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Evaluation of economic loss due to irrigation system inefficiency: a case study of nepal gandak west canal irrigation system[1]

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Abstract

Introduction: The main objective of this study is to estimate the total economic loss due to inefficient supply of irrigation water in the command area of Nepal Gandak West Canal Irrigation System. Several approaches have been used for this purpose. The optimal level of water needed for different crops is calculated using the methods suggested by the PDSP manual using Penman-Montheith Equation based on the available hydro-metrological data and field assessment of crop calendar. Crop yields in the developing world are consistently higher in irrigated areas than in the rainfed areas. Nepal Gandak West Canal Irrigation System (NGWCIS), under AMIS also have the similar problem; it has some uplands and also poor access to irrigation during dry season. Within the command area, there are several shallow tube wells are in operation, which increased the cost of irrigation even already have canal irrigation system.

Materials and Methods: The water available is calculated based on the sediment assessment and evaluation of reduced canal capacity based on the method proposed by Khazratov (2020). The timeliness of supply and quantity of water is crucial, which motivated the farmers to explore the alternate water sources. The data on water use, cropping pattern, agricultural system, and issues with water availability, inventory on alternate water use and associated cost, and types of energy uses for alternate water sources were collected through focus group discussion, observation checklist, and key informant

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interview. The command area of the system is characterized by high agriculture area with very low sign of urbanization, few industrial expansions and most farmers owing a shallow tube well as a supplementary irrigation source due to unreliability of operation of the system. The irrigation system is also characterized by high silt entry and deposition consequently reducing the bulk water delivery of the system.

Results: Farmers are using their own diesel pump to irrigate their farm land from shallow tube well within the command area. Mostly Farmers are depending on canal (surface) water, rainwater, and groundwater for their irrigation as per requirement. The economic assessment of the tubewells was carried out based on the deficit of water, operation hour of pump and total cost associated with the operation and this is considered to be the total economic loss due to poor irrigation system. The total estimated economic loss for this was calculated to be 406 thousands USD which should be addressed through proper rehabilitation and operation and maintenance techniques. The requirement of each crop with seasonal variation is entirely attributed to the variation in their growth from seedling to maturity, potential evapotranspiration attributed by the climatic variation and effective rainfall. The highest value is observed in August where the command area is mostly covered by Paddy while the lowest area is observed in June where most of the area is fallow with very small area covered by Maize.

Conclusions: The effect of the operation schedule which also includes the maintenance period doesn’t ensure the year-round irrigation system in the large irrigation systems and similarly poor sediment control mechanism continuously reduce the capacity of the canal which restrict the limited supply of water to the farmers. The realization of high productivity from the timely and sufficient irrigation facility encourages the farmers to search and install alternative irrigation facility and giving additional production cost to the farmers.

Keywords: Crop water requirement, Canal water, Shallow tube wells, Poor performance efficiency, Agricultural productivity, Nepal.

