Proceedings of 15th IOE Graduate Conference
Peer Reviewed
Year: 2024 Month: May Volume: 15
ISSN: 2350-8914 (Online), 2350-8906 (Print)

Solar PV Lift Irrigation for Agriculture in Narainapur Rural Municipality, Banke

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Abstract
Climate change is a pressing global issue and its impact is already seen on various sectors like water sources, agriculture, biodiversity and livelihood. The agricultural sector, in particular, faces substantial challenges which can potentially trigger global food crisis in future. In 2022, Narainapur Rural Municipality (NRM), previously a major contributor to agricultural production of Banke district of Nepal, was declared drought hit area due to lack of proper rainfall. Therefore, this study aims to investigate the feasibility of solar powered lift irrigation to improve the agriculture productivity and livelihood in NRM. To determine the peak photovoltaic power required to irrigate a hectare of land in NRM, time series analysis was done on climatic datas from 1996 to 2023 for forecasting future trends upto 2040. Using FAO's Cropwat 8.0, the irrigation water requirement (IWR) for two major crops (rice and wheat) was calculated, identifying the maximum IWR of about 133.84 m3/day/hec in April in the year 2023. Similarly, ground water levels were analyzed from 2001 to 2023 for 18 wells located around the Banke District and ground water maps were prepared in Esri's ArcGIS 10.3 using Universal Kriging Method with the highest level of 9.87m found in the month of April. Based on these datas, the peak photovoltaic power required to operate a conventional pump was calculated to be 3.24 kWp. Then, system sizing was done to select economical solar irrigation components. A life cycle cost analysis was performed comparing the solar PV irrigation system with existing diesel based irrigation system. It was found that solar pv irrigation system was more economical and cost effective than the diesel based irrigation system. Thus, the study highlights the potential of solar-powered lift irrigation as a sustainable solution to address agricultural challenges in Narainapur rural municipality and similar regions.

Keywords
Irrigation water requirement (IWR), Ground water interpolation, Peak solar PV power, System sizing, Life cycle cost analysis

1. Introduction

Narainapur Rural Municipality (NRM) 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 to Banke's overall crop yield. However, the region has become a hotspot of the extreme climatic condition with possibility of hottest days and night, droughts, etc [1] resulting in rapid decline in agricultural productions in recent years. 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 [2]. Meanwhile, the progress of sikta irrigation project, a national pride project, remains slow with only 45% work completed on the eastern canal as per 2020 report [3] and it may take several years before it become fully operational for Narainapur which is located at the canal's tail end.

In response to these challenges, groundwater lift irrigation emerges as a promising solution. Groundwater offers a reliable and year-round water source to meet the irrigation water requirement (IWR) of agricultural fields. Today, the irrigation through solar power is gaining wider attention than ever before. Rapid increment of solar panel efficiency and falling cost have made it a suitable alternative for pumping water for higher and sustained agricultural yield. Nepal has huge solar energy resources about 50,000 terawatt-hours/year, which is one hundred times bigger than its hydro resource and 7,000 times greater than its present electricity consummation [4]. The use of clean energy also strips expenditure for diesel used in pumps, and reduces Nepal's petroleum import bill. The whole system of solar PV pumping system includes the solar panels, inverter and controllers, Motor, Pump and other miscellaneous parts like cables, pipes, etc.

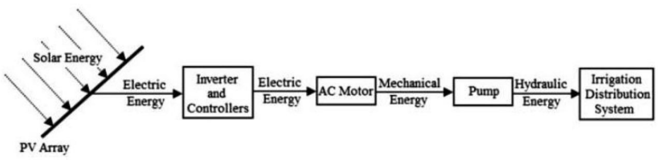

Figure 1: Schematic Diagram of PV solar irrigation system [5]

1.1 Problem Statement and Objective

According to the NEA's DCSD report for the fiscal year 2077/78 [6], the electrification status of Narainapur is at a mere 9.71%. The region suffers heavily due to power shortages, irregular electrical supplies and voltage fluctuation. Furthermore, the absence of farmland-to-farmland national grid connection intensifies this issues. Therefore, this study was undertaken to assess the feasibility of utilizing solar photovoltaic (PV) power for irrigation in Narainapur rural municipality . The specific objectives are: (1) To determine the IWR of the Narainapur rural municipality based on soil-type and climate characteristics. (2) To determine the monthly ground water levels in the area. (3) To calculate peak PV power required to fulfill the determined IWR. (4) To develop an economical sizing of solar PV system for irrigation (5) To conduct a cost comparison between solar PV system and the existing diesel based irrigation practice in the region

1.2 Literature review

The movement of water from plants to the atmosphere in the vapor form i.e. evapotranspiration (ET) serves as the basis for calucation of water requirement of plants. The Penman–Monteith method is considered one of the reliable methods for estimation of ET and IWR. FAO's software 'Cropwat,' which utilizes the Penman–Monteith method, is extensively used today for ET calculations.

