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Assessment of green energy for vegetable cultivation in tribal areas of Koraput district, Odisha in the Eastern Ghats region

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ABSTRACT

Undulating topography and lack of irrigation compel tribal farmers of Koraput district in Odisha to leave their agricultural fields fallow during post-monsoon season. Using a solar irrigation system can be an appropriate alternative for farmers to go for vegetable cultivation during the post-monsoon season using stored subsurface water in stone-pitched *jhola kundi* (shallow dug well). In this study, 60 stone-pitched *jhola kundis* were constructed, and solar-powered irrigation pumps were installed in 2022 and 2023 to irrigate the farmer's fields. The diameter of these *jhola kundis* varies between 4.0 to 6.2 m, whereas depth ranges from 3.0 to 7.8 m. These *jhola kundis* are equipped with a one-horsepower (hp) surface-mounted solar-operated pump. The harvested water irrigates a nearly 145-ha area covering 207 farmers. Vegetable cultivation enhances farmers' monthly income from ₹ 4644 to 19676 and holds the potential for further income growth. At the same time, it helps increase the crop diversity index values to as high as 0.85. There is a saving of 48336 kWh^{-1} power per annum, considering 70% pump efficiency. Further, it helps reduce carbon dioxide emissions by 280 kg per ha of CO_2 per annum. Therefore, the promotion of this technique will not only help to achieve assured irrigation to crops but also protect the environment by reducing the emission of greenhouse gases.

HIGHLIGHTS

- Irrigation potential created by constructing 60 nos. of stone-pitched *jhola kundi* is 145 ha.
- It helps enhance farmers' monthly income threefold.
- Annual reduction in CO_2 emission is 280 kg/ha.

1 | INTRODUCTION

Koraput district is a tribal-dominated area situated on a section of Eastern Ghats in Odisha state and has a total geographical area of 8379 km^2. The district's total population is 13,79,647 as per Census 2011, of which 50.6% are scheduled tribes. Agriculture and forest products are the mainstays of the economy of the Koraput district, with around 83% of the population depends on it. The soil and climate in the district are favorable for taking up agro-horticultural activities. The cultivable land is 3 04,000 ha (only 36.28 %) with the irrigated area (*kharif*) of 143,673 ha (17.14% of total geographical area), irrigated area (*rabi*) 92,599 ha (11.05% of total geographical area) Agricultural Statistics, 2019). The sources of irrigation include canals (upper Kolab, lower Kolab, and Telengiri irrigation projects), lift irrigation points, deep bore wells, and diversion-based spring water (Agricultural Statistics, 2019). The major portion of the district is ecologically fragile hilly upland vulnerable to resource degradation and environmental stress. Though the district is bestowed with a good amount of rainfall (annual average rainfall: 1316 mm) (Dash *et al.,* 2020), however undulating topography, shallow soil depth, low soil organic carbon, and fine textured soil hinder infiltration of water into the soil. Additionally, irregular monsoon cycle often causes long dry spells and drought-like situations, render rainfed agriculture a high-risk endeavor, and contribute to low agricultural production. Small and marginal farmers with small land holdings (82.68% of farmers are under marginal and small land holdings in Koraput district) with single crops during *kharif* have faced food insecurity and reduced income from farmlands (Agricultural Statistics, 2019). Not only erratic monsoons but also the non-availability of water during post-monsoon season led most farmers to leave their fields fallow. The farmers also mainly cultivate paddy, finger millet, and other minor millet. As most of the district's area falls under rain-fed mixed farming and the dependency on rainfall is very high, water provision during the post-monsoon season is a prerequisite to enhance the economic conditions of small and marginal farmers. In this context, constructing water harvesting structures and efficiently utilizing stored water is required. Among various water harvesting structures, *jhola kundi* (shallow dug well) can be considered a viable irrigation source during the post-monsoon and summer seasons, and the harvested water in *jhola kundi* can be used for vegetable cultivation. *Jhola kundi* is a low-cost sub-surface water harvesting structure usually constructed on or adjacent to the *jhola* land (terraced low land) as this land has a favorable hydrological condition that ensures availability of water at, or near, the surface for most of the year (Panda *et al.,* 2010; Dash *et al.,* 2019). It is a circular shallow well dug manually with depth varying from 3 to 8 m and a diameter of about 3 to 5 m (Panda *et al.,* 2011, IISWC Annual Report, 2021). Traditional water lifting devices called Tenda or Krishak Bandhu pumps / diesel or solar-operated pumps can lift the water for irrigation.