1. Introduction

Improved access to irrigation infrastructure will contribute in the food security with increased crop production, farm income and reduction in inequalities in income distribution, and poverty (Odorico *et al.* 2020; Bhattrarai *et al.* 2002). Crop yields in the developing world are consistently higher in irrigated areas than in the rainfed areas. Nepal is considered to be rich in per capita water availability with total annual runoff of about 225 billion cubic meters, even though utilization is very less and several hectors of land is under rainfed agriculture (WECS 2005). Agriculture is the mainstay of the economy of Nepal contributing 27% to the National GDP and engaging about 60 percent of the population (NPC 2020). With the increase in the agriculture practice and existing community harmony in the ancient time, farmers started developing their own irrigation system with their own traditional operational and maintenance techniques and were considered as Farmers Managed Irrigation System (FMIS), (Pradhan & Belbase, 2018). It is believed that more than 16700 FMIS were developed, operated, and managed by farmers themselves within the Country (Pradhan, 2000). Government direct investment was first initiated after the construction of Chandra Nahar and this kind of systems are considered as Agency Managed Irrigation System (AMIS). Of the estimated total of 2.64 million ha cultivable land of Nepal, about 47.5% i.e., about 1,252,476 ha area is provided with irrigation facilities under different scenarios and rest of the area is under rain-fed cultivation. As of end of the 10th five-year plan (July, 2007) a total of 1,194,628 ha cultivated land area (66% of irrigable land) has been provided with some or the other form of irrigation facility. Desired situation is that all irrigable land area will be provided with year-round assured irrigation to its optimum possible water resources availability (DOWRI, 2019). Recent statistics on irrigation inventory shows a total of 2254 irrigation systems with a command area of 728000 hectors (ha) including both joint managed irrigation system (JMIS) and farmers managed irrigation system (FMIS), of which 81% (591000 ha) are on Terai (DOWRI, 2019).Most of these systems are now characterized by poor performance efficiency, weak institutional capacity and non-existing of water management tools. Attempts have been made for the rehabilitation and modernization of existing irrigation infrastructures through participatory irrigation Management, irrigation management transfer or direct investment of the Government for the operation and maintenance of the system. Due to immature program implementation, poor structural arrangements, insufficient fund availability and incapable Water Users Association (WUA), the performance of the irrigation system is still not in a satisfactory level and it is believed that they are far from the present concept of modernization of irrigation system. AMIS in Nepal are either Government operated or jointly operated by Government and Water Users Association. The resource mobilization of Water Users Association is mostly dependent on Irrigation Service Fee (ISF) and the mechanism and collection rate are very poor. Poor resource mobilization by both state and WUA forces farmers to operate their system at low efficiency condition or search for alternative sources of irrigation at their own cost. In most of the AMIS, some of the lands are in upland (will not receive irrigation water from the system even having within the command area), inequal distribution of water in head, mid, and tail reach of the command area. In this situation, to optimize the water use farmers are developing their own temporary irrigation systems like shallow tube wells (those are either funded or private investment), which are mostly operated during inefficient irrigation or no irrigation water received form the AMIS. This could be the impact of improper irrigation system design and ultimate impact on cost of irrigation, economic return from the irrigation, and irrigation system life expectancy (Zazueta & Haman, 2017).

Nepal Gandak West Canal Irrigation System (NGWCIS), under AMIS also have the similar problem; it has some uplands and also poor access to irrigation during dry season. Within the command area, there are several shallow tube wells are in operation, which increased the cost of irrigation even already have canal irrigation system. In this study, the associated cost from installation of tube well to operation and maintenance has been considered as cost of irrigation, which is ultimately the economic loss of farmers within the command area due to inefficient water delivery at the farm level.

In this context, this study is intended to evaluate the total investment done by the farmers at their own level to support their productive agriculture system with alternative irrigation mechanism, which is considered as total economic loss due to Irrigation System inefficiency in the Nepal Gandak West Canal Irrigation System (NGWCIS)'s command area.

2. Materials and Methods

2-1. Description of the Study Area

Nepal Gandak West Canal Irrigation System (NGWCIS) was developed as a part of well-known Gandak Treaty between Government of Nepal and Government of India and developed for irrigation, flood control and hydropower generation. The intake is located in Gandaki Province and most of the command area are within Lumbini Province. The system irrigates a total command area of 8700 ha. The construction of the system was completed in 1976 AD. The intake of the system is about 600 m upstream from Gandak barrage developed with 36 gates with the design flood discharge of 850000 cusec. On the Indian side, it has Main Western Canal running through Nepal with the design capacity of 18000 cusec and Eastern Canal with the design capacity of 14400 cusec irrigating agricultural land in Bihar and Uttar Pradesh States of India (field study). Two additional offtakes are provided in the Main Western Canal to irrigate 1600 ha of agricultural land within Nepal territory between Main Western Canal and Nepal-India border.

The command area of the system is characterized by high agriculture area with very low sign of urbanization, few industrial expansions and most farmers owing a shallow tube well as a supplementary irrigation source due to unreliability of operation of the system. The irrigation system is also characterized by high silt entry and deposition consequently reducing the bulk water delivery of the system. The location map and command area of the system are illustrated in Figure 1.