Thakali [7] presented a study for calculation and supply of IWR of Tiri village in Mustang district. The study focused on utilizing water from the Khahare River. Two alternatives were explored: solar-powered and diesel-powered pumping. The findings indicated that the solar PV system was the preferable option when compared to its diesel-powered counterpart. Cuadros [8] presented a procedure to estimate the required size of PV system installation designed for a pumping system for a drip irrigation of an orchard of olive tree in Spain. The method involved determining the IWR, the depth of the aquifer, and calculating the peak PV power necessary to irrigate a 10-hectare plot. The method calculated the results with dependable in optimizing the sizing of the pv system. Parajuli [9] explored energy alternatives for pumping drinking water in a remote rural village of Nepal. Three technical scenarios for water pumping were formulated: utilizing petro-diesel, biodiesel, and solar PV pumps. The design process involved sizing the system components and estimating reservoir capacity. The analysis revealed that solar pumping emerged as the most viable option for efficiently pumping drinking water. Khan [10] conducted a study on the viability of solar-powered irrigation in Bangladesh, exploring the potential of PV technology to provide water for crop cultivation. Two alternatives: diesel and PV irrigation systems were considered, analyzing their costs over a ten-year period. The result revealed that the solar PV system significantly outperformed the diesel-based system in terms of cost savings.

2. Materials and methods

2.1 Study Area

The study area cover Narainapur rural municipality situated in Banke district in Lumbini Province, Nepal positioned at coordinates 27.93^0N and 81.66^0E. It spans an area of 172.34 km2 and is comprised of six VDCs. The area has a rough population of 34,942 and the region shares its border with the Indian state of Uttar Pradesh. The terrain elevation above the sea level is 141m. The lithological formation of the area is mostly comprised by recent formation having small portion of lower siwalik formation and upper siwalik formation in the upper region.

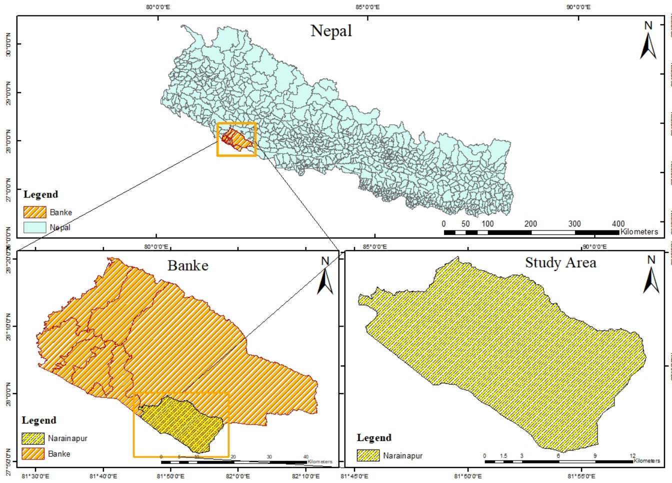

Figure 2: Map of Narainapur (Derived from GIS)

2.2 Data collection

The data required includes the meteorological data, soil characteristics and the ground water data. Table 1 tabulates these data, their range, the data sources and the results that are intended to be produced using these data.

Table 1: Climatic data, their sources and uses

S.N.	Data	Range	Data Source	Derivation
1	Rainfall Min Temperature Max Temperature Humidity Wind Velocity Sunshine Hours	2001-2023	Department of Hydrology and Meteorology	Irrigation water requirement (IWR)
2	Soil Characteristics	-	National Agriculture Research Centre (NARC)	Input values for Cropwat
3	Ground water data	2001-2023	GW-Nepal	Ground water level map

