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THESIS NO:

SOLAR PV LIFT IRRIGATION FOR AGRICULTURE IN NARAINAPUR RURAL MUNICIPALITY, BANKE

By

Prajwol Lamichhane

A THESIS

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DEPARTMENT OF MECHANICAL AND AEROSPACE ENGINEERING

The undersigned certify that they have read, and recommended to the Institute of engineering for acceptance, a thesis entitled "Solar PV lift irrigation for agriculture in Narainapur rural Municipality, Banke" submitted by Mr. Prajwol Lamichhane in partial fulfillment of the requirements for the degree of Master in Energy System Planning and Management.

Supervisor, Associate Prof. Dr. Ajay Kumar Jha

Department of Mechanical and Aerospace Engineering

Pulchowk Campus

External, Dr. Krishna Raj Shrestha

Chairman

Centre For Energy and Environment, Nepal

Committee Chairman, Associate Prof. Dr. Sudip Bhattarai

Head

Department of Mechanical and Aerospace Engineering

Institute of Engineering, Pulchowk Campus

Date: November, 2023

ABSTRACT

Narainapur rural municipality sits within the major rice growing region in Banke district of Nepal. It is one of the rain-fed dominant agricultural regions of Nepal which contributes a considerable proportion of cereal crops i.e., Paddy rice, maize, and wheat in Banke's overall agricultural production. Though Ministry of Environment in 2010 placed the whole Banke under very less vulnerable, recent studies reveals that it is a hotspot of the extreme climatic condition with possibility of hottest days and night, droughts. In 2022, Narainapur Municipality was declared a drought-hit area as rice planting and farming activities could not be done due to lack of sufficient rainfall. The majority of the farmers relies on pump for certain time or yearly irrigation. On the other side, only 45% work on the eastern canal of Sikta irrigation project has been completed as per 2020 report and it may take several years before it become fully operational for Narainapur which is located at the canal's tail end. However, Solar powered lift irrigation is gaining popularity owing to its cheaper operational cost and flexibility. Therefore, this study aims to estimate the present and future irrigation water requirement (IWR) of the crops, prepare the monthly ground water level map and determine the peak solar photo voltaic power required to operate a conventional pump to fulfill the required IWR. The IWR(s) was found out using FAO's Cropwat 8.0 using climatic datas for each year from 1996 AD to 2021 AD. A graph was plotted between IWR(s) and time (Years) which showed that IWR decreases with increase in time. The maximum IWR was found in the present year 2023 AD. The maximum water requirement is calculated to be 133.84 m^3/day/hectare for the year 2023AD in the month of April. Then, Real time ground water levels were also collected from 2001 to 2021 for 18 wells located around the Banke District. The mean of all the year for each month was taken to obtain the average to be used to make ground water map. The map was prepared in Esri's ArcGIS 10.3 using Universal Kriging Method. It was found that the water table depth is highest in the month of April which is 9.87m and it is lowest in the month of August 1.36m. The obtained datas were then used to determine the photovoltaic power required to operate a conventional pump which was determined to be 3.24 kWp. Then the system sizing was done for the required peak power and structural analysis was done for the solar frame to obtain economical solar irrigation components. For the required peak power, 16 solar

panels of 250W. It was found that where ISB 25 x 25 x 2.6 was found to be sufficient to withstand all the relevant loads acting in the solar panel system. Two alternatives were considered for the PV system for continued supply of water during no-sunshine hours (i) system operated on batteries, and (ii) system with concrete water tank. Out of these, it was found that the system with concrete water tank is more economical and cost effective than the system operated on batteries. Therefore, solar pv system with concrete water tank storage is recommended for Narainapur region irrigation. The findings in this study can be of high significance for planners, irrigation engineers and agriculturist for planning and management of agricultural operations related to rice and wheat cultivation in the Narainapur region.

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Prajwol Lamichhane

Department of Mechanical and Aerospace Engineering

Pulchowk Campus, Institute of Engineering

Pulchowk, Lalitpur

Nepal

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LIST OF ACRONYMS AND ABBREVIATIONS

NARC	Nepal Agricultural Research Council
NRB	Nepal Rastra Bank
GHG	Green House Gases
CSi	Computers and Structures
IPCC	Intergovernmental Panel for Climate Change
GDP	Gross Domestic Product
PAN	Pratical Action Nepal
MoSTE	Ministry of Science, Technology and Environment
MOAC	Ministry of Agriculture and Cooperatives
CDKN	Climate and Development Knowledge Network
DADO	District Agriculture Development Office
IWR	Irrigation Water Requirement
AEPC	Alternate Energy Promotion Centre
NEA	Nepal Electricity Authority
DCSD	Distribution and Consumer Service Directorate
NRM	Narainapur Rural Municipality
FAO	Food and Agricultural Organization
CWR	Crop Water Requirement
IWR	Irrigation Water Requirement
GWRBD	Ground Water Resources Development Board
GIS	Geographic Information System
USGS	United States Geological Survey
ANSYS	Analysis System
CFD	Computational Fluid Dynamics
GCM	General Circulation Model
ARIMA	Auto Regressive Integrated Moving Average

SARIMA	Seasonal Auto Regressive Integrated Moving Average
ANN	Artificial Neural Network
IDW	Inverse Distance Weighing
RMSE	Root Mean Square Error
PRECIS	Providing Regional Climate for Impact Studies
VDC	Village Development Committee
NARC	National Agriculture Research Centre
GWT	Ground Water Table
DHM	Department of Hydrology and Metereology
USDA-SC	United States Department of Agriculture Soil Conservation
DEMA	Double Exponential Moving Average
ETABS	Extended Three-Dimensional Analysis of Building System
ISB	Indian Standard Beam

Chapter 1: Introduction

1.1 Background

Climate change has emerged as a worldwide concern, with evident repercussions on several sectors including health, water resources, agriculture, biodiversity, and livelihoods. This is a crucial matter that has significant implications both domestically and globally. climatic change refers to the alteration of the Earth's climatic patterns during a certain timeframe as a result of both natural phenomena and human activities affecting the environment (IPCC, 2014). Various research have found that the global mean temperature and global mean precipitation are growing at a concerning pace. The escalation is a result of the release of greenhouse gases (GHG) caused by human activity. Anthropogenic activities include many human actions such as mining, the discharge of industrial waste, the combustion of fossil fuels, especially coal, and the use of pesticides, herbicides, and fertilizers. These activities are primarily accountable for a significant release of greenhouse gases into the environment. A significant amount of these emissions arises from the burning of fossil fuels for the purpose of electricity generation.

Historically, it is obvious that industrialized nations have been primarily accountable for the bulk of greenhouse gas emissions that have accumulated in the atmosphere. They bear the responsibility for the majority of the emissions that have been released into the atmosphere and contribute to the trapping of heat, particularly since the onset of the industrial revolution. Developing nations such as Maldives, Cuba, and others bear the brunt of climate change, while being little contributors to its causes. The most vulnerable individuals in developing nations are disproportionately impacted by a changing climate. They continue to experience the full force of a scorching environment, enduring intense heat waves, floods, and droughts that result in catastrophic flooding, particularly affecting those

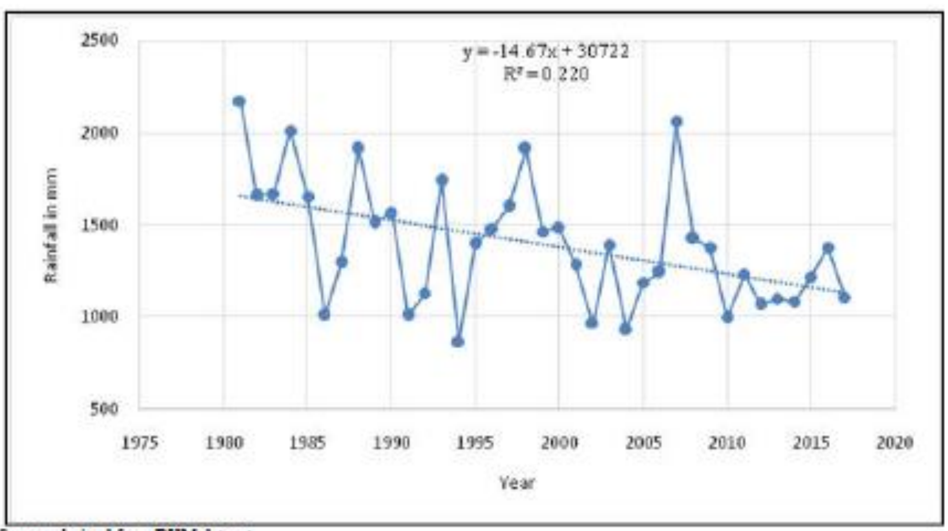
without any financial reserves. Among all industries impacted by climate changes, the agriculture industry is most severely affected. Weather and climate have a significant impact on agriculture. It is strongly dependent on water, land, and other natural resources that are influenced by climate. The impact of climate change on agriculture will be contingent upon the speed and intensity of the shift. Agriculture contributes around 4% of the worldwide gross domestic product (GDP), and in the least developed nations, it may make up more than 25% of GDP. Hence, it is vital for fostering economic development. Enhancing agricultural development is a very effective strategy for reducing extreme poverty and promoting shared prosperity.

Agriculture plays a crucial role in Nepal's economy, contributing significantly to the country's objectives of ensuring food security, creating job opportunities, and reducing poverty. Nevertheless, when assessing the increase in total factor productivity, it is evident that the agricultural sector has seen a substantial decline in performance over the last twenty years in comparison to its South Asian counterparts. The adverse effects of climate change are considered one of the primary causes for this decline. Nepal has a diverse and intricate composite climate, which is significantly influenced by its geography. The region consists of lowland areas characterized by a warm and humid sub-tropical climate, whereas the high altitude areas have frigid temperatures that sometimes drop below freezing in winter (Practical Action Nepal (PAN), 2009). Nepal has the 4th position in terms of vulnerability to the consequences of climate change, according to the Maplecroft report in 2014. Additionally, it ranks 7th in the Climate Risk Index, which measures the effect of climate change on countries, as stated by Kreft et al. in 2016. Furthermore, the Ministry of Science, Technology, and Environment (MoSTE, 2014) has designated Nepal as one of the four worldwide areas most vulnerable to climate change hazards, primarily because of its rugged and harsh terrain. These data highlight the ongoing effect of climate change on several sectors of Nepal, particularly the agricultural sector.

In recent decades, Nepal's agricultural productivity has sharply declined, leading to a growing reliance on neighboring countries to meet its daily food needs. The agricultural sector is mostly subsistence-based and adheres to traditional practices, rendering it particularly susceptible to the impacts of climate change. The bulk of the population in this nation consists of farmers with tiny land holdings who adhere to traditional agricultural practices. The alteration in rainfall patterns and the rise in temperature have led to a significant decrease in productivity. The elevated temperature has a detrimental effect on crop productivity in the long run by accelerating the rates of respiration and evapo-transpiration. This leads to a moisture deficit in both the soil and the plant system, mostly caused by the heightened emission of greenhouse gases. Conversely, rainfall patterns are becoming more erratic, adversely impacting agricultural productivity since farmers rely on certain times for planting and harvesting their crops. It is essential to provide a comprehensive action plan for agricultural growth that incorporates techniques that align with local spatial planning, taking into account the economic, social, and political environment.

The Terai area of Nepal is sometimes referred to as the "granary of Nepal" because of its capacity to grow and yield food. The Terai region, while covering just 23% of the total geographical area, accounts for 56% of the entire national grain output (MOAC, 2010). The primary agricultural commodities cultivated are Rice, Maize, and Wheat. In general, rice is planted during the monsoon season, but maize and wheat are mostly grown during the arid seasons before or after the monsoon. The Terai area contributes 65% and 22% to the overall wheat and maize output of Nepal, respectively. These crops are mostly grown in rainfed environments and with less reliance on commercial fertilizers. Within the Terai area of Nepal, Banke district is one of the leading producers to the country's rice production, which is a key cereal crop. Based on the data from the Agricultural Statistical Yearbook 2017, it accounts for around 14% of the rice production in the mid-west area. The district's contribution to national agriculture is around 2.4% for rice, 0.9% for maize, and 2.9% for wheat (GWP, 2014). The primary cereal crops cultivated in this district during the monsoon and winter seasons are paddy rice and wheat, respectively. In the Banke district, paddy rice and wheat constituted 55% and 28% respectively in the 2016/2017 year (Devkota, 2014). Typically, farmers transplant rice seedlings in the second week of August and harvest them between the second and third week of November. Wheat, on the other hand, is sown in the first week of January and harvested in the second week of May.

A recent research financed by the Climate and Development Knowledge Network (CDKN) has shown that climate change and related severe events are causing an annual loss of around 0.8% of agricultural GDP. The analysis indicates that droughts and floods pose significant challenges to agricultural productivity and food security. The Banke area in Nepal has scorching temperatures, with the mercury soaring to a high of 45°C during the month of May. In 2010, the Ministry of Environment classified Banke district as having low vulnerability to climate change, extreme temperatures, irregular rainfall, and dependence on rain-fed agriculture (70% of arable land). However, this classification has led to a significant decline in agricultural productivity in recent years. The impact of climate change is clearly evident in the region, manifesting as recurrent instances of flooding and drought, which in turn lead to the devastating consequences of agricultural loss, economic decline, and loss of human life. The primary effects result from changes in precipitation patterns and rising temperatures. Joshi et al. (2019) reveals that the mean annual rainfall in Banke district for the last 37 years is around 1395mm, ranging from 868mm to 2173mm each year. The data also indicates a significant variance, with a standard deviation of 338mm.



Source: derived from DHM dataset

Fig 1: Actual & Linear Trend of Annual Rainfall in Banke, 1981 - 2017 (Joshi et al., 2019)

Similarly, Shrestha et al, 2015 shows that the Banke district is a hotspot area of the extreme climatic conditions with possibility of hottest days and night, flood, drought, chilling winter without sun for weeks or more. The average maximum temperature is 40°C and goes well above it in the month of April and May. The studies have predicted that there will be 0.014°C yearly increase in the maximum temperature during monsoon time in Terai region.

In comparison to an average maximum temperature during the period, the maximum temperature peculiarly is very high in Banke district during the monsoon period. In July, annual maximum temperature increase is 0.07°C highest among other monsoon months. The Rate of temperature increase projected is 0.05°C in August and September. These events have resulted in drought in several part of the district which cause high impact agricultural production.

A predominant way to tackle climate change is through year-round irrigation. The proper availability of water to suffice the irrigation water requirement (IWR) can promote better agricultural production in Banke. Even though rainfall-based farming is still prevalent among many farmers, national and regional irrigation facilities are slowly paving the way for better and continual all-round irrigation in the district. One of the national pride projects, the Sikta irrigation project was started with an aim of providing reliable irrigation facilities on a total 42,766 hectares of land of the district. The Project was started from F.Y.2062/63 by the Government of Nepal from its own resources, covers an area of 33766 hectares on the western side and 9000 hectares on the eastern side of the Rapti River. However, it has almost been over 17 years since its beginning and the project is only 67% completed taking in a considerable portion of budget each year. Unfortunately, the canal collapsed during the 2 tests conducted in 2016 and 2018. This raises a question over its long-term performance and its closure time. On the other hand, ground water irrigation has been an effective alternative to tackle the climate change impact as well as fulfilling the water requirement in the field upto the time when a durable & robust irrigation project can supply the continual discharge. Ground water irrigation simply consist of pumping out water from the ground water level which can be done using fossil fuels or solar power. Fossils-based energy generations were used to be the only way to pump the water from the ground to irrigate but it produces greenhouse gas (GHG) emission which further increase the climatic change. But with the arrival of modern technology, the energy generation through solar power is gaining wider attention. Rapid increment of solar panel efficiency and falling cost have made it a suitable alternative for pumping water for irrigation activities for higher and sustained agricultural yield. Solar powered water pumps in fact have a greater chance to elevate poor families from subsistence-agriculture and poverty, which has been escalated by climate derived water shortage and the economic falling due to pandemic.

Solar energy is by far the largest and most sustainable energy resource in the world, which is also true for Nepal. Nepal has high solar potential, moderate hydro power resources and small potential for wind and bio energy resources. Hydropower struggles to match with the suppleness and lower cost of solar, particularly because the solar power cost continues to decrease. Nepal has huge and low-cost solar energy resources. The solar potential in Nepal is 50,000 terawatt-hours/year, which is one hundred times bigger than Nepal's hydro resource and 7,000 times greater than Nepal's present electricity consummation. Solar can easily meet all future energy needs in Nepal. Today, Solar power has become a requirement to shift to higher-value crops and change the livelihoods & living of subsistence and smallholder farmers. This is why it has become the Nepal government's priority to promote solar irrigation to address the food-energy-water cohesion and the climate interlinks. As of August 2019, Nepal had already set up 1,600 solar irrigation arrangements worth eight million dollars all over the country. More than seventy-five percent of these were financed by the Alternative Energy Promotion Centre (AEPC), an top body on renewables promoting solar irrigation under the Renewable Energy Subsidy Policy (2016) and Subsidy Delivery Mechanism Guidelines (2016). Collectively, these arrangements irrigate 550 hectares of farmland and generate 2.5 megawatt of energy. In a country where only a quarter of the 3.5 million hectares of cultivable land is irrigated, and two-thirds of farms rely on the rains, solar irrigation systems are important for increasing the agriculture.

There is great feasibility for solar irrigation systems as a solution to food security for small stake holders because it can grow agricultural yield to match the pace with food demand while at the same time harmonizing to the changes in weather patterns due to climate change. This will lead to enhanced livelihoods and help in poverty reduction. The use of clean energy also strips expenditure for diesel used in pumps, and reduces Nepal's petroleum import bill. Much of the effort has been concentrated on improving access to solar technologies so far through innovation in infrastructure and financial sources. There is now a need for synchronous investment in optimization of energy generated through solar irrigation systems. New innovative technologies could transform excess energy generated by solar systems beyond irrigation.

The whole system of PV solar pumping includes the Solar panels, Inverter and controllers, Motor, Pump and other miscellaneous parts like cables, pipes, etc.

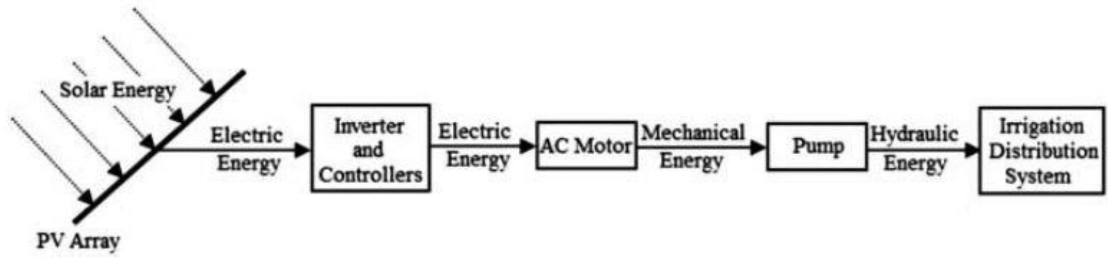


Fig 2: Schematic Diagram of PV Solar Irrigation System (El-Shimy, 2012)

The components are as follows:

i) Solar Panels and Modules: These are the primary components in the solar irrigation system that will provide electricity to drive the solar pump. As the energy source, many of these solar panels are joined together in arrays to provide DC power. To get the appropriate voltage and power for the pump, interconnections are created utilizing series or parallel combinations.

ii) Solar pump: Any centrifugal or submersible pump may be directly attached to the solar array to start the operation that is powered by the DC energy provided by the solar array. These pumps are widely accessible on the market, depending on the needs of the user.

iii) Electrical interconnections: The installation includes a set of appropriate-sized cables, junction boxes, connectors, and switches.

iv) Plumbing: As part of component installation, pipes and fittings must be connected to the pump, which necessitates plumbing.

A simple 50-watt PV solar array may provide enough electricity to operate a common 12-volt pump that can move between 1250 and 2500 lit/hr. These components are linked to an irrigating pump by standard included body fittings and half-inch pipes. A sturdy platform should be built for a water tank that can deliver water during periods of low sunlight and also provides gravity flow; a frame should be built to allow the optimal tilting angle for the solar panels, which can also be utilized with a sun tracker to maximize input. Multiple filters are required to maintain and extend the service life of the irrigation pump, as well as to reduce clogging caused by impurities such as sand and silt in sprinkler emitters and tubes. A solar pump paired with any inexpensive surface or subsurface irrigation kits may be used to water a larger area with a decent choice of high-value commercial crops. Water usage efficiency must be enhanced with little fertilizer loss in order to achieve a greater degree of irrigation in the hilly terrain.

According to market circumstances, research in solar pv array has to rise in efficiency, and the purchase cost of the array is also decreasing compared to the previous year. On the other hand, the price of petroleum products is steadily growing. This might happen owing to a lack of production, a conflict in an oil-rich nation, or other factors. There will undoubtedly come a day when the cost of solar PV will be less than half that of gasoline. Many telecom towers in Nepal use diesel as a power source, which may eventually be replaced by a solar panel built just inside the perimeter of such tower. However, because to greater setup costs, solar power is still estimated to be more costly than the cost of fuel or gasoline for pumping water. However, awareness has been raised via the media and other ways to boost the usage of solar power. A submersible pump can run at a head of 30m with 1 kilowatt of electricity.

Solar panel installation and mounting are also relatively straightforward. The most efficient usage of the panel happens when it is tilted at the appropriate degree to create the most energy. If the battery system, which may also be utilized during non-sunny hours, is eliminated, it becomes even more cost efficient. Even with a direct connection between the PV array and the pump, ground water may be simply pushed. The effective usage includes the storage of water, which is pumped during the daylight hours into a tank and subsequently utilized when there is no sun. The total efficiency has been measured to be more than 3% (Daud and Mahmoud, 2005).

numerous case studies and publications are available that investigate the viability of solar electricity in numerous South Asian nations such as Bhutan, Nepal, Bangladesh, India, and others. From an economic standpoint, studies have clearly proven that it may be a game changer for those who live on subsistence and rely only on subsistence farming for a livelihood. The initial installation cost of a PV system is somewhat greater than the cost of a standard energy system, but it is much less expensive in the long run. It also lowers the chopping of woods since it is an important fuel source for those living in the Alps and Himalayas. Our nation, Nepal, which has over 300 days of sunshine every year, may greatly benefit from solar farm energy production technologies. The benefits outnumber those of conventional energy generation methods.

Rural villages in Nepal are often situated too far away from where current grid lines are built, making extending grid lines to each of such settlements prohibitively costly. Even if the fuel is accessible inside the nearby district premises, people find it difficult to carry such fuel on a daily basis for the purpose of agriculture, which needs a larger chunk of fuel to effectively irrigate the area. As a result of this, people may understand the appeal and flexibility of using renewable energy such as solar power. The shipment of solar power components is quite inexpensive, and the government also helps with installation by sending specialists over to assist the people. The life cycle cost study of both systems demonstrates that the PV water pumping system is the most cost-effective option over the diesel water pumping system (Narale et al., 2013).

Because of its flexibility, dependability, low maintenance and operating costs, solar water pumping systems are now widely accessible for both household and commercial usage. These systems may also be combined with solar pumps, which are current agricultural innovations that give an environmentally favorable, pollution-free, and longer operating period. Furthermore, they run on sunshine, which is given by nature. Even with the usage of energy storage devices or any water storage system, they may give unrivaled service when compared to the present conventional irrigation methods such as utilizing diesel or gasoline pumps. These solar pumps may be put in areas where there is no access to the national power grid (Ahmet and Shafikur, 2012).