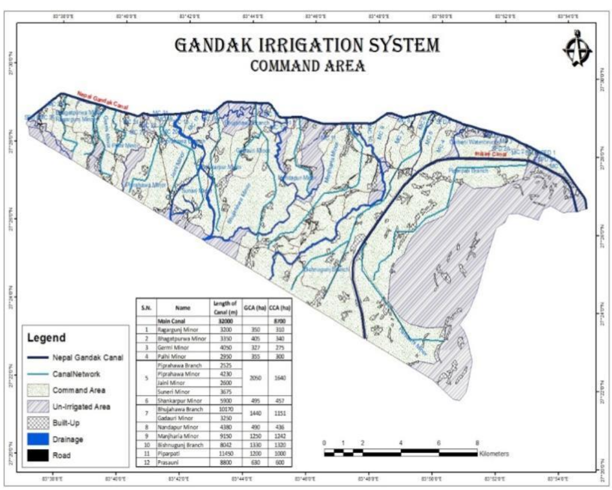

Figure 1. Location of the Project Area

2-2. Data Used and Method of Collection

Most of the field data for the present study were obtained from Nepal Gandak West Canal Irrigation management Office (herein after referred to as collected data) while some of the data were collected during the field study in 2018. The hydro-meteorological data were obtained from Department of Hydrology and Meteorology (DHM). The data collected includes command area details, hydro-meteorological data, and agricultural data. Sediment assessment was carried out for the estimation of the sediment load in the canal system.

2-3. Crop Water Requirements

The Crop Water Requirements (CWR) is derived from Penman Method as per the Planning and Design Strengthening Project (PDSP) Manual, 1989 followed by Department of Water Resources and Irrigation (DWRI). The methods used are based on FAO Irrigation and Drainage Paper Number 24 (1977).

The meteorological parameters used for the study are presented in Table 1 derived from the time series data of DHM.

Table 1. Meteorological Data used for Crop Water Requirement

Month	Monthly Ppt (mm)	wind speed (km/hr)	Monthly Sunshine (hr)	Relative Humidity (%)
Jan	15.8	44.86	4.55	73.72
Feb	20.4	61.92	7.35	66.03
Mar	20.45	65.1	8.76	52.31
Apr	38.56	75.34	9.11	42.7
May	96.01	68.2	9.39	50.82
Jun	339.04	57.62	7.47	62.45
July	573.26	34.84	5.05	74.92
Aug	426.22	26.59	5.67	76.73
Sept	268.38	29.98	6.53	76.97
Oct	69.34	25.68	8.26	73.13
Nov	6.72	27.93	7.68	68.12
Dec	15.73	31.33	6.02	70.88

The other related information such as a Ea, f(u), W, Ra, N, C were derived from PDSP manual used for the crop water requirements in case of Nepal.

2-4. Laboratory Assessment of Sediment

The major problem in the irrigation system in high concentration of silt entry into the system. There is no settling basin or silt ejector in the system to control silt entry and this is considered as the first problem for sustainable management of the system. A laboratory assessment of sediment concentration, particle size distribution and mineral content has been carried out for a period of 79 days from 2019 July 5 to 2019 September 22. The period is selected based on the time of operation of the canal and the wet season where the concentration of sediment is high to identify the maximum sediment concentration that can enter the canal system. A total of four samples were collected each day two each from the canal and river on a point location basis. The characteristics of the samples are presented in Table 2.

Table 2. Characteristics of the Samples

Character		River		Canal	
		Number	**In Percentage**	**Number**	**In Percentage**
Water Color	Clear	113	71	99	63
	Turbid	42	26	54	34
	No	5	3	5	3
Rainfall Condition	No	98	61	100	63
	Low	47	29	44	28
	High	15	9	14	9
Sediment Concentration (ppm)	0-1000	70	44	32	20
	1000-2000	60	38	84	53
	2000-5000	24	15	35	22
	5000-10000	4	3	6	4
	>10000	2	1	1	1

The Particle Size Distribution (PSD) analysis shows that the sediment contains large quantify of fine (clay particles and fine silt) which exists in the form of mud lumps with the size fraction of 5 to 75 μm. The particle samples contain 58% of suspended Quartz, 22% Mica and others are carbonate minerals, clay lumps and highly weathered rock fragments.

