for irrigation type of the crop to be irrigated etc. But in this project work it is aimed to develop only prototype of wind driven water pump and test it is simply developed a prototype for analysis of the amount of delivery of different wind speed its functionality at different speed of wind. In overall the project work includes of the following step

- Selection of area
- Construction of windmill
- Constructing of water pump
- Testing the functionality

3.4 Selection of Area

Selection of the project area depend and on the availability of wind speed from annual wind speed analysis of Ethiopia metrology agency.

Wind resource data for Ethiopia is available from the following three sources. The most recent of these studies was completed in 2012 and now serves as the main source of wind and solar resource data as well as for wind and solar project planning purposes.

Master Plan Report of Wind and Solar Energy in the Federal Democratic Republic of Ethiopia, Ministry of Water and Energy, 2012. [27]

Solar and Wind Energy Resource Assessment or SWERA (UNEP/RISOE and Ministry of Mines and Energy, 2006), and Measured or observed wind speed data is very limited in Ethiopia and resource estimates from all three sources depend heavily on simulation. Available meteorological data in Ethiopia also suffers from other constraints, including

Location: most meteorological stations are located in urban areas, usually not the areas where these projects are implemented;

Quality: measured data from some meteorological stations suffer because of obstructions from building and other objects (buildings obstructing wind flow or putting shades on solar radiation measuring instruments); and

Appropriateness: available meteorological data may not be useable or appropriateness; for example, wind measurements at heights of 2m instead of the desirable 10m or higher, or sunshine duration for solar energy instead of irradiation.

There are significant differences in data resolution and resource estimates among all three sources (and these differences have not been sufficiently explained or resolved by the recent reports).However, the Ministry of Water, Irrigation and Energy has now accepted the Master Plan Report of Wind and Solar Energy (2012) as the main source for wind and solar energy resource data and also for planning wind and solar energy projects.

The wind energy resource data from the Master Plan Report is recommended for design of wind water pumping systems in this manual. The resource maps from the Master Plan Report are overlaid with Wereda (district) border maps to ease reference for planners to locate specific areas of interest. Mean annual wind resources from this report are shown in the following figures [25].

Wind speed at 10m, which is the range for most wind pump turbines, is high along the Rift Valley stretching from East to Southwest, along a strip from the Center to the north, and a large area in the Southeast as shown below. In these areas mean annual wind speed at 10m ranges between 5 and 8m/s. Most other parts of Ethiopia fall under a wind regime ranging between 3 to 5at 10m⁄s. Wind speed is highest in the months between October and December in most parts of Ethiopia and falls in the months June to September, falling by as much as 50% of the annual high (annual high recorded in October and annual low recorded in July). Seasonal (and monthly) variation of wind speed is high in the highlands and relatively low in lowlands of Ethiopia. (see figure 9) [30]

Design of wind water pumping systems will depend on monthly average values of wind resource as well as monthly values of demand for potable water. Depending on the method of sizing adopted the month with least wind resource or the month with the highest ratio of water demand to resource availability is usually used.

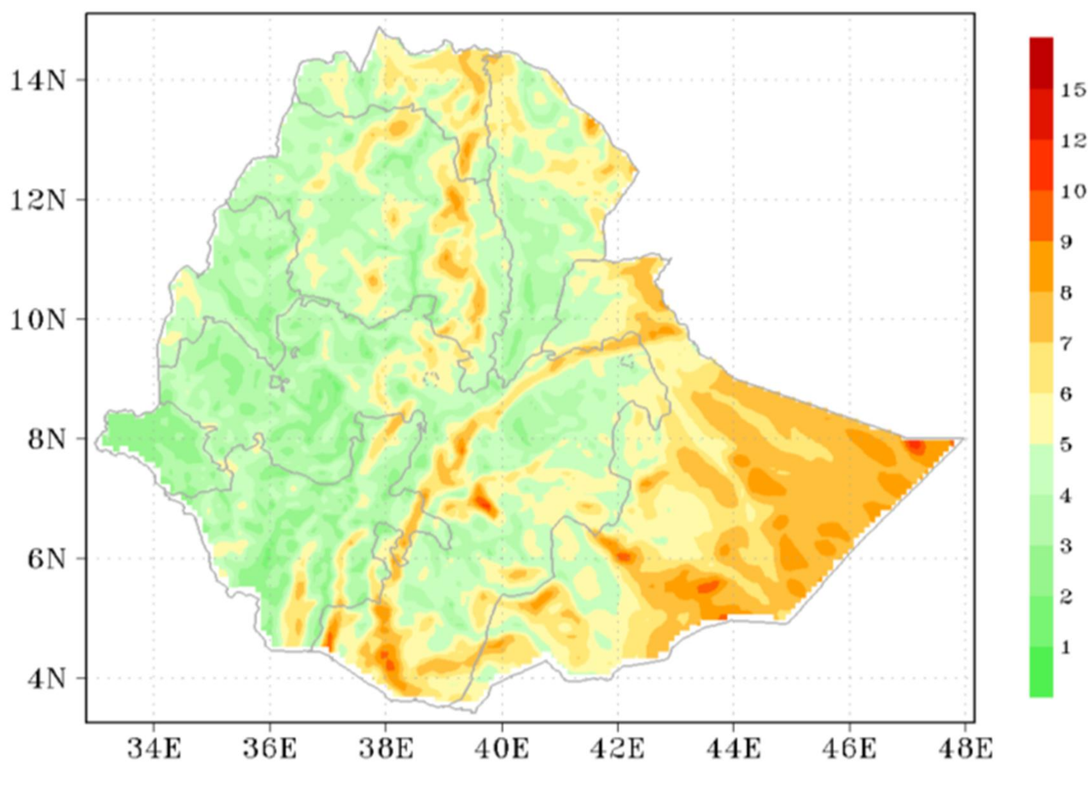

Figure 9: Average wind speed of Ethiopia at 10m height, m/s [25]

Table 2: Steps of implementation of the project

Step	Description
1	Gather basic information
2	Determine water requirement and source
3	Determine system layout
4	Determine hydraulic energy requirement
5	Determine wind resource
7	Determine type of wind pumping machine
8	Determine the size of the wind turbine (diameter of the rotor
9	Determine the pump type and size

The annual average wind speed of Ethiopia at 10 m height in m/s is indicated on the figure above that it has the maximum of wind speed at eastern part of the canter central through rift valley and from the central part to the north. In this part of the country the wind turbine driver water pump can be used.

In order for design' wind water pump it is necessary to follow some steps. These are indicated in table 4.

The important step in water pumping system development is to understand water requirements for the intended application. If the requirement is for potable water for people and their animals, the per capita requirement (requirement for one person or one animal) and the number of people and animals to be served must be known. These two variables are used to compute the total water requirement of the population (both people and animals) (see table 5) at a particular point in time [26].

Table 3: Water requirements for people and animals [26]

Potable water	Liters/day
People – rural	15
People – urban	20
Animals	
Dairy cattle	40
Beaf cattle	30
Camels	20
Donkeys	20
Horses	50
Sheep	5
Goats	5
Poultry	1

Irrigation	m^3/ha/d
Cereal grains	45
Sugar cane	66
Cotton	55
Rice	100

Water demand levels and population sizes may vary seasonally. Hence, water demand estimation must always take the highest expected demand as the design requirement.

