Appendix 3A: Irrigation methods and water requirements for various crops

Name of Crop	Method of Irrigation	Width of Bed (cm)	Bed to Bed Distance (cm)	No. of Canals	Required water Height (cm)	Water Volume (m^3/hectare)
Rice	Basin	n/a	n/a	n/a	5	500
Wheat	Basin	n/a	n/a	n/a	7	700
Potato	Furrow	25	60	118	4	283
Maize	Furrow	110	30	72	7	152
Onion	Furrow	100	30	78	2.5	58
Tomato	Furrow	100	30	78	3.5	82
Sugarcane	Furrow	120	30	67	12.5	253
Cotton	Basin	n/a	n/a	n/a	7	700
Chili	Furrow	100	30	78	5	117
Carrot	Furrow	100	30	78	5	117
Soybean	Basin	n/a	n/a	n/a	6	600
Garlic	Furrow	90	30	84	6.5	164
Brinjal	Furrow	100	30	78	3	70
Gourd	Furrow	560	40	18	4	28
Sunflower	Basin	n/a	n/a	n/a	8	800
Ginger	Furrow	100	30	78	3.5	82
Strawberry	Furrow	100	90	53	8	383
Turmeric	Furrow	90	30	84	4.5	114
Lentil	Basin	n/a	n/a	n/a	5	500
Pumpkin	Furrow	330	30	29	6	52
Cabbage	Furrow	90	30	84	5	126
Cauliflower	Furrow	100	30	78	4	93
Mustard	Basin	n/a	n/a	n/a	5	500
Banana	Furrow	105	30	75	4	90
Ladyfinger	Furrow	100	30	78	3	70
Papaya	Furrow	200	30	44	5	67
Groundnut	Furrow	40	20	167	4	134

Appendix 3B: Demographics and socioeconomic profile of Villages in the study area

Sl No.	Village Name	No. of Household	No. of Surveyed Households	Village Population	Avg. Monthly Income of Household
1	Ahataguri	209	26	1045	₹ 12,418
2	Alisinga Urium Guria	506	22	2024	₹ 13,682
3	Amolapaam	474	29	2370	₹ 13,043
4	Baghchong	209	25	1045	₹ 12,412
5	Barghat	693	23	3465	₹ 12,957
6	Betani Jhar	552	25	2760	₹ 11,892
7	Bhaluk Jharani	365	10	2190	₹ 13,200
8	Bharali Chapari	357	31	1785	₹ 12,245
9	Bhito Suti	695	31	2780	₹ 13,255
10	Bhitor Poruwa	237	28	1185	₹ 12,377
11	Bihia Gaon	167	33	835	₹ 13,026
12	Bokajan	960	36	4800	₹ 13,388
13	Borguri	917	27	4585	₹ 13,066
14	Chaki Ghat	190	27	950	₹ 12,402
15	Chala T.E	528	28	2640	₹ 12,569
16	Chalabasti Gaon	210	28	1050	₹ 12,436
17	Chamdhara	487	41	2435	₹ 11,737
18	Chatai Chapari	848	30	4240	₹ 12,559
19	Chilabandha Sonari	90	32	450	₹ 12,858
20	Chola Gaon	486	31	2430	₹ 13,022
21	Dikaraijan	542	30	2710	₹ 12,852
22	Gorchinga Bihia	396	30	1980	₹ 12,890
23	Goroimari	352	29	1760	₹ 12,772
24	Haleswar	187	28	935	₹ 12,607
25	Harigaon	1135	33	6810	₹ 10,515
26	Jaglowani	357	29	1785	₹ 12,565
27	Jahajduba Gaon	248	30	1240	₹ 12,689
28	Karai Bari	631	30	3155	₹ 12,746
29	Karaiani Bangali Gaon	527	31	2635	₹ 12,836
30	Karaini Nepali	420	31	2100	₹ 12,879
31	Kashi Kani	209	30	1045	₹ 12,829
32	Khalihamari	718	38	3590	₹ 16,807
33	Khanamukh	307	29	1535	₹ 12,737

34	Korokani	441	5	1764	₹ 9,800
35	Napam	924	29	4620	₹ 12,705
36	No. 1 Makua Chapari	31	29	155	₹ 12,676
37	No.1 Gataimari	403	30	2015	₹ 12,688
38	No.1 Malijan	382	30	1910	₹ 12,743
39	No.1 Tenga Basti	85	30	425	₹ 12,796
40	No.2 Gotaimari	355	30	1775	₹ 12,805
41	No.2 Makua Chapri	27	30	135	₹ 12,797
42	No.2. Malijan	150	30	750	₹ 12,765
43	No.3 Gotaimari	234	29	1170	₹ 12,727
44	No.3 Makua Chapari	41	30	205	₹ 12,710
45	Parmai Gauli Gaon	38	30	190	₹ 12,722
46	Poruwa	641	10	2564	₹ 10,602
47	Poruwa Bagisa	112	30	560	₹ 12,742
48	Pung Pani Bangali	395	30	1975	₹ 12,766
49	Puniani	655	30	3275	₹ 12,781
50	Purani Alimur	234	30	1170	₹ 12,778
51	Rajgor	372	30	1860	₹ 12,766
52	Saikia Chuburi Dekar	288	30	1440	₹ 12,759
53	Salani Gaon	246	30	1230	₹ 12,761
54	Salmara	559	30	2795	₹ 12,744
55	Singitali	677	30	3385	₹ 12,733
56	Siruani	404	30	2020	₹ 12,733
57	Sita Basti	154	70	770	₹ 13,500
58	Sola Gaon	486	30	2430	₹ 12,744
59	Tangana Jhar	434	30	2170	₹ 12,758
60	Tengabasti	85	30	425	₹ 12,766
61	Urium Guri	544	30	2176	₹ 15,567