2-5. Morphological changes in the Canal

The morphological changes in the canal were estimated by the Exner equation as sediment continuity equation referred by Khazratov (2020) with an assumption that the deposited sediment is distributed equally throughout half of the canal length and in the entire wetted perimeter as observed during the field visit. The sediment deposited in the canal is estimated based on the canal discharge and concentration of the sediment. Based on the sediment deposited, the morphological changes in the canal were calculated by estimating change in canal bed, change in cross section area, new cross-sectional area, new wetted perimeter and new hydraulic radius. With the estimation of the morphological changes in the canal and new canal capacity is estimated. The fifteen days estimation is continued throughout the operation period.

2-6. Inventory study of Shallow Tube well

The crop cut survey report of 2018 shows that the productivity of rice and wheat in the study area are respectively 5.42 Mt/ha and 3.28 Mt/ha which are higher than the National average. This figure contradicts with the physical performance of the study. During the field study it was found that the water deficit within the command area is supplemented by the individual shallow tube well existing in the field, which may have significant contribution for the increased crop production. An inventory survey was carried out to identify the total number of tube wells in the study area. Three sample branch canals were selected for the inventory study with location of each tube wells presented in the GIS platform. The location of the tube well was later upscaled to the command area level to identify the total number of shallow tube wells are in operation in the command area as a supplementary irrigation facility due to poor performance of the existing surface irrigation facility to meet the crop water requirement.

3. Results and Discussion

3-1. Total Irrigation Water Requirement

The major coverage of the crop in the study area are Paddy and Wheat. Paddy covers highest area (92%) during the summer with small area covered by summer vegetables. Wheat further covers about 50% of the total area during winter season with additional area coverage by pulses, winter vegetables, oilseeds and potatoes while maize are grown during the spring. The coverage of each crop is presented in Figure 2. The cropping intensity is 184%.

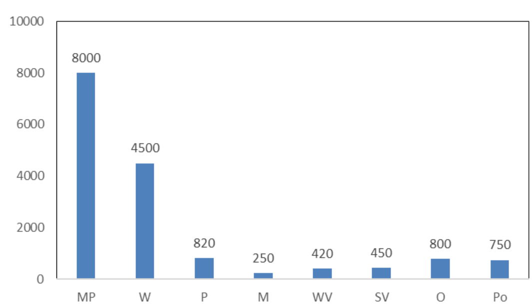

Figure 2. Crop Coverage in the study area in ha

The total irrigation water requirement is maximum at the month of August as a requirement for Paddy which also has highest coverage in the area and it is lowest in the month of November due to minimum coverage of the crop and initiation of winter vegetables. The crop water requirements are presented in Figure 3. The water requirements range from 96 l/s to 10226 l/s in the canal system.

Since the diversion capacity of the irrigation system is only 8500 l/s and the operation of the barrage is scheduled for 1st week of July to 2nd week of October in Summer and 4th week of December to 2nd week of March, the system is operated at deficit water availability condition. Since the importance of water has been well realized by the farmers, the supplementary supply of irrigation water is provided through the tube wells operated at the farm level.

The requirement of each crop with seasonal variation is entirely attributed to the variation in their growth from seedling to maturity, potential evapotranspiration attributed by the climatic variation and effective rainfall. The highest value is observed in August where the command area is mostly covered by Paddy while the lowest area is observed in June where most of the area is fallow with very small area covered by Maize. The diversion requirement is in line with the barrage operation time whereas requirement is very low when the barrage is shut down for annual maintenance.