3.4 Water Source

Potable water is available from surface and subsurface sources. Surface sources include streams, ponds and springs; subsurface sources can be either shallow or deep wells or boreholes. The type of potable water source influences the type and configuration of pumping system that is used (including system component types, sizes and locations)

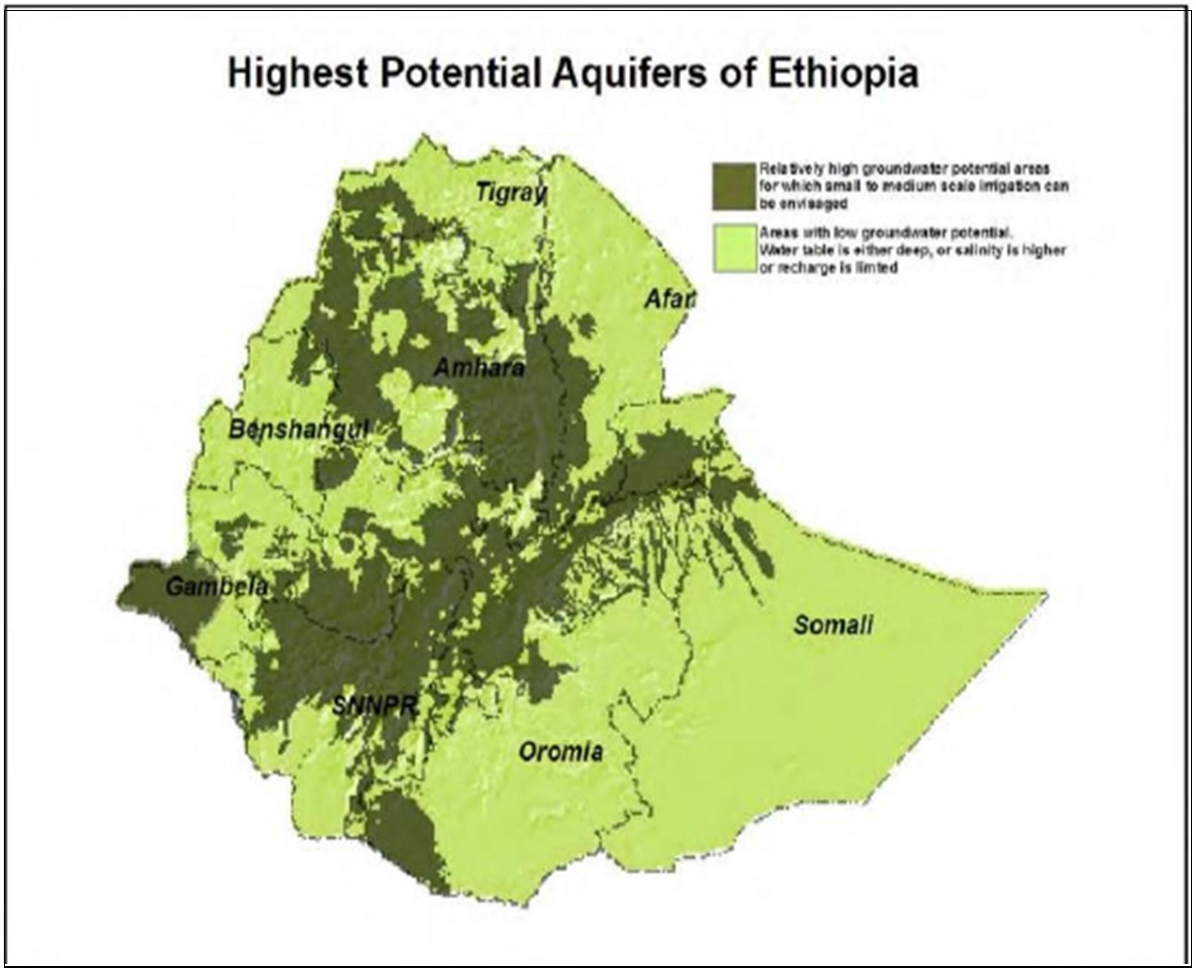

Figure 10: Highest Potential Aquifers of Ethiopia [27]

As it indicates on the fig 10 above that area of the canary which have maximum underground water is on the rift valley parts, most of the Amahara region Gambela and SNNP. On the fig 11 below as the study by the Addis Ababa University indicates the part of the region which use large scale irrigations are the areas of the rift valley. Those areas also have higher wind speed. Therefore to implement this project the area selected is Meki which is located on the awash basin.

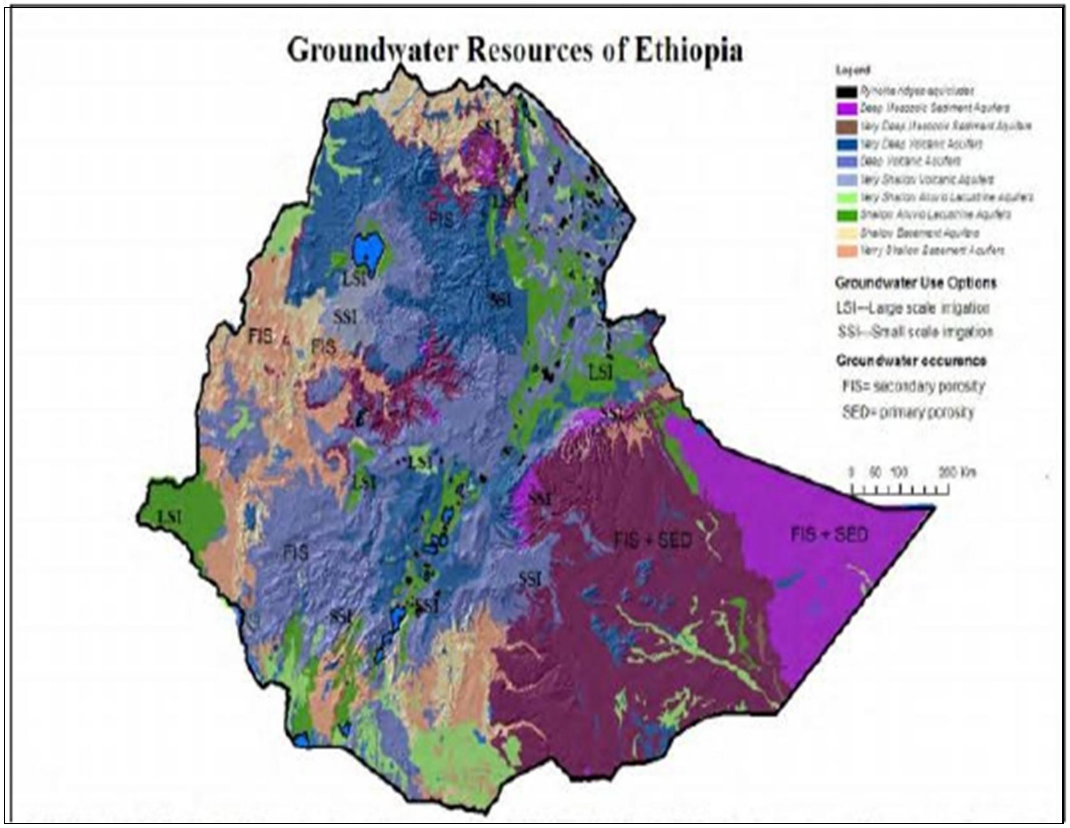

Figure 11: Ground Water Resources of Ethiopia [27]