2.3 Methodology

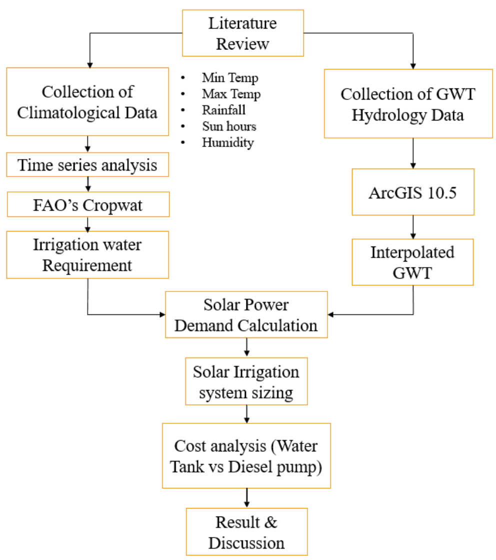

Figure 3: Methodology Flowchart

2.3.1 Time series analysis

A unique way of evaluation of a sequence of data points which are collected over a period of time is called a time series analysis. There are several methods for the analysis i.e., Seasonal & Non-seasonal method, ARIMA, multi linear regression etc. For the study, Oracle's crystal ball was used for statistical forecasting. The software automatically detects where it is stationary or has a seasonality and finds the best fit model for a given set of data along with its predicting accuracy.

2.3.2 Irrigation water requirement

Potential evaporation (PE) serves as a crucial metric for predicting Irrigation Water Requirement (IWR), utilizing relevant climatological data Modified Penman-equation is one of the best methods for estimation of evaporative values under diverse agro-climatic condition of any area. Programs like FAO's Cropwat offers various in-built method from which such values can be estimated effectively. The penman equation requires following data

a. Climate data: The data necessary for penman equation includes monthly rainfall, maximum and minimum temperature, relative humidity, wind velocity, sunshine hours. These data can be obtained from the relevant meteorological department within the region.

b. Effective rainfall: Effective rainfall is that proportion of rainfall that is utilized to fulfill the water requirement of the crop. Cropwat provides four empirical equations for estimating effective rainfall: fixed rainfall, empirical formulas, Dependable rain and USDA Soil conservation method. Bokke and shoro [11] suggests to use Dependable rain method in regions with adequate water availability whereas USDASC method in areas facing water scarcity when estimating effective rainfall. This mitigate the risk of water shortages.

c. Crop coefficient (K_c): It is defined as the ratio of actual crop evapotranspiration to reference crop evapotranspiration. It represents the combined influence of factors such leaf area, plant height, crop planting date, degree of canopy cover, canopy resistance, soil and climatic conditions and management practices. Kc values vary across different crops, the growing period and growth stages. Relevant data can be obtained from Irrigation and drainage paper no. 56 [12].

d. Soil moisture data: It is the moisture held in the pore spaces of the soil mass and which lies near the surface and within the crop root zone. Soil moisture plays vital role in transporting nutrients to plants and facilitating related physiological processes. Moreover it directly contributes to evaporation in the atmosphere.

Table 2: Soil texture and their corresponding available water [13]

S.no.	Soil Texture	Available Water 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

Table 3: Basic infiltration rates for various soil types [13]

S.N.	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

e. Irrigation schedule: It involves timing the supply of irrigation water precisely according to the water needs of the crops. Irrigation schedule deals with two primitive questions, (i) How much one has to irrigate? and (ii) How often one has to irrigate?. These factors are dependent upon the water needs of the crop.

All the data are passed into the software which gives the IWR for each considered crops and the supply scheme plan detailing the timing and amount of irrigation water required for each crops. Depending upon factors such as field application type and water conveyance through the available soil, irrigation efficiency is deduced by which the gross IWR is calculated which is then used for designing the final solar components.

2.3.3 Ground water level map

Today GIS is extensively used for the preparation of ground water level map. Spatial interpolation methods are applied to create these maps which employs mathematical functions to predict values at locations where no measured values are available. These method falls into two categories: deterministic and geostatistical. Most commonly used interpolation methods are Inverse distance weighing (deterministic) and Kriging (geostatistical).