1.2 Problem Statement

Narainapur rural municipality is one of the administrative constituents of the Banke which is majorly dependent on rainfall for its agriculture water requirement. Several studies have shown, on one hand that the amount of annual rainfall in the region has a decreasing trend and it will continue to decrease over the coming years. On the other hand, the temperature of the region is continually rising concurrently due to global shift in temperature which causes prolonged effect in the productivity of cereal crops grown in the area.

According to the NEA's DCSD report 2077/78, the electrification status of Narainapur is only 9.71% which shows level of disparity the people have been facing till now. There is no running industries and majority of local population depends on agriculture for fulfilling their economic needs. One of the national pride projects "Sikta irrigation" initiated in 2062/63 in Banke was proposed to irrigate 42000 hectares of the agricultural area through its 2 canals: Eastern and Western Canal. The Eastern canal which passes and ends at Narainapur rural area is only 45% completed as per 2020 progress reports and the project often comes under criticism in media due to consecutive failure in test runs and poor construction practices employed by the construction agency.

The following problems prompted the need for this study for Narainapur which are as bulleted below:

- The agricultural yield from the region is decreasing year by year due to lack of irrigation facility causing arable land to become barren
- Farmland-to-Farmland national grid connection is not available for Narainapur
- The region is suffering heavily due to power shortages, irregular electrical supplies and voltage fluctuation
- Furthermore, the crop water requirement for this localized region has not been studied in depth before as most researches have taken larger basins for the study.

1.3 Research Gaps

To support the need for this investigation, the following research gaps have been found:

- The researches related to solar irrigation for agriculture in the Narainapur region has not been done before as the region used to get more or less required amount of precipitation for the agriculture until few years ago.
- The crop water requirement for the localized region like Narainapur rural municipality has not been studied in depth before because most of the research take into account a larger region or basin.
- Investigations regarding ground water level around this study area has been scarcely performed in the past by the researchers due to lack of sufficient ground water database as well as representative area being too small.

1.4 Research Questions

Following research questions were designed to address the main problem outlined in this research which are as below:

- Since the effect of climate change continues to have an impact on agriculture, is it possible to know the water requirement of the crop in the future time period?
- Can we estimate the ground water level in the concerned region and generate a ground water level map using the available well data?
- Can we estimate the peak solar PV power required to fulfill the water demand of the crop using the ground water?
- Can we determine the economical sizing of the solar pv system.

1.5 Objective

The following are the objective of the study

Main Objective: To determine the peak photovoltaic power required to irrigate a hectare of land in Narainapur rural municipality.

Specific Objectives:

- To determine the irrigation water requirement of the Narainapur rural municipality (NRM) according to Soil-type and Climate characteristics.
- To determine the monthly ground water level of the area.
- To calculate to peak PV power and solar panel area to be installed, taking into consideration the overall yield of the PV-pump irrigation system.
- To develop an economical sizing of solar PV system with its frame and do a structural analysis on Etabs.
- To do a cost comparison of the PV system operated on batteries and the PV system with concrete water tank.

1.6 Significance of the study

Farmers in Narainapur depends heavily on rainfall for agriculture due to lack of irrigation facility. On the other hand, water use is excessive in rice cultivation. One of the best ways to fulfill the water demand of the region is through ground water pumping. During the rice cultivation phase, the optimal temperature range is between 18°- 33°C for the seedling germination. After this phase, the seedlings roots need an optimum temperature of 25° - 28°C for proper development. However, if the temperature exceeds 35°C, it creates inhibitory effect in growth of rice seedlings. Therefore, the only pragmatic solution to maintain the required temperature for the germination and seedling growth process is through frequent irrigation.

On the other side, there is no farm-land to farmland connection within the area. Therefore, there is lesser chance for garnering irrigation through national grid lines. Similarly, very scanty information of crop water requirement, increasing shortage of irrigation water, erratic monsoon and changing time of rice transplanting due to climate change has encouraged to study about the crop water requirement of rice and wheat in Narainapur area based on the meteorological datas. Therefore, estimation of CWR will be very useful for planners, irrigation engineers and agriculturist for planning and management agricultural operations related to rice and wheat cultivation; the primary crops grown in the region.

Knowledge of estimation of crop water requisite of rice and wheat will help farmers, irrigation engineers and agriculturists to increase the crop yield by utilizing the water properly. The evapotranspiration estimates obtained can be used on a near real time basis for irrigation scheduling purposes, water resources utilization and distribution planning and drought monitoring in the land.

Chapter 2: Literature Review

2.1 Crop water Requirement

The amount of water needed by the various crops to grow optimally is called the crop water requirement (CWR). It is generally defined as the depth of water which is required to balance the losses of water through the process of evapotranspiration. The amount of water required to compensate for evapotranspiration losses from a cropped field during the specified period of time is also called the crop water requirement. It is usually expressed in mm/day. Mm/month or mm/season and they are utilized for management purposes: Irrigation water need estimation, irrigation scheduling, and water supply timing. The crop water requirement (CWR) refers to crop grown under best conditions i.e., completely shading the ground, uniform crop, no any pending effect during growing stage, no pests or disease-causing conditions and suitable condition of soil including fertility and water. The crop water requirements of one crop variety vary from one place to another place due to climatic parameters variations and therefore, different evapotranspiration, different planting date and length of growing season, different crop coefficient values etc also make such changes.

The crop water need mainly depends on

(i) The climate: Hot climate crops need more water per day than cool climate crops.

(ii) Crop Type: Crops like paddy, sugarcane etc. needs more water than crops like millet or sorghum.

(iii) Growth stage of the crop: Fully grown crop needs more water than crops that have just been planted.

The amount of water that crop uses includes the water which gets transpired by the plant and the water that is stored in the plant tissues after the photosynthesis. The water stored in the plants tissue is a tiny fraction of the water which is actually used by the plant. So, the water use of a crop is considered to balance the water transpired or evaporated by the plant. The water which is transpired by the plant composes a major proportion of water.

Therefore, the rate of evapotranspiration is measured to find the water use of plant which is nothing but the movement of water from soil or plants to vapor in the atmosphere.

Two-step approach is where the estimation of crop evapotranspiration relies on. In the first step, a reference evapotranspiration is firsly determined and then, in the second step, the crop evapotranspiration (ET_c) is calculated as a product of reference evapotranspiration (ET_o) and crop coefficient, Kc i.e.:

$$ET_c = ET_o \times Kc \tag{1}$$

The estimation of the evapotranspiration from the "reference surface" is called the reference evapotranspiration. A hypothetical grass reference crop with an supposed crop height of 0.12 m, a fixed surface resistance of 70 s/m and an albedo of 0.23 is taken as the reference surface. It closely resembles an extensive surface of flourishing green grass of uniform height, growing activelyand fully shading the ground. The fixed surface resistance of 70 s/m means a moderately dry soil surface resulting from about a weekly irrigation frequency.

The Kc or crop coefficient has to be determined experimentally. The Kc values represent the combined effects of changes in crop characteristics, leaf area, irrigation method, soil and climate conditions, plant height, degree of canopy cover, rate of crop development, crop planting date , canopy resistance, and management practices. In general, a plant growth stages can be divided into 4 major stages; initial, crop development, mid-season, and late season. Each of these stage's period have their dependency on the crop type, planting date, climate, latitude, elevation and cultural practices. Local field tests are best for the evaluation of growing phase of the crop so the Kc values has to be determined or adjusted accordingly to predict better results.

The calculation methods implemented in FAO Penman-Monteith equation, as outlined in the FAO Irrigation and Drainage Paper 56 is as below. This equation can be written as follows:

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T_{mean} + 273} u_2(e_s - e_a)}{\Delta + \gamma(1 + 0.34\, u_2)} \tag{2}$$

Where,

ET_o = reference evapotranspiration [mm/day],

R_n = net radiation at the crop surface [MJ/m^2/day],

G = soil heat flux density [MJ/m^2/day] which can be neglected (G=0),

T_{mean} = average air temp [°C],

u_2 = wind speed at the height of 2 m [m/s],

e_s = vapor pressure (saturated) [kPa],

e_a = actual vapor pressure [kPa],

e_s-e_a = saturation vapor pressure deficiency [kPa],

D = slope of the curve of vapor pressure [kPa/°C],

g = psychrometric constant [kPa/°C].

Though Crop evapotranspiration and crop water requirement have similar values, the latter represent the water that required to be supplied, while the former refers to the water which gets lost through the process of evapotranspiration. The irrigation water requirement, IWR, basically represents the difference in the effective precipitation and crop water requirement. The IWR also includes excess water that accounts for leaching of salts and that which compensates for non-uniform use of water.

2.1.1 Use of Cropwat to determine the crop water requirement

When using scientifically grounded irrigation water management strategies, it is essential to accurately calculate crop evapotranspiration. According to Penman (1956), Ushkarenko (1994), Xu and Singh (2002), there are many approaches used to calculate evapotranspiration, including mass transfer-based, radiation-based, and temperature-based approaches. In order to estimate evapotranspiration and crop water needs, the Penman–Monteith approach is widely used globally and is regarded as one of the most complete and trustworthy methods (Abendinpour, 2017: Noreldin et al., 2016).

The FAO created a program called Cropwat that allows users to do all of the computations needed to calculate evapotranspiration. In order to calculate evapotranspiration, irrigation water needs for different crops and their annual circulation, irrigation schedule formulation, and other related factors, the application employs the Penman–Monteith technique. widely used globally to define the water needs of crops (Feng et al., 2007: Stancalie et al., 2010:

Surendran et al., 2015). It is perhaps one of the most often used instruments for planning the irrigation schedule for the crop. Utilizing the Penman-Monteith equation and the location's crop, soil, and climatic data, the computer determines the amount of water required. The required time series data are (i) minimum temperature, (ii) maximum temperature, (iii) latitude, longitude, altitude, (iv) sun hours, and (v) wind velocity.
To manage water resources as efficiently as possible in modern agriculture, it is critical to estimate crop water requirements, or CWR. Understanding CWR effectively helps reduce irrigation water usage, boosts water application efficiency, improves nutrient utilization, supports crop root growth, boosts water productivity, and ultimately lowers the cost of cultivating most crops, including wheat and rice. Any crop's need for water is influenced by a number of variables, including the soil, crop, and climate.

• Crop factors: These pertain to plant population, growing season, crop variety, and crop growth level period.

• Factors pertaining to soil: topography, depth, texture, and structure

Temperature, relative humidity, and wind speed are examples of climate variables.

• Aspects of management: Fertilizer kinds, equipment types, tillage operations, etc.

According to Doorenbos and Kaasam (1979), the amount of water required by paddy rice crops for evapotranspiration varies depending on the climate and duration of the growing season. The range of needs is between 450mm and 700mm. rice with a growth season of 100–130 days needs between 350 and 700 mm of water at its ideal level (Malla, 2008). For a wheat crop that grows for 100 to 130 days, 350 to 700 mm of water is the ideal amount of water needed (Malla, 2008).

2.2 Ground water Level Mapping

The level at which hard soil or rock is saturated, either below the ground or above the datum, is known as the groundwater level. This denotes the upper limit of the saturated zone and also alludes to the water table. The unsaturated zone is situated above the water table. It also serves as a relative indicator of the ways in which human activity and climate change have affected the volume of water held underground and the volume of water that emerges from the earth and flows into various other bodies of water. The depletion of groundwater supplies has significant environmental, social, and economic ramifications.

Groundwater resource exploration began in Nepal in 1967 under the Department of Irrigation. The Government of Nepal (GON) created the Ground Water Resources Development Board (GWRBD) under the Irrigation Department in 1976 to further ground water research and study.

Due to rising water demands and surface water limitations brought on by population growth and fast urbanization, the extraction of ground water has progressively grown. In order to manage, utilize, and conserve ground water, it is important to verify the ground water's geographical and temporal invariability. The main source of data about the hydrologic pressures operating on the aquifer and how these stresses impact ground water storage, recharge, and outflow is water level measurements from observation wells (Taylor & Alley, 2001). When mapping ground water, effective programs like Arc GIS or MODFLOW 6 are often used. Radar scans are used to map the underground water in dry places. Aside from this, if water level measurements from many wells within the research region are available, interpolation techniques are sometimes used to estimate the likely ground water level.

2.2.1 Use of GIS in Ground water level mapping

According to Lo and Yeung (2002), GIS may be broadly characterized as a subset of spatial analytical tools, a kind of database system, computer-based mapping and cartographic application, or an area of academic research. GIS can be defined simply as follows: (i) "GIS is a system of hardware, software, and procedures designed to support the capture, management, manipulation, analysis, modeling, and display of spatially referenced data for solving complex planning and management problems" (Rhind, 1989); (ii) "GIS is a computer system capable of assembling, storing, manipulating, and displaying geographically referenced information" (USGS, 1997). These are the two definitions common definitions of GIS.

Said another way, a geographic information system (GIS) is a collection of computer-based tools used to manage geographical data—that is, data that is related to and represented at a geographic scale—and use that data to address a range of spatial issues.

A mathematical function or technique known as GIS interpolation is used to estimate and forecast values in un-sampled locations. Accuracy evaluation is necessary since the chosen approach must provide a surface that is meant to ideally reflect empirical reality. The two types of interpolation methods are called geostatistical and deterministic. When it comes to deterministic and geostatistical interpolation, the most often used techniques are IDW and Kriging.

To bolster scientific irrigation, Ruan et al. used a geostatistical technique to examine the geographical and temporal variability of ground water level in the Qingtongxia irrigation region. To investigate the spatial distribution of nitrate in an agricultural plant area, Liu et al. compared the Ordinary Kriging technique with the Cokriging approach. The groundwater level decline in Beijing is estimated by Xiao et al. (2016) using data from thirty observation wells that were based on geostatistical theory. It was evident from the data that the basic kriging approach was the most dependable. In other research, the IDW, radial functions, and kriging technique of groundwater depth interpolation in China's

Minqinoasis area were evaluated. According to Sun et al. (2009), the findings indicated that the basic kriging approach was better suitable for this region.

2.3 PV power requirement

Currently, solar energy is one of the most sought-after renewable energy sources worldwide. Particularly in distant and rural places, the use of photovoltaic (PV) pumping systems for irrigation is receiving encouraging feedback (Cuadros et al., 2004: Arrouf and Ghabrour, 2007). However, at the moment, diesel and electric water pumps are the market leaders, with diesel pumps accounting for the bulk of pumps (Kamel and Hassan, 2003). Many government assistance programs now aim to reduce the completion of water and economic alleivation in the majority of underdeveloped nations. As a result, diesel-pumped water will become much more expensive. Because of this, PV water pumps will become more attractive due to their very cheap operating costs. Pollution to the environment will also decrease along with it. The Alternative Energy Promotion Center (APEC) has been giving Nepali solar energy plant designers and developers financial assistance. The solar plant has to have optimal size and initial installation costs if it is to replace the conventional petroleum-based farm. There are several approaches to sizing stand-alone photovoltaic systems (PV) (Qoaider and Steinbrecht 2010: Kelley, 2010; Kenna and Gillett, 1985: Cuadros et al., 2004: Hontoria et al., 2005: Glasnovic and Margeta, 2007). Sometimes, a large quantity of input data—the majority of which are challenging to obtain—is needed for certain procedures.

In order to power irrigation pumping systems based on AC motors, El-Shimy (2012) proposed an effective non-traditional direct way for optimizing the size of photovoltaic (PV) generators. It accounts for the PV-array tilt affects as well as the efficiency of all those different components that make up a PV pumping system. The suggested approach for proposing the least amount of electricity needed for PV generators is then contrasted with the Kenna and Gillett technique and the RETScreen method. Ibrahim et al. (2020) offered a thorough analysis for a completely working design of the solar pumping system's component parts with different water needs. The system design and solar simulation model were provided by a computer software that was created for the project. For all parties involved in PV solar water pumping, including consumers, the author argued that the model was vitally important. Kelly (2010) introduced a similar approach for determining if photovoltaic-powered irrigation is feasible. The expression is based on location, which includes local temperature data, aquifer depth, and pricing, which includes local government policies like carbon taxes and greenhouse gas emissions. According to the author, PVP irrigation is both technically and financially possible, given that there is sufficient area for the solar array. In order to provide a submersible pump system for the household water needs of five isolated residences situated in a remote part of Morocco, Allouhi et al. (2019) investigated the ideal PV system configuration.

2.4 Economical sizing & structural analysis of solar PV system

Because solar panels are becoming more and more popular in Bangladesh in the modern era, Haque (2001) conducted research on its economical size. In order to establish the size of the PV array, the author computed the area's irrigation water consumption as well as the necessary water outflow. The outcomes were then contrasted using life cycle cost analysis with the diesel-based engine's equivalent. Although solar panels have a higher starting cost than typical fuel-based engines, the author came to this conclusion.

The size and design of a stand-alone solar power system for a home in Iraq were investigated by Al-Shamani (2015). An affordable way to generate power for every family was suggested by the author. The author developed an affordable method of sizing the different components of the solar power system based on the voltage needed in the system and its power consumption. Additionally, the author has highlighted the factors that influence the size and design of each piece of equipment to be employed.

In their 2020 research, Panjawani et al. want to build solar panels' structural components such that they may be directly coupled with water pumps without the need for a power storage system. Both residential and business users may install the system to the rooftop or the ground. In accordance with IS 873, the study took wind, live, and dead loads into account. We utilized CFD and ANSYS for analysis.

2.5 Other past studies

In specifically, Shrestha (2013) focused on the irrigation water demand (IWR) in the Bagmati river basin while examining the effects of climate change on the rice-wheat cropping pattern. In order to anticipate the future temperature and precipitation in the immediate area, GCM results were applied to SRES Scenarios A2 and B2, followed by statistical downscaling. After that, it was entered into Cropwat to get the IWR estimate. The outcome demonstrated that all agricultural development stages have the same lowest influence from climate change. The IWR is trending downward in the Terai area.

Using time series analysis incorporated into many built-in R-Language models, Kothapalli and Totad (2017) tried to anticipate future weather conditions. In the experiment, just humidity and temperature were taken into account. It is believed that the finest models for carrying out this kind of analysis are those like multiple linear regression (MLR), auto-regressive integrated moving average (ARIMA), and artificial neural networks (ANN). The outcomes of these models were compared. For time series data, the ARIMA model produced superior results.

Using the IDW and Kriging models in ArcGIS, Almoderasi et al. (2019) conducted a qualitative examination of the ground water quality of the Yazd aquifer in Iran. Using the Schuler and Wilcox criteria in a GIS setting, qualitative features were derived at a few different sites. Next, using IDW and Kriging techniques, it was interpolated for the full area and compared. The results demonstrated that while assessing the quality of ground water, the IDW model outperformed the kriging model.

An effective solar PV water pumping system for banana irrigation was designed and analyzed by Narale et al. (2013). The method was ultimately designed by the author using the plant's peak water need, FAO crop coefficient values, and the average monthly pan evaporation rate.

A thorough analysis of the many methods used by the scientific community to map ground water and determine agricultural water requirements is provided below.

Table 1: Comprehensive Literature review

S.no.	Thesis	Purpose	Methodology	Findings
1	A real time weather forecasting and analysis. (Kothapalli and Totad, 2017)	Time series analysis was done using various model in R language for future weather forecast	Climatic data were collected from meteorological office and it was analyzed in R language	Of the various methods like ARIMA, Multiple Linear Regression, Artificial Neural Network, Arima model was better in predicting forthcoming datas.
2	ARIMA based daily weather forecasting tool: A case study for Varanasi (Shivhare et al., 2019)	ARIMA based daily weather forecasting for Varanasi	60 years of climatic data were collected from meteorology office and analyzed using ARIMA model in R Language	RMSE values was 0.094 so the error is minimal. More than 90% of the value predicted by ARIMA was accurate.
3	Impacts of climate change on irrigation water requirement for rice- wheat cultivation in Bagmati river basin, Nepal. (Shrestha, 2013)	Highlights the spatial and temporal impacts of climate change on Irrigation water requirement (IWR)	GCM outputs is applied to Various SRES Scenarios to forecast future climatic conditions and used in Cropwat	Climatic Change impact will be consistent in all stages of crop growth. In mid hills, IWR has decreasing trend whereas in terai, increasing trend.

4	Assessment of climate change impact on crop yield and irrigation water requirement of two cereal crops (rice and wheat) in Bhaktapur district, Nepal. (Shrestha and Shrestha, 2017)	Studied climate change impact on yield and irrigation water requirement of cereal crops	Future climate projection data were derived using PRECIS model simulation and used in Aquacrop to estimate the irrigation water requirement	Crop yield was mainly constraint by water scarcity and proper water management should be emphasized.
5	Estimation of crop water requirement for Jabalpur, India. (Chakravarti et al., 2022)	Estimated crop water requirement using manual calculations	Climatic datas were obtained from relevant meteorological office and modified Penman Equation was used for calculation	Effective water management was needed for maximizing crop yield. Wheat had the highest water requirement in the area.
6	Estimation of ground water depth using ANN-PSO, kriging and IDW methods (Case study: Salman Farsi Sugarcane plantation, Iran. (Shahraki, 2021)	Simulate ground water depth using IDW, Kriging and neural network in Salman Farsi Industry	160 observation wells were constructed and ground water data were collected for 2-year period and the data were fetched into various models for interpolation	Highest accuracy was related to ANN model. Among IDW and kriging, the accuracy of kriging model was higher than IDW model.

7	Selecting proper method for ground water interpolation based on spatial correlation. (Jie et al., 2013)	To analyze the various interpolation method in ArcGIS, compare them and recommend the method yield better result	90 samples were collected from monitoring wells in Yinchuan Area, China and water level, salinity and nitrate were analyzed.	The results showed that kriging method is a reliable method for interpolation.
8	Spatial Distribution of Ground water quality with geostatics. (Mehrjardi et al., 2008)	IDW, Kriging and cokriging methods were used for the prediction of distribution of ground water quality	Data were related to 73 wells in Ardakan-Yazd plain, Iran and fetched into GIS system for interpolation	Based on RMSE, the best method was selected. The results reveals that kriging and cokriging methods performed better against IDW method.
9	Comparison of deterministic and stochastic method to predict spatial variation of ground water depth. (Adhikary and Dash, 2014)	Performance of IDW, Ordinary Kriging (OK), Universal Kriging (UK) were analyzed to recommend the best method	Pre and post monsoon ground water level data for year 2006 was taken from 110 different location over Delhi and used in GIS for interpolation	Analysis revealed that Ordinary Kriging (OK) and Universal Kriging (UK) outperformed the IDW method and UK method was better than OK method.
10	Research and current status of the solar photovoltaic water pumping system: A review. (Li et al., 2017)	Provides a broader outlook on Solar PV Pumping system	Literature Reviews	It was concluded that the combined effect of wind and solar energy is an optimimal solution to meet high demand of water for irrigation.

11	Design and sizing of stand-alone solar power system a house Iraq (Al-Shamani, 2015)	Proposes an economical method of sizing the various component of solar PV system	A case study was done on a residence of Iraq	It was concluded that a case study residence, it was found that is cheaper than the conventional fuel-based energy system.
12	Photovoltaic water pumping system for irrigation (Haque, 2001)	The author proposed a method of sizing the solar PV component and compared it with diesel-based system.	The PV system sizing and diesel system sizing was done and then life cycle cost analysis was made for comparison	It has been shown that the pv system for irrigation is more feasible in Bangladesh.
13	Design and analysis of solar structural and mounting for solar panels (Panjawani, 2020)	The author proposed an economical and stable design using ANSYS and CFD softwares.	The author uses the dead load, live and windload according to IS 873: 2015 for the analysis.	About 9-15% of total cost of solar panel is into the frame. With analysis, it determined most stable and economical section for the use.