Appendix 3C: Python script to simulate the performance of a PV system using pvlib-python

```
import pvlib

import pandas as pd

import calendar

import matplotlib.pyplot as plt

import json


def simulate_pv_energy_output_monthly(system_size_kw, temp_data_c,
monthly_insolation_kwh_m2, module_type, module_efficiency):

    # PV system configuration

    location = pvlib.location.Location(latitude=26.0, longitude=91.5)  # Example
coordinates (Assam, India)

    surface_tilt = 30  # Typical tilt angle in degrees

    surface_azimuth = 180  # South facing


    # Create a fixed tilt PV system

    module_parameters = {

        "pdc0": system_size_kw * 1000,  # System size in W (converted from kW)

        "gamma_pdc": -0.004,  # Typical temperature coefficient of power

    }


    inverter_parameters = {

        "pdc0": system_size_kw * 1000,  # Inverter size in W (matching the system
size)

    }


    # Define the PV system with specified parameters

    system = pvlib.pvsystem.PVSystem(

        surface_tilt=surface_tilt,

        surface_azimuth=surface_azimuth,

        module_parameters=module_parameters,

        inverter_parameters=inverter_parameters,

        modules_per_string=1,
```

```
        strings_per_inverter=1,
    )

    monthly_energy_output = []

    # Loop through each month to calculate energy output
    for month in range(1, 13):
        # Get the number of days in the month
        days_in_month = calendar.monthrange(2024, month)[1]

        # Convert daily insolation to hourly GHI (Global Horizontal Irradiance) in Wh/m^2
        ghi = monthly_insolation_kwh_m2[month - 1] * 1000  # Convert kWh/m^2 to Wh/m^2
        times = pd.date_range(start=f"2024-{month:02d}-01 00:00", end=f"2024-{month:02d}-{days_in_month} 23:00", freq="h", tz=location.tz)
        ghi_data = pd.Series([ghi / 24.0] * len(times), index=times)  # Spread daily GHI over 24 hours for each day
        temp_data = pd.Series([temp_data_c] * len(times), index=times)  # Constant temperature data for the month

        # Create a DataFrame for weather data including GHI, temperature, and wind speed
        weather = pd.DataFrame({
            "ghi": ghi_data,
            "temp_air": temp_data,
            "wind_speed": [0] * len(times),  # Assume no wind
        })

        # Calculate plane-of-array (POA) irradiance
        solar_position = location.get_solarposition(times)  # Get solar position data for each timestamp
        poa_irradiance = system.get_irradiance(
            solar_zenith=solar_position['apparent_zenith'],
            solar_azimuth=solar_position['azimuth'],
```

```
            dni=weather['ghi'],
            ghi=weather['ghi'],
            dhi=weather['ghi'] * 0.2  # Assume 20% of GHI is diffuse irradiance
(adjustable based on region)
        )

        # Calculate cell temperature using the PVSyst model
        temp_cell =
pvlib.temperature.pvsyst_cell(poa_global=poa_irradiance['poa_global'],
temp_air=temp_data, wind_speed=weather['wind_speed'])

        # Calculate DC power output using PVWatts model
        dc_power = system.pvwatts_dc(poa_irradiance['poa_global'], temp_cell)

        # Convert DC power to AC power using inverter model
        ac_power = pvlib.inverter.pvwatts(dc_power, inverter_parameters['pdc0'])

        # Integrate AC power over the month to get total energy output in kWh
        monthly_energy_output_kwh = ac_power.sum() / 1000  # Convert Wh to kWh
        monthly_energy_output.append(monthly_energy_output_kwh)

    # Calculate total annual energy output by summing monthly outputs
    total_annual_energy_output_kwh = sum(monthly_energy_output)

    return monthly_energy_output, total_annual_energy_output_kwh

if __name__ == "__main__":
    # Get user inputs with validation
    try:
        # Input for system size
        system_size_kw = float(input("Enter the system size in kW (positive number):
"))
        if system_size_kw <= 0:
            raise ValueError("System size must be a positive number.")
```

```
        # Input for average ambient temperature
        temp_data_c = float(input("Enter the average ambient temperature in Celsius: "))

        # Monthly insolation input for each month
        monthly_insolation_kwh_m2 = []
        for month in ["January", "February", "March", "April", "May", "June", "July", "August", "September", "October", "November", "December"]:
            insolation = float(input(f"Enter the average daily insolation in kWh/m^2 for {month}: "))
            if insolation <= 0:
                raise ValueError("Insolation must be a positive number.")
            monthly_insolation_kwh_m2.append(insolation)

        # Module type selection
        module_choice = int(input("Select the module type: 1 for polycrystalline, 2 for monocrystalline: "))
        if module_choice == 1:
            module_type = 'polycrystalline'
        elif module_choice == 2:
            module_type = 'monocrystalline'
        else:
            raise ValueError("Invalid choice. Please enter 1 or 2.")

        # Input for module efficiency
        module_efficiency = float(input("Enter the module efficiency (as a decimal, e.g., 0.20 for 20%): "))
        if module_efficiency <= 0 or module_efficiency > 1:
            raise ValueError("Module efficiency must be between 0 and 1.")

    except ValueError as e:
        # Handle invalid input
        print(f"Invalid input: {e}")
```

```
        exit(1)


    # Calculate energy output
    monthly_energy_output, total_annual_energy_output_kwh =
simulate_pv_energy_output_monthly(
        system_size_kw, temp_data_c, monthly_insolation_kwh_m2, module_type,
module_efficiency
    )


    # Print monthly and annual energy outputs
    for i, month in enumerate(["January", "February", "March", "April", "May",
"June", "July", "August", "September", "October", "November", "December"]):
        print(f"Estimated energy output for {month}: {monthly_energy_output[i]:.2f}
kWh")
    print(f"Total estimated annual energy output:
{total_annual_energy_output_kwh:.2f} kWh")


    # Graphical Representation of monthly energy output
    plt.figure(figsize=(10, 5))
    plt.bar(
        ["January", "February", "March", "April", "May", "June", "July", "August",
"September", "October", "November", "December"],
        monthly_energy_output, color='skyblue'
    )
    plt.xlabel("Month")
    plt.ylabel("Energy Output (kWh)")
    plt.title("Monthly Energy Output")
    plt.xticks(rotation=45)
    plt.tight_layout()
    plt.show()


    # Export results to a JSON file if the user chooses to
    export_choice = input("Do you want to export the results to a JSON file?
(yes/no): ").lower()
    if export_choice == "yes":
```

```
        output_data = {
            "monthly_energy_output": {month: output for month, output in zip(
                ["January", "February", "March", "April", "May", "June", "July",
"August", "September", "October", "November", "December"],
                monthly_energy_output
            )},
            "total_annual_energy_output_kwh": total_annual_energy_output_kwh
        }
        with open("pv_energy_output.json", "w") as json_file:
            json.dump(output_data, json_file, indent=4)
        print("Results exported to 'pv_energy_output.json'")
```

Appendix 3D

SURVEY FORM (Household)

1. **Name of Respondent :**____

2. **Address: House No.**__________________________**Locality** __________________________

   Village/Town__________________________**Development Block**______________________

   P.O ______________________ **District**____________________**PIN** __________________

Household type (Please tick)

Residential	Commercial	Community building	Educational Institute	Others (Please specify)

Location: Latitude:______________________ **Longitude:** ___________________________

3. **Family Members** (*Please indicate number of members*):

Adults	Children (Below 18 Years)

4. **Educational status/Occupation of family members**

Name	Sex	Occupation	Primary (level 1-5)	High school (level 6-10)	College or University	Other

5. **Monthly income of the household**

₹____

6. **Cooking Fuel used?**

Fuel Type	**Kerosene (liter)**	**Biogas (Capacity, m³)**	**LPG (cylinder)**	**Firewood (kg)**	**Dung (kg)**	**Agricultural residue (kg)**	**Coal (kg)**	**Charcoal (kg)**	**Any other (e.g., electricity)**
Amount consumed monthly									
Price of fuel (₹/unit)									

(**N.B**: *In case you collect any fuel please write collected in place of price*)

7. **Problem faced to get cooking fuel** *(Please Tick √)*

Frequently	**Never**	**Rarely**	**Cannot say**

8. **When you choose a fuel, what is most important to you? Please, rank your preference 5 to 0 (5 the most important and 0 not important at all)**

Item	**Ranking**
Price	
Convenience	
Cost of the stove/burner	
Low smoke level (cleanliness of the workplace)	
Conserve energy	
Save environment	
Availability	

9. **Type of stove used for cooking.**

Stove types	**Tick**	**Remarks, if any**
Traditional mud stove		
Improved mud stove		
Pressurized Kerosene stove		
Wick kerosene stove		
LPG burner		

SURVEY FORM (Household)

Department of Energy, Tezpur University

Biogas stoves		

10. A) Willingness to change cooking fuel (Mark √)

Yes	No

B) If "Yes" at above, reason to change? Please, rank your preference 5 to 0 (5 the most important and 0 not important at all)

Reasons	Ranking
To save money spent in fuel	
To get rid of smoke	
Care the occupants including children	
Collecting fuel takes long time	
Cannot cook typical food	
Other, specify:	

C) Would you be willing to pay more to change the cooking fuel?