Therefore the expected design area for irrigation is on the rift valley range of Awash basin that the irrigation purpose is for grain and vegetable there for the requirement of water for this per hectare per day is 45 metric cube. Since the design is expected for the higher demand it is chosen to be design for 50 metric cube of water per day

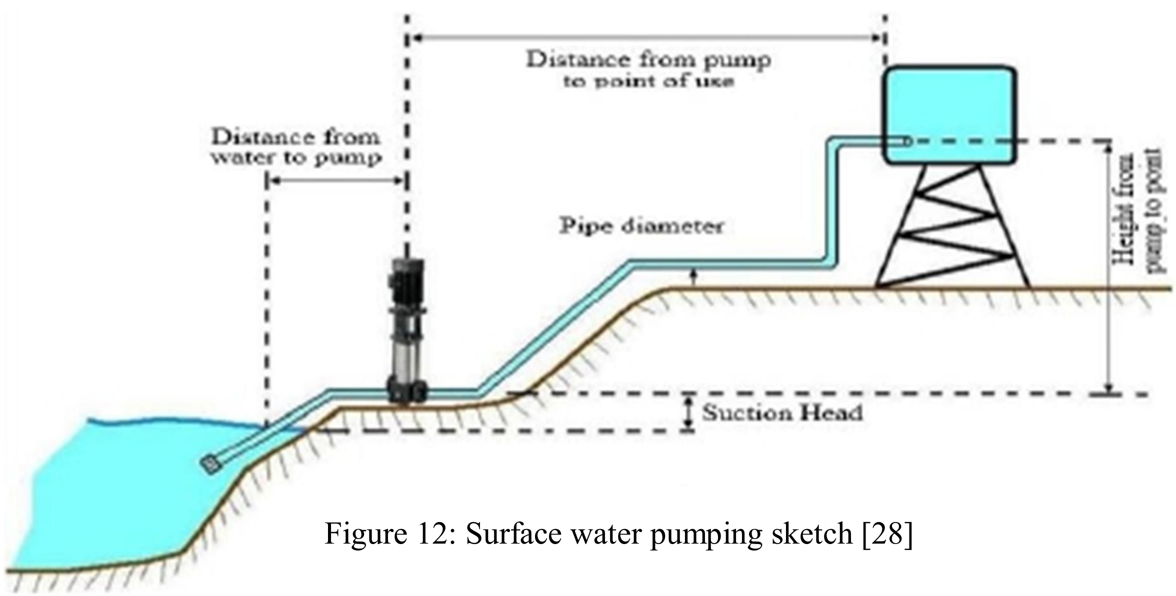

Figure 12: Surface water pumping sketch [28]

3.4.1 Power for Water Pumping

For Wind power operated water pump design is crucial and front step. Every design proceed with calculation of energy requirement. To determine the hydraulic power requirement, the total daily water requirement and the total dynamic head should be known. The equation below is used to calculate the hydraulic power requirement: This hydraulic energy in joule can be calculated by the following formula

$$E = fm_{spec}V^3 \tag{5}$$

Where V is in m^3/s

P hydraulic = 0.113 H V   where V is in m^3/day

ρ_w – Density of water = 1000 kg/m^3

g - Gravitational acceleration = 9.8 m/s^2

H - Total Dynamic Head (m) = Static Head (m) + Head losses (m)

3.4.2 Wind turbine

Selecting of the wind turbine to implement the project is depends on the following comparison table 6.

Table 4: Selection of wind turbine

Types of wind turbines	Horizontal Axis Wind Turbine (HAWT)	*Vertical Axis Wind Turbine (VAWT)*	
		Savonius	Darrius
1. Dependability.	Wind	Wind	Wind
2. Availability of repair parts.	Not aveilable	Easely to periods	Less available
3. Simplicity to permit easy repairs.	The reper is difficult due to the turbine and component are on tower	Technically easy to Repair	Relatively Difficult
4. Economical installation and operation.	High initial cost	Very low capital Costs	Relativily high
5. method of starting	Self starting	Self-starting	Need initial power for starting

The savories vertical type of wind turbine is selected for the implementation of the project based on the criteria comparison made in table 6 above.

3. 4.2. Power Coefficient

Power coefficient, (Cp) of a wind turbine is the ratio of maximum power obtained from the wind to the total power available in the wind [19]. This hypothesis shows the relationship between the power coefficient (Cp) and the wind speed (V), which expresses the basic theory of the Savonius wind turbine. Principally the power that the savonius rotor can extract from the wind (Pw) is less than the actual available from the wind power (Pw). The available power (Pw), which is also the kinetic energy (KE) of the wind, can be defined as:

$$KE = Pw = ½\ m.v^2 \quad (6)$$

$$P = ½\ \rho \times As \times V^3 \quad (7)$$

Where:

m = wind mass flow rate striking the swept area of the wind turbine (kg/sec). = ρ. As. V

But, the swept area (As = H × D), therefore the actual power becomes:

$$Pw = ½\ \rho.H.D.V^3 \quad (8)$$

The power that the rotor extracts from the wind is:

$$\boldsymbol{Pw} = \boldsymbol{T} \times \boldsymbol{\omega} \quad \text{(Watt)} \quad (9)$$

Where: Pw = the power that the rotor extracts from the wind (Watt).

The power coefficient (c_p) is given by:

$$c_p = \frac{\text{the extracted power from the wind}}{\text{the available power of thewind}} = \frac{p_w}{\text{p}} \quad (10)$$

The maximum power coefficient of a savonius wind turbine is c_p = 0.3

:-

$$P = ½ c_p .\ \rho.H.D.V^3 \quad (11)$$

3.4.3. Swept Area

As the rotor turns, its blades generate an imaginary surface whose projection on a vertical plane to wind direction is called the swept area [9]. The amount of energy produced by a wind turbine primarily depends on the rotor area, also referred to as cross-sectional area, swept area, or intercept area. The swept area for Savonius wind turbine can be calculated from the dimensions of the rotor (see Figure 13).

$$\text{Savonius area} = \text{the swept area} = As = H \times D \quad (12)$$

Where: H = the rotor height (m).

D = the rotor diameter (m).