2.3.4 Peak solar PV power

Cuadros [8] proposed a procedure to estimate the required size of PV system installation designed to start a pumping system for a drip irrigation of an orchard of olive tree located in Spain. The daily hydraulic energy, E_H required to pump a volume Q to a height H, is

$$E_H = \frac{\rho g Q H}{3600} \quad (1)$$

All notations refers to conventional symbols. 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, μG, of the photovoltaic generator (iv) the yield, μf , of the AC/DC converter (v) the yield, μMB, of the pump. Then the maximum energy input that has to be managed from the photovoltaic generator, E_{el}, will be:

$$E_{el} = \frac{(E_H + R)}{(G_d(> G_{threshold})\, x\, \mu G x\, \mu f\, x\, \mu MB)} \tag{2}$$

Acceptable optimized values of R is around 10% of E_H. Regarding the yields in the denominator part of the equation, Lorenzo (1994) [14] gives the values: $G_d > G_{threshold} = 0.95$, $\mu G = 0.85$, $\mu f = 0.90$, $\mu MB = 0.43$. The product of these yields gives the actual yield of the generator pump, i.e. in this case μ = 31.26 %. The power, P_{el}, of the photovoltaic generator is

$$P_{el} = \frac{E_{el}}{h} \tag{3}$$

Where, E_{el} is the required electrical energy (kWh), and h is the effective or functional number of hours of sun/day Finally, the power losses that occurs when the panels are operating above the standard 25°C can be taken into account which is near to 10% of the P_{el}. The required peak photovoltaic power, P (kWp) will be:

$$P = P_{el}(1 + 0.1) \tag{4}$$

2.3.5 System sizing

The process where the adequate voltage and current ratings for each component of the photovoltaic system is figured out to match the electric demand at the user's facility and calculating the total cost of the whole PV system from the design phase to the fully operational phase including shipment and labor is called the system sizing. Al-shamani [15] gives the economical sizing procedure for the the solar pv component which is as below:

a. Solar array sizing: The total daily energy in watt hours (E), the average sun hour/day, the arrangement's DC voltage (V_{dc}) must be ascertained before sizing.

Daily energy requirement,

$$E_r = \frac{\text{Daily avg. energy consumption}}{\text{Product of component efficiencies}} \tag{5}$$

$$\text{Peak power } (P_p) = \frac{\text{Daily energy requirement}}{\text{Min peak sun hours/day}} \tag{6}$$

$$\text{Total current required } (I_{dc}) = \frac{P_p}{V_{dc}} \tag{7}$$

$$\text{No. of parallel modules } (N_p) = \frac{I_{dc}}{I_r} \tag{8}$$

$$\text{No. of series modules } (N_s) = \frac{V_{dc}}{V_r} \tag{9}$$

$$\text{Total number of modules} = N_p \times N_s \tag{10}$$

b. Battery bank :

Requirement amount of rough energy storage,

$$E_{rough} = E \times D \tag{11}$$

Accounting safety factor,

$$E_{safe} = \frac{E_{rough}}{\text{Max depth of discharge (MDOD)}} \tag{12}$$

The capacity of battery bank (in amp-hrs),

$$C = \frac{E_{safe}}{V_b} \tag{13}$$

c. Voltage controller:

$$\text{Rated current of voltage controller}(I) = I_{sc} \times N_P \times F_{safe} \tag{14}$$

The factor of safety is employed to make sure that the regulator handles maximum current produced by the array to handle load current more than planned.

Number of controllers required,

$$N_{controller} = \frac{I}{\text{Amps of each controller}} \tag{15}$$

d. Invertor: The invertor is choosen which is reliable for the overall load. The voltage capacity of the selected invertor preferably be more than fifty percent than the design voltage on which the system operates. This ensures the invertor does not get damaged.

e. Irrigation pump: With the determination of design discharge and pumping height, the type of pump suitable for the study can be obtained using figure 4:

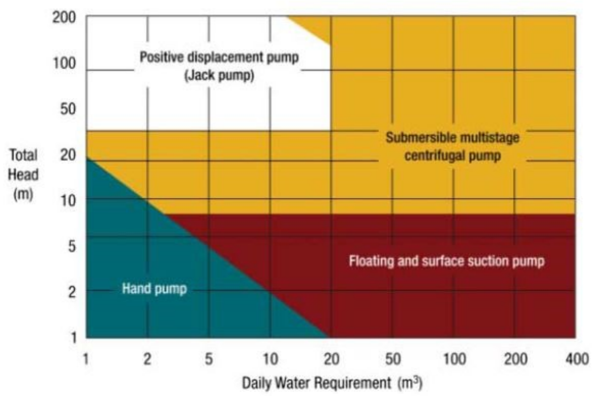

Figure 4: A guideline for pump selection [16]

2.3.6 Life cycle cost analysis

Life cycle cost is one of the method 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. All the future cost associated with project such as operational, replacement and maintenance associated is converted into the present worth to compare the alternatives in same base time period. Haque [17] explains the process as below:

