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Techno–economic evaluation of shallow tube well in the dry river bed of coastal Odisha

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ABSTRACT

A feasibility study for installation of shallow tube well in the dry river bed of defunct Ekdal river lift (RL) project of Narasingpur block of Cuttack district of Odisha was carried out, which has 40 ha command area. For this purpose, estimation of water requirement of the crops grown in 40 ha area was done. A pumping test was conducted to determine various hydraulic parameters by Theis recovery method. Using the determined values of the hydraulic parameters and following Darcy's formula, the base flow was calculated. The base flow was found to be enough to meet the water requirement of crops. The values of various economic indicators such as net present value (NPV) were found to be ₹ 24806749/– for a 40 ha command area with a BCR of 1.48. The internal rate of return (IRR) was 35% along with a payback period (PBP) of 6 years. From these values of economic indicators, it can be said that the installation of a shallow tube well in a dry river bed in a defunct RL project of the study area is both technically feasible and economically viable.

1. INTRODUCTION

The government of Odisha frequently encounters much difficulty for its river lift (RL) projects to provide irrigation during *kharif* and *rabi* seasons. In Odisha, either the river water recedes below the river bed or the river changes its course from the installation point of the project after the rainy season. There are also some project locations where river water is not available at the installation point even in the *kharif* season. A number of rivers in the coastal districts of Odisha change their course frequently resulting in a good number of RL projects becoming not operable. As a result, the farmers of the command area are deprived of irrigation facilities for *kharif* and *rabi* crops which are mainly paddy, vegetables, sunflower, groundnut, and green gram resulting in non–cultivation of crops (Mohapatra *et al*., 2003).

During the *rabi* and summer season, it is found that the water table recedes 1 m to 2 m below the river bed in the rivers flowing in Odisha. Also, the depth of saturated sand ranges from 3 m to 20 m in non–perennial rivers in coastal Odisha. The change of river course is about 100 m away from the installation site of the RLs projects (Mohapatra *et al*., 2003; Paul *et al*., 2014; Paul and Panigrahi, 2016). The number of RLs projects in Odisha as of the year 2019 is 29200 out of that approximately 5200 RL projects are defunct (Annonymous, 2019). Shallow tube wells installed in the saturated dry river bed of rivers depend upon the transmissivity of the underground saturated sand (aquifer), groundwater slope, and quantity of sub–surface flow. Rivers in alluvial deposit areas, where the flowing stream changes its course away from RL installation point, the aquifer is replenished with water drawn due to pumping from induced recharge flow towards it from the flowing stream. This underground flow is most effective because the granular zone of the river bed is largely of unconsolidated formation of permeable sand and gravel. Aquifer and flowing stream are hydraulically connected with this formation. Pumping will largely depend on induced recharge and the amount of water–induced is directly proportional to the rate of pumping (Mohapatra *et al*., 2003). The above image well concept is applied to design the shallow tube well and find out its discharge (Michael *et al*., 2008; Panigrahi, 2013). For any agricultural enterprise, it is essential to work out its economics so that farmers may know the importance and can utilize the area under their command to the best of their knowledge. Several research workers in the past have used techno–economic analysis of other studies (Panigrahi and Panda, 2003; Mishra *et al*., 2008; Paul *et al*., 2012, 2019).

Keeping these things in view, an attempt was made to tap the sub–surface flow from the dry river bed through the installation of a shallow tube well to make the existing defunct RL project operable all round the year. An attempt was also made to determine the techno–economic feasibility of the shallow tube well so that it will be popularly adopted.

2. MATERIALS AND METHODS

The study was taken up in the river bed abutting to Ekdal village (N20˚24'26.5″, E85˚07'36.8″) where a RL project namely, Ekdal lift irrigation project having command area of 40 ha, was lying defunct due to shifting of the watercourse of about 750 m from the river bed. The study site is located about 120 km from Cuttack and about 234 km downstream to Hirakud dam. It is well connected by road from Cuttack and Bhubaneswar *via* Nayagarh through the Sidhamula river bridge over the Mahanadi. The location map of the study area is given in Fig. 1.