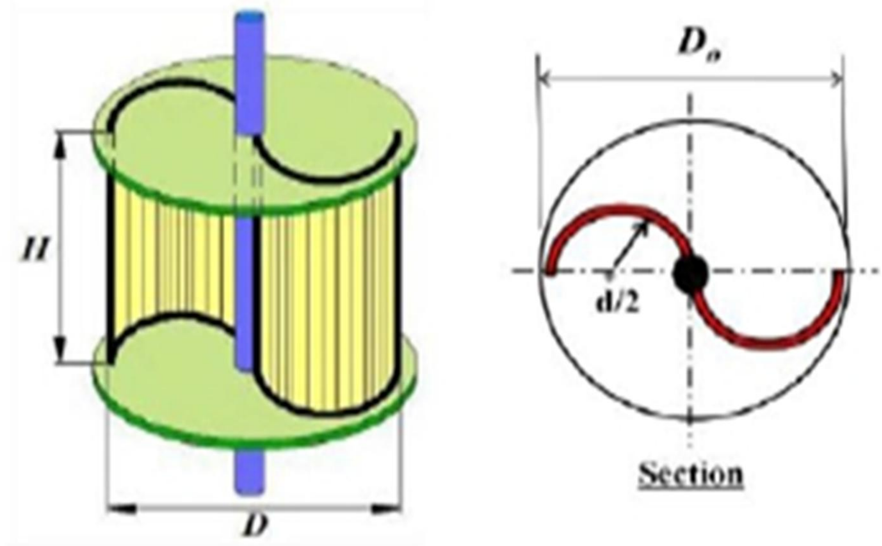

Figure 13: Schematic diagram of Savonius rotor wind turbine

3.4.4. Wind speed

This is very important to the productivity of a windmill. The wind turbine only generates power with the wind. The wind rotates the turbine (horizontal or vertical) axis and causes the shaft on the water pump to rotate. If the wind speed increases the power of the wind of water pump increases and vice versa.

3.4.5. The Tip speed ratio (TSR):

The tip speed ratio is the ratio of the product of blade radius and angular speed of the rotor to the wind velocity [19]. The tip peripheral velocity of the rotor (V rotor) is defined as (see Figure 14):

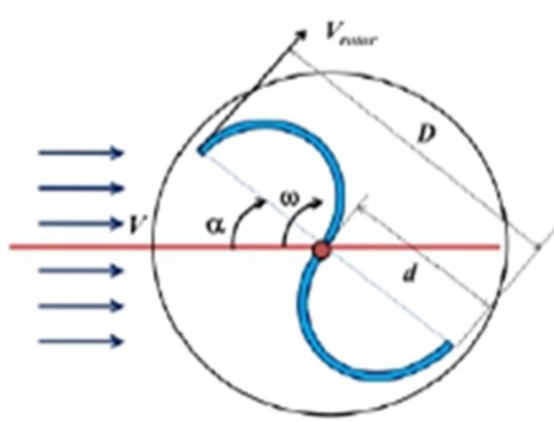

Figure 14: Scheme of a Savonius rotor showing the tip velocity of the rotor

$$V_{rotor} = \omega \times d \quad (13)$$

Where: V_{rotor} = the tip speed (the peripheral velocity of Savonius rotor) (m/sec)

ω = the angular velocity of Savonius rotor (rad/sec).

d = the diameter of the semi-cylindrical Savonius rotor (m).

v = wind speed

Now the Tip Speed Ratio (TSR) of a turbine is expressed as:

$$the\ tip\ speed\ ratio\ (TSR) = \lambda = \frac{\mathrm{v}_{\text{rotor}}}{v} = \frac{w \times d}{v} \quad (14)$$

3.4.6. Tower height

Wind velocities increase at higher altitudes due to surface aerodynamic drag (by land or water surfaces) and the viscosity of the air. The variation in velocity with altitude, called wind shear, is most dramatic near the surface. Typically, the variation follows the wind profile power law, which predicts that wind speed rises proportionally to the seventh root of altitude. Doubling the altitude of a turbine, then, increases the expected wind speeds by 10% and the expected power by 34%. To avoid buckling, doubling the tower height generally requires doubling the diameter of the tower as well, increasing the amount of material by a factor of at least four [19]

3.4.7. Chord length

The chord is the length between leading edge and trailing edge of the blade profile. The blade thickness and shape is determined by the airfoil used, in this case it will be a NACA airfoil, where the blade curvature and maximum thickness are defined as percentage of the chord.

3.4.8. The Torque Coefficient (Ct):

It is defined as the ratio between the actual torque developed by the rotor (T) and the theoretical torque available in the wind (Tw) [19], thus the torque coefficient (Ct) is given by:

$$ct = \frac{\text{therotor torque}}{\text{the wind torque}} = \frac{T}{Tw} = \frac{T}{1/4 \times \rho\ \times \text{As} \times\ \text{d}\ \times\ v^{A}} \quad (15)$$

Where:

Ct = the torque coefficient

T = the rotor torque (N.m)

Tw = the wind available torque (NM)

ρ = the air density (kg/m^3)

Another concept that can be used to measure the wind turbine performance is the static torque (Ts), which measures the self-starting capability of the turbine. Static torque is defined as a maximum value of the torque when rotor is blocked i.e. without ability to rotate [19]. So, the static torque coefficient is given by:

$$Ct = \frac{T}{Tw} = \frac{T}{1/4 \times \rho\ \times \mathrm{As}\ \times \mathrm{d}\ \times\ v^{A}} \tag{16}$$

Where:-

Cts = the static torque coefficient

Ts = the rotor static torque (N.m)

3.4.9. Angular velocity

Increasing the angular velocity of the rotor/ turbine /generator increases the output power and vice versa.

3.4.10 Solidity

Is usually defined as the percentage of the circumference of the rotor which contains material rather than air, Savonius is a high solidity machine. It generates much higher starting torque than low-solidity machines, like Darrie us for example, Another advantage of high-solidity machines is that they do not need to be made with as much precision as low-solidity ones. This type of turbine is self-starting and provides high torque at low speeds.

Solidity is related to tip speed ratio. A high tip speed ratio will result in a low solidity. Solidity is defined as the ratio of blade area to the turbine rotor swept area.

For VAWT, the solidity is defined as

$$\sigma = n\ d\ /R \tag{17}$$

Where n is the number of blades, d is the chord length or can be defined as the diameter of each half cylinder, and R is radius of wind turbine. Many researchers have proved that the higher the number of blades, the higher the performance of most wind turbine. However, some researchers found that the two-bladed Savonius rotor has higher performance than three-bladed Savonius rotor [31]. Referring to researchers then the two-blade rotor has been chosen for this project.

3.4.11. Aspect ratio

This is one of the parameters that are used in describing blade configuration of the rotor. It is defined by the ratio of height of the rotor to its diameter. It is an influential factor in determining the optimum blade configuration for a particular blade profile. Power output for a given cross-sectional area of the rotor varies significantly with a variation of aspect ratio [20].

Aspect ratio is a crucial criterion to evaluate the aerodynamic performance of Savonius rotor. The Savonius rotor is designed with rotor height twice of rotor diameter and this lead to better stability with proper efficiencies [31].

$$AR = H/D \tag{18}$$

Tip speed ratio, λ is defined as the ratio of the linear speed of rotor blade ω.R to the undisturbed wind speed, V. ω is the angular velocity and R represents the radius revolving part of the turbine.

The maximum tip speed ratio that Savonius rotor can reach is 1. Write that high tip speed ratio improves the performance of wind turbine and this could be obtained by increasing the rotational rate of the rotor.

$$\lambda = \omega.R / V \tag{19}$$

$$V_{\text{cut in}} = 0.5V_{aveg} \tag{20}$$

$$V_{\text{Rated}} = 1.5V_{aveg} \tag{21}$$

$$V_{\text{cut out}} = 3.0V_{aveg} \tag{22}$$

All these parameters depend on the value of average wind speed. The average wind speed $Vavg$ was found 4.34m/s by taking the data from the metrology agency of Meki town, Table 7.