In India, water for irrigation in agriculture is mainly pumped using either diesel or electric pumps. However, the increasing price, uneven distribution of diesel fuel and electric power, and adverse effect of emission of greenhouse gases have diverted the attention of researchers, policy-makers, and planners to go for eco-friendly and low-cost irrigation systems vis-a-vis solar-operated water pumps. In total, 72% of CO_2 contributes to human-emitted greenhouse gases, and the share of fossil fuel combustion is the maximum (IEA, 2012). Substituting diesel-operated pumps with solar-powered pumps can considerably reduce carbon emissions as the energy source for solar-operated pumps is solar radiation and is abundantly available in tropical countries like India. There is an availability of about 300 clear sunny days in a year with variations of solar insolation from 4 to 7 kWh $m^{-2}day^{-1}$ in India, depending upon the locations (Chandel *et al.,* 2017). In Odisha, the availability of solar radiation is ~5 kWh $m^{-2}day^{-1}$ occurs for nearly 300 days (www.oreda.com). Solar-powered water pumps have been proven to be technically feasible and economically viable, particularly for small-scale applications in the irrigation sector for vegetable cultivation (Badra, 2018; Ghosal *et al.,* 2021). Apart from this, solar-operated water pumping systems have been proven to be favorable to the environment concerning emissions and require very little maintenance and no cost involvement for the fuel (Chandel *et al.,* 2015).

Therefore, stone-pitched *jhola kundi* constructed and solar-powered irrigation systems were installed in *jhola kundis* across eight blocks of Koraput district to help farmers cope with water-related risks or uncertainties during winter and summer seasons and to avert the impending water crisis in crop production. This study assessed the impact of the *jhola kundi* - based solar-operated irrigation system on socio-economic and environmental benefits.

2 | MATERIALS AND METHODS

2.1 | Location and details of *jhola kundi* based solar powered irrigation system

Sixty stone-pitched *jhola kundis* were constructed, and solar-operated irrigation pumps were installed in eight blocks of Koraput district, Odisha, during 2022 and 2023. The location of these systems is presented in Fig.1, and their distribution in various blocks of the Koraput district is presented in Table 1. In the Koraput and Pottangi blocks, a maximum of 10 systems have been installed, whereas the Boipariguda and Lamataput blocks have only four systems. All these locations in the Koraput district receive a good amount of solar radiation for about 4 to 5 hours a day over nearly 300 days a year (Anonymous, 2013). The Google Earth image shows three of these systems located in Lingamguda village, Pottangi block, shown in Fig. 2. A total of 51 villages are covered, and 207 nos. of farmers have been using the stored water for vegetable cultivation during winter and summer seasons. The diameter of constructed stone-pitched *jhola kundi* ranges between 4.0 to 6.2 m, while its depth varies from 3.0 to 7.8 m depending on the location. The designed dimension of *jhola kundi* was based on previous research works by Panda *et al.* (2011). Each *jhola kundi* has a solar-operated surface-mounted irrigation pump (1 hp) with three solar panels. The capacity of each solar panel is 300 watts, and the suction head is 7 m. The cost of each system is ₹ 2,50,000/-, which includes a) construction of stone pitched *jhola kundi* (₹ 1,50,000/-) and installation of the solar-powered pump (₹ 1,00,000/-). The farmers generally irrigate their fields by conveying water through high-density polyethylene (HDPE) pipes and cultivate various vegetable crops.