Computation of Water Requirement of Crops

The water requirement of the crops grown in the command area was computed by using the FAO Penmen–Monteith method (Allen *et al*., 1998). Reference crop evapotranspiration was computed by CROPWAT 8.0 model. Data required for CROPWAT 8.0 was collected from the District Agriculture Office of Cuttack district. Crop coefficients (K_C) of the crops grown in the area were taken from FAO guidelines (Doorenbos and Pruitt, 1977).

Theis Recovery Test

The pumping test was conducted at the site. At the end of pumping, when the pump is stopped, the water levels in pumping and observation wells will begin to rise. This is referred to as recovery of groundwater levels, while measurements of drawdown below the original static water level (before pumping) during the recovery period are known as residual drawdown. The transmissibility of the aquifer can be calculated by analyzing residual drawdown. The rate of recovery during the recovery period is assumed to be constant, whereas it becomes difficult to control the pumping rate in the field.

The residual drawdown s' can be calculated as follows (Michael *et al*., 2008).

$$s' = \frac{Q}{4\pi T}\left[W(u) - W(u)'\right]$$

Where, $u = \frac{r^2 s}{4Tt}$ and $u' = \frac{r^2 s}{4Tt'}$

For the small value of r and large value of t'

$$s' = \frac{2.30Q}{4\pi T} log \frac{t}{t'}$$

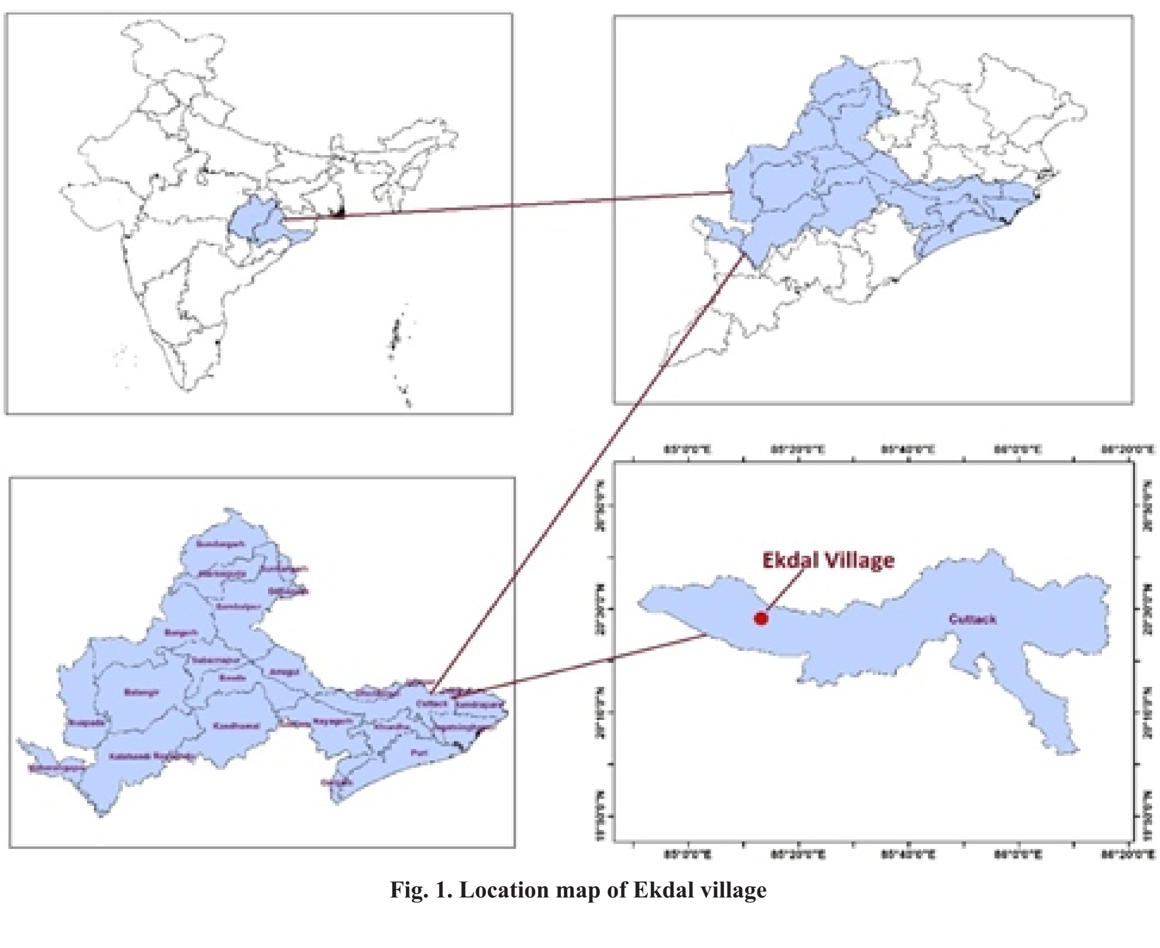

Fig. 1. Location map of Ekdal village

The residual drawdown s' vs $\frac{t}{t'}$ are plotted on a semi−logarithmic paper. The slope of the straight line so plotted equals to $\frac{2.30Q}{4\pi T}$, so that for $\Delta s'$, the residual drawdown per log cycle of $\frac{t}{t'}$, the transmissibility becomes:

$$T = \frac{2.30Q}{4\pi\Delta s'}$$

Based on these aquifer parameters, the base flow was computed using Darcy's law (Panigrahi, 2013). Then this computed base flow was compared with pump discharge to ascertain whether the base flow is sufficient to meet the crop water demand.