3.5 Summary of the Speed Parameters

Since on the selected area there is no metrology data available, data is gathered from the nearby metrology agency which is given in table 7 below.

Table 5: Average wind speed in m/s per each month for 5 years at 10m [30]

Month	YEARS				
	2010	2011	2012	2013	2014
Jan	4.774194	5.006452	3.032258	4.76129	4.787097
Fe	2.890323	3.470968	4.587097	4.76129	3.896774
Mar	3.548387	3.787097	5.348387	3.793548	4.419355
Apr	3.064516	3.56129	5.316129	3.096774	4.064516
May	2.883871	3.883871	5.051613	4.219355	4.148387
Jun	4.032258	9.535484	3.375484	5.258065	4.729032
Jul	2.864516	3.477419	4.56129	4.909677	4.96129
Aug	3.63871	3.322581	8	4.529032	4.212903
Sep	5.445161	2.645806	4.890323	3.870968	2.993548
Oct	4.141935	4.870968	5.530968	3.529032	3.96129
Nov	2.851613	3.845161	5.019355	4.606452	4.987097
Dec	3.96129	5.070968	5.070968	4.651613	4.916129
AWSPY	3.674731	4.373172	4.981989	4.332258	4.339785
					4.340387

$V_{cut\text{-}in}$ = 0.5 × 4.340387 = **2.1701935**

V_{rated} = 1.5 × 4.340387 = **6.5105805**

$V_{cut\text{-}out}$ = 3 ×4.340387 = **13.021161**

Table 6: Value of cut-in speed, rated wind speed, and cut-out speed.

Wind Speed Parameter	Equation	Calculation
Cut-in speed, Vcut-in	$V_{cut-in} = 0.5\ V_{avg}$	2.17 m/s
Rated wind speed, VRated	$V_{Rated} = 1.5\ V_{avg}$	6.51m/s
Cut-out speed, Vcut-out	$V_{cut-out} = 3\ V_{avg}$	13.02 m/s

3.5.1 Geometry calculation

The required energy of the pumps highly depend on the demand of water and the head of water level.

From the table 5 the demand for irrigation of water per hector per day is 45 metric cube but since the demand is varies with season it is important to have 50 metric cube per hectare per day. This means that the water demand to feed five hectare per day is 250 metric cube. The pump is deigned to lift total head of 30 m from the equations (5) the power needed is

$$P=0.113 \times 30m \times 250m^3 = 850W$$

From equation the power which is converted by the turbine depend and on the area. Then the area of turbine which is required to produce this power is given by but the average wind speed for the last five consecutive year is 4.5m/s and it is taken for the design wind speed

$$850w = 1/2 \times 0.3 \times 1.225 \times (4.5)3 \times A$$

$$A = 50.76m^2$$

The savonius has high efficiency if it has aspect ion ratio of 2

$$\text{Aspect ion ratio} = H/D$$

$$H/D = 2$$

$$H = 2D$$

From the area calculation of savonius wind turbine

$$A = DH$$

$$2D^2 = 50.76m^2$$

$$D = 5.04m$$

$$:-H = 10.08m$$

Whereas: - A = Area

D = diameter of turbine

H = turbine high

3.6. Pump Selection

The factors that should be considered in selecting pumps for construction applications include;

1. Dependability.
2. Availability of repair parts.
3. Simplicity to permit easy repairs.
4. Economical installation and operation.
5. Operating power requirements.

Table 7 Show that the comparison of facture selecting water pump for contraction and application.

Table 7: Comparison selection of pumping [21]

Types of Pump	Positive displacement			velocity		
	Hand pumps plunger type	Motor wind drive plunger type	Chain or continuous bucket	Centrifugal	Deep – well turbine	Jet
Operation	Very simple	Simple	Very simple	Simple	More difficult needs attention	Simple locks can cause trouble
Maintenance	Simpl butvalves and plunger require attention more difficult when pump cylinder is in the well	Same as hand pump maintenance of motors sometimes difficult in rura l areas	Simple	Simple but attention is necessary	More difficult and constant skilled attention is necessary	Simple but Attention is necessary
Capacity (litres/ minute)	10 -50	40 -100	15 – 70	Very wide range; 5 to unlimited	Very wide range 100-20000	25- 500
Head(metres)	Low	High	Low	5 – 500	20- 500	Low
Cost	Low but higher when cylinder is in the well	Low but higher when cylinder is in the well	reasona ble	Reasonable	Higher especially deep wells	Reasonable
Power	Hand or animal	Wind/ motor	Hand animal wind motor	motor	motor	Motor

Table 8: Water pump advantages and disadvantages

No	Name of pump	Advantages	Disadvantages
1	centrifugal pumps	-simplicity, -compactness, -weight saving, -adaptability to high-speed prime movers.	**-** relatively poor suction power
2	Piston Pumps	Reciprocating pumps will deliver fluid at high pressure (High Delivery Head). They are 'Self-priming' - No need to fill the cylinders before starting.	-Reciprocating pumps give a pulsating flow. -The suction stroke is difficult when pumping viscous liquids. -They give low volume rates of flow compared to other types of pump.
	Diaphragm Pumps	High efficiency No priming needed Can deliver water at high pressure Can work in wide pressure range Continuous rate of discharge	More parts mean high initial cost High maintenance cost No uniform torque Low discharging capacity Pulsating flow Difficult to pump viscous fluid High wear in parts

Table 10 above compares same advantage and disadvantage.

Since the piston pump has high efficiency it is selected for this project work for delivering water to highest head and to deliver 250m^3/day. The pump is designed to have a flow rate of 2.9lit/minute. In the design of the pump stroke to diameter ratio is assumed as 5.

The maximum tip speed of savonius rotor at its high efficiency of 1 is estimated from

From the equation (18)

λ tip speed ratio, v is wind speed R is turbine radius ω is angular speed of turbine

$\lambda = (\omega \times R)/ v$

$\omega = \frac{\lambda \times v}{R} = 1x\ \frac{1 \times 4.5}{2.502}$

$= 1.799\ {rad}/{sec}$

$= 17$ rpm

Therefore to discharge 250 m^3 day with the design turbine rotational speed of 17 rpm, it should pump 180 l/min

Due to this the designed pump should have 10.5lit ($0.0105m^3$) stroke volume

The stroke to diameter ratio of the pump is taken as 5

Volume of cylinder is given by

$$V = \frac{\pi}{4} D^2 \times s \tag{23}$$

V is stoke volume, S is stroke length and D is diameter of cylinder

$V = \frac{\pi}{4} D^2 \times s = 0.0105m^3$

$\frac{s}{D} = 5$

D = 87.4 mm

S = 437.25mm

Table 9: Geometrical value of savonius turbine

Parameter	Value
Power required	850W
Swept Area	50.76 m^2
Vrated	6.51 m/sec
Aspect Ratio	2
Tip Speed Ratio	1.0
Diameter – Height	5.04m – 10.08 m
Number of Blades	2

Table 10: Geometrical value of piston pump

Parameter	Value
Stroke discharge Volume	10.08liter
Cylinder diameter	87.4 mm
Stroke	437.25 mm
s/d	5
Number of piston	1

3.8. CAD modeling

Computer-aided design (CAD) is defined as the application of computers and graphics software to aid or enhance the product design from conceptualization to documentation. CAD is most commonly associated with the use of an interactive computer graphics system, referred to as a CAD system. Computer-aided design systems are powerful tools and in the mechanical design and geometric modeling of products and components.