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

$$PW = C_a \times P_a \tag{16}$$

Where,

$$P_a = \frac{\left[1 - \left\{\frac{(1+i)}{(1+d)}\right\}^N\right]}{(d-i)}$$

d = discount rate,
i = interest rate

3. Results and Discussion

3.1 Irrigation water requirement

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

Climate data: Narainapur does not have any weather recording instrument. Therefore, the study was conducted by taking the nearest climate gauge station present at Nepalgunj Regional Airport. It is located at an elevation of 165m (Lat 28°6'N and Long 81°40'E) from the sea level. The data from 1996 AD to 2021 AD (25 Years) from department of hydrology and meteorology (DHM).

Time series analysis: Crystal Ball's CB predictor was applied to find the trend of the meteorological data from a period of 1996 AD-2023 AD. Climatic parameters i.e., Rainfall (sum), maximum temperature, humidity, wind speed, sunshine hours showed that it aligns with the Seasonal-ARIMA model except for min temperature which fits with seasonal additive method. The predictor was used to forecast future data from 2023 AD to 2040 AD The root mean-square values (RMSE) shown by the program is as tabulated in Table 4.

Table 4: Climatic Parameters and their models

S.N.	Climatic Parameter	Best Fit Model	RMSE
1	Rainfall (Monthly Sum)	SARIMA Model	68.03
2	Min Temperature (Monthly average)	Seasonal Additive	1.0
3	Max Temperature (Monthly average)	SARIMA Model	1.5
4	Humidity (Monthly average)	SARIMA Model	1.5
5	Wind (Monthly average)	SARIMA Model	0.3
6	Sunshine Hours (Monthly average)	SARIMA Model	1.13

Effective rainfall: Dependable rain (FAO/AGLW formula) is used in the study as it fits best for Nepal since, every year in the monsoon Nepal gets good amount of rainfall.

Crop coefficient: Majorly, Narainapur grows paddy rice and wheat as the agricultural crop 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 because of increase in rooting depth & water needs. The various data that are required for Cropwat are tabulated in Table 5.

Table 5: Crop Coefficient Data

Particulars	Paddy Rice	Wheat
Planting Date	1st of July	7th of January
Harvesting Date	27th of December	16th of May
Crop Coefficient (Kc)		
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

Soil moisture data: A digital soil map of the country is made available by National Agricultural Research Centre (NARC). The soil data within the study area is taken and then fetched into Soil-Water Characteristics software by FAO through which relevant drainage characteristics to be used for the Cropwat was generated. 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 study area. Additionally, FAO's Irrigation and drainage paper no. 56 [12] was referred to obtained other required data.

Crop calender: The cropping patterns were studied, 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. In this study, rice and wheat are only taken into study.

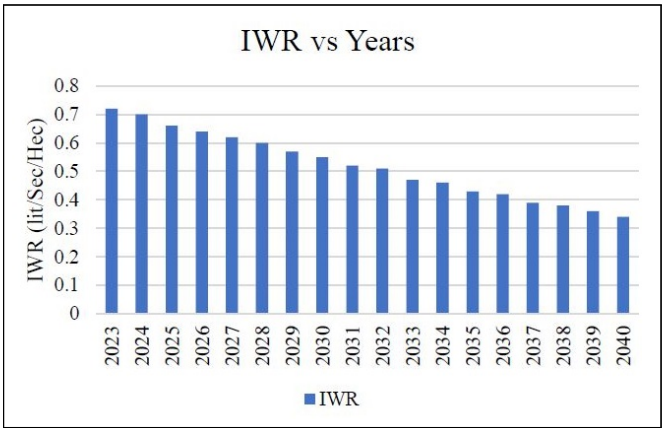

Figure 5: IWR vs Time

Irrigation water requirement: Paddy is generally transplanted in the 1st week of July; month which receives the highest rainfall for year. All forcasted data for each year from 2023 AD to 2040 AD were fetched into cropwat and IWR was calculated for each year and a graph was obtained between IWR(s) and time which is shown in figure 5. Taking into study only the two major crops i.e.. rice and wheat. The highest net IWR was found in April of 2023 AD which was found to be 0.72 lit/sec/ hec (68.25 m^3/day/hec). Surface irrigation is assumed for providing water in the field through furrow earthen canal in loamy soil for which conveyance efficiency and field application efficiency can be assumed as 85% and 60% [18]. The irrigation efficiency comes out to be only 51% which thereby concluded the gross IWR to be 133.84 m^3/day/hec.