To find out the economic viability of this project, four different economic indicators namely net present value (NPV), benefit−cost ratio (BCR), internal rate of return (IRR), and payback period (PBP) were evaluated as suggested by Michael *et al*. (2008), Mishra *et al*. (2009), and Paul *et al*. (2019). Using these indicators, analysis was carried out for the cultivation of *kharif* and *rabi* crops by shallow tube well.

Net Present Value (NPV)

The most straightforward discounted cash flow measure of project worth is the NPV. The NPV may be computed by subtracting the total discounted present worth of the cost stream from that of the benefit stream. To obtain the incremental net benefit, the gross cost is subtracted from the gross benefit of the investment cost from the net benefit. The mathematical statement for net present value can be written as:

$$NPV = \sum_{t=1}^{t=n} \frac{B_t - C_t}{(1+i)^t}$$

Where, B_t = benefit in each year; C_t = cost in each year; t = 1, 2, ………….., n; i = discount rate.

Benefit−Cost Ratio (BCR)

This is the ratio obtained when the present worth of the benefit is divided by the present worth of the cost. The formal selection criterion for the BCR for a measure of project worth is to accept projects for a BCR of 1 or greater. In practice, it is probably more common not to compute the BCR using gross cost and gross benefit, but rather to compare the present worth of the net benefit with the present worth of the investment cost plus the operation and maintenance cost. The ratio is computed by taking the present worth of the gross benefit less associated cost and then comparing it with the present worth of the project cost. The associated cost is the worth of the goods and services over and above those included in project costs needed to make the immediate products or services of the project available for use or sale. Project economic cost is the sum of installation costs, operation and maintenance costs, and replacement costs.

Mathematically, the BCR can be expressed as:

$$\text{Benefit−cost ratio} = \frac{\sum_{t=1}^{t=n} \frac{B_t}{(1+i)^t}}{\sum_{t=1}^{t=n} \frac{C_t}{(1+i)^t}}$$

Internal Rate of Return (IRR)

The IRR can be found out by systematic procedure of trial and error to find that discount rate which will make the net present worth of the incremental net benefit stream equal to zero.