For this project solid work software is used for 3D modeling. The developed CAD models of savonius turbine and piston pump are shown in fig 15, fig 16, fig 17.

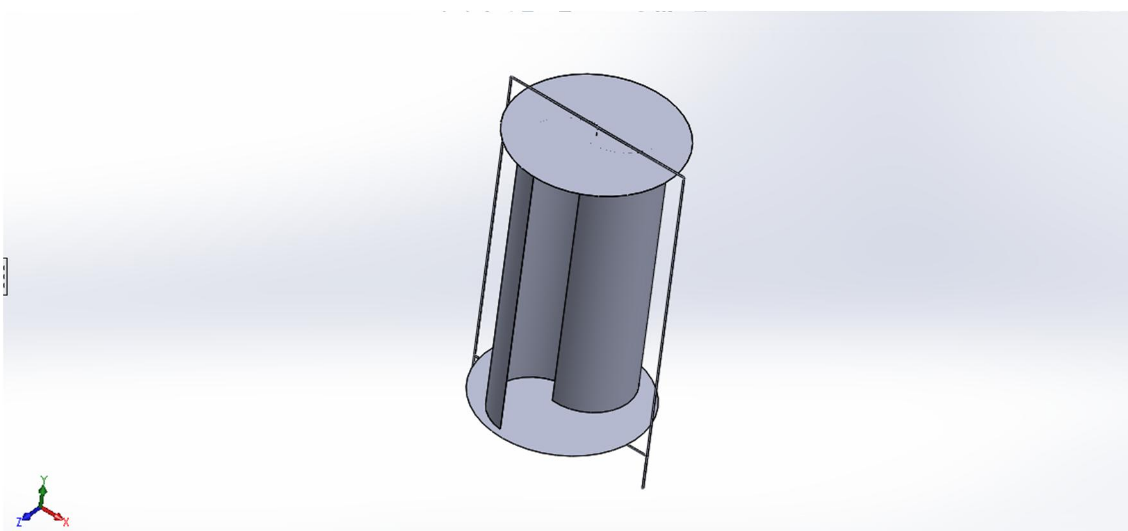

Figure 15: 3D isometric CAD modeling of savones turbine

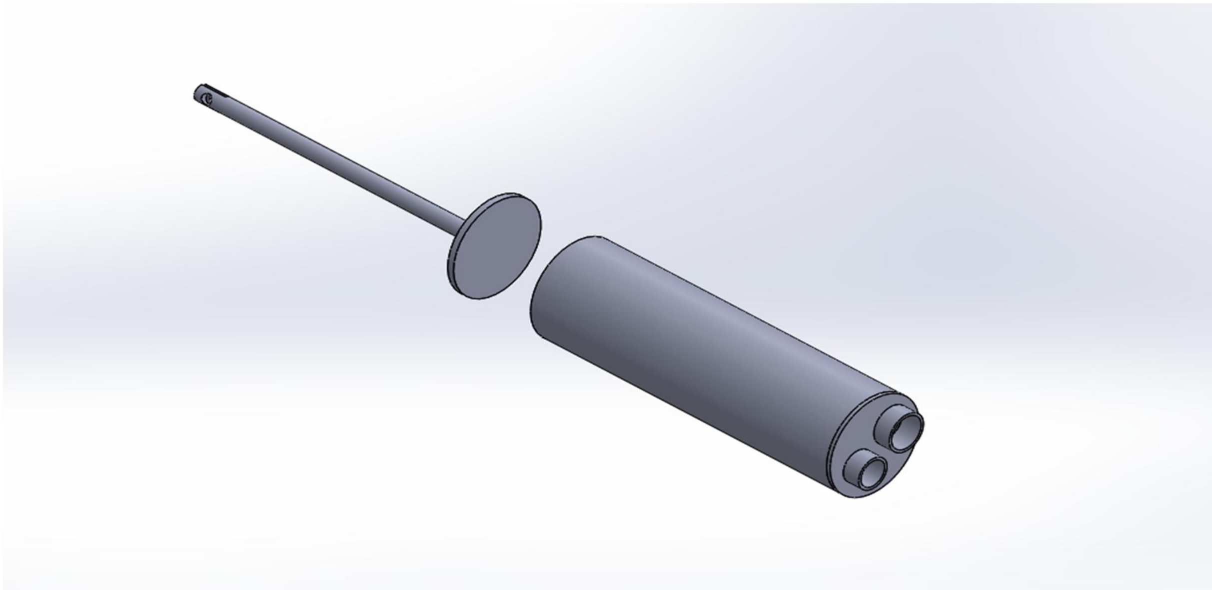

Figure 16: 3D isometric view of piston pump assembly

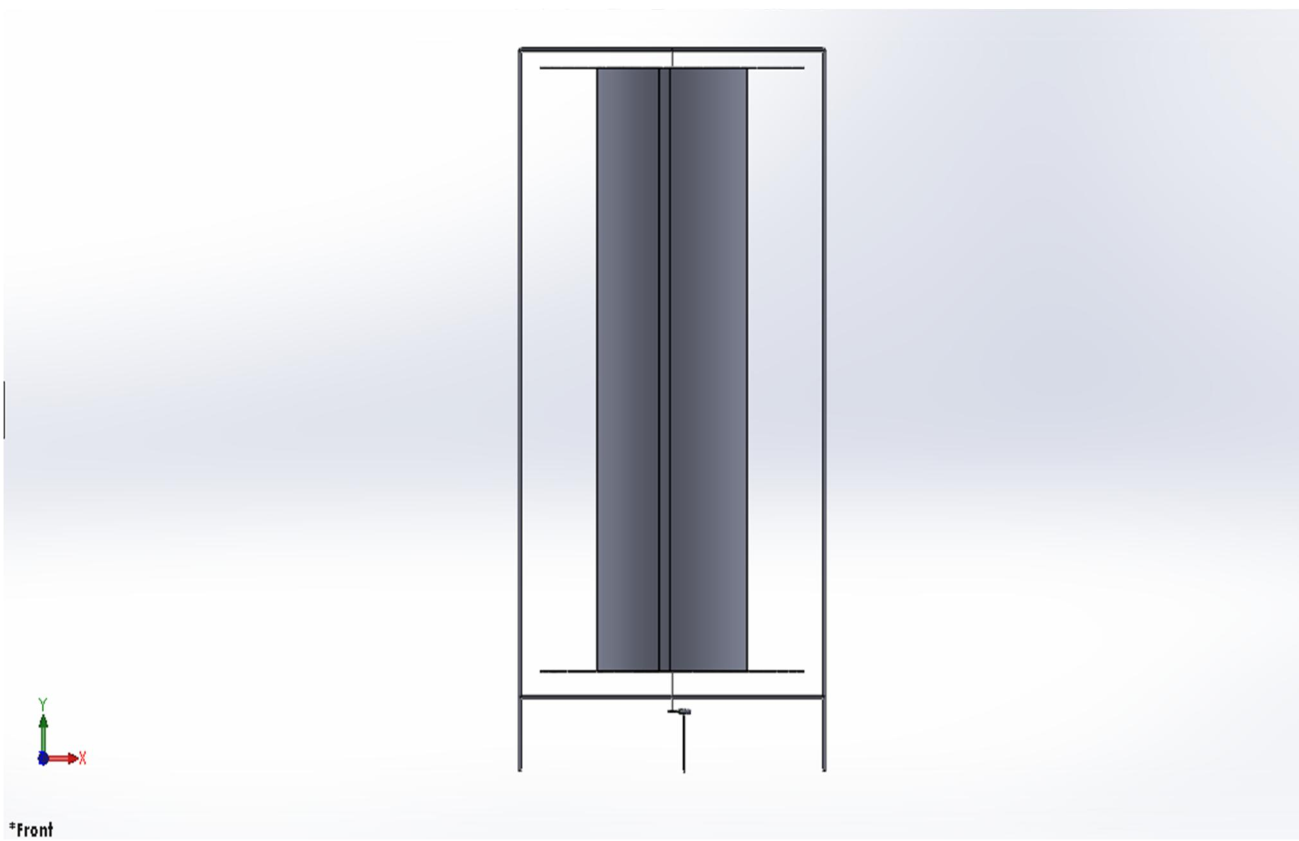

Figure 17: 3D CAD assembly modeling of wind turbine water pump

4. RESULTS AND DISCUSSION

In line with the ret objective of constructing wind operated water pump for small scale irrigation purpose the necessary data pertaining to wind pattern was collected from meteorological center and average wind speed was calculated to be 4.34 m/se in selected area of rift valley near Meki. The size of the wind turbine was calculated to operate the water pump.

The power output from the turbine is very low at the wind speed is low around 2m/s which is unable to drive the water pump. When the wind speed is more than 2.5 m/s it start pumping a water and operate between the 5 m/s to 8 m/s in which it the converts the operating power of the water pump see (table 13).

: - equation (11)

$$Pa = \frac{1}{2} Cp \times \rho \times H \times D \times V^3$$

$$\text{Power (pa)} = 1/2 \times 0.27 \times 1.255 \times 5.04 \times 10.08 \times (2.5)^3$$