Chapter 3: Materials and Methods

3.1 General Description of the study area

The Narainapur rural municipality, which is in the Banke district of Lumbini Province, Nepal, with coordinates of 27.93oN 81.66fE, is included in the research area. It touches the Indian state of Uttar Pradesh and spans an area of 172.34 km² with 6 VDCs. The approximate population of the region is 34,942. The terrain is thought to be 141 meters above sea level. The terrain of the region is plain in the south and undulating in the north, starting at the Chure Hill Range.

Basic services and transportation were hindered by a ten-year war. The NEA study states that Narainapur's electricity rate is just 9.71%, illustrating the degree of inequality the locals have had to deal with up to this point. Their primary sources of income include seasonal employment, cattle, and agriculture. The majority of people in the area are employed in agriculture, with the other two sectors coming in second.

Geologically, the area is divided into three soil types: calcareous fluviols, eurythraean gleysols, and calcareous phaeozozems; the higher section is made up of dystric regosols. The area's lithological formation is mostly made up of recent formation, with a little amount of upper and lower Siwalik formation in the higher part.

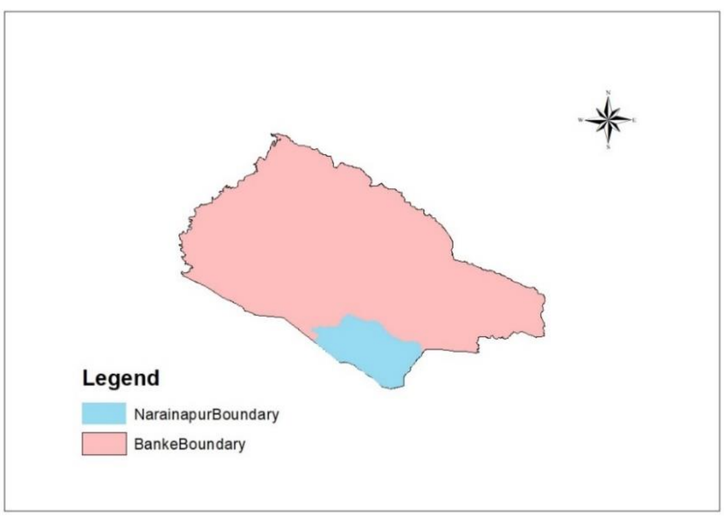


Fig 3: Narainapur Municipality in Banke District

3.2 Data Collection

Various data set that are used in this study calculating the crop water requirement as well as ground water level map of the study area. These data include the meteorological datas, soil characteristics data and the ground water datas. The following table tabulates these datas, the range within which these datas are taken, the datas sources and the results that are intended to be produced using these datas.

Table 2: Climatic datas, their sources and its use

S.No.	Data	Range	Data Source	Derivation
1	Rainfall Min Temperature Max Temperature Humidity Wind Velocity Sunshine Hours	2001-2021	Department of Hydrology and Meteorology	Irrigation water requirement (IWR)
2	Soil Characteristics	-	National Agriculture Research Centre (NARC)	Input values for Cropwat
2	Ground water datas	2001-2021	GW-Nepal	Ground water level map

Classification of rainfall

On the annual basis, the rainfall years were classified as:

(i) Normal year (± 25% departure of rainfall from long term mean)

(ii) Wet year (> + 25%) and

(iii) Dry year (<-25%)

The whole year is divided into 4 seasons i.e., monsoon season (June to September), Post monsoon season (October to November), Winter Season (December to February) and Pre-monsoon season (March to May). Likewise, the year is also divided as Rice season (June to October), Wheat season (November to March) and pre-monsoon/dry season (April to May).

3.3 Methodology

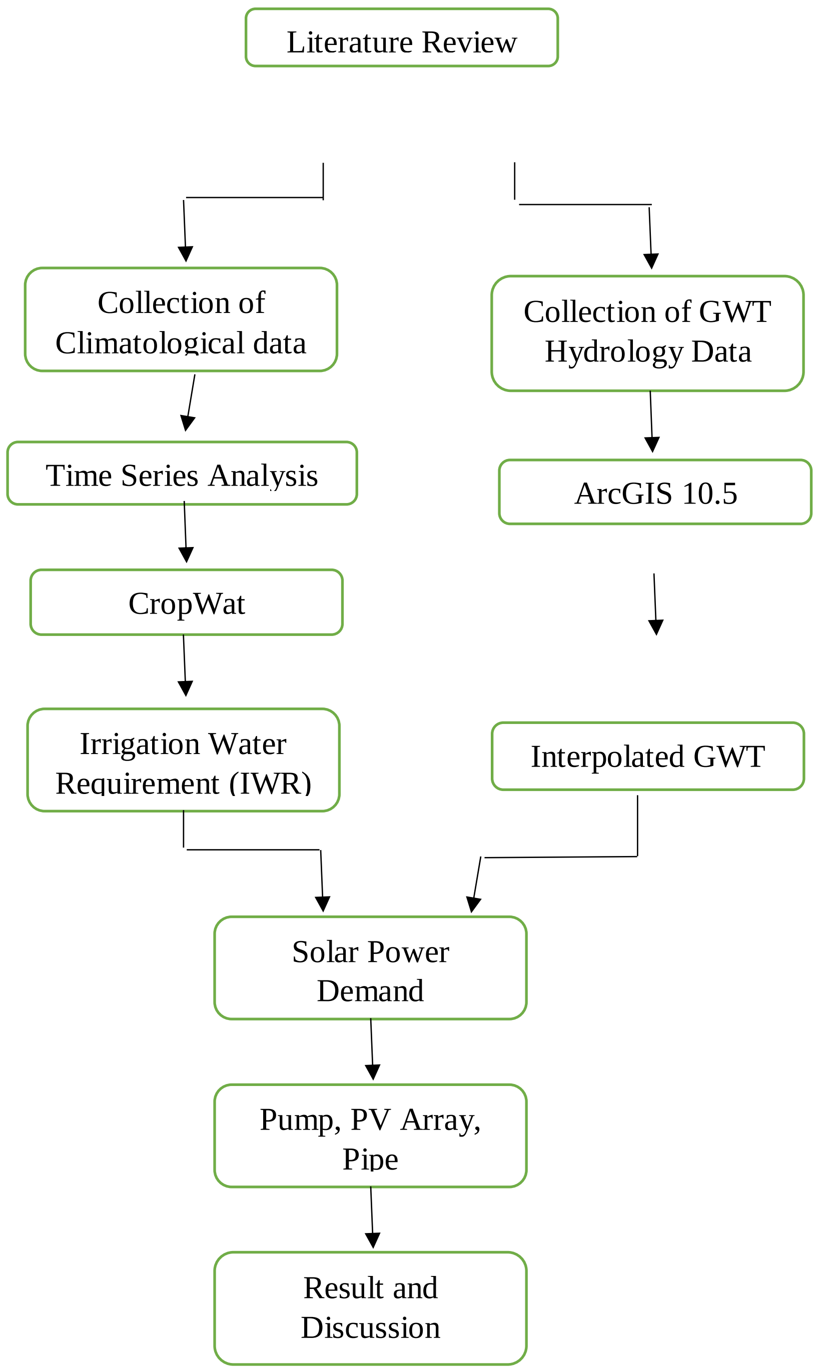


Fig 4: Methodology Flow Chart

3.4 Crop Water Requirement (CWR) estimation using CROPWAT

Important climatological data are often used to calculate potential evaporation (PE), which allows agricultural water requirements to be estimated. Under the current agro-climatic conditions of any research region, it is calculated using the modified Penman equation, which is thought to be the optimum method for using climate data for evaporative value assessment (Bhattacharya et al., 1996). Although a large amount of water is lost to evaporation in Nepal's greater than average rate of rainfall, many crops in the country still need irrigation. Crop productivity will ultimately be impacted by the increased demand for water brought on by an increase in ETo. By using the estimated technique, which multiplies the crop coefficient (Kc) by the ETo value to get the crop's water need, the required amount of water may be determined.

Using the Penman-Monteith equation, CROPWAT determines the potential evapotranspiration. In the Penman-Monteith equation, the primary factors influencing the potential evapotranspiration rate are temperature, wind speed, humidity, solar radiation, and ambient temperature. Given that the current global water situation makes it imperative to choose wisely when using water, the most practical means of enhancing agriculture seems to be via the implementation of tactical, contemporary irrigation systems and enhanced water management practices. To accurately design and schedule irrigation systems, the FAO created a window-based model called CROPWAT to evaluate ETo, or reference evapotranspiration. The only formula used in this application to calculate ETo is the FAO's Penman-Monteith Equation, which will also be helpful in increasing agricultural productivity.

3.4.1 Climatological Data

The data included are the monthly rainfall, temperature (maximum and minimum), relative humidity, wind velocity, evaporation and sunshine hours. These datas can be obtained from the relevant meteorology department within the region. Department of Hydrology and Meteorology (DHM) is the chief body concerned with the climate data in Nepal. The datas can also be obtained from regional agricultural research station within the country. These can be further used for planning and management of crop cultivation. For the study, the datas were obtained from DHM from 1981 to 2021 AD. These datas helps in generating the reference crop evapotranspiration (ETc) which illustrates the evaporative power of the surrounding. This entity reflects the standardized vegetated surface evapotranspiration.

3.4.2 Effective Rainfall

It is the primary way for the fulfillment of crop water requirement in the region. At the study area, the rainfall occurs due to monsoon from June to September. The rain gauge is not available in the study area; therefore, the nearest gauge station is taken for the study which is present in Nepalgunj Regional Airport. The datas required are obtained from DHM.

High intensity rainfall or larger amount which produces runoff are not useful for the crop. Similarly, rainfall on an already saturated soil is lost through deep percolation. Small amounts of rainfall which only wet the plant canopy are sometimes referred to as ineffective. However, they may contribute to the satisfaction of the evaporation demand. So, a concept of effective rainfall is utilized in the calculation. Effective Rainfall (P-eff) is that proportion of rainfall that is utilized to fulfill the water requirement of the crop.

Cropwat model uses four inbuilt empirical equations that estimates effective rainfall for irrigation system planning and design. These methods include: Fixed rainfall, empirical formula, Dependable rainfall and USDA Soil conservation service method. According to the analysis made by Bokke et al, USDA SC method is found useful in case of water scarce area and dependable rain method is suitable in water sufficient areas like Nepal. The determination method for rain used in the software must be tested using soil-water balance method before choosing any particular approach to be used in irrigation planning and design. If testing is not approachable during the study, the author recommends to use dependable rain method where rainfall occurs more or less sufficiently in the area whereas USDA-SC method in location where there is water scarcity for estimating the effective rainfall. This helps being secure from shortage of water that can cause yield reduction.

For our study, dependable rain method of calculation of effective rainfall inbuilt in Cropwat is used as the area is not a water scarce region.

3.4.3 Crop Coefficient

The evapotranspiration, or the water requirement of a specific crop (ET crop) mainly depends upon the climate which is the most important factor for the amount of water loss by evapotranspiration from the crop. It is the multiplication of the crop coefficient (K_c) and the reference crop evapotranspiration (ET_o).

$ET_{crop} = K_c \text{ x } ET_o$

ET_{crop} is estimated using the above equation. The following table gives the crop coefficient for several crops for the different growing stages including the final coefficient at harvest time.

Table 3: Crop Coefficient (K_c) for different crop at various development stage

Crop	Initial	Development	Mid-Season	Late Season	At Harvest
Paddy Rice	1.10-1.15	1.10-1.50	1.10-1.30	0.95-1.05	0.95-1.05
Wheat	0.30-0.40	0.70-0.80	1.05-1.20	0.65-0.75	0.20-0.25
Maize	0.30-0.50	0.70-0.85	1.05-1.20	0.80-0.95	0.55-0.60
Tomato	0.40-0.50	0.70-0.80	1.05-1.25	0.80-0.95	0.60-0.65
Cabbage	0.40-0.50	0.70-0.80	0.95-1.10	0.90-1.00	0.80-0.95
Groundnut	0.40-0.50	0.70-0.80	0.95-1.10	0.75-0.85	0.55-0.60
Pea	0.30-0.40	0.60-0.75	0.95-1.10	0.85-1.00	0.80-0.90
Sugarcane	0.40-0.50	0.70-1.00	1.00-1.30	0.75-0.80	0.50-0.60
Tobacco	0.30-0.40	0.70-0.80	1.00-1.20	0.90-1.00	0.75-0.85
Watermelon	0.40-0.50	0.70-0.80	0.95-1.05	0.80-0.90	0.65-0.75

Source: Manual for survey, design and construction of small hill irrigation systems in Nepal, Feb 1992 by (HADP and ITECO au company for international technical co-operative and development CH-8910 Affoltern a/A, Switzerland).

Values of Kc differ with crops, the growing period and the stages of growth. Four growth stages are generally distinguished, initial, development, mid-season, and late season. The values rise during the development stage and reaches a peak at mid-season stage and decline in the ripening period towards the late-season. The various crop development stages are described as follows:

- Initial Stage: This stage is from germination to early growth when the soil surface is not or only barely covered by the crop (cover <%).
- Development Stage: This stage is from the end of initial stage to the attainment of effective full ground cover (70-80%)
- Mid-season Stage: The stage is from the attainment of effective full groundcover to the start of maturing as indicated by discoloring of leaves and leaves falling off.
- Late-season Stage: This stage is from the end of the mid-season stage to until full maturity and harvest time.

The major crop cultivated in Narainapur is Paddy Rice and Wheat. Historically, it has contributed a significant proportion of rice to the overall district proportion.

3.4.4 Soil Moisture Datas

Soil moisture is the moisture held in the pore spaces of the soil mass and lying near the surface and within the crop root zone. It is also known as soil water. It is expressed in centimeter of water per given depth of soil. Soil moisture is available for transportation of nutrients by the plants and related physiological processes as well as direct evaporation to the atmosphere. Excess soil water percolates down to the deeper layers and join the ground water and finally to the stream.

Field capacity is the moisture content of a soil retained in the soil when gravitational water and free drainage has ceased. It is usually 24 to 36 hours after flooding (Michael and Ojha, 2006). It is also known as water holding capacity of soil or capillary capacity. The max quantity of water which the soil can hold against the gravitational force is called the field capacity. Any higher moisture input to a soil at field capacity simply drains away.

When the precipitation of a location is less than the potential evapotranspiration (PE) there occurs moisture deficiency in the soil. The plant continues to grow utilizing the available water. However, the plant starts to wilt when the soil gets drier. The difference between the field capacity of soil and the water content at the permanent wilting point is of prime importance as the irrigation system are supposed to fill the water content getting below the wilting point to the soils field capacity. The following table represents the soil texture and the corresponding available water

Table 4: Soil Texture and their corresponding available water (Khan at al., 2021)

S.no.	**Soil Texture**	**Available Water (AW) mm/m**
1	Coarse Sands	20-85
2	Fine Sands	60-85
3	Loam	100-175
4	Sandy Loams	90-130
5	Fine Sandy Loams	100-170
6	Loamy Sands	65-110
7	Silty Clay Loam	130-160
8	Silty Clay	125-170
9	Silty Loams	150-230
10	Clay	110-150
11	Peats and Mucks	160-240

Similarly, when the soil is dry, it goes on absorbing the precipitation or irrigation water. When there is excess rainfall, the surplus water finds its way into the stream either directly or as surface runoff or indirectly as infiltration. The infiltration water recharges the soil and joins the ground water table. The rate at which it enters into the soil is the infiltration rate and it varies according to the types of soil. the following table represents the type of soil and their basin infiltration rates.

Table 5: Basic Infiltration Rates for Various Soil Types (Khan at al., 2021)

S.no.	**Soil Type**	**Basic Infiltration rate (mm/hr)**
1	Sand	<30
2	Sandy Loam	20-30
3	Loam	10-20
4	Clay Loam	5-10

5	Clay	1-5

3.4.5 Irrigation Schedule

To determine accurate an irrigation schedule, it takes a lot of time and is complicated. This has been made easier using the computer programs and it is now possible to schedule the irrigation water supply just exactly in accordance to the water needs of the crops. Ideally, at the very start of the growing season, the amount of water given per application is low and frequent. It is due to low evapotranspiration of the young plants and their small root depth.

It deals with two primitive questions. These are (i) How much one has to irrigate and (ii) How often one has to irrigate. They are the dependent upon water needs of the crop. These in turn depends upon the type of crop grown in the region. It is partly fulfilled by the precipitation whereas the remaining is fulfilled by irrigation. In several cases irrigation scheduling is executed out based on the farmers's own experience, how a plant looks, watching the neighbor or just easily irrigating when water is available .

The number of days between two successive irrigations is called the irrigation interval. It relies upon several factors such as the effective rainfall, crop evapotranspiration, and the soil's water holding capacity in its root zone as well as management of allowable depletion.

Over the years, Many approaches have been developed for irrigation scheduling. Soil indicator method includes methods such as feeling and physical appearance of soil moisture. It is one of the oldest yet simple method of determining approximately whether the soil contain needed amount of moisture content. It can be done by visually observing and feeling the soil by our hand. The accuracy of judgement improves with experience. Another method is plant indices approach where it is believed that the plant readily responds to the water deficiency. It is used to schedule irrigation based on the plant responses.

3.4.6 Crop Evapotranspiration

Crop water requirements can be estimated by knowing evapotranspiration. It is the evapotranspiration from the ground surface and evaporation from plant surface. When the growth is not inhibited by water shortage, the evapotranspiration is called potential evapotranspiration (PE) which can be calculated by four prediction formula. They are:

(i) Adaptation of the Blaney-Criddle Method (ii) The radiation method

(iii) The Pan evaporation method (iv) The Penman Method

The study uses the penman method which is considered to be the best alternative referring to several research paper. It can be calculated by equation (1) as provided. For determining the reference evapotranspiration, the cropwat model is used (ETo) as it can give a fairly accurate result on actual water use which is calculated extensively worldwide owing to its reliability. To ensure efficient scheduling of irrigation water management, canal capacitiy designs, water resources planning, water course drainage, accurate crop water requirement are crucial. Farmers and field workers who practices agriculture and produces most of the crops also are unaware about all the required information on crop water and irrigation requirements. This research is thus an attempt to calculate the crop water needs of the main crops grown in the study area using the FAO CROPWAT model.

3.5 Time series analysis

Time series analysis is a special method of assessing a collection of data points that are gathered over time. Instead of simply or randomly capturing the data points, the analysis records the data points at regular intervals over a predetermined amount of time. The results of the study might show how variables vary over time. Time is a crucial component since it may show how the data harmonizes both at the end and throughout the data points. This analysis provides a predetermined sequence of dependencies between the data and an extra source of information. A large number of data points are usually needed to ensure the result's consistency and dependability. A large database guarantees a representative sample size that is excellent. It can also account for seasonal volatility and guarantees that any trends or patterns seen are not anomalies. Time series data may also be used to estimate or anticipate future data by using historical data.

Understanding the fundamental reasons behind trends or systemic patterns throughout time is aided by time series analysis. Business users may discover seasonal patterns and learn more about the reasons behind these trends by using data visualizations. These visualizations may be much more than just line graphs according to contemporary analytics technologies. A component of predictive analytics is time series forecasting. It may demonstrate expected variations in the data, such as seasonality or cyclical activity, which improves comprehension of the data variables and aids in more accurate forecasting.

3.5.1 Non seasonal method

Non seasonal method are simple classic forecasting method which does not take into account any repetitive pattern or sequence

Single moving average: By averaging the last several periods and projecting the last average value forward, it smoothens out the past datas. Volatile data with no trend or seasonality is the best suited data for this method. It results in a straight, flat-line forecast.

Double moving average: It smooths out past previous data by performing a moving average on a subset of data which depicts a moving average of an original set of data. That is, a second moving average is superseded on the first moving average. The second moving average application captures the trending effect of the data. The results are then weighted and forecasts are created.

Single exponential smoothing: A time series method for forecasting univariate time series data is the exponential smoothing. Time series methods is based on the principle that a prediction is a weighted linear sum of previous observations or lags. It works by assigning exponentially decreasing weights for past observations. Because the weight assigned to each demand observation is exponentially reduced, it is called what it is called so. It is a broadly accurate forecasting method reliable for short-term forecasts. Larger weights are assigned to more recent observations but as the observations get increasingly distant, exponentially reducing weights are assigned. This method is not reliable for long-term forecasts.

Double exponential smoothing: A variation on a indicator which is utilized to locate a potential rising trend or falling trend in the price of a stock or other asset is called the double exponential moving average (DEMA). Primarily it was used to find an upward or downward trend in costs and evaluate its strength. Marketers seeks for a price to move higher or lower than the DEMA. Few utilize multiple DEMAs with various lookback periods, seeking for the DEMAs to cross each other.

3.5.2 Seasonal method

Seasonality in a time series is defined as a regular pattern of changes that repeats over S time periods, where S is the number of time periods before the pattern occurs again. For example, monthly data exhibits seasonality, with greater values often occurring in some months and lower values typically occurring in other specific months. Seasonal approaches enhance the non-seasonal forecasting method by adding an extra component to reflect the seasonal nature of the data.

Seasonal supplement: This approach calculates a seasonal index for historical data that does not show a pattern. It generates numbers for the forecast's level and seasonal adjustment that are exponentially smoothed. The seasonal additive forecast is created by adding the seasonal adjustment to the level that was projected. Every time a certain season is experienced, additive seasonal effects usually occur on the same scale of magnitude. For data without a trend but with seasonality that does not increase with time, this approach works well. The outcome is a curved prediction that replicates the data's seasonal variations.

Seasonal multiplicative: A seasonal index is computed using historical data from the past that does not show any trends. This approach produces an exponentially smoothed number for the prediction's level and a seasonal adjustment to the forecast. A seasonal multiplicative forecast is produced by multiplying the seasonal adjustment by the amount that is anticipated. Every time a certain season occurs, multiplicative seasonal impacts often have an increasing effect. This approach works well with data that has seasonality, which increases or decreases over time, but does not have a pattern. This leads to the generation of a curved forecast that replicates the seasonal variations in the data.

Holt-winters additive: This technique, which is a variation of Holt's exponential smoothing, captures the seasonality of the data. This approach produces an exponentially smoothed values for a predicted level, forecast trend, and the seasonal adjustment for the forecast. The Holt-Winters additive forecast is ultimately produced by adding the seasonality element to the trended forecast using the seasonal additive technique. When dealing with data sets where the trend and seasonality do not grow with time, this strategy works well. The outcome is a curved prediction that illustrates the seasonal variations in the data.

The multiplicative Holt-Winters approach is comparable to the additive Holt-Winters method. It is also possible to determine the exponentially smoothed values for the forecast's level, trend, and seasonal adjustment using the Holt-Winters multiplicative approach. The Holt-Winters multiplicative forecast is generated by multiplying the trended forecast by the seasonality using the seasonal multiplicative technique. When dealing with data that exhibit trend and increasing seasonality over time, this strategy is perfect. This approach produces a curved prediction that replicates the seasonal variations in the data.

3.5.3 ARIMA

A statistical analysis model which utilizes time series data to either comprehensively understand the data set or to estimate trends in the forthcoming period is called an autoregressive integrated moving average, or ARIMA. If a statistical model predicts future values based on past values, it is called autoregressive. For instance, an ARIMA model might seeks to predict market prices of guitar company based on its past performance in the market or forecast a stock's prices based on its past records. An ARIMA model can be understood by outlining each of its elements explained as below:

Autoregression (AR): refers to a model that illustrates a changing variable that regresses on its own lagged, or prior, values.