The IRR is the discount rate 'i' such that:

$$\sum_{t=1}^{t=n} \frac{B_t - C_t}{(1+i)^t} = 0$$

Payback Period (PBP)

The PBP is the time from the beginning of the project until the net worth of the incremental production stream reaches the total amount of the capital investment. It shows the length of time between cumulative net cash outflow recovered in the form of yearly net cash inflows.

The following parameters have been considered for carrying out economic analysis.

i. The life of a shallow tube well is 10 years.

ii. The discount rate is assumed to be 7% as compared to bank lending interest rate (Kothari *et al*., 2001; Paul *et al*., 2012; Paul *et al*., 2019).

3. RESULTS AND DISCUSSION

Based on the water requirement of the crops grown in that area, the shallow tube well along with a submersible pump is designed. A pumping test was conducted to compute the hydraulic parameters using the Theis recovery method and base flow was calculated using Darcy's formula (Michael *et al*., 2008). A shallow tube well of 450 mm diameter was drilled at 120 m from the river bed by the direct rotary driller up to 12 m depth (Fig. 2). The water table was below 1 m from the ground level. A stainless steel well casing pipe of 300 mm diameter is installed and extended 1 m above the water level. Wire wound well screen with continuous V−shaped slots having very high open area (Johnson screens) with 1.5 mm slot opening were placed 3 m below the ground level and extends up to 9 m. The bottom end of the assembly is fitted with a 2 m meter length of blind pipe with a cap to close the bottom. The cap is known as a bail plug. The blank pipe at the bottom serves to collect the sand particles that enter the borehole during the development of the well, thus preventing choking the lower portion of the screen (Fig. 3). The inner casing and the well screen