2.2 | Environmental and socio-economic impact assessment

Various data on bio-physical and socio-economic parameters were collected through field visits, questioners, meetings, and Focused Group Discussions (FGDs) during pre- and post-installation of these systems. The total duration of the study includes 2 seasons for 30 nos. of the system and 1 season for the rest of the 30 nos. of the system. Periodic monitoring and measurement of water level in the *jhola*

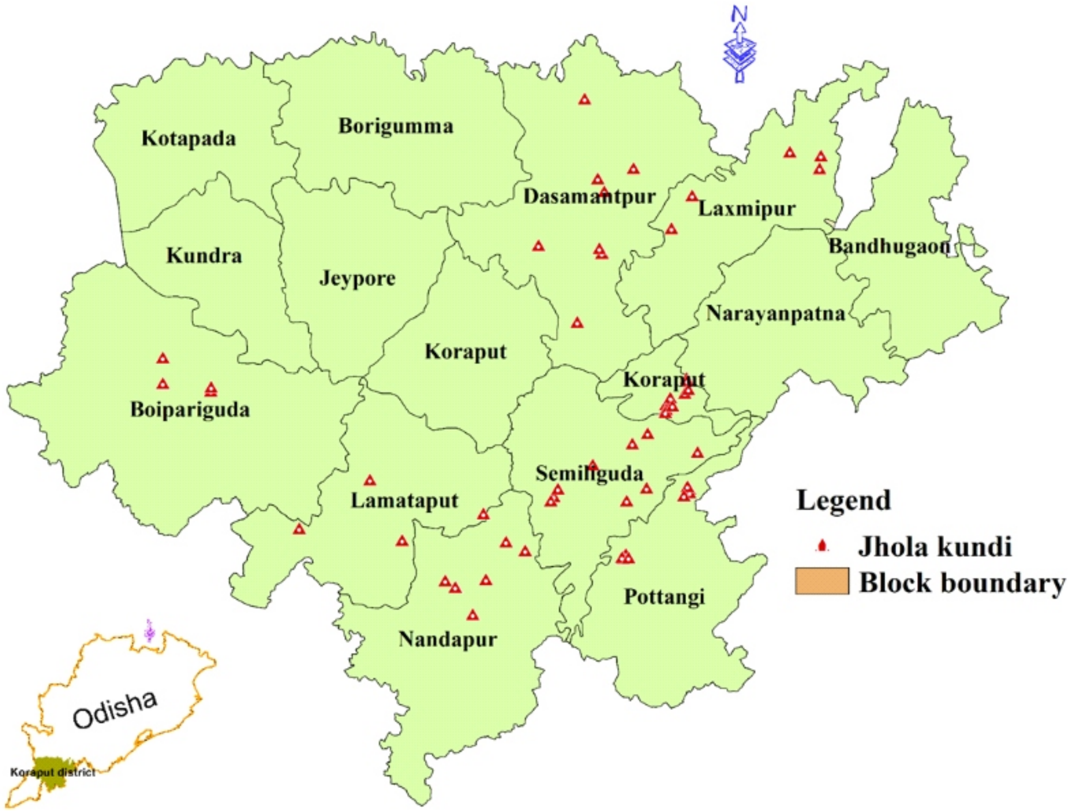

FIGURE 1 Map showing location of *jhola kundi* based solar powered irrigation system in Koraput district