3.2 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 data were taken from 18 well points which included both shallow and deep wells. The map presented in figure 6 is the boundary map of Banke along with the respective wellpoints. The lower corner is the study area whose ground water depth is interpolated from these 18 well points. Universal Kriging Interpolation was employed for the water level interpolation in Esri's ArcMap. The location of all those wells and their mean level were put into the software and interpolated to obtain the ground water map of the study area. The maps were prepared all months in the year which is as shown in figure 7 and 8.

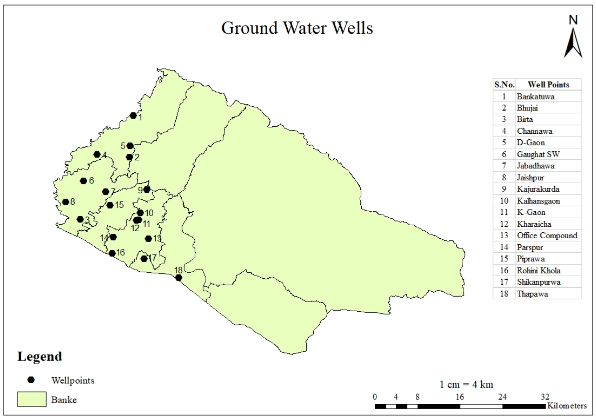

Figure 6: Location of ground water wells

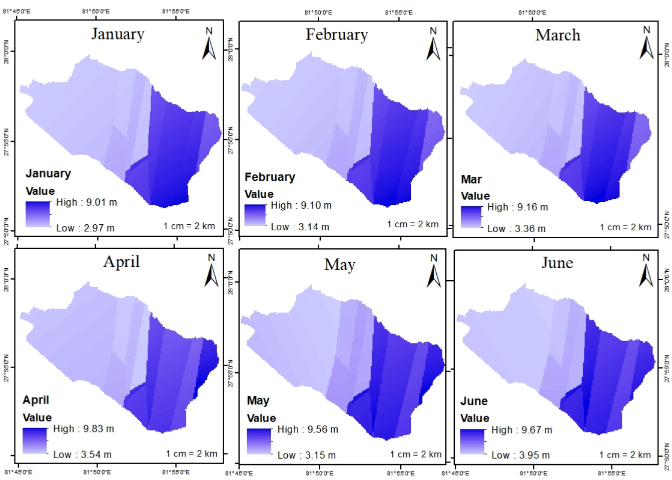

Figure 7: Ground water map (Jan-Jun)

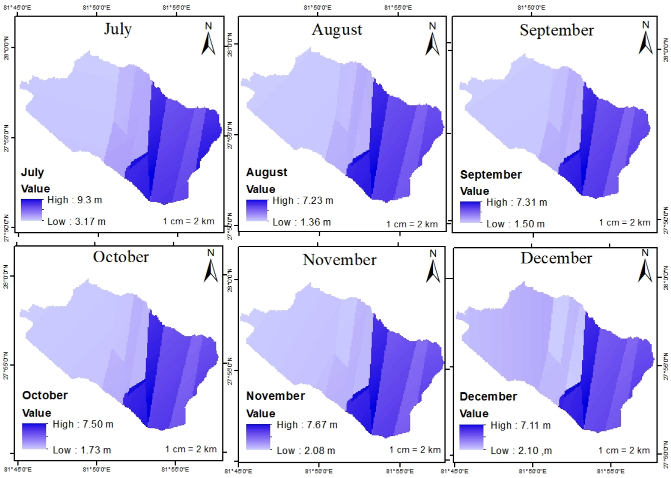

Figure 8: Ground water map (Jul-Dec)

The map shows the ground water depth for the first six month of the year. The color shade represents the depth of the water table i.e., lighter the shade shallower is the depth of the water table and vice versa. The result shows that in the month of April, the water table fluctuates in the range of 3.54m to 9.83m depth below for Narainapur. Similarly, the remaining six month of the year is also represented as shown. The results show that in the month of August, the water table fluctuates in the range of 1.36m to 7.23m depth for Narainapur. 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.

3.3 Peak solar photovoltaic power

The IWR is obtained from the Cropwat whereas, the ground water depth is obtained from map created using the GIS interpolation technique. Using the obtained results, the peak solar photovoltaic power is then computed.