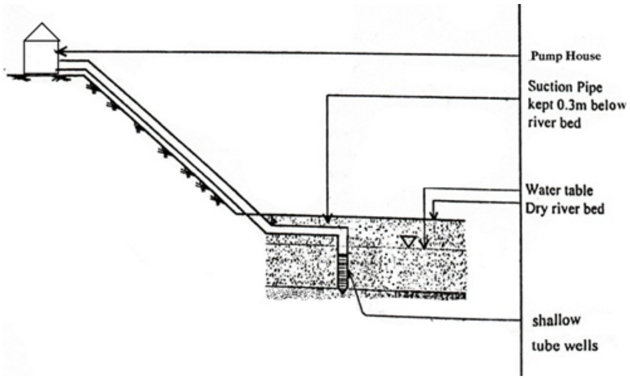

Fig. 2. Cross–section of a shallow tube well in the dry river bed

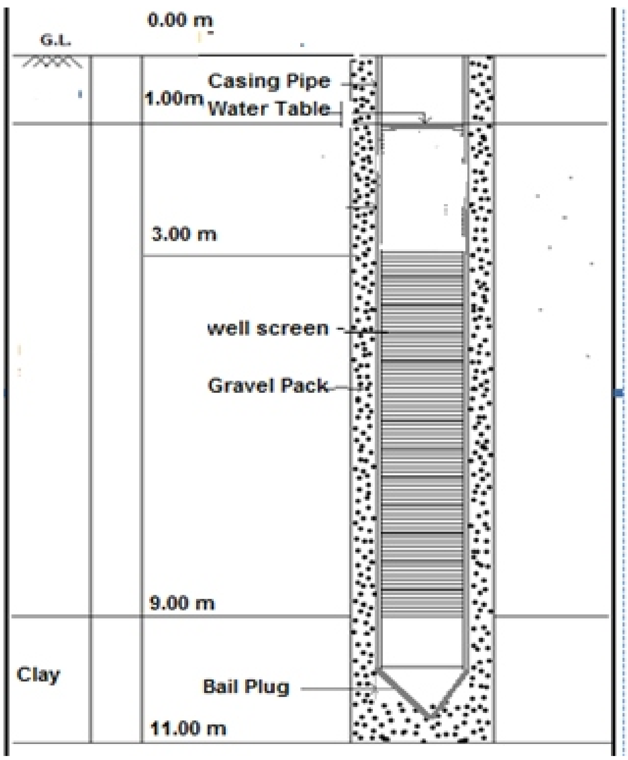

Fig. 3. Cross–section of the tube well assembly

are centered in the outer casing. The annular space between the two casings is filled with rounded tea gravel of 4–6 mm size. When the well is pumped, the gravel pack will retain much of the aquifer material that would otherwise enter the well. A combination of backwashing and surging methods is used for the development of well.

The water requirement for all the *kharif* and *rabi* crops grown in the tube well command area was computed and is presented in Table 1. The maximum water requirement is 1.82 cusec during the *summer* season. Hence the submersible pump will be designed for 2 cusecs or $0.056\ m^3\ sec^{-1}$.

Design of Submersible Pump

- Static head = 8.0 m
- Total draw down (well loss + aquifer loss) = 4.88 m

Table: 1
Water requirement of crops in the project area

Month	*Kharif* paddy		Groundnut		Sun flower		Vegetable		Green gram		Wat. req during month	Seepage loss*	Total wat. during month	Water req. per day in ha–cm	Wat. req per hour (taking 12 hr day^{-1})
	Area in ha	Req. water in ha–cm	Area in ha	Req. water in ha–cm	Area in ha	Req. water in ha–cm	Area in ha	Req. water in ha–cm	Area in ha	Req. water in ha–cm					
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
June	40	150									90	18	108	3.6	0.3
July	40	300									180	36	216	7.2	0.6
August	40	300									180	36	216	7.2	0.6
September	40	300									180	36	216	7.2	0.6
October	40	150									90	18	108	3.6	0.3
November									8	20	20	4	24	0.8	0.07
December			12	180	8	120	12	225	8	20	545	109	654	21.8	1.82
January			12	150	8	100	12	225	8	20	495	99	594	19.8	1.65
February			12	120	8	80	12	225	8	20	445	89	534	17.8	1.48
March							12	225			225	45	270	9	0.75
April															
May															

**Seepage loss in the irrigation command irrigated by tube well is assumed to be 20% of the water requirement of crop in each month*

Table: 2
Pumping test data

Time since pump started in min (t)	Time since pump stopped in min (t')	Depth to water level in m	Residual Drawdown in m (s')	t/t'
181	1	2.34	0.31	181
	2	2.32	0.29	91
	3	2.32	0.29	61
	4	2.31	0.28	46
	5	2.30	0.27	37
	6	2.29	0.26	31
	8	2.28	0.25	23.5
190	10	2.265	0.235	19
	12	2.26	0.23	16
	15	2.245	0.215	13
200	20	2.23	0.20	10
	25	2.22	0.19	8.2
	30	2.21	0.18	7
	35	2.205	0.175	6.14
220	40	2.19	0.16	5.5
	50	2.175	0.145	4.6
	60	2.17	0.14	4
	70	2.15	0.12	3.57
	80	2.145	0.115	3.25
	90	2.135	0.105	3.0
280	100	2.135	0.105	2.8
	130	2.125	0.095	2.38
340	160	2.110	0.08	2.12

- Friction loss in (120 × 150) concrete pipe = 0.1 m
- Bed level to embankment level = 4.9 m
- Embankment to sump height = 2.5 m
- Total head = 8.0 m + 4.88 m + 0.1 m + 4.9 m + 2.5 m = 20.38 m
- Assuming efficiency to be 75%.
- $HP = \frac{1000 \times Q \times H}{75 \times \eta} = \frac{1000 \times 0.056 \times 20.38}{75 \times 0.75} = 20.28$

Hence, one 20 HP pump is used for discharge of 0.056 $m^3 sec^{-1}$ at 20 m head.