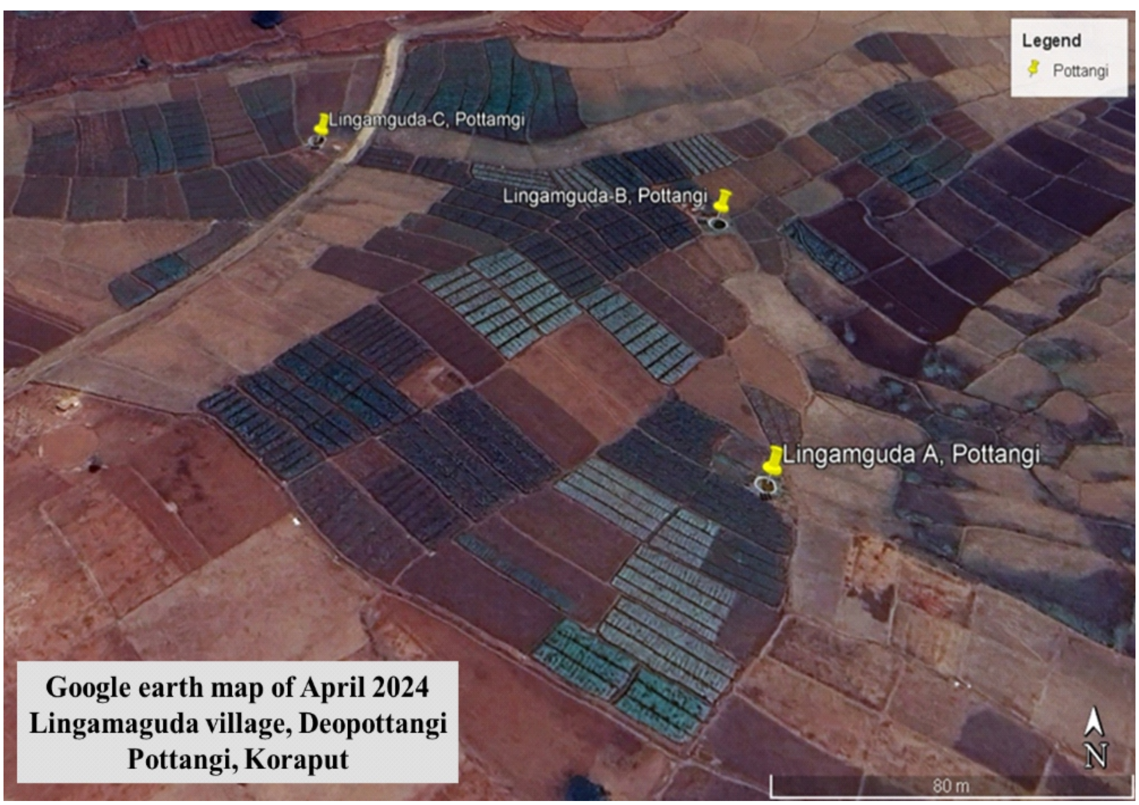

FIGURE 2 Google earth map showing installed *jhola kundi* based solar powered irrigation system in Lingamguda village, Koraput district

TABLE 1 Blockwise distribution of *jhola kundi* based solar powered irrigation system

Block name	*Jhola kundi* based solar operated irrigation system (No)	Beneficiary covered (No)	Villages covered (No)	Average area under cultivation (ha/farmer)
Boipariguda	4	9	2	0.35
Dasamantapur	9	36	8	0.49
Koraput	10	32	8	0.30
Lamataput	4	12	4	0.31
Laxmipur	5	15	5	0.42
Nandapur	9	27	8	0.39
Pottangi	10	42	7	0.50
Semiliguda	9	34	9	0.37
Total	60	207	51	

kundis, recuperation rate, discharge rate of solar-powered pump, and yield of crops were carried out. Information on the area under irrigation under each *jhola kundi* during the winter and summer seasons was collected. Crop-wise area under irrigation and crop yield were also collected from individual farmers. Apart from that, the environmental benefit of using a solar-powered irrigation system was also estimated. The various impact assessment indicators are presented below:

a) **Cropping pattern:** This refers to the proportion of land under cultivation of different crops at different times. It indicates the time and arrangement of crops in a particular land area. The cropping pattern before and after using solar-operated pumps in the villages was analyzed.

b) **Cropping intensity (CI):** Cropping intensity is the number of crops a farmer grows in a given agricultural year on the same field. It is another means of intensifying production from the same plot of land.