$$=134.489565w$$

Table 11: Wind speed vs. turbine power output

v(m/s)	p(w)
2.5	134.489565
4	550.869258
5	1075.91652
6	1859.18375
7	2952.31493
8	4406.95407
9	6274.74514
10	8607.33216
11	11456.3591
12	14873.47
13	18910.3088

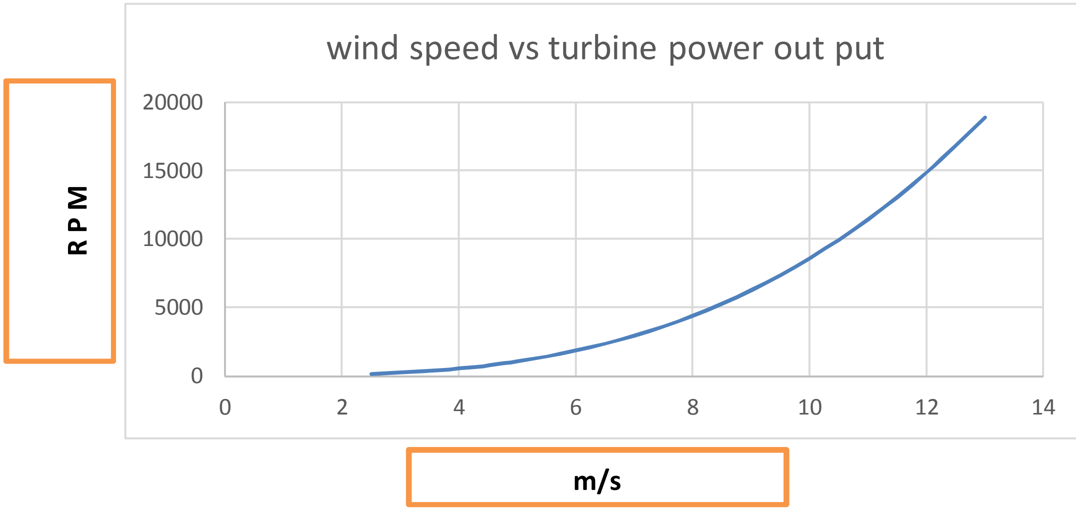

Figure 18 wind speed vs turbine power out put

As the (figure 18) shows that power output produced by the savonius turbine increases as the wind speed increases but at the less wind speed the power delivered is very much less which cannot drive the pump as a result the turbine is not rotate below the operating wind speed.

For the different wind speeds tested, the rotor blade gave different RPM and water flow rate. Although the design wind speed for the turbine which is velocity rated of 6.51 m/s, from the results it is observed that the turbine's capacity to capture power at lower wind speeds was still considerable.

Table 14 gives the results of the water flow rate pumped by water pump for different wind speeds the average working rang of turbine is 6.5m/s which is relatively approached to the amount of water pump for the design.

Table 12: water flow rate at different wind speeds

Wind speed (m/s)	Rotational speed (RPM)	Water flow rate lit/m
2	0	0
4	15.99	167.895
5	19.98	209.79
6	23.98	251.79
8	31.97	335.685
10	39.97	419.685
13	51.95	545.475