Theis Recovery Method

The pumping test data is presented in Table 2. The residual drawdown is plotted against $\frac{t}{t'}$ on a semi–log paper and the graph is presented in Fig. 4. The value of $\Delta s'$ per log cycle is found to be 0.3 m. The transmissivity was computed and found to be 1793.12 m^3 day^{-1}. Using these aquifer parameters the base flow was computed using Darcy's formula as shown below and found to be 6550 m^3 day^{-1} which is more than the pump discharge rate (4838.40 m^3 day^{-1}). So the pump will function satisfactorily.

$$T = \frac{2.3Q}{4\pi\Delta s'} = \frac{2.3 \times 2397.6}{4 \times 3.14 \times 0.3} = 1793.12 \quad m^2/day$$

Baseflow Calculation

Value of T = 1793.12 m^3 day^{-1}

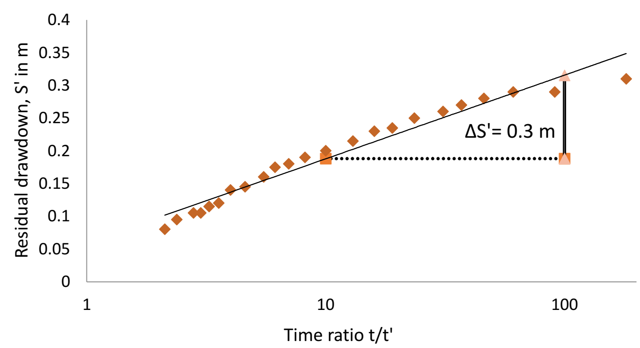

Fig. 4. Theis recovery test method

Hydraulic conductivity, $K = \frac{1793.12}{8} = 224.14\ m^3\ day^{-1}$

Hydraulic gradient, $I = \frac{drawdown}{length\ of\ flow} = \frac{0.147}{30.16} = 0.00487$

Area, A = 750 × 8 = 6000 m^3

Base flow = $K.i.A$ = 224.14 × 0.00487 × 6000 = 6550 m^3 day^{-1}

Requirement of water = 0.056 m^3 sec^{-1} × 86400 = 4838.40 m^3 day^{-1}.

As the base flow is more than the requirement of water, hence the shallow tube well will get a sufficient quantity of water for pumping.

The value of T is 1793.12 m^3 day^{-1}. The distance from the embankment to the stream course is about 750 m.

Considering a saturated sand bed of 8 m thickness, hydraulic conductivity of 224.14 m^3 day^{-1}, and hydraulic gradient of 0.00487, the base flow across the cross–sectional area of (750 × 8) m^2 is of the order of 6550 m^3 day^{-1}. The water requirement of crops is 4838.40 m^3 day^{-1}. Considering the above findings, it may be suggested that it would be appropriate to use a wire wound well screen with continuous V–shaped slots which have a very high percent of open area in the future for the construction of shallow tube well. Construction of 200 mm diameter shallow tube wells with such well screens were considered (Michael *et al*., 2008). The shallow tube well can be put to use by linking the structures with the existing distribution system of the defunct lift irrigation project. Considering the potential of the base flow in the river bed multiple tube wells can suitably be constructed and linked to the defunct delivery line of the lift irrigation project to augment irrigation potential.

The detailed income and expenditure for the project are presented in Table 3. The cost of cultivation was computed to be ₹ 6350968/- alongwith the initial cost of ₹ 590000/- for the construction of a shallow tube well. Total return from the project was calculated to be ₹ 10750384/- while repair and maintenance cost along with electric bill and pump operator charge was found to be ₹ 316750/-.