$$\textit{Cropping intensity (\%)} = \frac{\textit{Gross cropped area}}{\textit{Net sown area}} \times 100$$

c) **Crop diversification index (CDI):** Crop diversification refers to the distribution of land to grow various crops and is adapted to counteract the unfavorable consequences of current crop specialization and monoculture. It facilitates resource utilization, nutrient recycling, soil fertility restoration, and economic viability through value-added products and ecological enhancements (Acharya *et al.,* 2011). The level of crop diversification in an area can be measured using the crop diversification index. This index considers the number of crops grown in an area and the area under cultivation for each crop (Kumar and Gupta, 2015). For this study, the Simpson index (SI) is used and calculated by following the equation:

$$\mathrm{SI} = 1 - \sum_{i=1}^{n} p_i^2$$

Where, $p_i = \frac{A_i}{\sum A_i}$ is the proportion of the i^{th} activity in acreage. If SI is close to zero, it indicates that the region or area is near the specialization in growing a particular crop, and if it is close to one, then the zone is fully diversified in terms of crops.

d) **Net income:** Farmers' net income from vegetable cultivation during the winter and summer seasons was calculated by subtracting the cost of cultivation from gross income. The gross income was calculated by multiplying vegetable production with the selling price of those products in the local market.

e) **Environmental benefit assessment:** In India, diesel and electricity are the primary fuels used to operate diesel and electric pump sets for irrigation. Burning diesel in internal combustion engines and generating electricity in power plants contribute a lot to the emission of greenhouse gases into the atmosphere, causing more to the present concerns of global warming and climate change. In Odisha, nearly 3.00 lakhs and 2.00 lakhs of diesel and electric pumps are used, respectively, with the power rating ranging between 1 to 5 hp (Anonymous, 2017). It has been reported that a single one-hp engine consumes about 0.25 liter of diesel per hour (Ghosal *et al.,* 2021), and the burning of 1 liter of diesel releases about 3 kg of CO_2 into the atmosphere (Sharma and Maréchal, 2019). Similarly, the average carbon dioxide emission for electricity generation from coal-based thermal power plants is 1.58 kg kW^{-1} h^{-1} (Chel *et al.,* 2009). By knowing the annual working hours of this solar-powered irrigation pump and discharge rates, the mitigation of CO_2 emission by replacing diesel and electric pumps was calculated.

3 | RESULT AND DISCUSSION

This study installed 30 nos. of *jhola kundi*-based solar-powered irrigation systems in 2022 and the rest in 2023. The water level in these *jhola kundi* varied between 2.5 to 7.2 m depending on location and time. Similarly, the mean discharge rate of the pump ranged from 1.6 to 3.3 l sec^{-1}. The mean discharge rate of the solar pump was calculated by taking an average of discharge measured at 9.00 am, 12.00 pm, and 3.00 pm. There are several techniques to determine the potential yield of dug wells. The most commonly used techniques include a) the well recovery or recuperation, b) specific capacity, and c) the peak demand tests. Specific capacity and recuperation are science-based tests, whereas peak demand tests are more subjective. Therefore, in this study recuperation test was carried out to determine the potential well yield, by following standard procedure. The measured potential yield of *jhola kundis* ranged between 55 to 137 m^3 day^{-1}. However, in many cases, the stream water has been diverted and directly entered into the *jhola kundis* by farmers. Therefore, the stored water is adequate to supply water for vegetable cultivation. The creation of irrigation facilities increased the irrigated area. The details of the potential area under irrigation created in different blocks during the winter and summer seasons are presented in Fig. 3. The Total area irrigated during the summer season is 84 ha, while the same during the winter season is 61 ha, covering a total area of 145 ha. Among the blocks, the area under irrigation in Pottangi block is maximum (36.1 ha). In contrast, the Boipariguda block has a minimum irrigated area (5.4 ha), followed by Lamataput (6.4 ha), due to only 4 no. of systems installed in those two blocks.