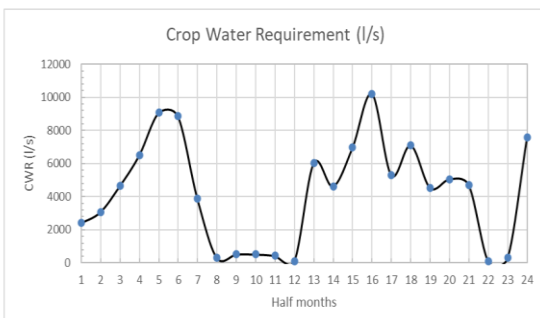

Figure 3. Crop Water Requirements in the Study area

3-2. Morphological Changes in the Canal

The initial sediment entry at the original discharge of 8.5 m^3/s and sediment concentration of 2000 ppm was calculated as 16561.41 m^3/s and subsequent deposition of the sediment is calculated. The revised bed width and the wetted perimeter calculated at the time step of 15 days is presented in Figure 4. With the continuous deposition of the sediment during 120 days period, the flow depth decreases by 0.68 m, bed width increases by 3.16 m, wetted perimeter increases by 0.7 and the discharge decreases by 2.57 m^3/s. This shows that the canal capacity decreases by 30% over the 120 days of irrigation period in absence of sediment removal structures or provisions. The estimation of the change in the discharge is based on the method proposed by Khazratov (*2020)* which needs further validation and more robust methods can be applied to obtain the best estimate.

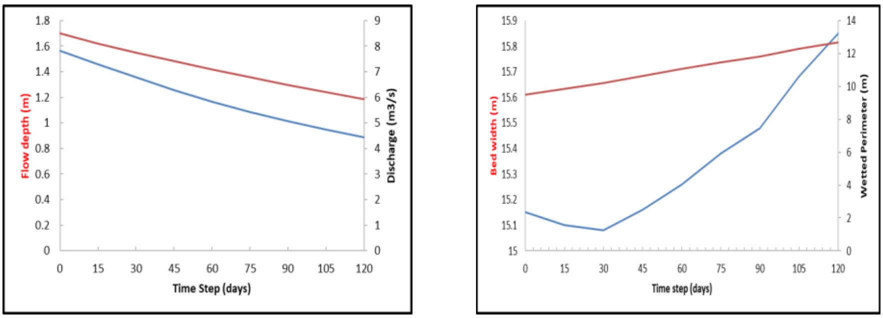

Figure 4. Change in Bedwidth, Wetter Perimeter, Flow Depth and Discharge of canal due to continuous deposition of sediments

3-3. Water Deficit from Surface Irrigation System

The bulk water delivery of the system under ideal condition is 8.5 m^3/s and it is expected from the agency side to delivery this water throughout the cropping period due to the existence of Gandak Barrage. The operation of the barrage is scheduled for 1st week of July to 2nd week of October in Summer and 4th week of December to 2nd week of March and there is no water available beyond this period.

The water deficit in the study area is created by two situations. One condition is dependency of the canal on the barrage operation schedule which are operated only in two seasons summer and winter. The spring season period is the maintenance period of the system and during this period the barrage operate at zero water discharge condition. Second reason is the reduced discharge capacity of canal due to heavy silt deposition. The barrage in the system provides full supply level for the head regulator but due to heavy silt deposition in the canal and absence of silt ejector or settling basin to control silt entry into the canal, the canal capacity continuously decreases. As there is no possibility to stop the canal and carry out silt removal, the canal has to be operated at decreased capacity condition.

Since the importance of water has been well realized by the farmers, the supplementary supply of irrigation water is provided through the tubewells operated at the farm level. Table below shows the total water required in the study area, total diversion available and water deficit. Out of 24 fortnightly assessments only 7 fortnights are provided with sufficient supply but rest of the period the canal is operated at deficit condition.

Since the actual data of discharge on the canal at different seasons are not available, the methods proposed by Khazratov (2019) has been applied to estimate the actual water available in the canal.