Yes	No

11. Electrification status (Please tick)

Electrified	Non-electrified

12. If electrified then please provide the following details (As per Electricity Bill)

Consumer No.	Consumer category	Total connected electrical load (kW)	Average monthly consumption	
			Summer	Winter

13. Electrical network data

Electrical network connected to (Please tick(√))		Distance to nearest transmission pole	Location of transmission pole		Nearest Electricity Sub-station	Distance to Electricity Sub-station
			Latitude	Longitude		
HT (11 kV and above)						
LT (440 V)						
LT (240 V)						

14. Roof top status

Roof type (please tick)		Roof Condition	Total rooftop area (m^2)	Shadow and obstacle free south facing roof area		
RCC	Tin Shed			Available	Not available	Total available area (m^2)

15. Fuels used for lighting. Please, specify the amount of fuel consumed monthly

Type of source	Amount	State (Regularly/Sometimes/Not frequently)
Kerosene (liters)		
Solar (Solar size (kW))		
Car batteries (Voltage*Current)		
Dry batteries (Voltage*Current)		
Candles (numbers)		
Diesel Generator (liters)		
Electricity (kWh)		
Others (Please specify)		

16. Uses of appliances (for electrified household)

Appliance	Number	Rating	Operating Hours (Per day)
Television			
Refrigerator			
Fan			
Air Conditioner			
Air Cooler			
Water Heater (Geyser)			
Electric kettle			
Mobile (Charging)			
Computer/Laptop (Charging)			
Incandescent Bulb			
Fluorescent Bulb			
CFL Bulb			
LED Bulb			
Water pump			
Others (Please specify)			

17. Use of vehicles/ heavy equipment

Type of vehicle	Number	Fuel	Amount of fuel/month	Cost per month
Scooter				
Motor Cycle				
Light Motor Vehicle (Car)				
Medium Goods Vehicle				
Heavy Motor Vehicle				
Heavy Goods Motor Vehicle				
Heavy Transport Vehicle				
Tractor				
Harvester				
Mill				

Others (Please specify)				

18. Water consumption?

Source	Used for (Please tick)				Amount Consumed (Liters per day)
	Cooking	Drinking	Washing	Others	
Tap water					
Public Tap water					
Own tube well					
Ponds					
Community tube well					
River					
Other (specify)					

19. Could you give us your production of various cereal and other agriculture products?

Descriptions	Varieties	Area	Owned or leased	Harvesting Practice	Yearly Production in Kg	Residue amount	Residue uses	Residue selling cost (₹/kg)
Rice								
Wheat								
Mustard seed								
Maize								
Vegetables								
Jute								
Sugarcane								
Other (specify)								

20. Land use/ Land Cover status

Area of Land owned	Land being used for	Surrounding Area Land use	Water body type in the area (if present)	Area of water body

21. Livestock and present practices of using manure. (If 'yes' Please indicate type and number of livestock owned)

Type of Livestock	Cow	Buffalo	Goat	Poultry	Duck	Pig	Other Specify
Number							
Main product							
By-product							
Manure							

Name of the Surveyor	
Contact	
Signature with Date	

Name & Address	Type of Industry	Manpower	
		Permanent	Temporary

A	About machinery					
	Name/type of machinery	Fuel consumption		Type of operation	Working hours/day	Specification/Remarks
		Type	Quantity/hr			
i						
ii						
iii						

B	About Inputs & Outputs				
	Inputs (Raw materials)			Outputs (Goods)	
	Type	Quantity/day	Type of use	Type	Quantity/day
i					
ii					
iii					

C	About fuel uses						
	Kerosene	Electricity	Petrol	Diesel	Coal	Fuelwood	Other
i	L/month	Monthly unit (KWh)	L/month	L/month	Tonne/month	Tonne/month	
ii							

D	About water uses				
	Tube well ,L/day	Well , L/day	Supply, L/day	Centrifugal pump (Rate of discharge, HP, hr/day)	Other
i					

E	About comfort						
	Item	Make, model	Purchase Yr	Size	No.	hr/day	Remarks
i	Fan						
ii	Electrical Heater						
iii	Air conditioner						
iv	Any other						

F	Difficulty faced in	Lighting	Transportation	Infrastructure	Any others

Personnel Experiences on Energy Crisis	Signature

Surveyor Name:______________________________**Contact no.**_______________________**Signature**__________________

Appendix 3E: Spatial map of monthly PVS output

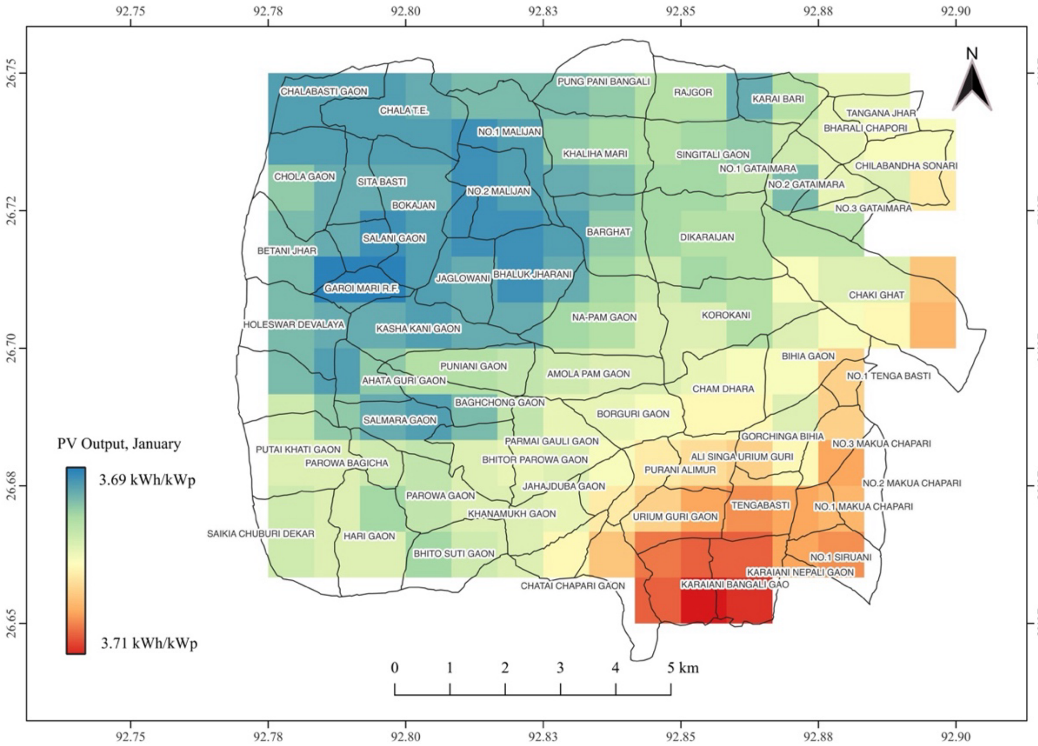

Fig 3E (a): Spatial map of monthly PVS output (January)

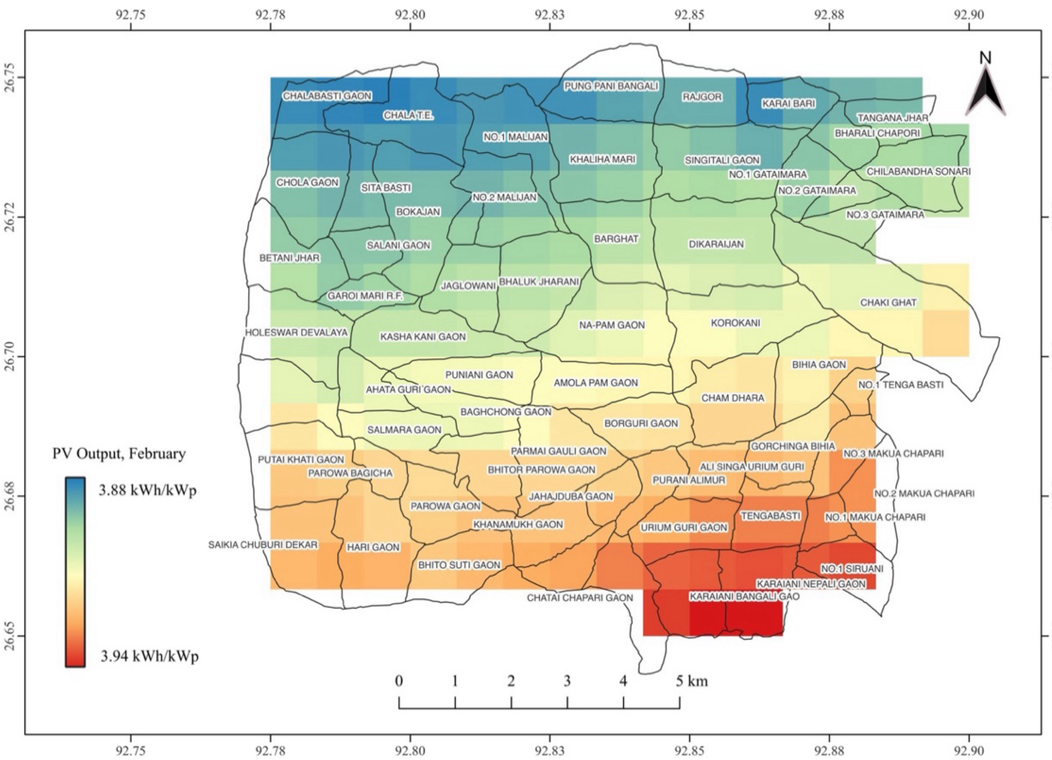

Fig 3E (b): Spatial map of monthly PVS output (February)