Before the creation of irrigation facilities, rice and finger millet were the dominating crops cultivated during the rainy season by all farmers, while only a few farmers such as 54 and 6% cultivated vegetables during the winter and summer seasons, respectively, based on the availability of water (Fig. 4). The creation of irrigation facilities helped farmers to cultivate a different type of vegetables such as tomato, beans, chili, brinjal, bitter gourd, yam, cabbage, cauliflower, capsicum, etc. The creation of irrigation facilities has changed the cropping pattern as presented in Fig. 4. During 2022-2023, among the project beneficiaries, the percentage of farmers who cultivated vegetables during winter and summer was 87 and 67%, respectively. Similarly, during 2023-24, the percentage of farmers cultivating vegetables during winter and summer increased to 100 and 82%, respectively. The reason can be attributed to the late construction of *jhola kundis*. Overall, it can be stated that after the creation of irrigation facilities, many farmers were able to cultivate high-value vegetable crops, which helped farmers earn every week.

Farmers could cultivate and grow different kinds of vegetables, evidenced by the crop diversification index (Fig. 5) calculated for different blocks coming under the project operational area. The crop diversification index varied from 0.25 to 0.55, with a mean value of 0.40 before the creation of irrigation facilities, and increased to a mean value of 0.8. A maximum value of 0.85 was observed in the project operational areas of the Pottangi and Nandapur blocks, whereas a minimum value (of 0.73) was obtained in the Boipariguda block. The difference in crop diversification among the blocks may be related to the availability of vegetable seeds, market demand, and farmers' willingness to cultivate different vegetables.

With the creation of irrigation facilities, there was an increase in the cropping intensity with the inclusion of vegetable crops in the winter and summer seasons. In other words, the field has a crop throughout the year. The cropping intensity has increased from 137% to 272% in the project operational area. With the increase in cropping intensity in the study area, the income of farmers increased in comparison to their earlier level of income (Fig. 6). Earlier, per farmer's monthly net income ranged between ₹ 3274/- to

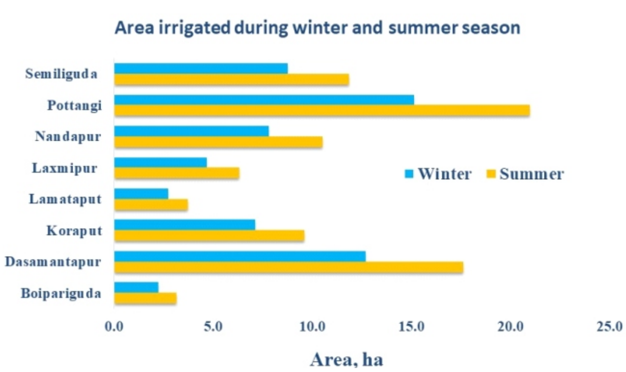

FIGURE 3 Block wise area created under irrigation

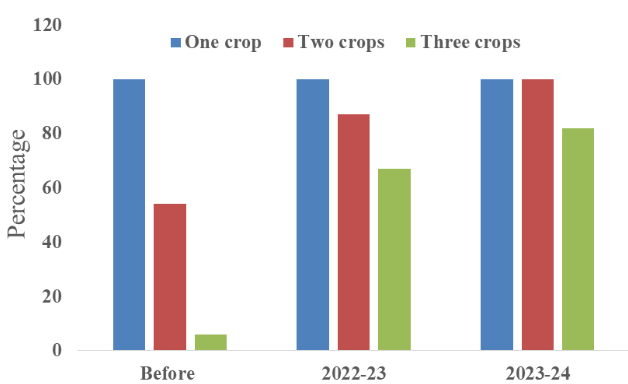

FIGURE 4 Cropping pattern in project operational area before and after creation of irrigation facility