Integrated (I): indicates the differencing of raw measurements to permit the time series to become stationary (i.e., data values are superseded by the difference value between the data values and the previous values).

Moving average (MA): includes the dependency between an observation and a residual uncertainty from a moving average model enforced to lagged observations.

Each element in ARIMA acts as a parameter which has a standard notation. A standard notation would be ARIMA with p, d, and q, where integer values replaces the parameters to identify the type of ARIMA model being used. These parameters are as described below:

p: Model’s lag observations, also known as the lag order.

d: how many times the raw observations are differenced; also called the degree of differencing.

q: the order of the moving average.

3.5.4 Multi linear regression: For explaining the relationships between variables by a best fit line in the observed data, regression models are used. Regression permits the users to predict how a dependent variable change as the independent variable(s) change. Multiple linear regressions are used for estimating the correlations between 2 or more independent variables and 1 dependent variable. This method uses many explanatory variables to predict the outcome of a response variable.

A dependent variable is scarcely described by only one variable. In those cases, an analyst prefers multiple regression method, which tries to describe a dependent variable by using more than 1 independent variable. The model, however, supposes that no major correlations between those independent variables is available.

Multiple regression also allows you The determination of the best fit (variance explained) model and the relative contribution of each one of the predictors to the total variance explained by the multiple regression function. For example, One might need to ascertain how much percentage of the variation in a test can be explained by revision time, stess and anxiety before the exam, total attendance in that class and sex "as a whole", but along with it also the "relative contribution" of all those variable which are not dependent on each other to explain the variance.

3.5.5 Oracle crystal ball

Oracle Crystal Ball is the popular spreadsheet-based software which is used for (i) predictive modeling, (ii) forecasting, (iii) simulation, and (iv) optimization, that gives unique insight into the all the significant elements which are affecting the risk. With Crystal Ball, Many of the tactical decisions can be taken safely with this software to obtain the required objectives.

The process of simulation process is complex and entails heaps of work but, fortunately, the spreadsheet can aids the user to do most of the work quickly and with a fair ease. Specifically, the software comes as an add-in package that helps make simulation in spreadsheet a straightforward process. The Crystal Ball add-in gives the following capabilities, which are not otherwise unknown numbers required in simulation; additional commands that are user friendly in setting up and running the simulation process; and graphical and statistical summaries of the results.

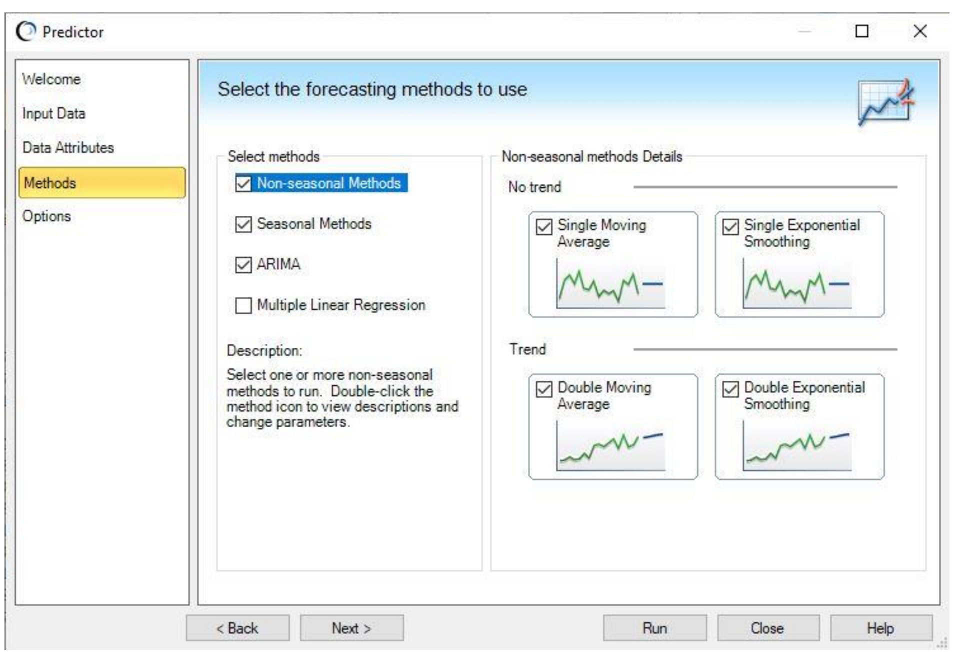


Fig 5: Oracle’s CB Predictor Interface

The climatic data which is obtained from any meteorological department can be fetched into an excel sheet. After that crystal ball is used and the dialog box appears as above. Then the values or the data in which one is interested in can be selected. The software automatically detects where it is a stationary or has a seasonality or not. Its analysis assigns the most fitting method of forecasting along with the accuracy with which it is predicting. For the study, oracle’s crystal ball was used.

3.6 Ground Water Level Map

The ground water level map can be prepared using GIS, commonly Esri’s ArcMap. The spatial interpolation methods which can be applied for the preparation of such map is available in the ArcGis’s spatial analyst tool. The method is a mathematical function which make the prediction of the values at places where there is no measured values. This interpolation supposes that the attribute data are continuous over space and through this assumption, the estimation of the values at any requisite location confined in the data boundary can be allowed. Similarly, another assumption in the method is that the attribute is spatially dependent, meaning the values which are near are more likely to be similar than those attribute which are farther apart. The goal of any spatial interpolations is to produce a surface that is supposed to ideally appear for empirical reality. Thus the method selected must be evaluated for accuracy (Azpurwa, 2010).

Interpolation method confines into two categories, which are: deterministic method and geostatistical method. Most commonly used methods for interpolation are IDW and Kriging method for deterministic and geostatistical method respectively for interpolation.

(i) Deterministic interpolation methods create surfaces from the measured points, Based on either the extent of similarity or the degree of smoothing, the deterministic methods of interpolation forms surfaces from the sampled or measured points. For instance, inverse distance weighing (IDW), radial basis functions as well as the splines function in the spatial analyst tool in Arc GIS. The IDW is built on the supposition that the attribute value of points which are not sampled is the weighted average of values of the sampled points in the neighborhood regions. Those measured values which are more or less close towards the unmeasured location will have more effect on the predicted values than those measured points which are farther away. Thus, IDW method supposes that each known point has a local influence that reduces with increase in the distance. It weights the point which are closer to the prediction place higher than the ones which are at a distance. It can be described mathematically by presuming z (x0) as the interpolated or predicted value, n which will represents the total number of sampled or known data values, xi is the ith data value, hij indicates the distance separated between predicted value and the sampled data value, and b denotes the weighting power:

$$z(x_0) = \frac{\sum_{i=1}^{n} \frac{x_i}{h_{ij}^{\beta}}}{\sum_{i=1}^{n} \frac{1}{h_{ij}^{\beta}}} \quad (1)$$

The selection of the weighting power can critically influence the quality of estimation. The ideal weighting power relies on the data's spatial structure and is affected by the skewness, of variation coefficient (CV), and data's kurtosis (Gotway et al., 1996: Mueller et al., 2001).

(ii) The spatial patterns and interpolation of the value of primary variable at unmeasured locations and quantification of the uncertainty or error of estimated surface can be easily described by the geostatistical methods of interpolation such as kriging method. This method, a geostatistical interpolation method, has been proven to be adequately functional and has gained popularity in many engineering fields. It has both the capacity of producing a predicted spatial surface, but also give some measures of the certainty or accuracy of that very prediction. It also tries to express trends which is suggested in the given set of data. Furthermore, Kriging has several types of different underlying assumptions which are suitable for different types of datas

- Ordinary kriging (OK) is a linear weighted-average appraoch, unbiased to expected errors or uncertainity values. It has extensive application for obtaining the linear unbiased approximation of a stationary random field with an unknown constant mean and expressed as follows:

$$\hat{Z}(x_0) = \sum_{i=1}^{n} \lambda_i Z(x_i) \quad (2)$$

Where, the 1st term is kriging estimate at place x_o, Z (x_i) is the sampled value at place x_i and the remained coefficient is the weight factor associated with Z (x_i).

- Universal Kringing (UK) assumes the model

$$\hat{Z}(x_0) = \mu(x_0) + \varepsilon(x_0) \quad (3)$$

Where, Z (X_o) is the variable interest, μ (x_o) is some deterministic function and ε (x_o) is random variation called microscale variation.

For ground water table underground depth, the going process of interpolation has become one of the two catagories i.e. either it has been deterministic, such as IDW and radial basis function (RBF) or it has been stochastic, like ordinary kriging and universal kriging (UK) (Adhikary et. al., 2017)

3.7 Peak Photovoltaic Solar Power Requirement

In order to initiate a pumping system for the drip irrigation of an olive tree plantation in Spain, Cuadros (2003) proposed a method for estimating the necessary size of a PV system installation. There were three key phases in the method: (i) The estate's irrigation needs are determined by taking into account the local climate and soil characteristics of that particular location in Spain. (ii) The hydraulic evaluation of the pumping system was conducted in accordance with the depth of the aquifer's location and the height necessary to maintain pressure equilibrium in the water distribution network. (iii) The actual yield of the photovoltaic pump system was taken into consideration when calculating the peak power needed to irrigate a 10-ha subplot. The following pertinent equations were recommended by the author for calculating peak solar photovoltaic power.

The daily hydraulic energy, E_H required to pump a volume Q to a height H, is

$$E_H = \rho g Q H / 3600 \quad (4)$$

In which,

E_H is expressed in Wh/day

Q is the total daily flow of water

g is the acceleration due to gravity

ρ is the density of water (1000 kg/m^3

Now, various factors are taken into account which are given as below,

(i) energy losses that occurs due to friction of the pipe in the irrigation system, R

(ii) The part of the day (in fraction) during which the solar radiation is higher than the threshold at which the linked pump of the system starts working, G_d (>$G_{threshold}$)

(iii) the yield, $\mu_{G,}$ of the photovoltaic generator

(iv) the yield, μ_f , of the AC/DC converter

(v) the yield, μ_{MB}, of the pump

Then the maximum energy input that has to be managed from the photovoltaic generator, E_{el}, will be:

$$E_{el} = (E_H + R) / (G_d (>G_{threshold}) \times \mu_G \times \mu_f \times \mu_{MB}) \qquad (5)$$

About 10% of EH is an acceptable range for optimum R values. According to Lorenzo (1994), the yields in the denominator portion of the equation are as follows: Gd> Gthreshold = 0.95, μG = 0.85, μf = 0.90, and μMB = 0.43. The generator pump's actual yield, μ = 31.26% in this instance, is obtained by multiplying these values.

The solar generator's power, or Pel, is

$$P_{el} = E_{el} / h \qquad (6)$$

Where,

The effective or functional number of hours of sunlight per day (h) is the number of hours per day over a threshold radiation intensity of one thousand W/m2. Eel is the needed electrical energy (kWh). It is equivalent in numbers to the average daily energy density (in kWh/m2) at the research location. Lastly, power losses (about 10% of the Pel) that arise when the panels operate beyond the usual 25 °C might be considered. Peak photovoltaic power, or P (kWp), that is needed is going to be:

$$P = P_{el}\,(1+0.1) \qquad (7)$$

El-Shimy, 2012 and Ibrahim et al, suggested similar formulas except few minor differences. Kelly, 2010 suggested an equation for calculating the required area for solar panel area, A_s which is given as

$$A_s = P_p / (I_p \times \eta_{sa}) \qquad (8)$$

Where,

Pp is the peak power expected for pumping the ground water in Watts

Ip is the avg amount of incidenting solar radiation on the panel during the peak sunshine hours within the daytime.

η_{sa} is the of the solar array and its electronics efficiency.

3.8 System sizing of Solar powered pumping system

The conventional irrigation method used in Banke often involves lifting groundwater and delivering it straight to the agricultural fields. When surface water is available, it is sometimes also used for irrigation. Diesel engines drive the extraction pumps in both scenarios. Nepal's national economy is impacted by the increasing amount of petroleum oil it imports from India each year. However, it also causes significant noise and air pollution. A solar pumping system uses replacement parts and is environmentally beneficial. Solar system sizing is carried out to support the power need after the amount of solar electricity needed to drive the motor has been determined.

3.8.1 Size of System

The conventional irrigation method used in Banke often involves lifting groundwater and delivering it straight to the agricultural fields. When surface water is available, it is sometimes also used for irrigation. Diesel engines drive the extraction pumps in both scenarios. Nepal's national economy is impacted by the increasing amount of petroleum oil it imports from India each year. However, it also causes significant noise and air pollution. A solar pumping system uses replacement parts and is environmentally beneficial. Solar system sizing is carried out to support the power need after the amount of solar electricity needed to drive the motor has been determined.

3.8.1 System Sizing

System sizing is the process of determining each photovoltaic system component's appropriate voltage and current ratings in order to match the facility's electric demand. It also involves calculating the overall cost of the system, including labor and shipping, from the design phase through to full operation. Avoiding oversizing and undersizing is necessary to provide a system design that is adequate, dependable, and inexpensive.

3.8.1.1 Residence Device: To determine the average energy demand in Watt-hour per day, the first step is to identify the electrical equipment that are used at the user's house, including their power rating and amount of usage throughout a 24-hour period.

3.8.1.2 Sizing of the solar array: Before sizing, it is necessary to determine the total daily energy in watt hours (E), the average solar hour/day, and the DC voltage (VDC) of the arrangement. After obtaining these variables, the procedure may proceed to the sizing. The system's electrical losses, which must be taken into account to avoid under sizing, may be calculated by dividing the daily power requirement in Wh by the sum of the system's component efficiencies to get the necessary energy Er.

To avoid under-sizing, the process must begin by dividing the total average energy demand per day by the efficiencies of the all attached system components to get the daily energy requirement from the solar array:

E_r = Daily average energy consumption / Product of component efficiencies . . . . (9)

To obtain the peak power, the previous result is divided by the sun hours per day (Mean) for the place where it is designated to be installed Tmin.

Peak Power (Pp) = Daily energy requirement / (Min Peak sun-hours per day) . . . . (10)

The total current expected can be calculated by dividing the peak power by the DC – Voltage of the system.

I_{dc} = Peak power / System DC Voltage . . . . (11)

All the solar modules must be linked in series and parallel according to the requirement to meet the desired voltage and current. Firstly, the number of parallel modules which equals the entire solar modules current divided by the rated current of one module I_r.

N_p = Whole module current / Rated current of one module = I_{dc} / I_r . . . . (12)

Second, the number of series modules which equals the DC voltage of the system divided by the ated voltage of each module Vr

N_s = System DC Voltage / Module rated voltage = V_{dc} / V_r . . . . (13)

Eventually, the total number of modules Nm equals the series modules multiplied by the parallel ones:

$N_m = N_s \times N_p$ . . . . (14)

3.8.1.3 Sizing of battery bank

The required amount of rough energy storage needed is equal to the product of the total power demand and the number of autonomy days without sunhine.

Erough=E×D.

For safety purpose, the solution obtained by the above equation is divided by the maximum allowable depth of discharge (MDOD):

E_{safe} = Energy storage required / Maximum depth of discharge = E_{rough} / MDOD. . . . . . (15)

At this moment, a decision in regards to battery's rated voltage Vb which is to be used in the battery bank. The capacity of the battery bank required in ampere-hours (AH) can be evaluated by dividing the needed or required safe energy storage by the DC voltage of one of the batteries choosen:

$C = E_{safe} / V_b$ . . . . (16)

According to the number obtained for the battery bank capacity, another step should be taken in regards to the capacity Cb of each of the batteries in the bank. The battery bank is composed of batteries. The total number of batteries is deduced by dividing the capacity C of the battery bank in ampere-hours by the capacity of one of the battery Cb choosen in ampere-hours:

$N_{batteries} = C / C_b$ . . . . (17)

The battery bank connection can be then easily figured out. The number of batteries (in series) equals the DC voltage of the system's direct current (DC) voltage divided by the voltage rating of one of the batteries selected:

$N_s = V_{dc} / V_b$ . . . .(18)

Then number of parallel paths Np is determined by the division of the total number of batteries by the number of batteries connected only in series:

$N_p = N_{batteries} / N_s$ . . . . (19)

Once the sizing of the battery bank is made available, the process is proceeded to the next system component.

3.8.1.4 Sizing of the voltage controller

It controls the current flow in the system. A good voltage regulator should be able to withstand the maximum current which is produced by the solar array as well as the generation of maximum load current. Sizing of the voltage regulator can be done by multiplying the current (Short circuit current) of the modules joined in parallel pattern by a safety factor, Fsafe. The result will gives the rated current (I) of the voltage regulator:

I = Isc x Np x Fsafe . . . . (20)

In order to ensure that the regulator can manage the maximum current generated by the array, which may exceed the tabulated amount, the safety factor is used. Additionally, in the event that equipment is added and the load current exceeds the anticipated amount. Stated differently, this safety factor permits a little system expansion. The number of controllers equals the array short current amps divided by the amps for each controller:
N controller = I / Amps each controller . . . .(21)

3.8.1.5 Sizing of the inverter

When sizing of inverter has to be done, the overall power that is drawn from all the electrical appliances which operates at the same time must be found out which is the foremost step. After its calculation an invertor has to be choosen which is reliable for the overall load. An important note has to be taken before choosing an invertor, which is the voltage capacity of the selected invertor should be fifty percent more than the designed voltage on which the system operates. This ensures the invertor does not get damaged.

3.8.1.6 Sizing of the system wiring

Choosing the optimal size and wire type shall definitely enhance the photovoltaic system performance and reliability. It is done as per prescribed guidelines from national electrical code.

3.9 Design and analysis of solar power frame system

A solar pumping system is considered to have 20-25 years of life span expectancy. So it becomes critically important to provide a good and strong structural arrangement which does not deteriorate with passing time and age due to climatic or environmental conditions. The components of the system should be made by adopting a process which is both economical and cost effective along with aesthetic appearance as well.

The solar mounting structure attaches the solar panels to either on the surface of ground or rooftop for applications within residential or commercial sectors. For industrial sheds installations in roofs, several of the variety of frames are used which relies on the fact that whether the solar pv system is attached on pitched or flat roof. Such structures aids the panels to mount comfortably, preventing it from being damaged or being displaced, instead more critically positioning them at required tilt angle to harness maximum sun’s energy as possible. Mounting the solar panels and frame structures can be done for rooftops, terrace of the buildings, ground and sun tracker sensor can be used which are nowadays have seen a lot of developments. There have been many technological benchmarks that have led to decreased cost, quicker and better installation, robust durability and with reliable output.

3.9.1 Finite Element Method

The numerical method which is used to search approximate solutions of partial differential equations is the finite element method (FEM). It originated from the functional requirement of solving various complex elasticity and structural analysis problems in various field of engineering. Finite element method aids in producing stiffness and strength visualizations in a structural analysis simulation. It also supports to reduces the design material mass which leads to reduction in cost of the structures. The method permits for detailed visualization and indications of distribution of all stresses and strains that acts inside and outside the body of any structural system. Several FEM softwares are robust in performing the job but is a sophisticated tool meant for professional engineers which can be learnt with the training and education necessary for interpret the solutions carefully and properly. This powerful design tool has considerably improved in the engineering discipline both the engineering designs standard and the design process methodology in civil, mechanical and aerospace industrial applications. The application of finite element method has significantly reduced the time from conception to the production line of the structural systems. Therefore, One must take the leverage of the incoming of generation of quick structural analysis softwares for the of engineering product analysis and design with required level of accuracy.

3.9.2 Autocad Architecture

AutoCAD is computer-aided design (CAD) software which is extensively used all over the world for clear and precise two dimensional and three-dimensional drafting, design, and modeling. The company has developed which also specifically caters to various industruties such as architecture, plant 3D, MEP, map 3D, electrical & mechanical as well as grid design, makes this software a highly sought after application for architects, engineers and construction professionals etcetera. Autocad 2018 was used for the study to make the plan and elevation of the solar frame that is to be used.

3.9.3 Etabs for solar panel analysis

In this work, a finite element method is used to subdivide the body into tiny, distinct areas. Finite elements is the term used to describe this. Interpolation functions and nodes define these in the structure. A global matrix is formed by combining these finite elements with their corresponding governing equations for each element. Next, this matrix's solution is found by applying the design loads and boundary restrictions. This work has made use of Etabs software, which operates on the finite element theory. This leads to the conclusion that a structure's stability depends on a wide variety of variables, including section characteristics, section configurations, structural modeling, etc.

Multi-story building design analysis is the software's primary purpose. The grid-like geometrical form that is specific to this type of user's structure is coordinated with the modeling tools and templates, load prescriptions based on codes, as well as the analytical and mathematical solution methodologies. The basic or sophisticated systems may be evaluated using ETABS under static or dynamic settings. Modal and explicitly applied time-history studies with Large Displacement and P-Delta effects may be used for a more in-depth assessment of the user's structure's seismic performance.

ETABS, having invested forty years of research and development, provides effective 3D modeling and visualization tools, rapid linear and nonlinear analytical power, easily comprehensible design for a broad range of materials, and highly insightful graphic displays, reports, and schematic drawings that enable users to quickly and easily interpret analysis and design results. The engineering design process is fully integrated with ETABS, starting with the conceptual design and ending with the generation of schematic drawings, which may either be utilized as templates to surface over ETABS objects or be directly turned into ETABS models. In addition, the capacity check for foundation plates and steel connections, as well as the design of composite beams and columns, steel joists, and shear walls, are covered. It is also possible to represent the working models, and the structure itself might display the whole outcome. Complete analytical output reports may be produced, and construction drawings including schedules, details, plans, and cross-sections for steel and concrete buildings are available.

Chapter 4: Results and Discussions

4.1 Crop water requirement

Crop water requirement of two widely used cereal crop; rice and wheat in Narainapur municipality of Banke District was studied Questionnaire survey with few farmers and municipality technical officers was surveyed out to obtain insights on the water and fertilizer management practices.

4.1.1 Climatic Data

Narainapur rural municipality is the least developed administrative region in the Banke district. Unfortunately, the district does not have any rain gauge or any other weather recording instrument. Therefore, the study was conducted by taking the nearest climate gauge station which is present at Nepalgunj Regional Airport. It is manned and automatic type of aeronautical station located at an elevation of 165m from the sea level. The latitude and longitude of the station are 28^{o}6’ N and 81^{o}40’ E. The datas recorded by the station were taken for a period of 1996 to 2021 from department of hydrology and meteorology (DHM). The datas included: Rainfall, Min and Max temperature, wind speed, sunshine hours and relative humidity.