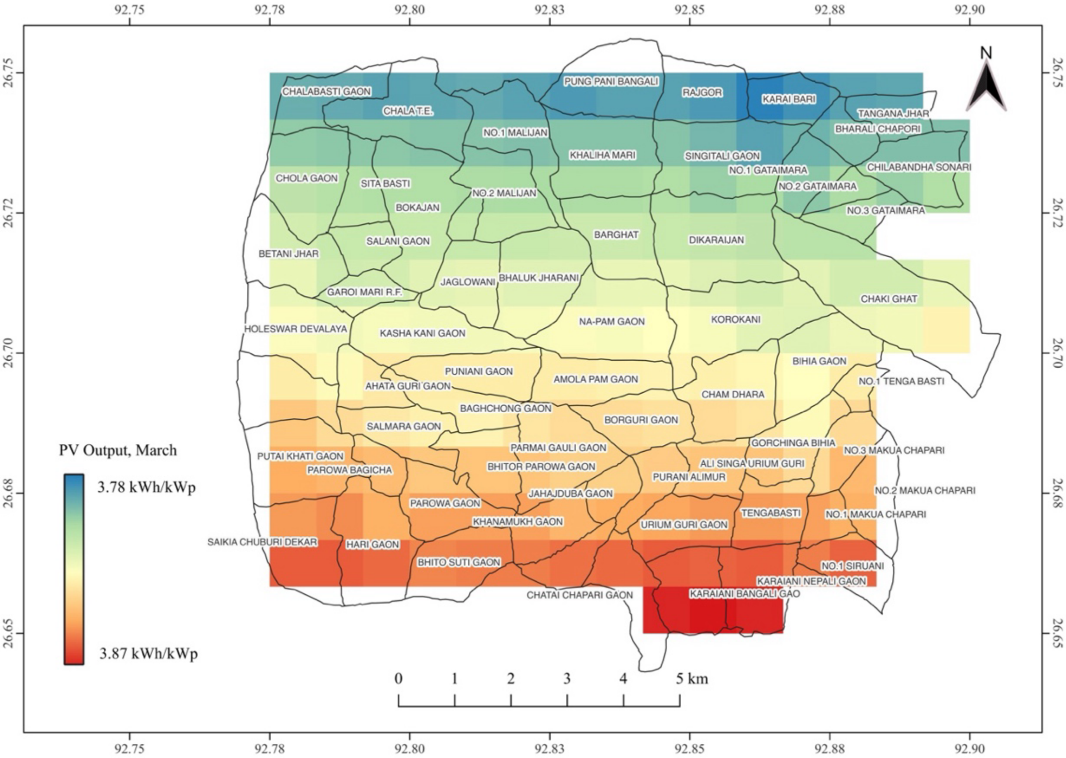

Fig 3E (c): Spatial map of monthly PVS output (March)

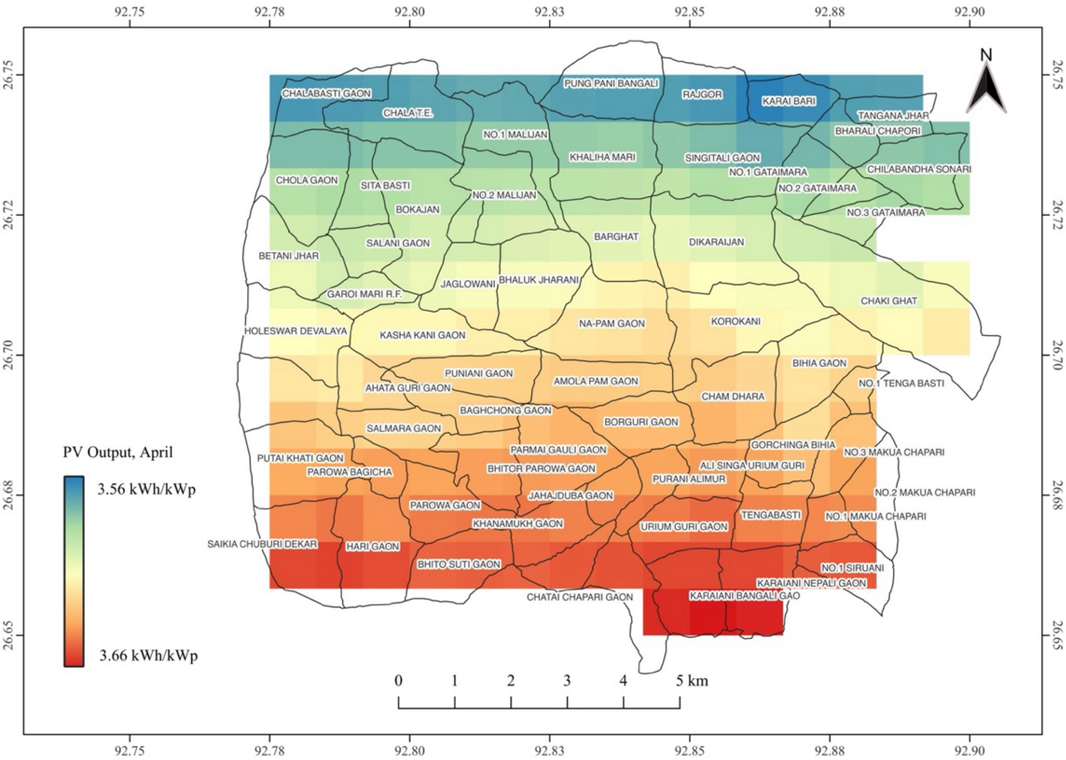

Fig 3E (d): Spatial map of monthly PVS output (April)

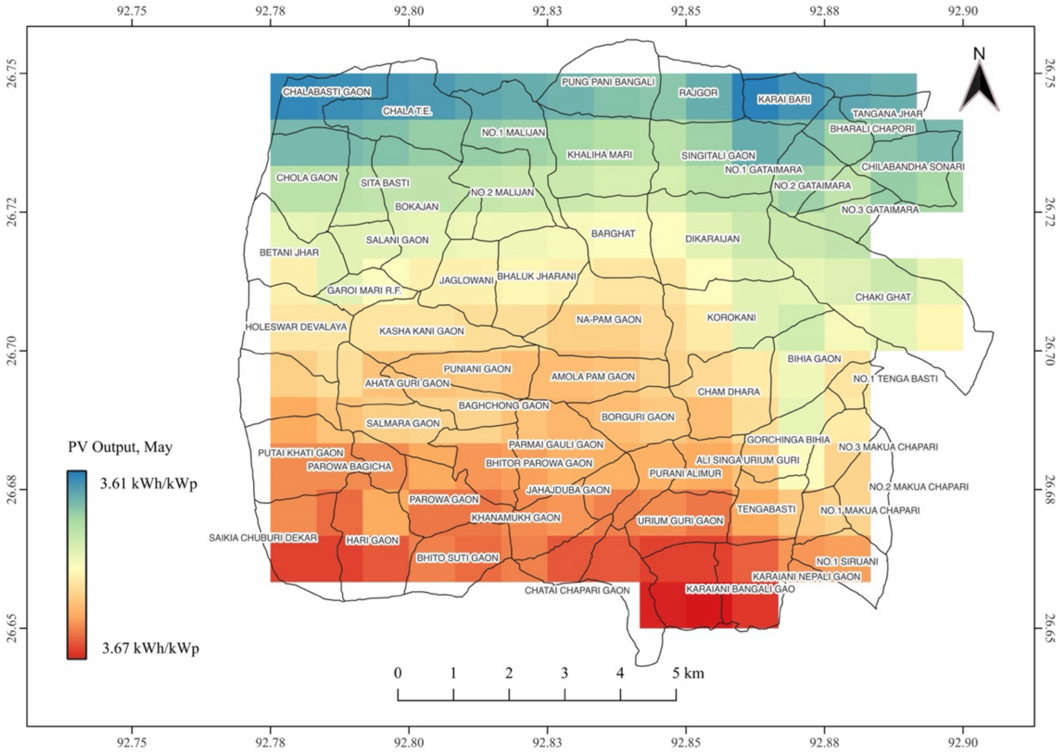

Fig 3E (e): Spatial map of monthly PVS output (May)