Solar panel Efficiency (E_{sa})= 14 %,
Gravity Constant (g) = 9.81 m/s^2,
Pump Efficiency (E_p) = 43 %,
Gross IWR = 133.84 m^3/day/hectare
ρ = 1000 kg/m^2
R = 10%
G_d = 0.95
μG = 0.85 (Light energy to Electrical energy conversion)
μf = 0.9 (Conversion factor DC to AC)
μMB = 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. Table 6 shows the calculation for the peak solar photovoltaic power using the equation for the study area.

It is assumed that the pumping height of the motor is 10m (interpolation result). 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. 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,

Table 6: Peak solar photovoltaic power

S.N.	Month	Sunshine Hours Per day	Pumping Height (m)	GIWR Required (Q) (m^3/day)	Daily Hydraulic Energy (Eh) (kWh/day)	Frictional Loss (R) (kWh/day)	Required Electrical Power, Eel (kWh/day)	PV Generator Power, Pel (kW)	Required Peak PV Power (kWp)
1	Jan	5.61	14	133.84	5.11	0.51	17.97	3.20	3.24
2	Feb	7.05	14	133.84	5.11	0.51	17.97	2.55	2.57
3	Mar	7.75	14	133.84	5.11	0.51	17.97	2.32	2.34
4	Apr	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	Jun	7.29	14	133.84	5.11	0.51	17.97	2.47	2.49
7	Jul	6.87	14	133.84	5.11	0.51	17.97	2.62	2.64
8	Aug	6.57	14	133.84	5.11	0.51	17.97	2.74	2.76
9	Sept	6.77	14	133.84	5.11	0.51	17.97	2.65	2.68
10	Oct	7.1	14	133.84	5.11	0.51	17.97	2.53	2.56
11	Nov	7.05	14	133.84	5.11	0.51	17.97	2.55	2.57
12	Dec	6.64	14	133.84	5.11	0.51	17.97	2.71	2.73

the required peak PV power is calculated to be 3.24 kWp.

Since, the design discharge, pumping height is known, the type of pump that is required is multi-stage submersible centrifugal pump as deduced from figure 4. The pump used is powered by AC primarily due to the challenges associated with maintaining and repairing DC pumps in rural areas. Moreover, DC equipment is not readily available in market for replacements. AC power offers a reliable means to operate the pump in most challenging circumstances.

3.4 System Sizing

Sizing of solar array: Solar universe india SUI 250W, 24V solar panel is selected for the study. The number of required panel to supply for peak pv power requirement is 16. The price of each array in the market is about Rs. 13,255. So, the total cost of the panel required is Rs. 2,12,080 NPR.

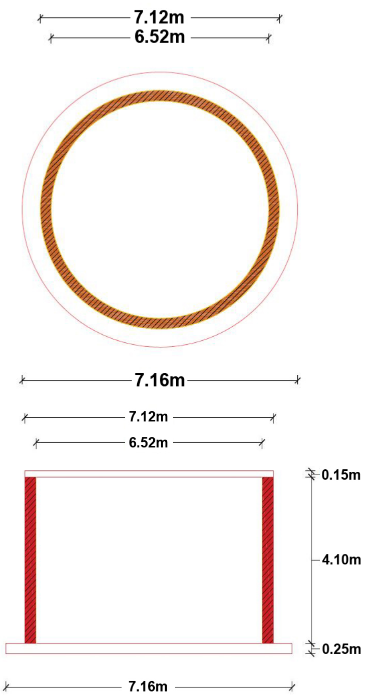

Figure 9: Concrete water tank

Sizing of concrete water tank: About 133.83 m^3/day water is required to irrigate a hectare of land. The back up water storage in case of cloudy days is taken as one day. 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. Essentially, the water tank has 3 section which are the base slab, wall and the top slab. About 0.25% of the volume of concrete is assumed to be of reinforcement for these parts. The cost of materials is taken from Banke's district rate 2079/80. The total cost associated to concrete tank comes out to be Rs. 7,08,360 NPR.

Sizing of voltage controller: For the voltage controller Daraz's luminous 20A solar charge Controller is used. The number of controllers required for the system operation is 7 and the total cost is around Rs. 16,625 NPR.

Sizing of 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 which cost about Rs. 3,000 NPR.

Sizing of submersible pump: For the study, Omax submersible 1 hp pump is used which costs Rs. 9,000 which is suffice for the given water demand. The 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.

The total cost associated with the solar PV system with concrete tank storage is approximately Rs. 10,13,040.