4.1.1.1 Time series analysis

Crystal Ball is one of the most powerful tools for statistical forecasting available for decision making. Crystal Ball’s CB predictor was applied to find the trend of the meteorological datas. The range of data that was available was from 1996 to 2021 which covers 25 years of data for various climatic parameters. This data was used in the analysis and most of the parameters showed that it aligns with the Seasonal-ARIMA model except minimum temperature which fits with seasonal additive method. The root mean-square values or the accuracy of prediction were also shown by the program which is also as tabulated below:

Table 6: Forecasted data for sample year 2040 AD

S.no.	Month	Rainfall (sum)	Min Temp	Max Temp	Humidity	Windspeed	Sun Hours
RMSE		**2.19**	**1.47**	**1.76**	**1.1**	**0.27**	**1.13**
1	**Jan**	127.85	5.77	29.79	34.71	2.42	6.54
2	**Feb**	133.11	8.61	32.74	33.08	2.59	7.02
3	**Mar**	125.93	11.71	36.52	31.47	2.87	7.23
4	**Apr**	133.04	17.95	38.58	30.91	2.89	7.29
5	**May**	221.21	22.22	39.72	29.81	2.74	7.13
6	**Jun**	359.52	24.93	38.64	28.15	2.55	7.03
7	**Jul**	586.22	23.96	35.35	28.65	2.5	6.86
8	**Aug**	443.13	23.54	33.53	28.2	2.44	6.87
9	**Sep**	275.76	21.52	33.56	28.95	2.33	7.01
10	**Oct**	148.64	16.85	33.25	31.61	2.22	7.05
11	**Nov**	104.56	12.5	31.21	28.92	2.23	6.95
12	**Dec**	115.49	6.95	29.94	33.06	2.3	6.8

The model that these climatic parameters fitted on when analyzed in oracle's CB predictor are as provided below:

Rainfall: SARIMA model

Min-Temp: Seasonal additive model

Max-Temp: SARIMA model

Humidity: SARIMA model

Wind: SARIMA model

Sunshine hours: SARIMA model

These forecasted data was then used to find the crop water requirement of Narainapur region of Banke. These data were fetched in the FAO's Cropwat software where, solar radiation and reference evapotranspiration were calculated using the Penman-Monteith equation. The maximum Solar radiation (Rad) was obtained as 22.4 Mj/m^2/day whereas maximum reference evapotranspiration (REt_o) was calculated to be 6.93 mm/day in the month of April (Baisakh). The minimum Rad and REt_o was found to be 11.2 Mj/m^2/day and 1.91 mm/day in the month of January.

Table 7: Reference Evaporation (ETo) 2023 AD

Country: Nepal

Station: Nepalgunj Airport

Altitude: 165m

Lat: 28.10 N Lon: 81.66 E

Month	Min Temp	Max Temp	Humidity	Wind	Sun hours	Rad	Eto
Units	ºC	ºC	%	km/day	hr	MJ/m2/day	mm/day
January	9.3	20.7	85	207	4.4	11.2	1.91
February	10.8	25.2	76	233	7.1	16.1	3.11
March	15.3	32.0	65	268	8.4	20.2	5.12
April	19.9	36.7	54	277	8.7	22.4	6.93
May	23.6	36.2	64	251	7.8	21.7	6.27
June	26.2	35.9	73	225	7.2	20.9	5.65
July	26.7	34.1	82	225	6.1	19.1	4.77
August	26.3	33.7	83	216	6.3	18.9	4.59
September	25.4	33.4	82	199	7.1	18.8	4.51
October	20.6	31.4	79	181	7.3	17.0	3.92
November	14.6	28.2	78	181	6.8	14.2	3.11
Decemeber	10.1	24.1	81	190	5.8	12.2	2.38

4.1.2 Effective Rainfall

There are 4 inbuilt methods for the calculation of effective rainfall which are

- Fixed percentage
- Dependable rain (FAO/AGLW formula)
- Empirical Formula
- USDA Soil conservation service

Bokke et al, 2020 suggests to use Dependable rain method in area where water is adequately available and USDASC method in areas where water is scarce while estimating effective rainfall so as to be secure from water shortages that can results yield of yield. Therefore, the dependable rain (FAO/AGLW formula) fits best for the study area as every year on the annual basis it gets good amount of rainfall to saturate the drying soil and infiltrate to the underground aquifer. Using this, the calculation of effective rainfall is done applying the equation below:

$P_{eff} = 0.6 \times P - 10/3$ for $P_{month} <= 70/3$ mm

$P_{eff} = 0.8 \times P - 24/3$ for $P_{month} > 70/3$ mm

The maximum effective rainfall is obtained as 445.0mm in the monsoon month of July. It is followed by August, June and September which comprises the monsoon month where the entire country receives over 90% of its annual rainfall. The Minimum effective rainfall was 59.6mm in the month of November.

Table 8: Effective Rainfall

S.no.	Month	Rain (mm)	Effective Rain (mm)
1	January	127.8	78.2
2	February	133.1	82.5
3	March	126.0	76.8
4	April	133.0	82.4
5	May	221.2	153.0
6	June	359.5	263.6
7	July	586.2	445.0
8	August	443.1	330.5
9	September	275.7	196.6
10	October	148.6	94.9
11	November	104.5	59.6
12	December	115.5	68.4
	Total	**2774.2**	**1931.4**

Effective rainfall is that part of the rainfall which is functionally used by the crop after accounting the losses of rainfall due to surface run off and deep percolation. The effective rainfall is the rainfall ultimately used to determine the crop irrigation requirements. More effective rainfall indicates that the roots will get more water which infers that there is no need for any irrigation requirement. However, as the effective rainfall decreases the moisture content within the soil starts to decrease in addition to the water loss due to evaporation. Therefore, depending upon the optimum water requirement of crop, the irrigation system should be designed in such a way that it fulfills the water requirement of the crop during all of its base period.

4.1.3 Crop Coefficient

Majorly, Narainapur rural municipality grows paddy rice and wheat as the agricultural crop in Banke district and it is one of the significant contributors to the overall production in Banke district. In addition to it, farmers grow potato, tomato, cabbage etc. as minor crops. The Crop coefficient of these crops varies according to their development phases. As the crop grows its crop evapotranspiration increases upto a point and reaches its maximum values and then again starts to decrease when the crop starts to reach its full maturity. For instance, it can be seen from the table that in the initial phase, the crop coefficient (Kc) of paddy rice is 1.05 and increases to 1.20 at mid-season growth of cro starts to peak and when the crop fully matures the evapotranspiration decreases and reaches to 0.50 only and the crop is get for harvest. Similarly, different stage of the crop requires their own time period, for instance paddy rice takes a total of 180 days for full development whereas the spring wheat only takes about 130 days. The various data that are required for CropWat are given as below:

Table 9: Coefficient of Paddy Rice and Wheat

Particulars	**Paddy Rice**	**Wheat**
Planting Date	1st of July	7th of January
Harvesting Date	27th of December	16th of May
Crop Coefficient (K_c)		
Initial Coefficient	1.05	0.30
Mid-season Coefficient	1.20	1.15
Harvest Coefficient	0.50	0.30

Stages (Days)		
Initial	30	30
Development	30	30
Mid-Season	80	40
Late-Season	40	30
Total	180	130
Rooting Depth (m)		
Initial	0.50	0.30
Full Grown	0.50	1.20
Critical Depletion (All Stages)	0.20, 0.20, 0.20	0.55, 0.55, 0.80
Yield Response (All Stages)	1.00, 1.09, 1.32, 0.5, 1.10	0.40, 0.60, 0.80, 0.40, 1.15

The rooting depth of the crop also increase with the development. Take spring wheat as an example, at the initial stages its depth is about 0.30m whereas the crop starts to grows it increases upto its capacity 1.20m. The larger depth helps the plant to absorb the water through capillarity. The soil moisture level where first drought stress occurs that affects the crop evaporation and crop production is represented by the other factor called the critical depletion factor. It normally varies within 0.4 to 0.6 with lower values for sensitive crops with confined rooting system under high evaporative condition and higher values for deeper and densely rooting crop system with lower evaporation values. At lower Etc, the value is higher and at higher Etc, the value is lower. For instance, the spring wheat, the initial values are 0.55 which infers that about 55% of the total available water is available for the depletion by the root in the root zone before any moisture stress. As the Etc increases, the lesser water is available in the root zone for depletion.

4.1.4 Soil Moisture Datas

A digital soil map of the entire country is made available by National Agricultural Research Centre (NARC) which is available in its website. The soil data within the study area is then obtained and then fetched into Soil-Water Characteristics software by FAO. It determines the type of soil present in the site along with its relevant drainage characteristics to be used for the Cropwat software. It has been found that the major portion of the study area is composed of Clay-Loam and the other minor portion is composed of Loamy soil which lies in the south-east part of the area as depicted by the software.

Along with it, several researches were studied for the drainage characteristics concerning the clay-loam type of soil. The relevant values are as tabulated below:

Table 10: General Soil data for CROPWAT

S.no.	Particulars	Units	Values
1	Total available soil moisture (TAM) (Field Capacity – Wilting Point)	mm/meter	140
2	Maximum rain infiltration rate	mm/day	240
3	Maximum rooting depth	centimeters	900
4	Initial soil moisture depletion	as % of TAM	0
5	Initial available soil moisture	mm/meter	140

4.1.5 Cropping pattern/Crop Calendar

The cropping patterns were studied and farmers were interviewed and standing field crops were observed in the study area. Rice and wheat are the major crops planted in the area supported by maize, potato, tomato and other general vegetables as preferred by the farmers to support their living. The crops and their respective planting and harvesting period are given as follows:

Table 11: Crop's Planting and harvesting period

Crops	Planting Time	Harvesting Time
Rice	1^{st} of July	27^{th} of December
Wheat	7^{th} of January	16^{th} of May

According to the topographical condition, soil condition and irrigation facility, the cropping pattern was studied and found to be Rice-Wheat Pattern.

4.1.6 Crop Water Requirement (CWR) & Irrigation Water Requirement (IWR)

The following table represents the results obtained from FAO's Cropwat for the crop water requirement of paddy rice. Paddy is generally transplanted in the first week of July which is the month which receives the highest rainfall for year. Also, the temperature in this month can increase more than 35 degree which is more than the average. With the meteorological data used in the software, the evapotranspiration for the month of July is 74.35 on an average during the initial phase of the development. Since rainfall in this month occurs more or less frequently, the irrigation water requirement for the month remains zero as all the requirement is fulfilled by the rainfall alone. The crop coefficient which is the ratio of actual crop evapotranspiration to reference crop evapotranspiration stays constant for the month. The total effective rainfall that occurs in this month is 445.0 mm/dec (monthly decadal).

Table 12: Crop water requirement for Paddy Rice (2023)

Month	**Decade**	**Stage**	**Kc**	**ETc**	**ETc**	**Eff rain**	**Irr. Req.**
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Jul	1	Init	1.05	7.56	75.6	125.7	0
Jul	2	Init	1.05	7.31	73.1	150.5	0
Jul	3	Deve	1.05	7.12	78.3	133.1	0
Aug	1	Deve	1.09	7.15	71.5	111.6	0
Aug	2	Deve	1.14	7.29	72.9	99.2	0
Aug	3	Mid	1.2	7.41	81.5	84	0
Sep	1	Mid	1.21	7.29	72.9	67.5	5.4
Sep	2	Mid	1.21	7.05	70.5	52.1	18.4
Sep	3	Mid	1.21	6.7	67	41.3	25.7
Oct	1	Mid	1.21	6.35	63.5	28.9	34.6
Oct	2	Mid	1.21	5.99	59.9	16.5	43.4
Oct	3	Mid	1.21	5.72	63	13.9	49.1
Nov	1	Mid	1.21	5.45	54.5	11.1	43.4
Nov	2	Late	1.2	5.14	51.4	6.8	44.6
Nov	3	Late	1.07	4.39	43.9	8.2	35.7
Dec	1	Late	0.91	3.54	35.4	10.1	25.4
Dec	2	Late	0.74	2.76	27.6	10.8	16.8
Dec	3	Late	0.6	2.25	15.8	7.6	3.8
				Total	1078.2	978.8	346.2

Similarly, from the last phase of July and through the most of the august the plant goes into the development phase where the seedling starts to grow to a young plant. The evapotranspiration rate starts to increase as evident from crop coefficient. It is about 7.28mm/day whereas, the effective rainfall for this month is 330.5mm/dec which easily fulfill the crop irrigation water demand. In the month of September to October, the crop enters its mid development phase which is characterized by higher need of water. During this period, the natural rainfall starts decrease as compared to earlier months and therefore, shortage of water occurs. In such circumstances, there will the need to fulfill the water requirement through irrigation. A portion of requirement is fulfilled by the rain and the rest has to be fulfilled by irrigation. The crop coefficient is constant and stays at 1.21 for both September and October. However, the irrigation water requirement goes on increasing and reaches its peak for the mid development phase at 49.1mm/dec in the last phase of October. From the month of November to December, the paddy rice crop which is planted on July gets ready for the harvest. The irrigation water requirement for the crop grows on decreasing. The maximum irrigation water requirement occurs in the month of October during its mid development stage. The total irrigation water required is 346.2 from the initial phase to fully grown phase.

Spring wheat is transplanted in the first week of January. Before, it the crop residue after the paddy rice harvest can be excavated using mechanical means to mix it with in the soil itself as it provides necessary nutrients for the soil after decomposition. The total effective rainfall that occurs in the month of January is about 78.2mm whereas the crop evapotranspiration is only about 1.1 mm per day. The water requirement required in the initial phases of the crop development is easily fulfilled by the natural rainfall. During the development phase from seedling to a young plant the total rainfall that occurs fluctuates in the range of 127.8mm to 133mm in the earlier months of the year, but as the plant starts to grow the water requirement increases and the natural rainfall is not sufficient to fulfill the demand. So, from the development phase irrigation water has to be provided to fulfill the water requirement for the crop. The water requirement reaches upto 24.1 mm/dec in the last phase of the February.

Table 13: Crop water requirement of Wheat (2023)

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Jan	1	Init	0.3	1.1	4.4	5.3	0
Jan	2	Init	0.3	1.1	11	14.4	0
Jan	3	Init	0.3	1.22	13.4	14.8	0
Feb	1	Deve	0.35	1.55	15.5	15.4	0.1
Feb	2	Deve	0.63	3.04	30.4	16.1	14.4
Feb	3	Deve	0.91	4.92	39.4	15.3	24.1
Mar	1	Mid	1.17	7.01	70.1	14	56.1
Mar	2	Mid	1.24	8.11	81.1	13.2	67.9
Mar	3	Mid	1.24	8.5	93.5	14	79.5
Apr	1	Mid	1.24	8.88	88.8	12.9	75.9
Apr	2	Late	1.21	9.04	90.4	12.5	77.8
Apr	3	Late	0.94	7.17	71.7	21.4	50.4
May	1	Late	0.63	4.88	48.8	30	18.7
May	2	Late	0.38	2.99	17.9	22.3	0
				Total	676.4	221.6	465

Most of the water requirement occurs in the mid development phase between March to first week of April. In the same period, the temperature of the region soars and its reaches upto 39 degrees, on the other hand, the effective rainfall for the crop remains same like the earlier month which further stretches the water requirement. In the last week of march, the irrigation water requirement reaches upto 79.5mm/dec, the crop coefficient increases to a maximum of 1.24 given the fact that the evapotranspiration rate reaches 7.63mm per day in the month of march. The crop water requirement starts to decrease as the day pass through the month of May and the spring wheat reaches its maximum growth and is ready to harvest. The total irrigation water requirement needed for a full growth is about 465 mm/dec.

Crop water requirement is the amount of water needed by the cropped field to compensate for crop evapotranspiration losses. The data shows that the highest crop evapotranspiration for paddy rice is 81.5 mm/dec on the month of August whereas, it is 15.8 mm/dec in the month of December which is lowest. For wheat, the highest crop evapotranspiration is 93.5 mm/dec in the month of March whereas, it is 11 mm/dec in the month of January which is the lowest. Rainfall on these above-mentioned months is not enough to meet the crop evapotranspiration except for July.

Considering both the paddy rice and spring wheat as the main grown crop in the region, the supply scheme can be generated to compare and use it to design the irrigation facility for providing water to the crop all-round the year. The table shows the precipitation fulfillment and its deficits in all the month of the year.

Table 14: Supply Scheme for Narainapur

S.no.	**Particulars**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
A.	Precipitation deficit												
	1. Rice	0	0	0	0	0	0	0	0	49.4	127	124	46
	2. Wheat	0	34.4	185.7	186.4	16.3	0	0	0	0	0	0	0
B.	Net scheme Irr. Req.												
	in mm/day	0	1.2	6	6.2	0.5	0	0	0	1.6	4.1	4.1	1.5
	in mm/month	0	34.4	185.7	186.4	16.3	0	0	0	49.4	127	124	46
	in l/s/h	0	0.14	0.69	0.72	0.06	0	0	0	0.19	0.47	0.48	0.17
C.	Irrigated area	0	100	100	100	100	0	0	0	100	100	100	100
	(% of total area)												
D.	Irr.req. for actual area (IAA)	0	0.14	0.69	0.72	0.06	0	0	0	0.19	0.47	0.48	0.17
	(l/s/h)												

Paddy rice has the highest precipitation deficits in the month of october which amounts to 127mm whereas for the spring wheat, the maximum deficit is in the month of April where the temperature soars. The net scheme irrigation required for paddy in the month of April is 127mm/month (0.47 litre/sec/hectare) whereas for wheat, it is 186.4mm/month (0.72 lit/sec/hectare) which is same as that of deficits values. These requirements should be essentially provided for proper development of crop. The supply can be done by construction canal if nearby source is available or ground water can be utilized which can be pumped and supplied in the field. The requirement for wheat is maximum which is about 0.72 lit/s/hec and this value can be used with presumption of losses for the design of supply system.

The process was repeated for each year of the forecasted values to obtain the irrigation water requirement for each year from where a graph was produced. The graph shows that the irrigation water requirement goes on decreasing as the time passes. It is due to the change in the climatic condition impending in the future.

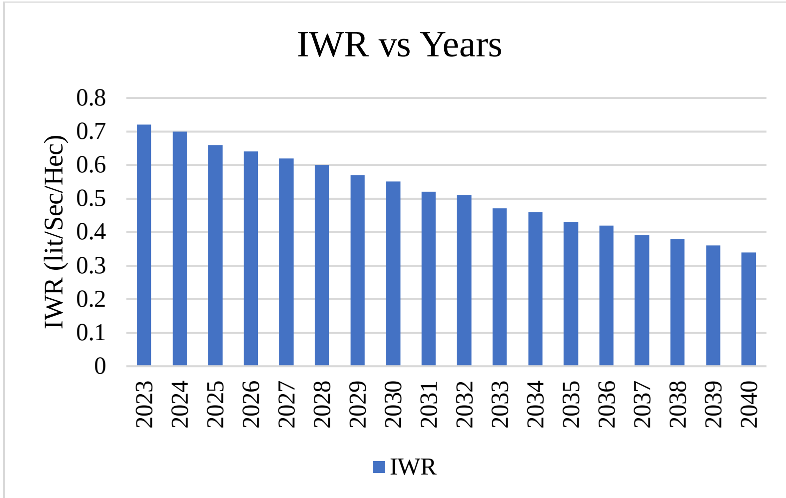


Fig (6): IWR vs Time (years)

4.2 Ground Water Map

Ground water data was collected from the ground water development board, Nepal from 2001 AD to 2021 AD. It was then tabulated in MS-Excel sheet. The datas were taken from 18 well points which included both shallow and deep wells.

Table 15: Names of the well point

D-Gaon	Kajurakurda	Parspur
Gaughat DW1	Kalhansgaon	Piprawa
Gaughat DW2	K-Gaon	Ramapurwa
Gaughat SW	Kharaicha	Rohini Khola
Jabadhawa	L-Gaon	Shikanpurwa
Jaishpur	Office Compound	Thapawa

The map presented below is the boundary map of Banke along with the respective wellpoints as mentioned in the table above. There are 2 deep wells out of 18 well points which is taken for the study. The data about the depth of the water level is obtained through digitalized ground water data. At the lower corner near the Indian border is the study area whose ground water is interpolated from these 18 well points to obtain the range within which it is present.

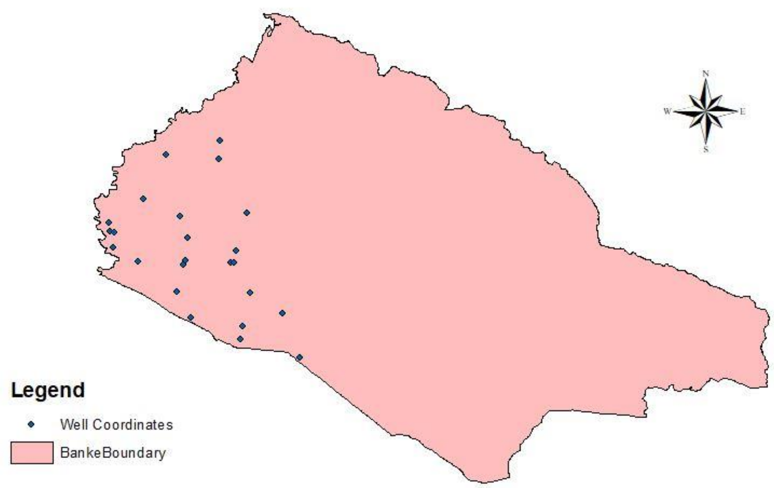


Fig 7: Banke District with Well point locations

Universal Kriging Interpolation was employed for the ground water level interpolation in Esri's ArcMap which is one of widely accepted method for interpolation for GW. The point location of all those wells and their mean level were fetched into the it and interpolated to obtain the ground water map of the study area. The following maps for every month of the year were prepared which are as listed below:

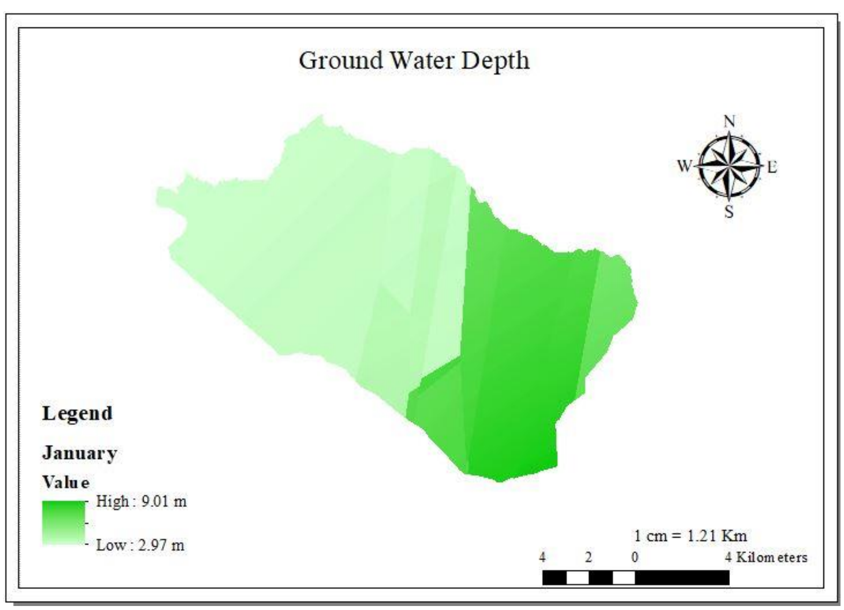


Fig 8: Interpolated Depth in Narainapur for January

The interpolated result shows that in the beginning month of the year the ground water table can be available at a mere 2.97m to a higher depth of 9.01m approx. The total rainfall in this month is about only about 127.8mm. The water level varies according to the location also. At the western side, it is available at relatively shallow depth whereas, in the eastern side of the area the ground water level decreases rapidly. In this month spring wheat is planted for agriculture in the area.