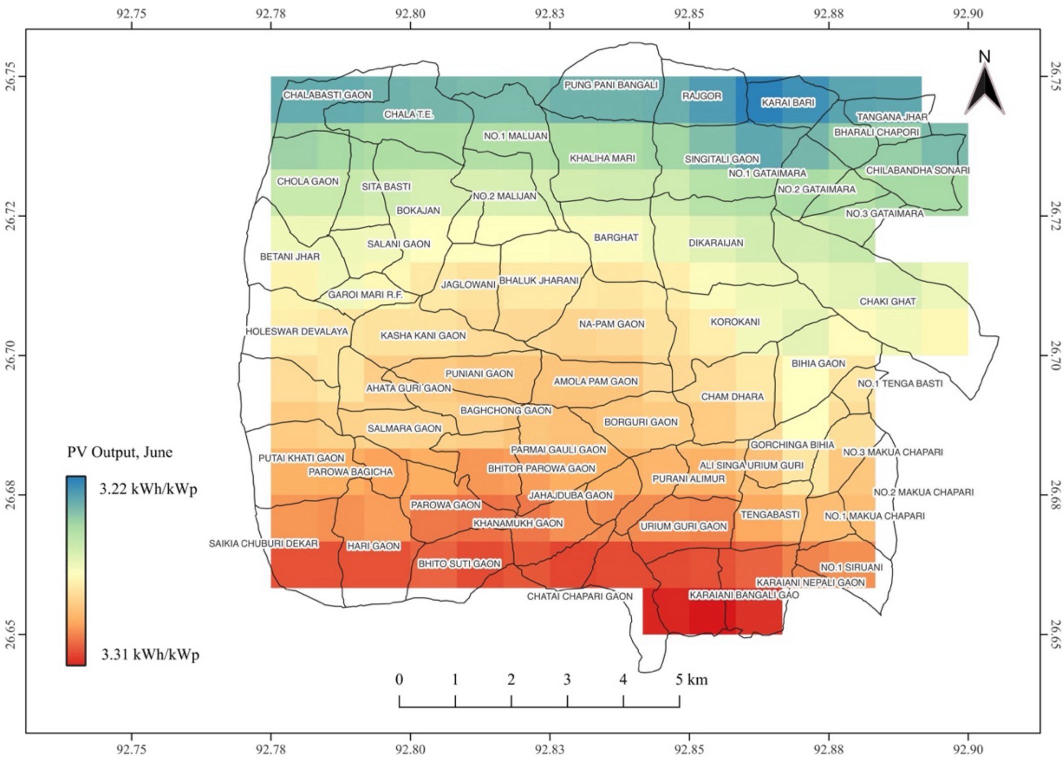

Fig 3E (f): Spatial map of monthly PVS output (June)

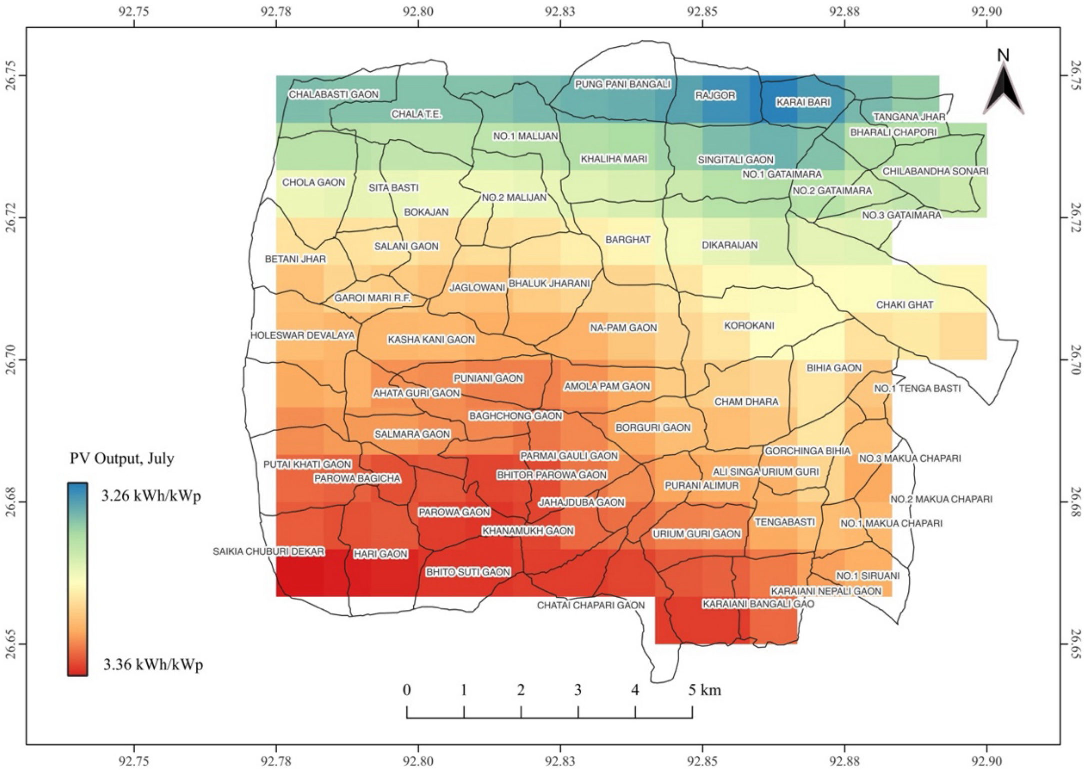

Fig 3E (g): Spatial map of monthly PVS output (July)