The present worth of the annual return was calculated yearly. Using data presented in Table 3, cost and revenue were tabulated for 10 years (Table 4). The last column of the table gives the discounted cash flow at the rate of 7%. The Sum of this column gives the NPV of the project. The NPV was found to be ₹ 24806749/-. The NPV is a positive value, so it indicates investment is worthwhile (Panigrahi and Panda, 2003). A similar type of NPV value was found out by Narayanamoorthy *et al.* (2018), Narale *et al.* (2014) for various agricultural systems.

The BCR for growing *kharif* and *rabi* crops by shallow tube well comes out to be 1.48. As the BCR is greater than 1, the project is feasible (Sevede *et al*., 2004; Mishra *et al*., 2008; Paul *et al*., 2012). It indicates that the BCR is good enough for the cultivation and hence it is worth constructing a shallow tube well for the LI project. In the present study, the IRR was found to be 35%. As the IRR is higher than the bank lending interest rate (7%), the cultivation of *kharif* and

Table: 3
Details of income and expenditure of shallow tube well

S.No.	Particulars	Yield / Cost
1.	Yield considering eight crops in a year (quintal)	6406.00
2.	Total revenue / year (₹)	10750384
3.	Cost of cultivation (₹)	6350968
4.	Initial investment (₹)	590000
5.	Repair and maintenance cost, electric bill and pump operator charge (₹)	316750

Table: 4
Cash flow for *kharif* and *rabi* crops by shallow tube well

Year	Cash outflow	PW cash outflow	Cash inflow	PW cash inflow	NPV
0	7257718	7257718	0	0.00	−7257718
1	6667718	6231512	10750384	10047087	3815575
2	6667718	5823843	10750384	9389801	3565958
3	6667718	5442844	10750384	8775515	3332671
4	6667718	5086770	10750384	8201416	3114646
5	6667718	4753990	10750384	7664875	2910884
6	6667718	4442982	10750384	7163434	2720452
7	6667718	4152319	10750384	6694798	2542479
8	6667718	3880672	10750384	6256821	2376148
9	6667718	3626796	10750384	5847496	2220699
10	0	0	10750384	5464950	5464950
Total	67267180	50699449	107503840	75506198	24806749

Table: 5
Computation of payback period of shallow tube well

Year	PW total cash (₹)	Cash inflow (₹)	PW total cash inflow (₹)	Cumulative cash inflow (₹)
0	50699449			
1		10750384	10047087	10047087
2		10750384	9389801	19436888
3		10750384	8775515	28212403
4		10750384	8201416	36413819
5		10750384	7664875	44078694
6		10750384	7163434	51242128

rabi crops by this project is economically viable (Mishra *et al*., 2009; Paul *et al*., 2019). The detailed computation of the PBP is presented in Table 5. The PBP for the present study is found to be 6 years, which was less than the life span of the shallow tube well (10 years). Thus farmers could pay back their investment in 6 years.

Based on estimated economic indicators it can be concluded that the construction of a shallow tube well in the dry river bed is economical and there is a substantial increase in farmer's income due to ensured irrigation of crops grown in the area.

4. CONCLUSIONS

Techno−economic evaluation of the shallow tube well for reviving the defunct Ekdal RL project of Narasingpur block of Cuttack district of Odisha was. The transmissivity (T) of the subsurface formation was found to be 1793.12 m^3 day^{-1}. The base flow in the study area was 6550 m^3 day^{-1}. The water requirement of crops was estimated as 4838.40 m^3 day^{-1}. The project was found feasible from a hydraulic point of view as the base flow was more than the pumping rate of the tube well (water requirement of crops). Considering the potential of base flow in the river bed multiple shallow tube wells can suitably be constructed and linked to the delivery line of the defunct lift irrigation project to augment the irrigation potential. The NPV and BCR of the shallow tube well were estimated as ₹ 24806749/- and 1.48, respectively. The IRR for the shallow tube well was 35%. The PBP of the project for *kharif* and *rabi* crop cultivation is 6 years. These economic indicators suggested that the construction of a shallow tube well in a dry river bed is technically feasible and economical for coastal Odisha.

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