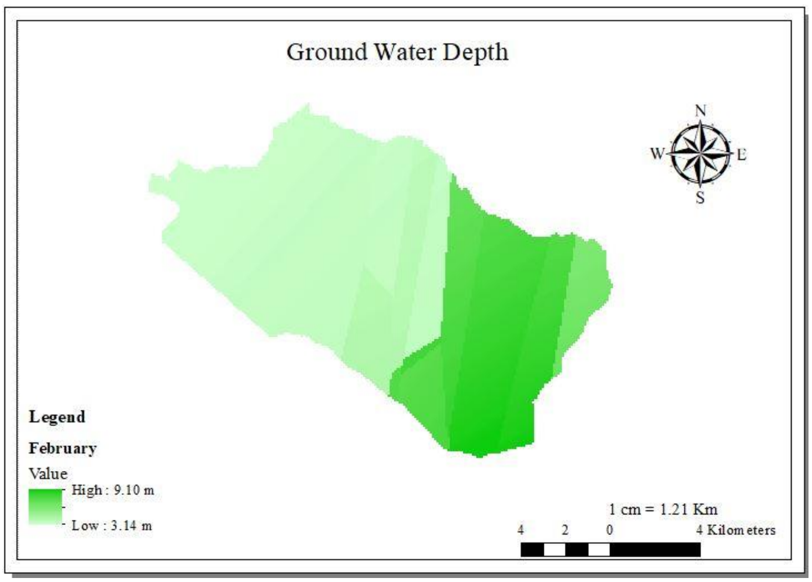


Fig 9: Interpolated Depth in Narainapur for February

The interpolated result shows that in the month of February the ground water table can be available at a shallow depth of 3.14m to a higher depth of 9.10m approx. Though the total rainfall in this month is about only about 133.1mm, the interpolation still showed water level decrease. It also varies according to the location also. At the western side, it is available at relatively lower depth whereas, in the eastern side of the area, the ground water level decreases rapidly.

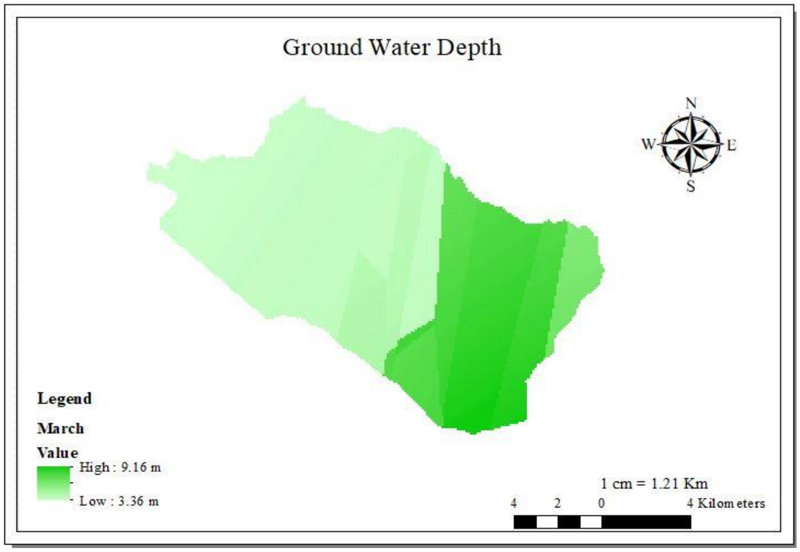


Fig 10: Interpolated Depth in Narainapur for March

The result below shows the interpolated depth of groundwater for the month of march. It receives lower rainfall than the previous month accompanied by increase in the temperature in the region. The ground water table falls in the range of 3.36m to 9.16m below the ground level. It is the last month of the winter season which receives about a total of 126.0mm rainfall. At the western side, it is available at relatively shallow depth whereas, in the eastern side of the area, the ground water decreases rapidly.

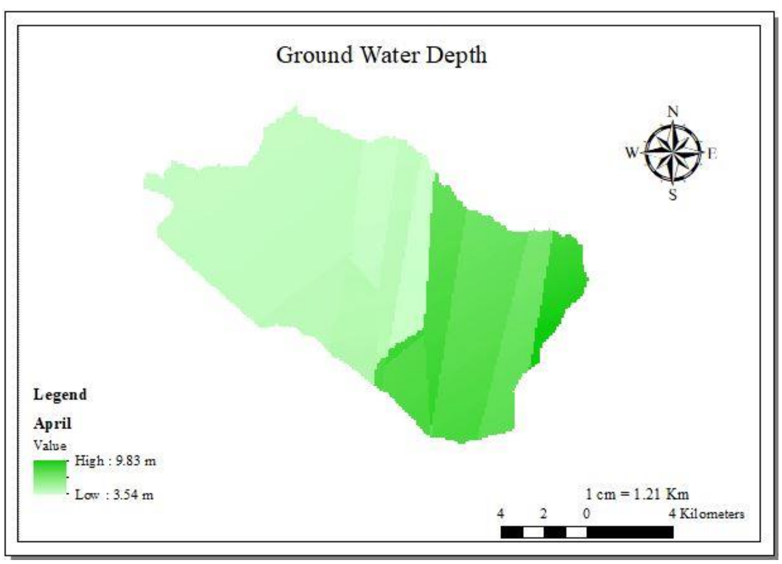


Fig 11: Interpolated Depth in Narainapur for April

The month of April is the beginning of summer season and also receives a good amount of rainfall i.e., about 133.0mm of total rainfall in the month. Spring wheat which is grown in the January reaches its maturity in this month. And, the interpolated depth for the ground water shows that its location ranges in the depth of 3.54m to 9.83m below the ground. The ground level depth goes on decreasing as one moves from west direction to the east in the area and in this month the table can be at highest depth in the year. During this month, the temperature can also reach its peak for the year.

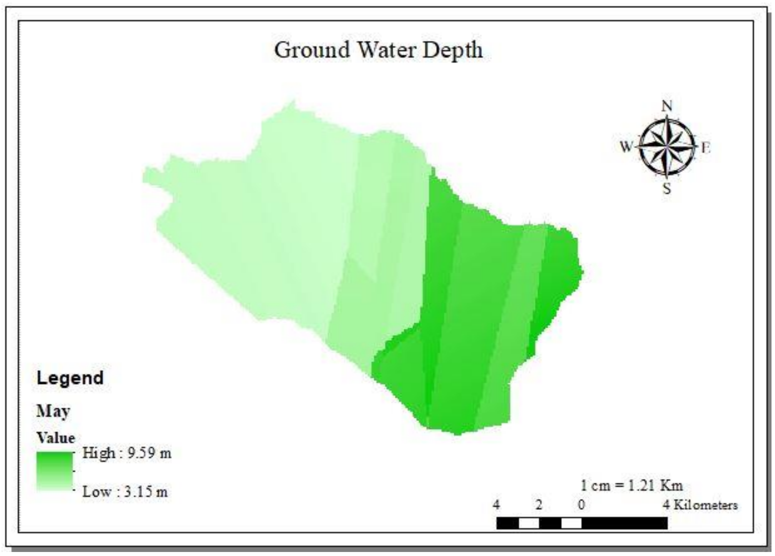


Fig 12: Interpolated Depth in Narainapur for May

The month of May entails increase in temperature to its peak for the year. On an average it receives 221.2mm of total rainfall which is higher than the earlier month. At the end of this month the spring wheat which is cultivated is harvested and roots are relived off to clear for next vegetation to cultivate. The water table in this month ranges at a depth of 3.15m to 9.59m as per the interpolation result. The water table gets shallower at most part of the western area which inhibits one of the large parts of agriculture area and areas of the eastern part.

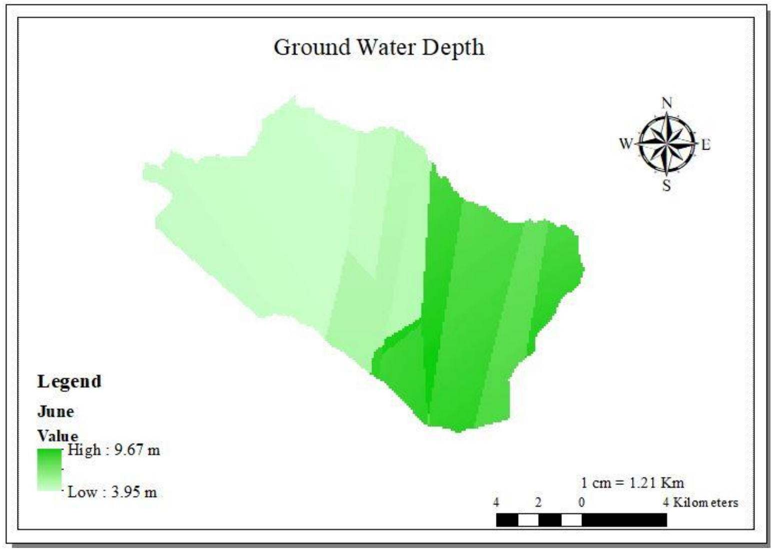


Fig 13: Interpolated Depth in Narainapur for June

The month of June encompasses high temperature as well as the slower beginning of winter season for the year. On an average it receives 359.5mm of total rainfall which is way higher than the earlier month. The water table in this month ranges at a depth of 3.95m to 9.67m as per the interpolation result. The water table gets shallower at most part of the western area which inhibits one of the large parts of agriculture area and areas of the eastern part.

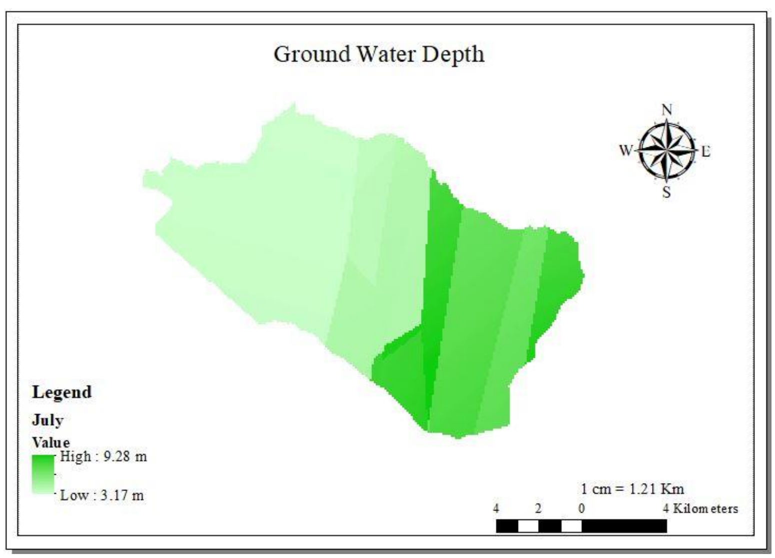


Fig 14: Interpolated Depth in Narainapur for July

The month of July receives the peak of monsoon precipitation which is about 586.2mm of total rainfall. It is also the month in which paddy rice is planted. The ground water table depth ranges between 3.17m to 9.28m below the ground water table as per the interpolation result. The water table gets shallower at most part of the western area which inhibits one of the large parts of agriculture area and areas of the eastern part.

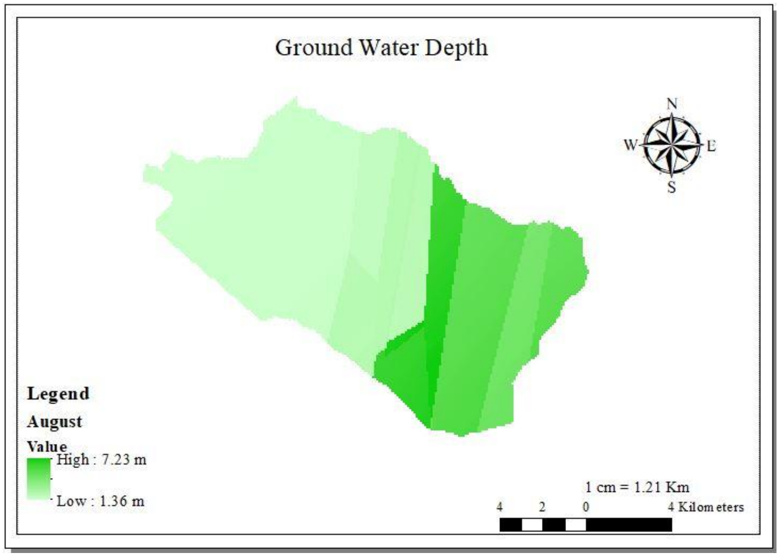


Fig 15: Interpolated Depth in Narainapur for August

In the month of August, a total rainfall of 443.1mm occurs which is lower than the earlier months. However, ground water table is at shallowest for the year i.e., 1.36m in the western side whereas, 7.23m in the eastern side as per the interpolation results. In this month, the paddy rice planted reaches its development stage and extracts water through capillary action from the ground water.

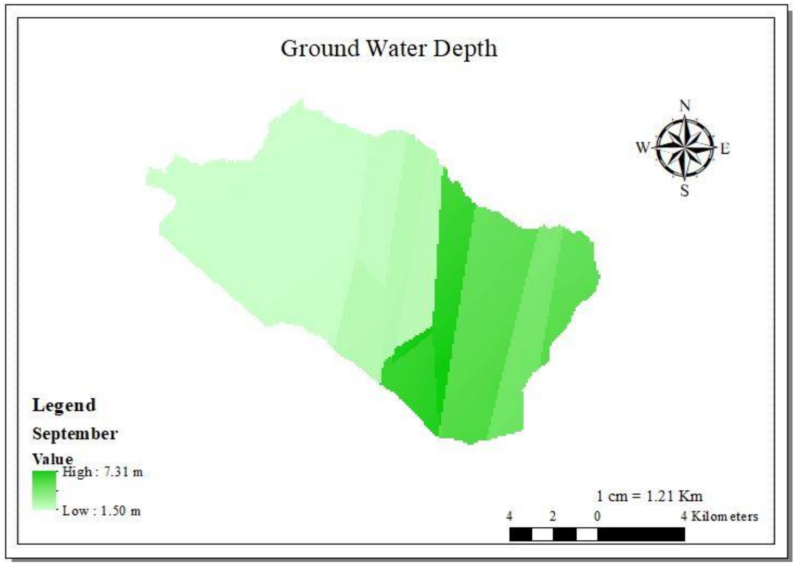


Fig 16: Interpolated Depth in Narainapur for September

The interpolated result shows that in the month of September, the ground water table is available at a shallow depth of 1.50m to a higher depth of 7.31m approx. Though the total rainfall in this month is about only about 275.7mm, the interpolation still showed water level decrease in the east. At the western side, it is available at relatively shallower depth whereas, in the eastern side of the area, the ground water level decreases rapidly.

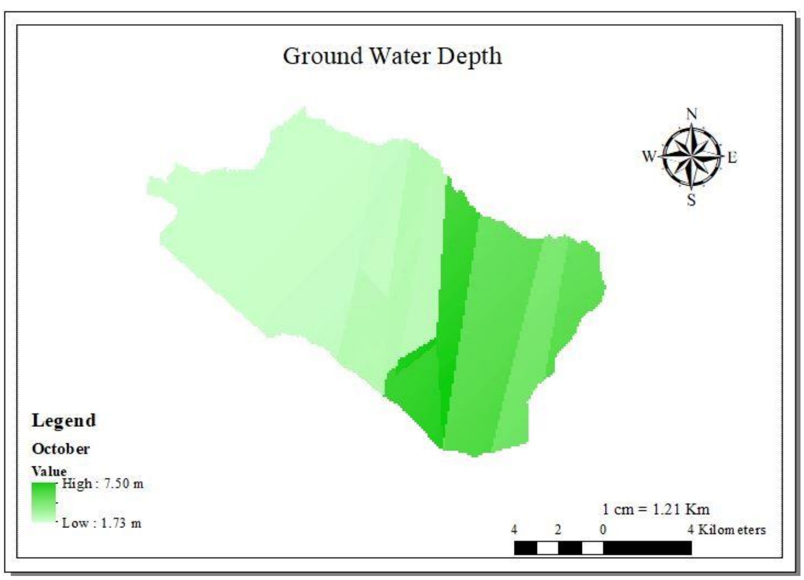


Fig 17: Interpolated Depth in Narainapur for October

The month of October is the last phase of the monsoon season and the start of winter season for the year. The paddy rice planted in July fully matures upto this month. It receives a total rainfall of 148.6mm. The universal kriging interpolation result showed that the water level on the west side is shallower at a depth of 1.73m whereas on the eastern side it is found at a higher depth of about 7.50m.

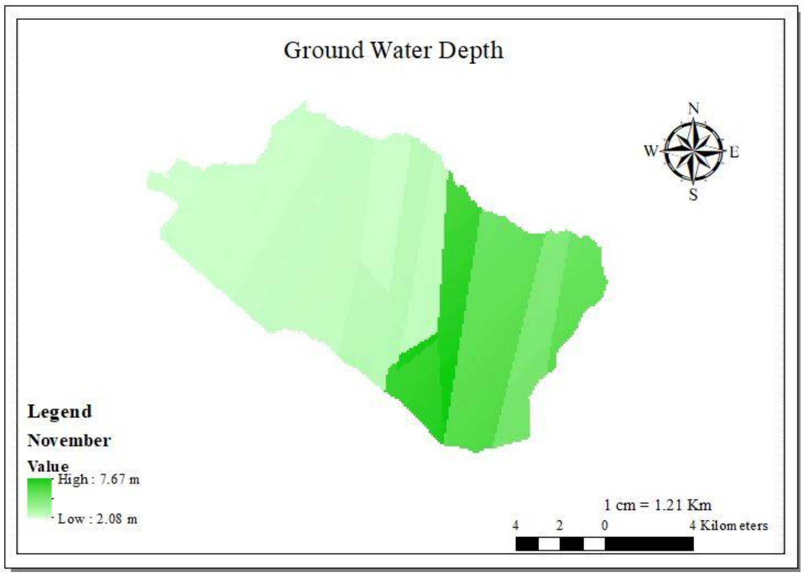


Fig 18: Interpolated Depth in Narainapur for November

The month of November entails colder temperature over the region. The temperature is lower than the earlier months. The interpolation results shows that the water level can be found at a shallower depth of 2.08m to a higher depth of 7.67m below the ground water table. In this month, a total rainfall of 104.5mm occurs. The water table as usual is lower in the western region than on the eastern region.

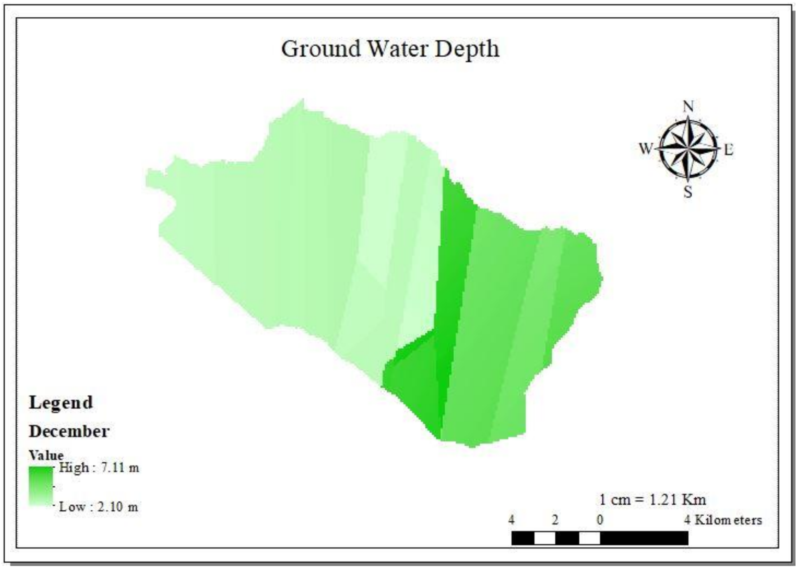


Fig 19: Interpolated Depth in Narainapur for December

The interpolation results showed that in the month of December the ground water level at the shallowest is available at a depth of 2.10m whereas, at 7.11m at the highest depth. The total rainfall in this month is about 115.5mm.

The maps show that, the western portion of the Narainapur area has high water recharge potential owing to its availability at a depth of within 2m whereas on the eastern portion of area, the water level seems to be present at a relatively greater depth up to 10m. The maximum depth of the ground water level determined to be 9.83m below the ground surface in the month of April (Baisakh). The lowest value of ground water depth is determined to be 1.36m below in the month of August (Shrawan) which is a monsoon month in Nepal. These values were confirmed by field visits and interviews with the municipality official to find that ground water level does falls within the estimated depth by the GIS.

4.3 Peak Solar Photovoltaic Power

Solar photovoltaic power that is needed for pumping ground water can be calculated after one obtains the quantity of discharge required to fulfill the irrigation water requirement. IWR is obtained from the FAO's Cropwat results for paddy rice and spring wheat. Then subsequently, the ground water depth is obtained using the ground water table datas from the well point and creating an Arc GIS map using the interpolation technique. The interpolated depth provides the range within the ground water fluctuate depending upon the data available. Using the obtained results, the peak solar photovoltaic power computation is as shown below:

For 1 hectare, the maximum IWR is required in the month of April (Chaitra-Baisakh)

Table 16: Maximum Irrigation water requirement

Max IWR=	0.72	liter/sec/hectare
1 Liter/Sec/Hectare=	86.40	m3/day/hectare
Max IWR=	68.25	m3/day/hectare

For the crop water requirement calculation, the method and condition to be applied are ciritical to be selected before calculation take place. These depends upon the climate, topography, availability or water and degree upto which irrigation has to be done. Therefore, the method for the water requirement calculation is as summarized below:

Table 17: Method employed for various irrigation parameters

S.no.	Particulars	Method Employed
1	Evapotranspiration, Et_o	Penman-Monteith Method
2	Effective Rainfall	Dependable Rain (FAO/AGLW Method)
3	Irrigation Timing	Irrigating at critical depletion
4	Irrigation Application	Refilling soil to field capacity

Conveyance Efficiency: The amount of water that gets tapped from the source is not fully acquired at the tail end because of percolation and evaporation along the running length of the canal. It generally depends upon the length of the canal and subsurface material under which canal is formed. The following table below list the conveyance efficiency of water relating length and soil above which the irrigation water flows.

Table 18: Conveyance efficiency for various types of soil

Soil Type	Sand	Loam	Clay	Lined Canal
Canal Length				
Long (>2000m)	60%	70%	80%	95%
Medium (200m-2000m)	70%	75%	85%	95%
Short (<200m)	80%	85%	90%	95%

Field Application Efficiency: It is the ratio between water that is available directly to the crop and that which is received at the cropping field inlet. It represents the water application in the field. Different method of field application has different efficiency. More the water is applied directly to the root zone, higher is the efficiency. These following table tabulates the irrigation method and its associated efficiency.

Table 19: Field application (F.A) efficiency for various irrigation methods

Irrigation Methods	Field Application (F.A) Efficiency
Surface Irrigation (Boarder, Furrow, Basin)	60%
Sprinkler Irrigation	75%
Drip Irrigation	90%

In the study, the field is assumed to get irrigation using surface water as pumping can be done in localized area and then directly fed into the field. The canal system that will be made will be short and the geographical area consists of loamy soils. Since the irrigation efficiency is the multiplication of conveyance efficiency and field application efficiency, the irrigation efficiency for the system is only about 51%. The calculation regarding it is as presented below:

The following datas are taken for the study area:

Conveyance Efficiency (CE): 85%

Field Application Efficiency (FE): 60%

Irrigation Efficiency: CE x FE = 51%

Assumptions

Solar Peak Radiation, I_p (W/m^2) = 1000 W/m^2

Solar panel Efficiency. E_{sa} (%) = 14 %

Gravity Constant, g (m/s^2) = 9.81 m/s^2

Pump Efficiency, E_p (%) = 43 %

Gross IWR = Net IWR / Irrigation Efficiency = 121.98 m^3/day/hectare.

Density of water = 1000 kg/m^2

Loss due to friction = 10%

Day's fraction where the pump works = 0.95

Yield of Photovoltaic Generator = 0.85 (Light energy to Electrical energy conversion)

Yield of AC/DC Generator = 0.9 (Conversion factor DC to AC)

Yield of the pump = 0.43 (Efficiency of Pump)

The pump is assumed to run at 220 Volts and it is a 1 HP (750 W) pump sufficient to fill the water requirement for more than 1 hectare.