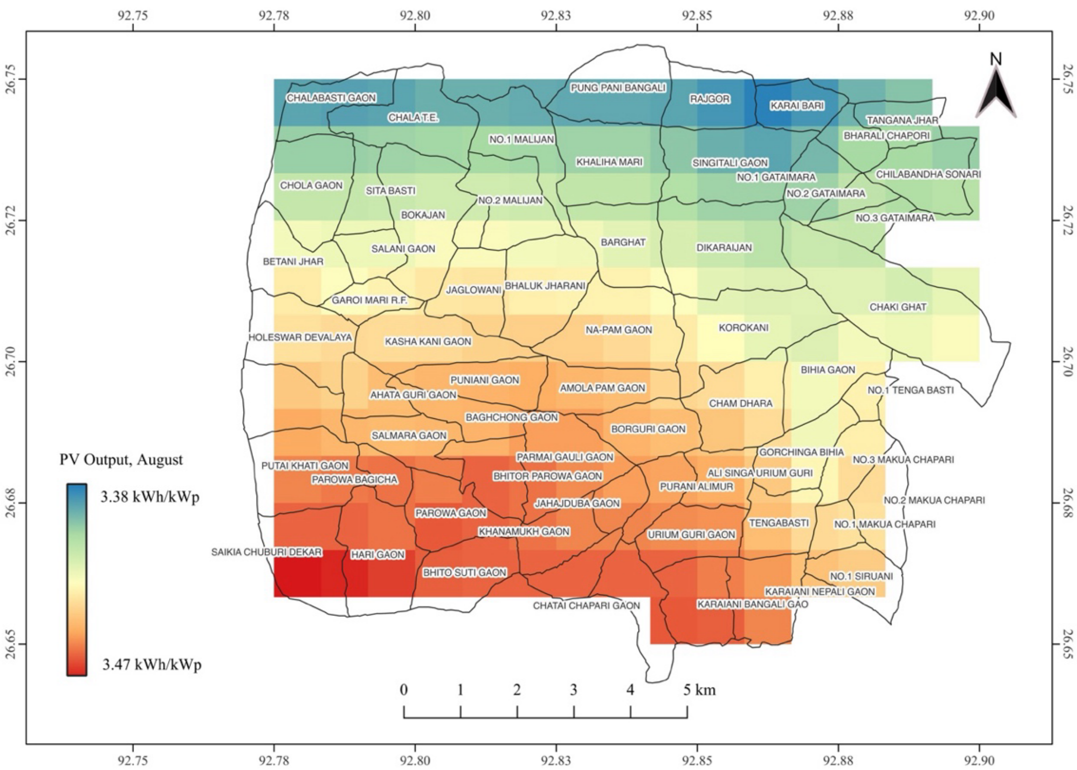

Fig 3E (h): Spatial map of monthly PVS output (August)

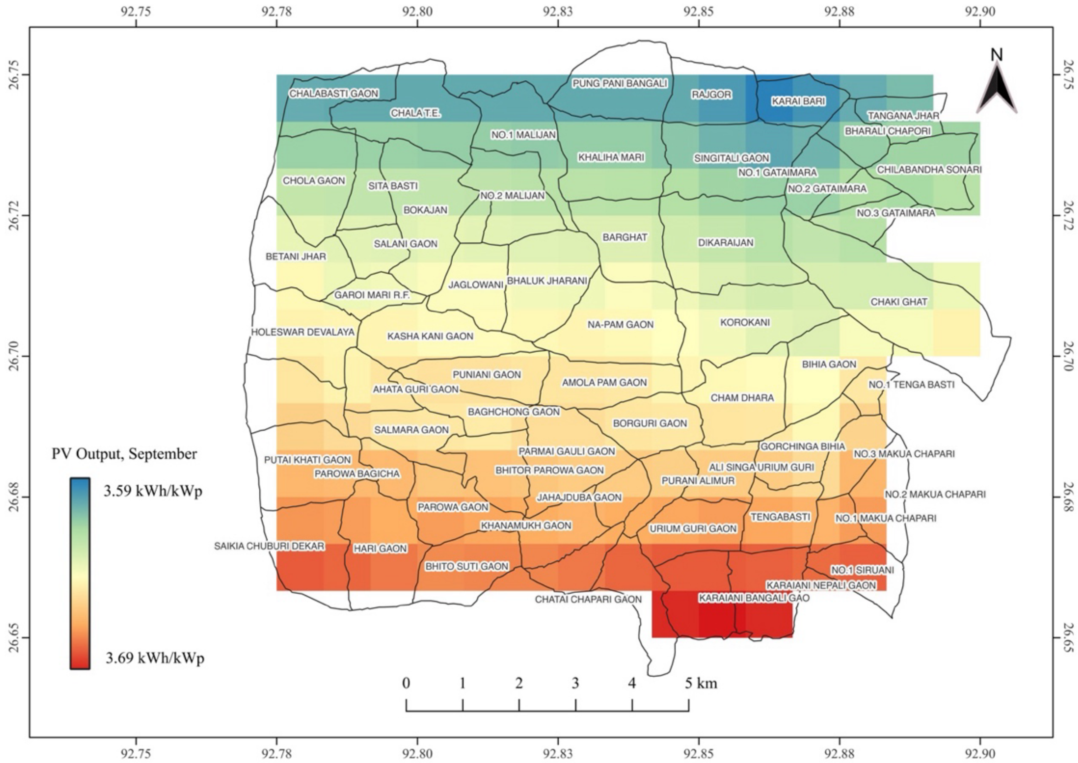

Fig 3E (i): Spatial map of monthly PVS output (September)

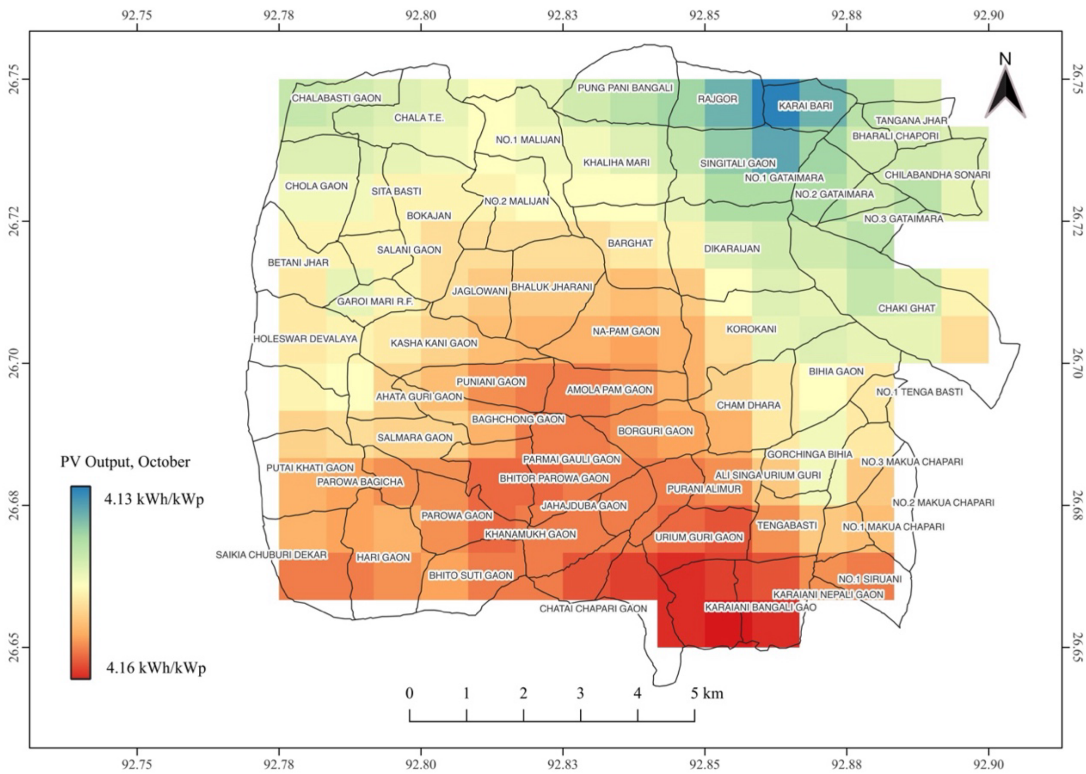

Fig 3E (j): Spatial map of monthly PVS output (October)