Table 3. Crop Evapotranspiration and Irrigation Water Requirements in the study Area

Month	Half monthly	Total Demand	Available Discharge	Deficit	Addition Irrigation Required
January	1	2407.40	8308.11	5900.71	0.00
	2	3078.79	7541.86	4463.07	0.00
February	1	4654.09	6886.07	2231.98	0.00
	2	6503.34	6286.86	-216.48	216.48
March	1	9068.01	5776.90	-3291.12	3291.12
	2	8852.56	0	-8852.56	8852.56
April	1	3886.34	0	-3886.34	3886.34
	2	316.61	0	-316.61	316.61
May	1	515.85	0	-515.85	515.85
	2	519.46	0	-519.46	519.46
June	1	431.35	0	-431.35	431.35
	2	113.65	0	-113.65	113.65
July	1	6046.91	8500.00	2453.09	0.00
	2	4633.20	7740.71	3107.52	0.00
August	1	6979.42	7069.32	89.90	0.00
	2	10226.89	6455.43	-3771.46	3771.46
September	1	5303.70	5891.71	588.01	0.00
	2	7118.93	5375.17	-1743.76	1743.76
October	1	4542.66	4978.78	436.12	0.00
	2	5066.80	0	-5066.80	5066.80
November	1	4691.36	0	-4691.36	4691.36
	2	96.22	0	-96.22	96.22
December	1	317.92	0	-317.92	317.92
	2	7580.47	8500.00	919.53	0.00

3-4. Shallow Tubewell as Supplementary Contribution in the Study Area

The count of shallow tubewell in the study area was carried out in three branch canals of the irrigation system as shown in Figure 5. These canals are Rangargunj Minor (232 ha), Shankarpur Minor (490 ha) and Manjharia Minor (1665 ha). The total area used for the shall tubewell counting is around 28% of the total area. The total shallow tubewell found in the study area are 42, 94 and 249 making a total of 385 tubewells within the area of 2387 ha. The GPS position of the tubewell within the branch command area are presented in the Figure 5. This shows that there are 6.2 tubewell/ha. Considering uniform distribution of tubewell throughout the command area the expected number of total tube wells in the command area is calculated to be 1370. The Gandak irrigation system was operated after 1980 and the canal was operated at full supply level with very low entry of silt into the system. The provision of irrigation facility has increased the crop coverage with increased production and productivity. The project gave realization to the farmers about the importance of irrigation facility. With due course of time, due to poor O&M facility, increasing silt entry into the system and dependency of water on the

Indian side, the timeliness of operation and bulk water delivery in the system made the system less efficient. Farmers then started installing the shallow tubewell as supplementary supply to their crops when the system operation in inefficient.

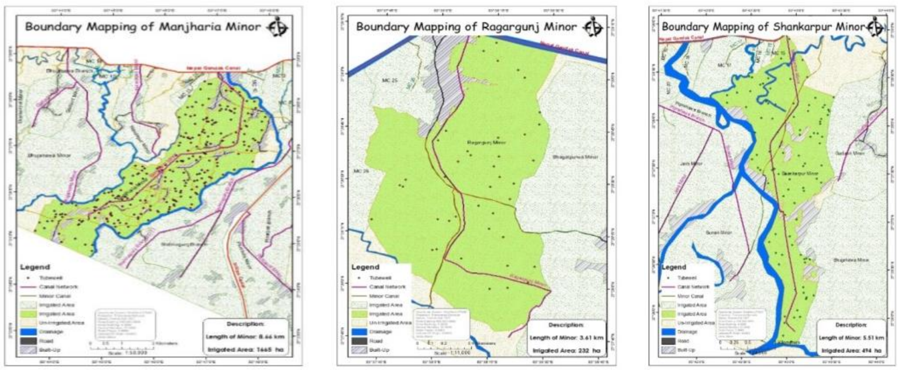

Figure 5. Distribution and location of shallow tubewell in the sample branch canals