The table below is the calculation for the peak solar photovoltaic power using the equation for the study area:

Table 20: Peak solar photovoltaic power

S.no.	Month	Sunshine Hour Per day	Pumping Height	GIWR Requied (Q)	Daily Hydaulic Energy (Eh)	Frictional Loss (R)	Required Electrical Power, Eel	PV Generator Power, Pel	Required Peak PV Power
	Units	hours/day	m	m3/day	kWh/day	kWh/day	kWh/day	kW	kWp
1	January	5.61	14	133.84	5.11	0.51	17.97	3.20	**3.24**
2	February	7.05	14	133.84	5.11	0.51	17.97	2.55	2.57
3	March	7.75	14	133.84	5.11	0.51	17.97	2.32	2.34
4	April	7.83	14	133.84	5.11	0.51	17.97	2.30	2.32
5	May	7.74	14	133.84	5.11	0.51	17.97	2.32	2.35
6	June	7.29	14	133.84	5.11	0.51	17.97	2.47	2.49
7	July	6.87	14	133.84	5.11	0.51	17.97	2.62	2.64
8	August	6.57	14	133.84	5.11	0.51	17.97	2.74	2.76
9	September	6.77	14	133.84	5.11	0.51	17.97	2.65	2.68
10	October	7.1	14	133.84	5.11	0.51	17.97	2.53	2.56
11	November	7.05	14	133.84	5.11	0.51	17.97	2.55	2.57
12	December	6.64	14	133.84	5.11	0.51	17.97	2.71	2.73

The table shows the calculation of required peak PV power for operating the motor to fulfill the irrigation water requirement. It is assumed that the pumping height of the motor is 10m since the interpolation results showed that the water table within the ground is present at about 9m depth below and extra 1m is taken for contingency. Sunshine hours data were taken from meteorological department and it is tabulated above. Similarly, pipe losses and friction are both assumed to be 10%. As per the result, in the month of January the sunshine hour per day is about 5.61 hours only and to operate in this month the required peak pv power is obtained as 3.24 kWp. This power is sufficient for all months of the year.

On an average Narainapur receives about 7 hours of sunshine per day, the lowest is in January and the highest is in April. The daily hydraulic energy is calculated to be 5.11 kWh/day and friction loss is 0.51 kWh/day. Finally, the required peak PV power is calculated to be 3.24 kWp.

The following datas are obtained from the above method calculation which can be used to find the type of pump to be selected for the study.

Design Discharge Quantity (Q) = 133.84 m^3/s

Height (H) = 10m

Required peak PV power (P_p) = 3.24 kWp (kilowatt peak)

With the design discharge, Q and Height, H

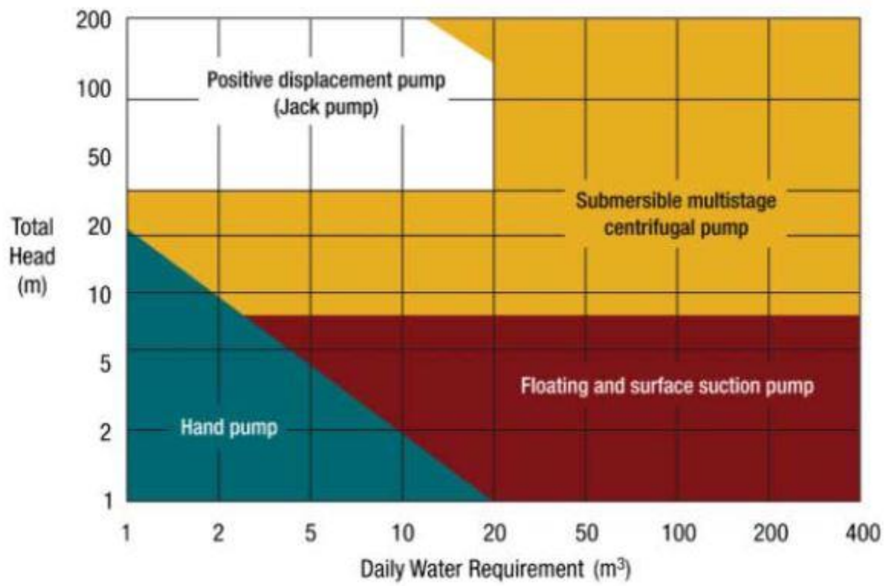


Fig (20): A guideline for pump selection (Photovoltaic Project Analysis 2005).

Using the given data, it is known that the pump required is a multi-stage submersible centrifugal pump. It is a pump in which water gets flowed through two or more than two impellers which are fitted in series. Such a pump has many water chambers or stages connected in series. Each stage consists of an impeller, a set of a diffuser and return guide vanes all encased within the same stage casing. The pump is installed underwater and water is pumped over to the surface after which it can be directed towards the field.

4.4 System Sizing

Numerous components make up a solar PV system, and they should be chosen with consideration for the system's kind, location, and intended uses. The components of a balanced photovoltaic system, which include an inverter, solar charge controller, battery, and photovoltaic module, together constitute a fully operational system that can provide electricity. System sizing is the process of determining which photovoltaic system component has the appropriate voltage and current ratings to meet the facility's electrical demand. It also involves calculating the total cost of the system, including design and implementation costs.

4.4.1 Sizing of the solar array

At the initial phase, the average daily energy demand in kWh per day is calculated. Starting with the solar array and ending with the system wiring, the required sizes and ratings of several components is determined with its cost estimate.

The selected panel is Solar Universe India SUI 250W, 24V solar panel. The specification is as listed below:

Table 21: Specification of Solar module

Solar Module Specification	**Unit**	**Qty**
Price	NPR	13255
Rated Power (Ir)	Watt	250
Rated Voltage (Vr)	Volt	24
Current at Max Power (Imp)	Amp	8.51
Short Circuit Current (Isc)	Amp	9.05
Voltage at Max Power (Vmp)	Volt	37.6
Peak PV Power Requirement	Wp	3236
System Voltage in DC	Volt	24
Total Current Needed (Idc)	Amp	134.82
Number of Parellel Modules	.	15.84
	Panels	16
Number of Series Modules		1
	Panels	1
Total Number of Modules	Panels	16

The required calculation is done referring to the equation as described in previous chapter. The overall number of panels that are required is 16. For the panel selected, the total price is obtained as Rs. 2,12,080 NPR

4.4.2 Sizing of the battery bank (Alternative I)

The number of batteries which is require is calculated based on equation presented in previous chapter. The calculation includes 48 hours of operating time with 80% of depth of discharge for the battery. Since at most 5 hours of operation is required to fulfill the water requirement demand, the system would sufficiently deliver water for more than a week. Nepalese company’s Su Kam 12V 200 AH battery is selected for the calculation.

The total number of batteries required is 11 and the price of the batteries is obtained as Rs. 534105 NPR.

Table 22: Specification of Battery Bank

Battery Bank Specification	**Unit**	**Quantity**
Price	NPR	48555
Maximum Depth of Discharge		0.8
Rated Voltage of Battery	Volt	12
Capacity of Battery	Amp-Hr	200
Total Energy Use	Watt-Hr	12838
Days with no-sun	Days	1.6
Rough Energy Use, E_{rough}	W-Hr	20540.8
For Energy Safety, E_{safe}	kWh	25676
Capacity of Battery Bank, C	Amp-Hr	2139.67
Total Number of Batteries, N_{bat}		10.69
	No. of Batteries	11
Number of Batteries in Series, N_s		6
Number of Batteries in Parallel, N_p	No. of Batteries	5
		5

4.4.3 Sizing of a Concrete Water Tank (Alternative II)

About 133.83 m3/day water is required to irrigate a hectare of land. It can be assumed that the absence of lighting or the number of cloudy days is only one. Therefore, the amount has to be stored to irrigate the agricultural field. For storage purpose, overground concrete water tank are most helpful in these scenarios. The tank is supposed to be made of concrete which is most common in developing countries like Nepal. Overground concrete tanks are cylindrical in size.

The cylindrical volume can be estimated as in the equation below:

Storage Volume = π x r^2 x h

Where,

r = Radius of Storage Tank

h = Height of Storage Tank

If the height is already known, say 4m, the radius of the tank after the calculation is 3.26m. However, free board has to be considered, therefore a height of 4.2m is taken for safety purpose. The dimensions of the concrete water tank are as given below:

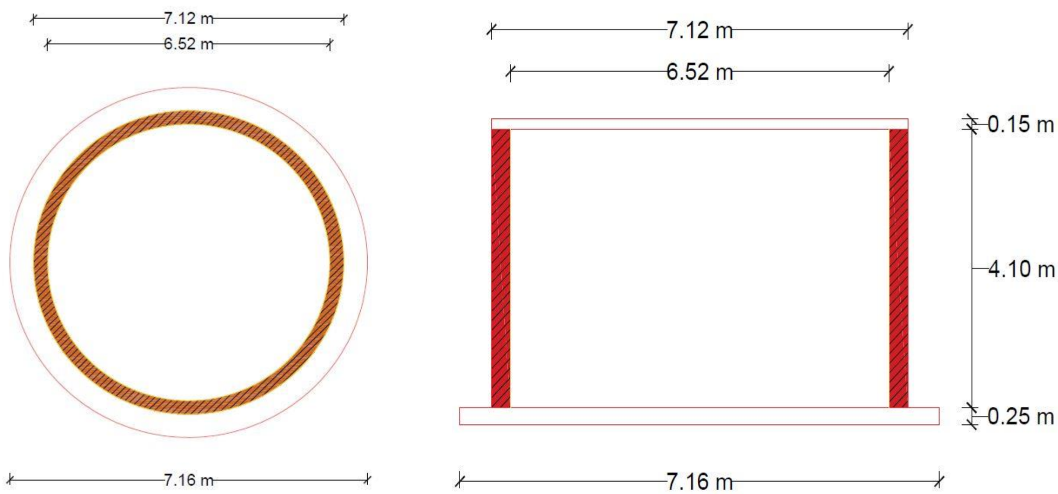


Fig (21): Top view and section of the concrete water tank

Essentially, the water tank has 3 major section which are the base slab, wall and the top slab. For the above dimensions, the quantity that will be required for its construction is as:

Table 23: Preliminary quantity measurement for concrete water tank

S. no.	Particulars	Area (m2)	Thick (m)	Volume (m3)	Rebars (%)	Rebars (m3)	Element	Rate Analysis	Amount (Rs)
1	PCC	40.20	0.075	3.015 (106)			PCC	Rs. 290/cft	Rs 30,740
2	Soling	40.20	0.10	4.02 (142)			Soling	Rs. 110/cft	Rs. 15,620
3	Base Slab	36.83	0.25	9.21	0.25	0.023	Concrete	Rs. 390/cft	Rs. 5,73,000
4	Wall	90.08	0.30	27.02	0.25	0.068			
5	Top Slab	35.72	0.15	5.35	0.2	0.011	Rebars	Rs. 100/kgs	Rs. 80,000
6	Misc.								Rs. 4,000
7	Annual Maintenan.								Rs. 5,000
	Total			**41.6 m3**		**0.102 m3**			**Rs. 7,08,360**

Total weight of rebars (W) = 7850 kg/m3 x 0.102 m3 = 800 kg

The cost of the various component required for the construction of concrete water tanks are mentioned as above. The total costing required for the construction of tank is Rs. 7,083,60 on an average which is less than the system with batteries.

4.4.4 Voltage Controller

The function of voltage controller is to control the flow of current. The number of controllers required for the system operation is 7 and the total cost is around Rs. 16,625 NPR. For the voltage controller Daraz's luminous 20A solar charge Controller is used. The following specification are as listed below:

Table 24: Specification of voltage controller

Voltage Controller Specification	**Units**	**Qty**
Price	NPR	2375
Safety Factor		1.25
Rated Current		20
Rated Voltage		24
Rated Current of Controller, I		135.75
No. of Controller Needed, Ncont	Nos	6.7875
	Nos	7

4.4.5 Inverter

The power factor for the invertor is taken as 0.8. For the invertor to be used it has to have capacity to operate under high fluctuation than the regular voltage, therefore, a factor of 1.5 is taken for the calculation which finally comes out to be 4.33 kVA. A 4.5 kVA invertor is selected for the study.

Table 25: Specification of Invertor

Invertor Specification	
Capacity	500-1000 VA
Rated Input Power	4.5 KVA
Wave Type	Sine
Output Power	50 KW
Type	Digital
Price	Rs 2000

4.4.6 Submersible Pump

The surface water source for the fields in Narainapur is farther to a point where it costs a financial burden to the concerned municipality to build a pipeline and pump it to all the field through a canal system. On the other hand, the ground water table is easily available at almost all the fields. Therefore, ground water pumping is more suitable which can be done through submersible pumps. For the study, Omax submersible 1 hp pump is used which is suffice for the given water demand.

Table 26: Specification of pump

Pump Specification	**Properties**
Name	Omax
Power	750W (1 Hp)
Head Max	30m
Rated Head	16m
Rated Flow	10 m3/h
Operating Voltage	180V - 230V
Rated Current	6A
Frequency	50Hz
Price (NPR)	Rs. 9000.00

After the determination of peak solar photovoltaic power, its system sizing was done using the conventional method using the equation as provided in method. It yielded the economical sizing of various composites of the solar PV pumping system which included 16 solar panel, 7 voltage controllers, 1 inverter, 1 submersible pump to supply for the required irrigation water requirement.

4.4.7 Life cycle cost analysis

Life cycle cost is one of the common methods to know the total cost of owning a facility or a project. Every aspect of it i.e. cost of obtaining, owning and finally disposing it is considered in this analysis. In this analysis, all the three alternatives will be assessed. The cost are divided into two parts: Capital cost and recurrent cost. The latter includes the replacement, maintenance and operation cost.

Three alternatives can be considered for continued supply of water (i) PV system operated with batteries, and (ii) PV system with concrete water storage tank (iii) Diesel engine-based irrigation water pumping. The third method is the most common way of farmers at the present to irrigate their land. All the future cost associated with the recurrent cost of the project such as operational, replacement and maintenance associated have to be converted into the present worth to compare the alternatives in same base time period. It is calculated as below:

The payment or benefits Ca that occurs yearly for N years inflating at a rate of i annually and discounted at a rate d, the present worth is

PW = Ca. Pa

Where, $Pa = [1-\{1+i)/(1+d)\}^{N}]/(d-i)$

Nepal Rastra Bank's inflation rate (2023/24), i = 7.50%

Base Interest Rate, d = 10.64%

Using this data, the following cost can be tallied to obtain the final life cycle cost of the project.

Alternative 1: Solar PV system operated with batteries

The cost of maintenance per year was assumed based on interviews with the solar PV suppliers which includes wiring, oiling and other preventive maintenance works. The replacement cost is same as the initial cost for procurement for most of the equipments. The life of the system is assumed to be of 20 years for the study. The life cycle cost regarding the solar PV with battery system is as tabulated below:

Table 27: Initial and Operational cost of Solar pv system with battery

Particulars	Nos	Unit	Price
Total Cost of Module	16	Rs	212080
Total Cost of Structure and Installation	1	Rs	60000
Total Cost of Battery Bank	13	Rs	592215
Total Cost of Voltage Controller	7	Rs	16120.3
Total Cost of Inverter	1	Rs	2000
Total Cost of Pump and Motor set	1	Rs	9000
Cost of maintenance per year	1	Rs	5000
Replacement Cost of Inverter	1	Rs	2000
Replacement Cost of Pump and Motor set	1	Rs	9000

Replacement Cost of Batteries	1	Rs	204480
Life of the system		years	20
Life of module		years	20
Life of inverter		years	10

The life span of such battery is about 6 years and that of PV system is about 20 years. The initial cost for the installation of battery system is about Rs. 534105 NPR. Since, the life span of batteries is about 6-7 years, it has to be replaced in every 6 years along with its periodic annual maintenance. The future cost associated is converted into present worth using above mentioned equation.

Table 28: Replacement cost for batteries

S.no.	Particulars	Years (N)	PW Factor	PW
1	Replacement on 6th year	6	5.055	Rs. 105660
2	Replacement on 12th year	12	9.31	Rs. 57370
3	Replacement on 18th year	18	12.89	Rs. 41450
	Total			Rs. 204480

The capital cost is the installation or intial cost required to set up the solar pv system. The invertor, pump and motor have a life of 10 years. Therefore, they have to be replaced at the end of their span. The present worth were obtained from the future cost. Therefore, the total life cycle cost of the solar pv system with batteries is Rs. 10,63,950 NPR.

Table 29: Life cycle cost of solar pv system with batteries

S.no.	**Particulars**	**Units**	**Annual Cost**	**Present Worth**
1	**Capital Cost (Installation)**	Rs	0	8,53,680
2	Replacement (Inverter)	Rs	0	2,000
3	Replacement (Pump & Motor)	Rs	0	9,000
4	Annual Maintenance	Rs	5000	69,750.0
	Pa = 13.95			
5	Present worth of recurrent costs (2,3,4)	Rs		5,788.5
6	Present worth of Batteries	Rs		2,04,480
	Life cycle cost (1,5,6)	Rs		10,63,950

Alternative 2: Solar PV system with concrete water storage tank

A concrete water tank is proposed for the storage of water based on the required irrigation water requirement of 133.83 m3/day. The tank is supposed to be made of concrete which is most common in developing countries like Nepal. The radius and height of the tank proposed is 3.26m and 4.2m respectively including a free board of 0.2m. The cost associated with the construction of the concrete tank along with its periodic annual maintenance is about Rs. 7,08,360 NPR based on the 2080/81 Banke's district rate.

Table 30: Life cycle cost of solar pv system with concrete tank

S.no.	Particulars	Nos	Unit	Price
1.	Capital Cost			
a	Total Cost of Module	16	Rs	20,2560.0
b	Total Cost of Structure and Installation	1	Rs	75,000
c	Construction of concrete water tank	1	Rs	7,08,360
d	Total Cost of Voltage Controller	7	Rs	16,120.3
e	Total Cost of Inverter	1	Rs	2,000
f	Total Cost of Pump and Motor set	1	Rs	9,000
2.	Recurrent cost			
a	Cost of maintenance per year	1	Rs	5,000
b	Concrete tank maintenance per year	1	Rs	5,000
c	Replacement Cost of Inverter	1	Rs	2,000
d	Replacement Cost of Pump and Motor set	1	Rs	9,000
	Pa = 13.95			
3.	Present Worth of Recurrent costs		Rs	10,788.5
4.	Life Cycle Cost (1,3)		Rs	10,13,040

Since, the calculation for the solar pv array and other accessories are already calculated, the cost of concrete water tank is included to obtain the final cost. The maintenance of concrete water tank is also included after converting it to the present cost. Therefore, the final cost of the solar pv system with concrete water tank is Rs. 10,13,040 NPR.

Alternative 3: Diesel engine-based irrigation

Diesel pumps are used to lift water in places where electricity is not available. They are also commonly used in Nepal for lifting the water for irrigation. The capital cost table summarizes the initial and future operational cost required for the system to meet the water demand. The replacement cost is assumed same as the new engine procurement cost.

Table 31: Initial and Operational Cost of diesel water pumping system

S.no.	**Particulars**	**Unit**	**Quantity**
1	Power of Engine	Hp	8
2	Cost of Set (Pump with Engine)	Rs	75000
3	Accessories and Installation cost	Rs	5000
4	Cost of Gasoline per litre	Rs	165
5	Cost of Lube per litre	Rs	1200
6	Consumption of fuel per Hour	Litres	0.75
7	Consumption of Lubricant Oil (% of Diesel)	%	1
8	Irregular rainfall or deficit months	No.	6
8	Number of Working Days per year	Days	180
9	Working Hours (4 hr/day)	Hours	720
10	Fuel's Total Consumption	Litres	540
11	Lube Total Consumption	Litres	5.4
12	Maintenance Cost	Rs	5000
13	System Head	meters	10
14	Annual Discharge	m3	96360
15	Life of (Pump, Engine)	Years	10

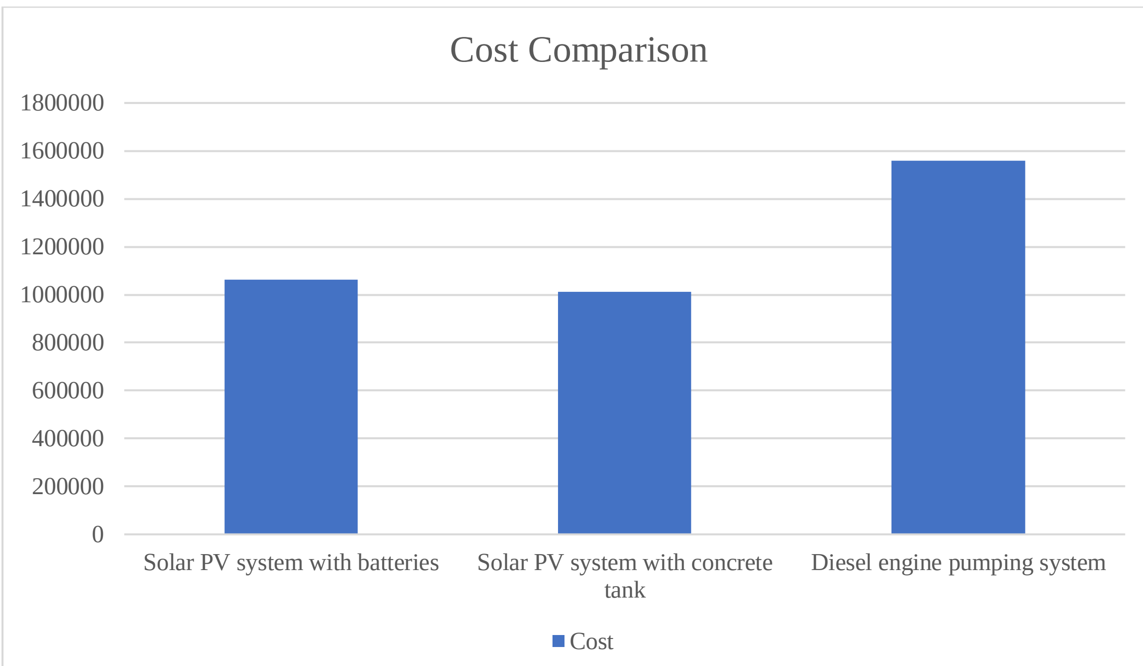
The engine selected is Honda's WV30D model of 8 hp capacity which is suffice to for the system. It accessories cost the fittings and water pipe that extract the water for the field. The engine consumes about 3 quarters of fuel per hour and it has to run for about 180 days for 4 hours to bring the irrigation water from the ground. The above table provides the consumption of various fuel entities in the annual basis. The maintenance cost includes cleaning, greasing and other preventive maintenance. The life of this pump is about 10 years.

Table 32: Life-cycle cost of diesel pumping system

S.no.	**Particulars**	**Annual Cost**	**Present Worth**
1	Capital Cost (pump & its accessorie)		Rs 80,000
2	Replacements (Pump & Engine)		Rs 75,000
3	Maintenance	Rs 5,000	Rs 69,750
4	Fuel, Lube Oil	Rs 1,19,475	Rs 13,33,341
	Total Annual Cost	Rs 1,24,475	
5	Life Cycle Cost		Rs 15,58,090

The following bar chart shows the life cycle cost comparison between all the alternative considered in the study. All the future cost associated in the project are converted to a base period and then are compared. As one can see from the chart, the best feasible alternative to go forward with is the solar pv system with concrete water tank. This seems more feasible and longer-term alternative. The solar pv system with batteries have many other issues like malfunction, irregular battery backup, reduced battery backup with time. However the most costly alternative is the diesel engine which the farmers have been using from a long time. It definitely cost more than the former two but also create environmental problems through GHH emissions. Therefore, solar pv system with concrete water is suggested for construction.