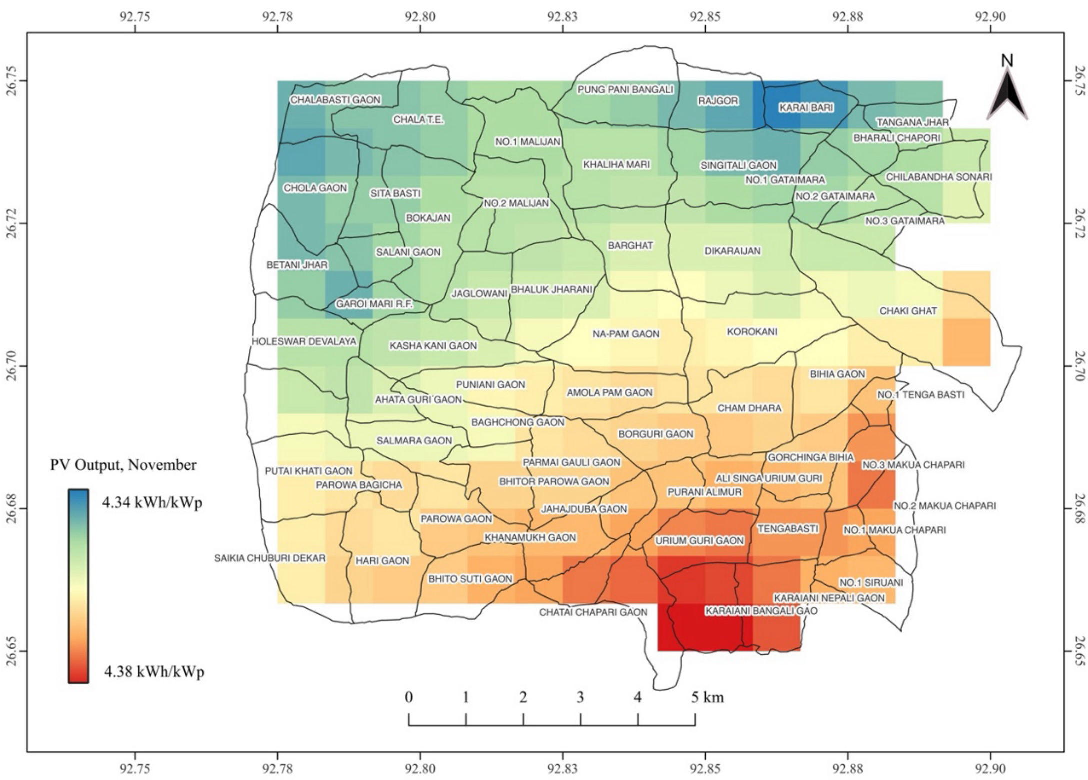

Fig 3E (k): Spatial map of monthly PVS output (November)

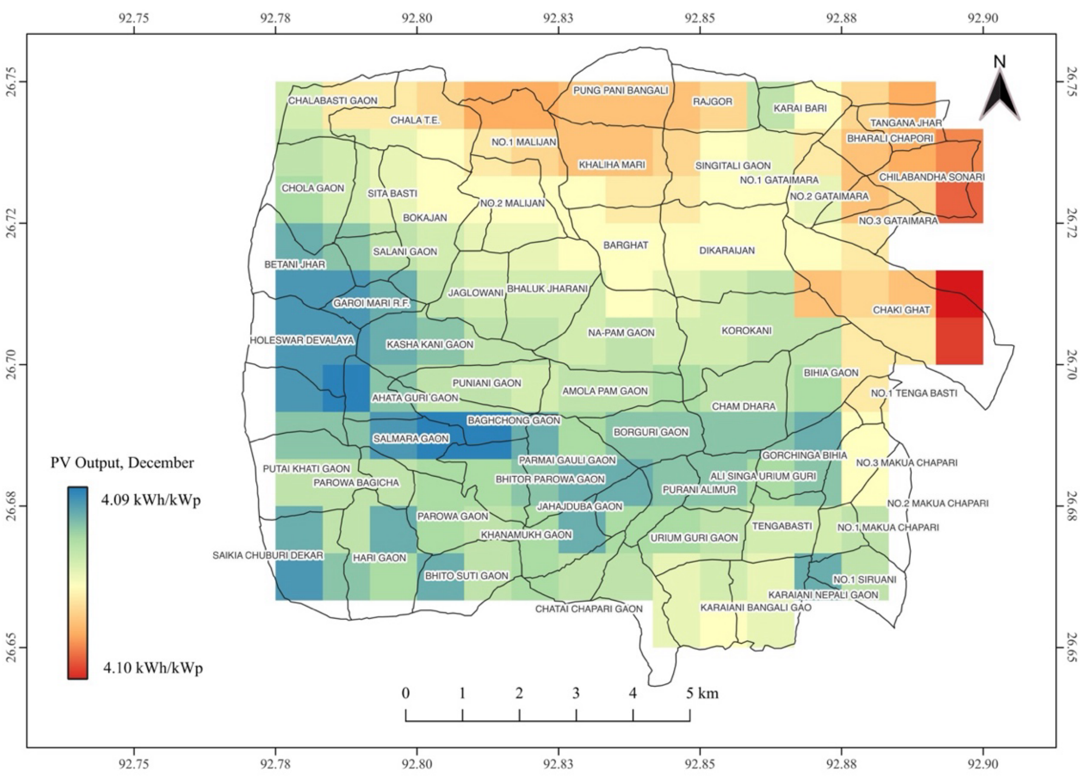

Fig 3E (l): Spatial map of monthly PVS output (December)