3.5 Life cycle cost analysis

Two alternatives are considered for continued supply of water (i) PV system with concrete water storage tank (ii) Diesel engine-based irrigation water pumping. The latter is the most common way of farmers irrigate their field at the present. From the report [19], Nepal Rastra Bank's inflation rate (2022/23), i = 7.50% Base Interest Rate, d = 10.64% was taken and the present worth factor (P_a) is calculated as 13.95%. Using this data, the following cost can be tallied to obtain the final life cycle cost of the solar based project. Similarly, the selected diesel engine is honda's WV30D model of 8 hp capacity which is generally employed in the field. The pump is assumed to be operated on specific time of the year which is taken as 6 months (about 4 hrs to pump the required quantity). Table 8 and 9 tabulates the operational and life cycle cost of diesel based system. Comparing the results in figure 10, solar pv system with concrete tank emerges as cost effiective is better and cost effective option than prevailing diesel based irrigation system in long term prospect.

Table 7: Life cycle cost analysis of solar PV system with concrete water tank

S.N.		Particulars	Nos.	Price (Rs.)
1.		**Capital Cost**		
	a	Total Cost of Module	16	20,2560.0
	b	Total Cost of Structure and Installation	1	75,000.0
	c	Construction of concrete water tank	1	7,08,360.0
	d	Total Cost of Voltage Controller	7	16,120.3
	e	Total Cost of Inverter	1	2,000.0
	f	Total Cost of Pump and Motor set	1	9,000.0
2.		**Recurrent cost**		
	a	Cost of maintenance per year	1	5,000.0
	b	Concrete tank maintenance per year	1	5,000.0
	c	Replacement Cost of Inverter	1	2,000.0
	d	Replacement Cost of Pump and Motor set (Pa = 13.95)	1	9,000.0
3.		Present Worth of Recurrent costs		10,788.5
4.		Life Cycle Cost (1,3)		10,13,040.0

Table 8: Operating cost of diesel based irrigation system

S.N.	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 liter	Rs	165
5	Cost of Lube per liter	Rs	1200
6	Consumption of fuel per Hour	Liters	0.75
7	Consumption of Lubricant Oil (% of Diesel)	%	1
8	Irregular rainfall or deficit months	No.	6
9	Number of Working Days per year	Days	180
10	Working Hours (4 hr/day)	Hours	720
11	Fuel's Total Consumption	Liters	540
12	Lube Total Consumption	Liters	5.4
13	Maintenance Cost	Rs	5000
14	System Head	meters	10
15	Annual Discharge	m^3	96360
16	Life of (Pump, Engine)	Years	10

Table 9: Life cycle cost analysis of diesel based irrigation system

S.N.	Particulars	Annual Cost (Rs.)	Present Worth (Rs.)
1	Capital Cost (pump & accessories)		80,000
2	Replacements (Pump & Engine)		75,000
3	Maintenance	5,000	69,750
4	Fuel, Lube Oil	1,19,475	13,33,340
	Total Annual Cost	1,24,475	
5	Life Cycle Cost		15,58,090

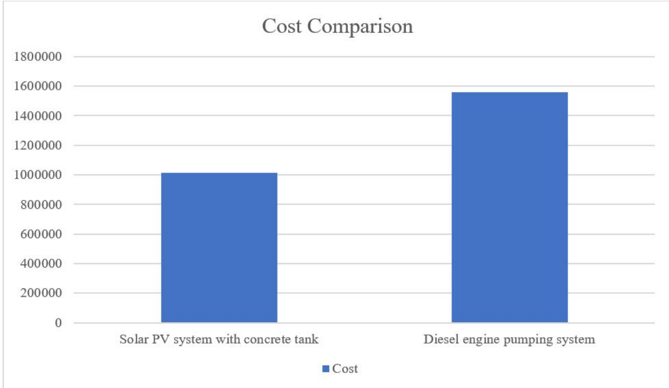

Figure 10: Solar based system vs Diesel based system

4. Conclusion

Narainapur holds signification solar potential which can be a reliable means to counter the concerning decline in agricultural productivity. While, the study focused on only two major crops, it is imperative to include other minor crops which are grown throughout the year. Understanding the diverse crop profiles of Nepal and conducting field testing to determine their specific crop coefficients would yield more accurate results. Additionally, the establishment of observation wells in strategic locations will provide more relevant data on water levels, which will surpass the limitations of interpolated depths derived from distant observations.

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