3-5. Economic loss estimation

The high agriculture productivity in the command area and poor performance of the irrigation system clearly justifies the role of shallow tubewell has played in the command area. Since the irrigation facility is Agency Managed and O&M of the surface system is carried out by the Government, the investment cost on the tube well and their O&M is entirely contributed by the farmers. The deficit water fulfilled by the tubewell and total cost associated to it is considered to be the total economic loss due to irrigation system inefficiency. It is found that the crop coverage in the command area is throughout the year but the canal is operational for about eight months. Considering the average operating hours of 6.5 daily and the water availability, the maximum number of tubewell needed for supplementing the deficit water is 1719 as shown in the Table 4 which is higher than the counted (1370) number of tubewell. Since the number of tubewell required range from 1719, the total number of tubewell installed by the farmers are still high.

The operation of the tubewell is carried out during no-flow condition in the canal and during deficit situation from decreasing canal capacity from silt deposition. Considering average investment cost of 71875 Rs (590USD) (Thapa *et al.* 2019), the total investment of the farmers to supplement the inefficient canal operation is estimated to be 0.8 Million USD. The total cost of the tubewell of the deficit period is 406, 330 USD.

Table 4. Estimation of Economic Losses

Particular	February	March		April		May		June		August	September	October	November		December
	2	1	2	1	2	1	2	1	2	2	2	2	1	2	1
Deficit water (cumecs)	216.48	3291.12	8852.56	3886.34	316.61	515.85	519.46	431.35	113.65	3771.46	1743.76	5066.80	4691.36	96.22	317.92
deficit (m3/day)	18,704	284,353	764,861	335,779	27,355	44,570	44,881	37,269	9,819	325,854	150,661	437,772	405,333	8,313	27,468
Discharge per day per pump @ 6.5 hr operation (m3/day)	121	121	121	121	121	121	121	121	121	121	121	121	121	121	121
Hour of operation to fulfill deficit	273	4,154	11,173	4,905	400	651	656	544	143	4,760	2,201	6,395	5,921	121	401
No of pumps to achieve deficit flow rate	42	639	1,719	755	61	100	101	84	22	732	339	984	911	19	62
Average installation cost all complete (4 inch Diesel pump) (NRS)	71875.0	71875.0	71875.0	71875.0	71875.0	71875.0	71875.0	71875.0	71875.0	71875.0	71875.0	71875.0	71875.0	71875.0	71875.0
Life of pump operation (hour)	30000	30000	30000	30000	30000	30000	30000	30000	30000	30000	30000	30000	30000	30000	30000
Installation cost per hour of operation	2.40	2.40	2.4	2.4	2.4	2.4	2.4	2.40	2.40	2.40	2.40	2.40	2.40	2.40	2.40
Average operation cost per hour	75	75	75	75	75	75	75	75	75	75	75	75	75	75	75
Total cost per hour	77.40	77.40	77.40	77.40	77.40	77.40	77.40	77.40	77.40	77.40	77.40	77.40	77.40	77.40	77.40
Total cost in each days (NRs)	**21,147**	**321,490**	**864,800**	**379,654**	**30,929**	**50,393**	**50,746**	**42,136**	**11,102**	**368,412**	**170,338**	**494,946**	**458,271**	**9,399**	**31,055**
Total Cost for 15 days (USD)	2,600	39,527	106,328	46,679	3,803	6,196	6,239	5,181	1,365	45,297	20,943	60,854	56,345	1,156	3,818

4. Conclusions

The expansion of irrigation infrastructure is Nepal can be considered satisfactory; however, the sustainability of these systems is undermined due to which the performance of the irrigation system is lowered. The realization of the farmers about the importance of irrigation in improving their agricultural productivity is clearly found in the study area which has motivated the farmers to install individually owned shallow tubewells to supplement irrigation facility when the surface system doesn't function. The effect of the operation schedule which also includes the maintenance period doesn't ensure the year-round irrigation system in the large irrigation systems and similarly poor sediment control mechanism continuously reduce the capacity of the canal which restrict the limited supply of water to the farmers. The realization of high productivity from the timely and sufficient irrigation facility encourages the farmers to search and install alternative irrigation facility and giving additional production cost to the farmers.

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