Appendix 4A: Groundwater prospect map

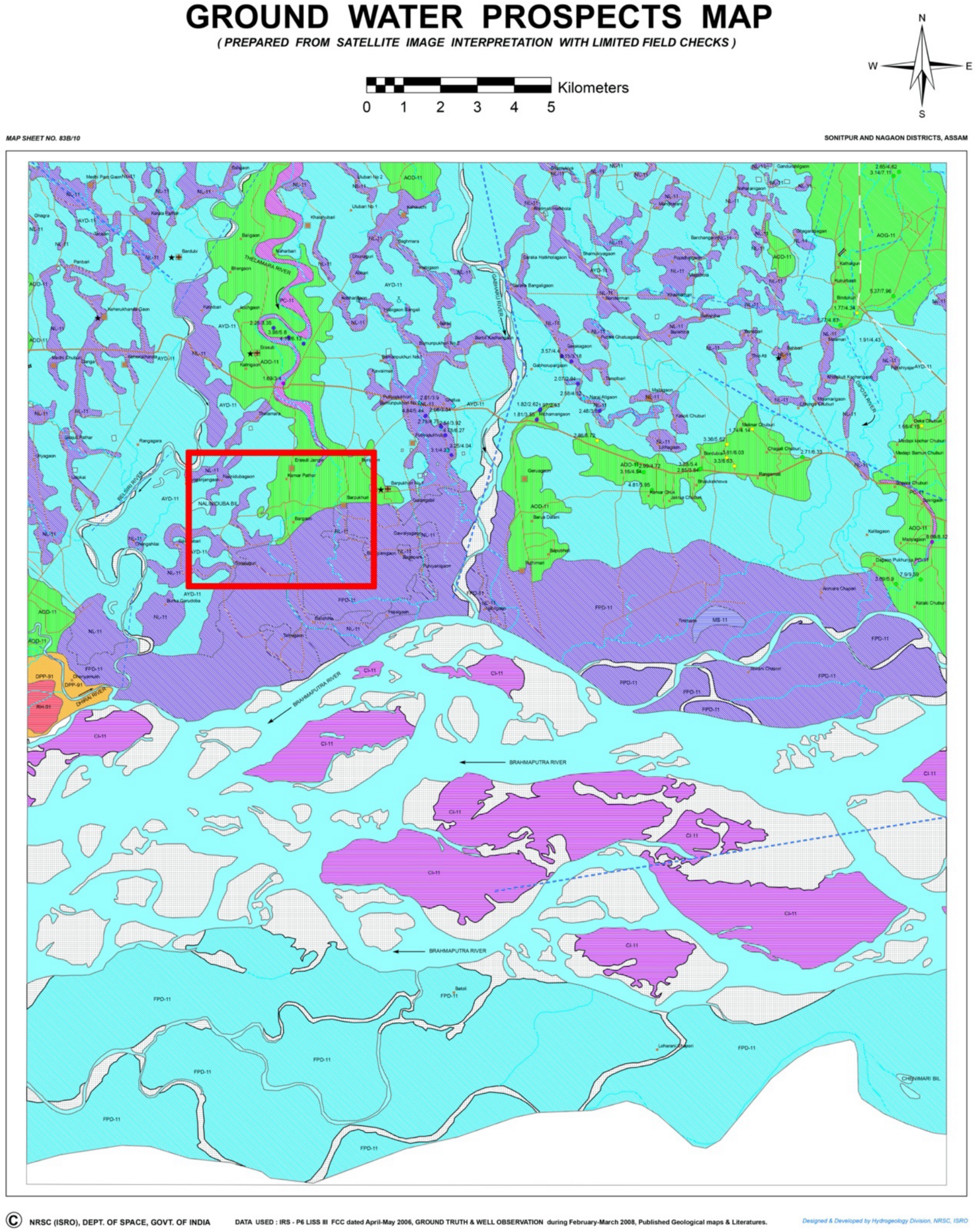

Fig. 4A: Groundwater prospects map of Jhawani-3 village area highlighted in red

Appendix 4B: Details of groundwater with legends and sources

Map unit		Geological sequence/ Rock type	Geomorphic unit/Landform	Water level depth[Summer/ Pre-Monsoon (Avg in meters)]	Type of wells suitable	Depth range of wells (Suggested) Min – Max (m)	Yield range of wells (Expected) (In LPM)
FPD-11	FPD-11 (Indigo)	Alluvium (Sand & Silt Dominant) (11)	Flood Plain Deep (FPD)	1.56-4.86 Rw-23	Tw Rw	40-60 5-8	400-600 LPM
AYD-11	AYD-11		Alluvial Plain Younger Deep (AYD)	1.91-2.71 RW-2	Tw Rw	30-60 5-8	300-400 LPM
AOG-11	AOG-11		Alluvial Plain Gullied(AOG)	1.77-5.37 RW-5	Bw	50-70	150-200 LPM

Hydrogeomorphic unit represented in the map with alphanumeric code. (Color indicates yield range and hatching indicates depth range), (represented in the map with numeric code). Abbreviations: Rw= ring well, Bw= bore well, Tw= tube well.

Appendix 4C: Details of irrigation scheduling for the crops considered

Crop rotation	DoI_1	DoI_2	DoI_3	DoI_4	DoI_5	DoI_6	DoI_7	DoI_8	DoI_9	DoI_10
Crop rotation 1										
Crop 1	24-Jun	12-Jul	25-Jul	15-Sep	nil	nil	nil	nil	nil	nil
Crop 2	24-Nov	27-Nov	30-Nov	07-Dec	14-Dec	21-Dec	05-Jan	20-Jan	04-Feb	14-Feb
Crop 3	20-Feb	24-Feb	18-Mar	30-Mar	19-Apr	09-May	25-May	nil	nil	nil
Crop rotation 2										
Crop 1	24-Jun	12-Jul	25-Jul	15-Sep	nil	nil	nil	nil	nil	nil
Crop 2	19-Nov	17-Jan	nil	nil	nil	nil	nil	nil	nil	nil
Crop 3	20-Feb	24-Feb	18-Mar	30-Mar	19-Apr	09-May	25-May	nil	nil	nil

Abbreviation: DoI – Days of irrigation (days)

List of Publications

Journal:

Terang, B., & Baruah, D. C. (2023). Techno-economic and environmental assessment of solar photovoltaic, diesel, and electric water pumps for irrigation in Assam, India.Energy Policy,183, 113807. https://doi.org/10.1016/j.enpol.2023.113807

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Patowary, D., Sarmah, T., Sarma, G. D., Terang, B., Patowary, R., & Baruah, D. C. (2018). Economic Feasibility and Environmental Sustainability of a Community Scale Multi-component Bioenergy System.8th International Conference on Sustainable Waste Management (8th IconSWM 2018). Acharya Nagarjuna University, Guntur.

B. Gogoi, B. Terang, D.C. Baruah. (2019). Impact of GIS based improved cook stove distribution on rural livelihood. National Conference on Recent Advances in Science and Technology (NCRAST-2019). Assam Science and Technology University.

Patowary, R. Baruah, D.C. Patowary, D. Baruah, D. Gogoi, B. Sarma, T. Brahma, B, Terang, B. (2019). An attempt to achieve the benefit of circular economy through bioenergy and byproduct. National Symposium on Sustainable Waste Management (SWM 2019). Tezpur University.

Book Chapter:

Patowary, D., Sarmah, T., Sarma, G. D., Terang, B., Patowary, R., & Baruah, D. C. (2020). Economic Feasibility and Environmental Sustainability of a Community Scale Multi-component Bioenergy System.*Energy Recovery Processes from Wastes*, 237-250.

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Techno-economic and environmental assessment of solar photovoltaic, diesel, and electric water pumps for irrigation in Assam, India

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ABSTRACT

This study assesses the techno-economic and environmental aspects of solar photovoltaic (PV), diesel, and electric water pumps for irrigation in Assam, India. Two practical crop rotations are considered: Sali rice, strawberry, and Ahu rice; and Sali rice, mustard, and Boro rice. A comprehensive analysis, including performance, cost-effectiveness, and CO_2 emissions, was conducted through field surveys and data analysis. The findings highlight the advantages of solar photovoltaic water pumps (SPVWP), including reduced CO_2 emissions, lower operational costs, and the potential revenue from selling surplus electricity generated and participating in carbon trading. The study explores the sensitivity to varying subsidy rates, emphasizing the potential to promote SPVWP adoption through revised policies. Factors like crop rotation, energy costs, and groundwater availability are also considered. SPVWP emerges as a viable and sustainable irrigation solution in Assam and similar regions with appropriate financial incentives and support. The research offers valuable insights for policymakers and advances the understanding of renewable energy-based irrigation systems.

1. Introduction

Agriculture in India is facing challenges, primarily due to low levels of crop production associated with higher input costs resulting in inadequate revenue from production. These issues are compounded by technological transitions and their environmental impact (Agrawal and Jain, 2018; Dwivedy, 2011). The degree of impact varies from region to region due to climate, soil, cultural differences, and varying land-holding patterns. Small and marginal farmers are particularly affected due to the smaller size of their cropland and the unaffordable cost of inputs (Malhi et al., 2021; Singh, 2012). Introduction and circumstances of subsequent withdrawal of farm laws (Tiwari, 2021) in recent times have highlighted the socio-political issues faced by crop-producing farmers in India.

There are various approaches taken by the government, research institutes, and crop producers to increase farm income through sustainable utilization of farm resources (Gupta et al., 2021). The government provides direct subsidies, and minimum support prices (MSP) and encourages the development of technologies (Kanika, 2022; Salunkhe and Deshmush, 2012) to reduce the hassles of farmers. Research and academic circles address key issues to find farmer-friendly solutions (Gangwar et al., 2017; Garg et al., 2016; Martis et al., 2021). Various successful examples of research outcomes for the betterment of crop production have been applied in crop variety (Martey, 2022), machinery (Baruah and Bora, 2008; Mehta et al., 2019), farm practices (Jung et al., 2014), irrigation (Knox et al., 2012), crop care (Garg et al., 2022) and post-harvest (Kumar and Kalita, 2017). The current study is an attempt to promote sustainable and economical options for irrigation.

Irrigation plays a critical role in crop production and has significant implications for the economy and sustainability of crop farms. In India, irrigation coverage extends to approximately 50% of the net crop area. However, there is considerable regional variation in irrigation status, with Assam having only 13% of its net sown area under irrigation, contrasting with more productive regions like Punjab (99%), Haryana (90%), and Andhra Pradesh (46%) (Golait, 2021). This inadequate provision of irrigation has adversely affected crop production in Assam.

Agriculture is a vital sector of Assam's economy, covering about 54% of the total geographical area (ENVIS Centre: Assam, 2015). Over 80% of the state's population depends on agriculture, including plantation crops, with rice being the primary staple food crop (Upadhyaya, 2022). Despite its agro-based economy, Assam's rice yield (2.15 t/ha) is 18% less than the national average yield (2.64 t/ha) and 47% less than Punjab's yield (4.13 t/ha) (Golait, 2021). The productivity analysis of rice cultivation in India classifies Assam in the medium to very low

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