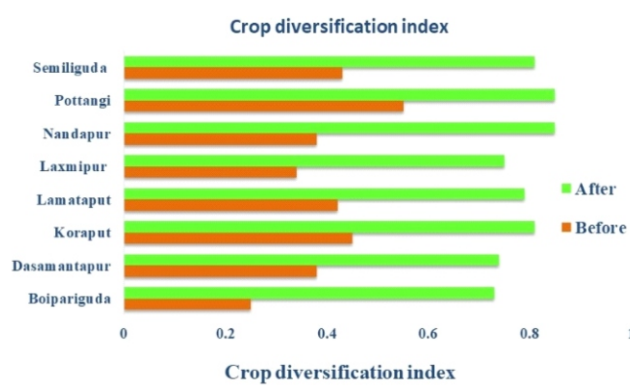

FIGURE 5 Crop diversification index in project operational area before and after creation of irrigation facility

₹ 5565/- with a mean value of ₹ 4644/-. With the construction of *jhola kundis*, the monthly income of project beneficiaries during the *rabi* and summer seasons was increased to a range of ₹ 13376/- to ₹ 22493/- with a mean value of ₹ 19676/-.

3.1 | Mitigation of CO_2 emission by the use of solar-powered pumps

In the study area, 60 nos. of solar-operated irrigation pumps were installed. Solar pumps are rapidly becoming more attractive than traditional electric and diesel-operated pumps. Further powered by renewable energy sources, solar pumps are especially useful in remote locations where a steady fuel supply or electricity supply is problematic. Apart from this, solar pumps are environment-friendly, with zero CO_2 emission. Considering the hypothesis that if 60 no. of diesel and electric pumps have the same horsepower, then the quantity of CO_2 emission from those pumps can be mitigated using these solar pumps. The environmental benefit of using solar pumps is presented in Table 2. There is a saving of 15900 liters of diesel fuel with a benefit of ₹ 15,90,000/- considering per liter diesel price as ₹ 100/-. Similarly, if an electric pump is used, the energy for cultivating vegetables in 145 ha of land is 48336 kWh. Overall, the annual reduction of CO_2 in using solar pumps per year is 40545 kg from 145 ha area, which is 280 kg ha^{-1} yr^{-1}.

4 | CONCLUSIONS

Solar-powered water pumping systems are gaining importance nowadays due to less maintenance and the use of renewable energy, and they can be used anywhere in rural and remote areas. Looking into the non-availability of water during the post-monsoon season in the Eastern Ghats highland region of Koraput district, the *jhola kundi* based solar operated irrigation system can be considered as a sustainable approach for the cultivation of vegetables, which helped farmers to increase their socio-economic conditions. By adopting this system, farmers' income increased threefold in the Koraput district, increasing the mean crop diversification index to 0.8. The present study's findings would provide insight to the state's farming community to adopt this technology to strengthen their agricultural production system with secured energy and water availability.

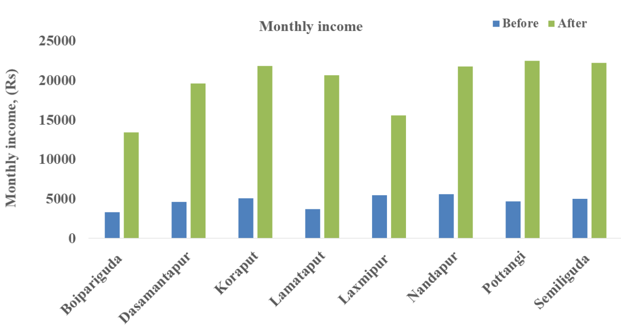

FIGURE 6 Monthly income of farmers in project operational area before and after creation of irrigation facility

TABLE 2 Environmental benefit of using a solar pump

Saving diesel fuel by replacing diesel pumps (liters)	:	15900
Saving of electric energy by replacing electric pump (kWh)	:	48336
Reduction in CO_2 emission per year (kg)	:	40545

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DATA AVAILABILITY STATEMENT

The data presented in this study are available upon request from the corresponding author.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR'S CONTRIBUTION

CJD: Conceptualization, data analysis, writing; JL: Data collection, analysis, review; MM: Conceptualization, guidance; HCHG and RD: Review and editing; GBN, GWB and PY: Data collection and analysis.

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