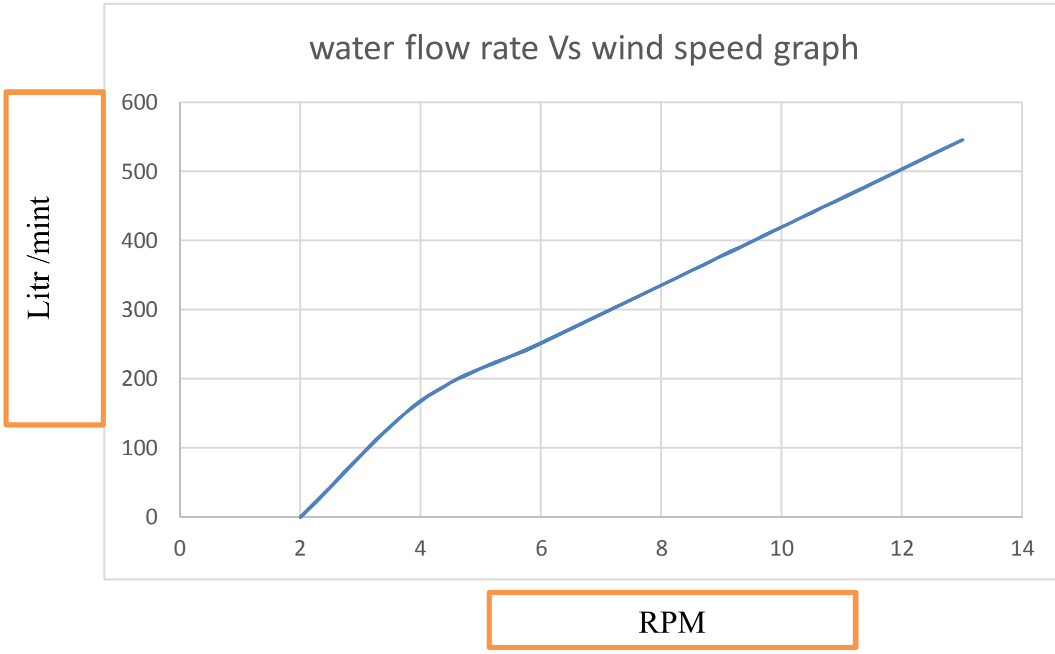

Figure 19 wind speed vs flow rate

The (figure 19) given above shows that as the wind speed increases the flow rate of the water increases. But if the wind speed is below the operating range it cannot pump water as a result there is no flow of water as well there is no rotation of turbine. If the wind speed is more than 4m/s it starts gradually to rotate and increases as the wind speed increases till the cutout wind speed of the turbine which is 13 m/s.

5. CONCLUSION AND RECOMMENDATION

5.1 Conclusion

This work and the results obtained so far are very encouraging and reinforce the conviction that vertical axis wind energy conversion systems are practical and potentially very contributive to the production of clean renewable energy from the wind even under varying condition. The Savonius wind turbine design is simple and can be constructed with locally available materials and with less skill. So it is very much suitable for less developed countries. The savonius wind turbine designed is ideal to be located on local farm land to pump water for irrigation and domestic use which is powered by wind. The elevated altitude gives it an advantage for more wind opportunity. If the project is implemented on farm land it is sufficient for 5 hector land for irrigation, for cattle and a family domestic use. The project area of implementation is selected on the rift valley of Ethiopia which the average annual wind speed nearly 4.5 m/s which is sufficient operating water pump.

So this wind operated pump can be used for small scale irrigation in selected area near Meki, where local formers mostly grow vegetable.

A prototype test shows that

- ❖ If wind speed very low 2m/s which is unable to drive the water pump.
- ❖ If wind speed is more than 4m/s it start pumping water.
- ❖ If different wind speed tested gave the different RPM and water flow rate.

5.2 Recommendation

Effects of the geometrical location, aerodynamic analysis simulation and actual test of the project at different season are also left for the future work.

In this project the windmill directly connected is:-

- ❖ Water pump without any intermediate transition mechanism. So it is recommended to have a mechanism to control speed and torque so that the pump works in different speed range.
- ❖ Effects of the geometrical location
- ❖ Aerodynamic analysis simulation

- ❖ Due to time and budget constraints only prototype was constructed in this project. It is recommended to develop full size wind operated water pump and implement in the selected area.

5.3 Educational Implications

The objective of the national TVET strategy is to create a competent, motivated, adaptable and innovative work force in Ethiopia contributing to poverty reduction, social and economic development through facilitating demand drive, high quality technical, vocational education and training, relevant to all sectors of the economy, at all levels and to all people in need of skill development transferring technology (National TVET strategy, MOE, 2006)

- ❖ Technological advance and progression, which naturally lead to economic release and independence.
- ❖ Evaluate new instructional program and draw lessons for further improvement
- ❖ To improve and develop the teaching and learning process
- ❖ Gain education decision makers in making decision and action
- ❖ Effective handling the issue of transfer of technology and attendant problems
- ❖ Conservation of the resource that could have spent in engaging the serving of foreign experts

The objective of this project is to show haw education can play great role in introducing and transferring Windmill Water Pump for Small-Scale Irrigation and Domestic Use to country can also to enrich understanding and create ability of university and TVET trainees through education. Accordingly the, finding of this project could have an impact in TVET education, and training the following area:

- ❖ It can help to transfer Windmill Water Pump for Small-Scale Irrigation and Domestic Use into TVET training
- ❖ It can initiate TVET experts to study farther for add a value and adapt it
- ❖ It can develop the potential of TVET trainees to create to application Windmill Water Pump for Small-Scale Irrigation and Domestic Use for mechanical fields

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APENDIX-1

National meteorological agency

Adama Branch Directorate

Average wind speed per each month for 5 years

Month	YEARS				
	2010	2011	2012	2013	2014
Jan	4.774194	5.006452	3.032258	4.76129	4.787097
Feb	2.890323	3.470968	4.587097	4.76129	3.896774
Mar	3.548387	3.787097	5.348387	3.793548	4.419355
Apr	3.064516	3.56129	5.316129	3.096774	4.064516
May	2.883871	3.883871	5.051613	4.219355	4.148387
Jun	4.032258	9.535484	3.375484	5.258065	4.729032
Jul	2.864516	3.477419	4.56129	4.909677	4.96129
Aug	3.63871	3.322581	8	4.529032	4.212903
Sep	5.445161	2.645806	4.890323	3.870968	2.993548
Oct	4.141935	4.870968	5.530968	3.529032	3.96129
Nov	2.851613	3.845161	5.019355	4.606452	4.987097
Dec	3.96129	5.070968	5.070968	4.651613	4.916129
AWSPY	3.674731	4.373172	4.981989	4.332258	4.339785

Station:-Nazret					'Element :- Monthly Average Max.Temp.(^{o}C)							
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2005	26.6	29.6	29.9	30.2	29.1	29.6	25.6	26.7	27.6	28.9	27.5	26.3
2006	27.5	28.7	28.6	28.8	30.6	29.9	25.9	25.2	26.4	27.9	26.9	25.1
2007	26.2	28.4	29.8	28.7	30.9	28.2	25.7	25.4	26.4	27	26.1	25.4
2008	26.8	27.1	30.4	29.7	30.1	28.5	25.4	25.2	26.9	27.3	24.7	25.1
2009	25.8	28	30.2	29.8	30.9	31.5	26.8	26.2	28.7	27.1	27.2	26
2010	26.6	27.3	27	29.9	30.2	29.8	25.8	26	26.7	28.2	27.2	26.1
2011	27.3	29.4	29.4	31.7	30.8	30	27.4	26.2	26.7	27.9	26.9	25.1
2012	25.5	27.4	29.7	29.4	30.4	29.8	24.8	24.5	26.5	27.3	27.5	26.7
2013	27.31	29.41	31.01	31.2	31.15	30.35	26.08	26.32	27.99	28.08	27.48	26.35
2014	28.1	29.5	29.8	30.7	31.4	31.6	28.3	26.7	27.3	26.9	27.5	26.2

Note: - ---------------> NA ----------------> Data not Available

Meteorological seasons

- Bega: October –January
- Belg: February – May
- Kiremt: June –September

Adama Station-

Longitude=8^{o}33”23.8’N .

Latitude=39^{o}17”02.5”E

Dominating climate of the city is hot/arid climate type

Altitude = 1648m above sea level

Distance from Addis Abeba is 99 km

APPENDIX-2

The prototype of the piston pump

The prototype of the piston pump with wind turbine assemble