Fig 22: Cost comparison between various alternatives



4.5 Structural analysis of the solar PV pumping structure

The field of civil engineering has now seen advent of a lot of new innovation. The long and arduous analysis of structure has now been made easy by several structural analysis softwares. The market offers several authentic analysis software which can be used to analyze the behavior of structure. Extended 3D analysis of buildings system (Etabs) is one of the prominent software used today developed by Computer and Structures (CSi) Ltd. It can be used in variety of building ranging from a simple truss to high rise buildings above 100m in height.

In this study, Etabs is used for the stability structural analysis of the solar frame proposed. According to the calculation presented above, a total of 12 solar panel was found to be sufficient to meet the daily solar requirement to run the pump. Another supplementary software used was Autodesk's Autocad which is an architectural drawing software. It was used to draw plan and section of the solar frame.

4.5.1 Structure Data

The structure is a simple frame sections built solely to support the solar panel at desired angle of tilt to procure maximum amount of sunlight as possible since it induces DC electricity. Its foundation is fixed below the ground using the concrete block to provide rigid stiffness. The structure is made up of column, purlins (Horizontal member), rafters (inclined member). The solar panel are supported by purlins which is supported by rafters which in turn is supported by column which transfers the load acting on the solar panel into the foundation. The autocad plan is provided below to visualize the structure which is taken up for the study.

4.5.2 Material properties

One of the earlier steps in Etabs analysis is defining the material properties. The material that is used in solar panel frame is the Fe 250 (mild steel) IS tube section which is easily available in the market and the other is the concrete which is placed below the foundation to provide a rigid support to the columns.

4.5.3 Frame sections

In this study, ISB 49.5 x 49.5 x 3.6, ISB 38 x 38 x 2.6 and ISB 25 x 25 x 2.6 are used represents the Indian standard frames with dimensions corresponding to Length x breadth x thickness. The former member was defined and used for the analysis and if the frame seems feasible does not stretch upto its potential capacity, a lower capacity member can be used as its reduces the cost associated for building the structure. The following section made in Autocad software represents the structure's section.

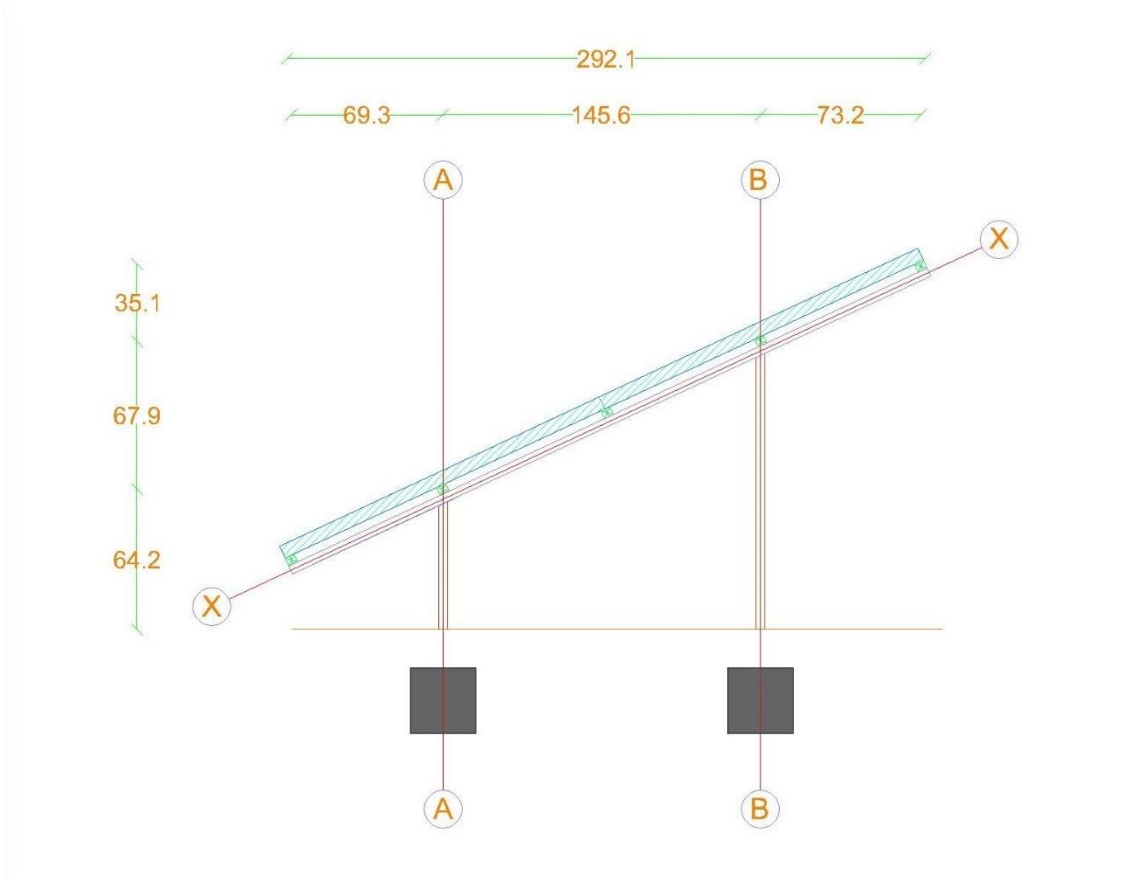


Fig 23: Section of the solar PV panels (Dimensions in cm)

The solar panel receives higher sunlight using a 25-degree inclination which is taken according to the geographical location of the place. Tubular columns were taken for structure elements i.e., purlins, rafters and support column. The foundation below the surface is assumed to have a fixed support which can be made using concrete block for the columns' tubes below. The spacing between the two columns is taken as 1.45m. The inclined length of the rafter supporting the purlins is the total length of the solar panel i.e. 3.20 m and the horizontal length is equal to 2.92 m.

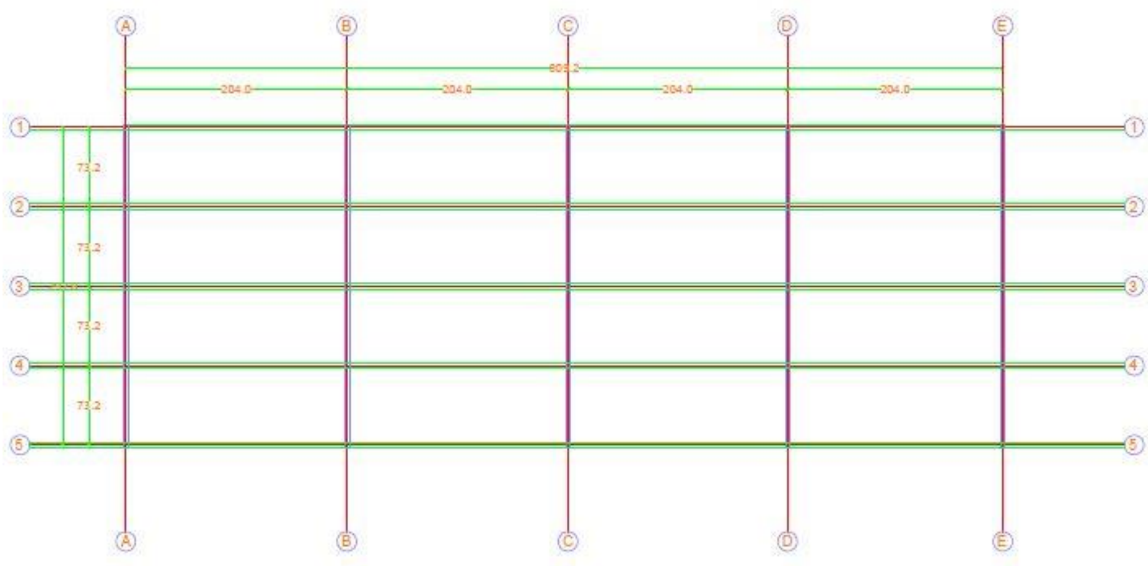


Fig 24: Solar panel Plan in Autocad (Dimensions in centimeters)

The solar panel is fixed on the purlins which runs longitudinally in the solar frame. All the loads that act on the solar panels are taken up by these purlins. The purlins further transfer the load to the rafters which runs transversely in the solar frame. The load from these rafters is further transferred to the columns which finally transmits into the subsurface concrete blocks. The average length of the purlins is 6.12m and is spaced regularly at 0.73m centre to centre in perpendicular direction. The average length of the rafters is 2.92m and is spaced regularly at 0.20m centre to centre in orthogonal direction.

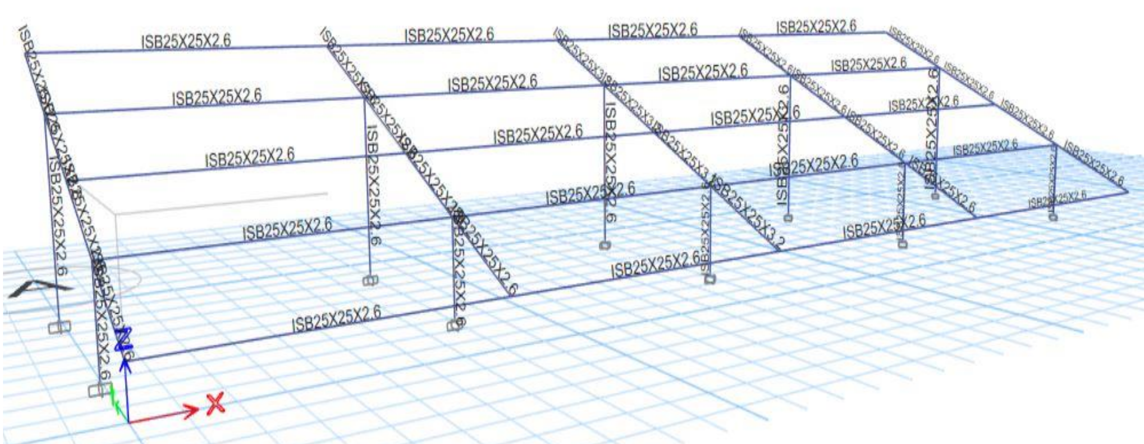


Fig 25: Etabs Model of solar panel for structural analysis

The plan and elevation drawn in the Autocad model helps to specify all the dimensions properly and the data is fetched into Etabs software to make the model as shown. Here initially ISB 38 x 38 x 2.6 was taken for purlins and rafters and ISB 49.5 x 49.5 x 3.6 is taken for columns sections. The connection is assumed to be pinned connection within the section joint which is entailed by rivet or bolted connections in practical conditions. The end of the column is assigned as fixed connection as the end is concrete below the ground.

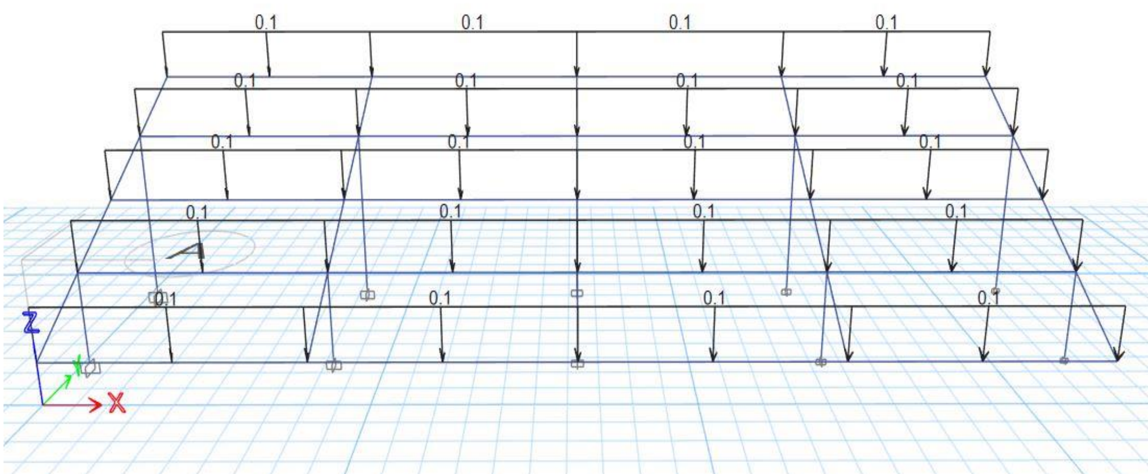


Fig 26: Solar panel load assignment in Etabs 18

The model is first prepared and then load is assigned in the frame. Primarily the load that acts on the solar frame model is dead load and wind load. Since the structure is not subjected to any live load, it is assumed as zero. The dead load includes the self-weight of the frame elements i.e., purlins, rafters and columns and the weight of the solar panel that is place on the frame. Each solar panel has a weight of 6kgs and the total weight of the solar panel amounts to 72 kg (12panels). The load is assumed to be equally distributed along the length of the purlins that comes as 0.1 kN/m. It is then assigned longitudinal in the purlins.

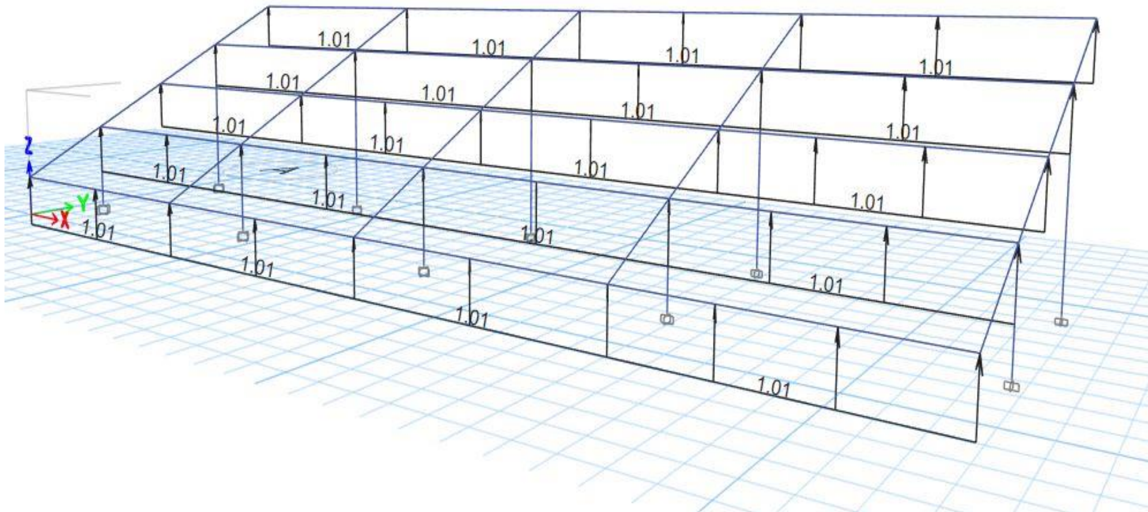


Fig 27: Wind load assignment in Etabs 18

The wind load that acts on the structural system varies according to the speed of the wind, therefore it varies from place to place. The wind load is calculated using Indian Standard code IS 875: 2015. The meteorological studies over the region reveals that the average wind speed in the location is 47m/s. The codal standard reveals the region falls in the terrain category 2. The importance of the structure and risk coefficient is normal for this kind of structure so it is taken as unity. The windward coefficient, Cp is taken as 0.4 and the leeward coefficient, Cp is taken as 0.6. Such condition creates a wind load that acts from inward to outward. The final wind load according to codal equations comes to be -1.01 kN/m

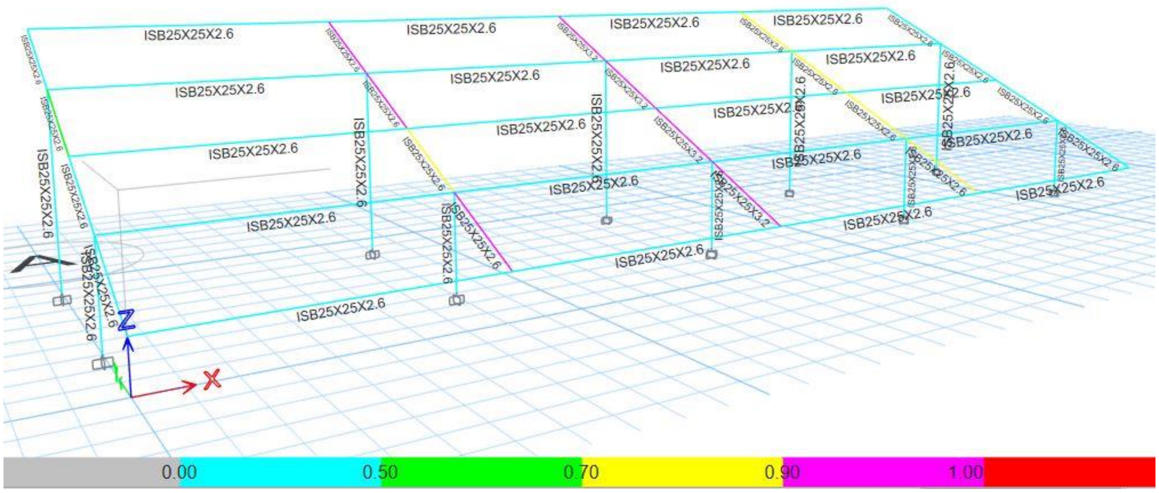


Fig 28: Analysis Result in Etabs

The analysis reveals that the structure easily passes the given loading condition using the assumed ISB frame sections therefore the analysis is redone assuming the lower size available. The iteration of the model involved ISB 25 x 25 x 2.6 in all the structural elements i.e. purlins, rafters and columns. The results showed that it passes easily in the same loading condition and frames would be using only upto 70% of their capacity. Therefore ISB 25 x 25 x 2.6 can be used for all the elements for assembling the solar frames.

Chapter 5: Conclusion and Recommendation

Narainapur is rich in solar potential which can be a reliable means to increase the ever-decreasing trend of agricultural production. The study has only taken two major crops for the study; however, many other minor crops are also grown in various seasons. All these crops can be taken into account forming a crop calendar which then can be used in CropWat to accurately predict the quantity of water required. The utmost requirement to maintain temperature which is increasing due climatic impact, for germination and seedling growth would be frequent irrigation. Nepal has its own variety of crop that are grown and the crop coefficient for those crops can be found out through field testing. This could be done for thorough calibration of Cropwat to properly estimate the water requirement. Few observation wells also should be dugged for finding out the water level which would be more relevant than the interpolated depth using distant well observation. Flooding rice continuously throughout the cropping season does not necessarily increase the yield. Draining the field for 7 to 14 days at tillering stage could be followed to save irrigation water.

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APPENDIX 1: AVERAGE GROUND WATER DEPTH

S.N	Wells	Lat	Long	Jan	Feb	Mar	Apr	May	Jun
1	Banjaregaon	28.0781	81.59331	2.07	2.22	2.48	2.75	3.16	3.01
2	Bankatuwa	28.2065	81.63073	3.20	3.20	3.43	3.74	4.17	4.23
3	Bhujai	28.0929	81.64787	1.89	1.95	2.30	2.81	3.38	3.28
4	Birta	28.0493	81.66163	3.36	3.53	3.92	4.29	4.60	4.34
5	Channawa	28.1874	81.6301	1.19	1.38	1.41	1.71	2.16	1.87
6	D-Gaon	28.1287	81.58943	2.17	2.45	2.51	2.90	3.36	3.09
7	Gaughat DW1	28.1223	81.51662	11.17	11.34	11.35	11.37	11.48	11.46
8	Gaughat DW2	28.1132	81.5173	10.01	10.63	10.36	10.30	10.31	8.86
9	Gaughat SW	28.1114	81.52169	3.12	3.52	3.86	4.20	4.48	4.49
10	Jabadhawa	28.2577	81.63618	2.95	2.97	2.96	3.11	3.79	3.81
11	Jaishpur	28.0243	81.60028	2.90	3.12	3.38	3.71	4.06	4.24
12	Kajurakurda	28.106	81.59716	2.14	2.10	2.44	2.70	3.04	3.04
13	Kalhansgaon	28.1465	81.55199	1.67	1.79	2.11	2.78	2.94	3.03
14	K-Gaon	28.0818	81.54664	4.24	4.85	4.70	5.23	5.42	4.50
15	Kharaicha	27.9833	81.71329	2.18	2.34	2.60	2.82	3.12	3.08
16	L-Gaon	28.096	81.52114	10.93	11.29	11.36	11.38	11.53	11.22
17	Office Compound	28.0812	81.64506	2.48	2.70	3.02	3.44	3.91	3.59
18	Parspur	28.0513	81.60245	2.49	2.73	3.01	3.60	3.94	4.09
19	Piprawa	28.1318	81.65881	2.60	2.71	3.12	3.48	3.81	3.76
20	Ramapurwa	28.0828	81.59568	1.90	2.17	2.57	2.71	3.07	3.12
21	Rohini Khola	28.0805	81.64193	3.27	3.48	3.68	4.17	4.47	4.00
22	Shikanpurwa	28.0151	81.65435	2.38	2.63	2.78	3.02	3.65	3.70
23	Thapawa	28.192	81.57475	1.40	1.58	1.52	1.95	2.18	2.13

S.N	Wells	Lat	Long	Jul	Aug	Sep	oct	Nov	Dec
1	Banjaregaon	28.0781	81.5933	2.29	1.59	1.32	1.49	1.68	1.91
2	Bankatuwa	28.2065	81.6307	2.98	2.54	2.34	2.39	2.33	3.07
3	Bhujai	28.0929	81.6479	1.52	0.58	0.64	0.82	1.27	1.58
4	Birta	28.0493	81.6616	3.22	2.77	2.65	3.15	2.88	3.28
5	Channawa	28.1874	81.6301	1.24	0.60	0.57	0.39	0.71	1.03
6	D-Gaon	28.1287	81.5894	2.01	1.24	1.06	1.16	1.55	1.92
7	Gaughat DW1	28.1223	81.5166	10.98	10.22	10.92	10.93	11.14	11.09
8	Gaughat DW2	28.1132	81.5173	9.47	7.93	9.05	9.35	9.81	9.47
9	Gaughat SW	28.1114	81.5217	2.97	2.46	2.32	2.47	2.69	2.98
10	Jabadhawa	28.2577	81.6362	2.54	2.04	2.02	2.15	2.38	2.72
11	Jaishpur	28.0243	81.6003	2.80	1.81	1.94	1.93	2.33	2.60
12	Kajurakurda	28.106	81.5972	2.11	1.50	1.32	1.45	1.69	1.93
13	Kalhansgaon	28.1465	81.552	1.95	0.89	0.74	0.85	1.17	1.45
14	K-Gaon	28.0818	81.5466	4.38	2.79	3.48	3.10	3.78	4.26
15	Kharaicha	27.9833	81.7133	2.12	1.50	1.31	1.51	1.69	1.96
16	L-Gaon	28.096	81.5211	10.66	9.97	10.49	10.68	10.84	10.82
17	Office Compound	28.0812	81.6451	2.00	1.41	1.42	1.60	1.99	2.44
18	Parspur	28.0513	81.6024	2.61	1.91	1.89	2.06	1.98	2.33
19	Piprawa	28.1318	81.6588	2.35	1.83	1.69	1.81	2.06	2.47
20	Ramapurwa	28.0828	81.5957	2.36	1.01	1.11	1.06	1.13	1.61
21	Rohini Khola	28.0805	81.6419	3.25	2.65	2.65	2.35	2.77	3.16
22	Shikanpurwa	28.0151	81.6543	2.41	1.30	1.28	1.48	1.89	2.05
23	Thapawa	28.192	81.5747	1.53	1.38	1.28	0.94	1.18	1.55