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Situational and sustainability assessment of irrigation systems to Nepal from the Koshi Barrage

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ABSTRACT

The Koshi Barrage was constructed in the Nepalese territory as per the Kosi Agreement signed between Nepal and India in 1954 and amended in 1966. Two irrigation systems, viz. the Koshi Distributary System and the Koshi Pump Lift Irrigation System, starting off from the Koshi Western Main Canal in India, are irrigating 11,300 and 13,180 ha of land in the Saptari District of Nepal, respectively. The average annual amount of water available in the Koshi Pump System and Koshi Distributary System is found to be 60.28 and 136.97 million cubic meters (MCM), respectively. The existing cropping intensity of these two systems is 170 and 190%, respectively. The sustainability of these irrigation systems was assessed using the Multi Criteria Analysis (MCA). The Koshi Pump Irrigation System is found to be a Sustained but At-Risk Project, whereas the Koshi Distributary Irrigation System is found to be a Not Sustained Project. Furthermore, the study concluded that these irrigation systems have low crop productivity and the conditions of the existing infrastructures are poor.

Key words: irrigation systems, irrigation water management, Kosi Agreement, sustainability

HIGHLIGHTS

- The Koshi Barrage was constructed mainly for the flood control in the Indian State of Bihar and to the Saptari district of Nepal acquiring the mutual benefits between the two nations according the 'Kosi Agreement,1954'.
- Nepal is also getting some irrigational benefits from this barrage.
- Irrigation systems are poorly performing and are found at risk.

1. INTRODUCTION

The Koshi Barrage was constructed in the Nepalese territory as per the Kosi Agreement between Nepal and India. The Kosi Agreement was signed on 25 April 1954 mainly to construct a barrage, headwork, afflux, and flood banks on the lands lying within the territories of Nepal. It was primarily meant to control the massive floods and devastation in the Bihar State of India. Bagale (2020) claims that more focus was given in the agreement to flood control, and irrigation benefits were undermined. The agreement was amended on 19 December 1966 to address the concerns of the Nepal side including the sovereignty of the land and the life of the agreement (Bisht 2008). Both nations worked in collaboration to harness the irrigation benefits on either side.

The Koshi Eastern Main Canal and the Koshi Western Main Canal starting off from the Koshi Barrage irrigate 612,500 and 356,610 ha of land, respectively, in the State of Bihar, India. Nepal has a pump canal system and a direct gravity irrigation system to irrigate the Saptari District from the Koshi Western Main Canal (Pradhan 2021). The irrigation benefits were made available to Nepal from the Koshi Barrage only when the construction of two irrigation systems, viz. the Koshi Distributary Irrigation System (11,300 ha) and the Koshi Pump Irrigation System (13,180 ha) were started by India and completed after 12 years. These irrigation systems were handed over to Nepal in 1989. However, as a result of their constructive cooperation, the two nations have made progress in building irrigation canals for the benefits of larger communities on both sides of the border. This has increased the potential for irrigation in the Saptari and some districts of Bihar while also addressing the problem of flooding. During the handing over, these projects were in very poor condition and, therefore, the rehabilitation of these projects was started by Nepal in 1995 (DOWRI 2020). At present, the systems are operated in joint management of the Water Users Association (WUA) and the government agency of Nepal. The sustainability of these irrigation facilities is a matter of study, as these are the only tangible benefits to Nepal from the Koshi Barrage.

2. SUSTAINABILITY OF IRRIGATION SYSTEMS

Sustainability of any irrigation system constitutes infrastructural, institutional, and economic and socio-environmental aspects (Cai *et al.* 2001). The infrastructural aspect of irrigation system sustainability mainly depends on the design, construction, and status of physical structures such as headwork, canal networks, cross drainage structures, water distribution structures, and others. It determines the conveyance and water application efficiency of the system. To ensure structural sustainability, the irrigation system should be designed, constructed, and maintained in such a way that the water delivery should be flexible, reliable, and timely (Norton 2004). The institutional aspect of sustainability in the irrigation system includes the role of irrigation offices, Water User Associations (WUAs), executive committees, and branch committees. Irrigation management in Nepal is done mainly in three ways: agency-managed, farmer-managed, and joint management by both agency and water users. The performance of the farmer-managed irrigation system (FMIS) in Nepal is found more effective than agency-managed irrigation systems (Dhakal *et al.* 2018). The third aspect of the sustainability of the irrigation system is the economic aspect. The irrigation systems need funds for regular operation and maintenance (O&M). An irrigation system will only be sustainable when it can manage its O&M cost. The cost of sustaining irrigation will vary depending on the available resources and economic development (Wichelens & Oster 2006). Irrigation Service Fee (ISF) is one of the income sources in irrigation systems. ISF collection can be improved by increasing the productivity of irrigation water and management of the irrigation systems. The crop productivity in the irrigated area can be increased through appropriate farming systems, selection of high-value and high-yielding varieties, and efficient use of water. The socio-environmental aspect is equally important for the sustainability of irrigation systems. Sometimes the irrigation systems create environmental degradations in the command area. Such degradation includes water logging, salinity, siltation, soil erosion, and others. The environmental condition in the command area needs to be improved to ensure the sustainability of the irrigation system.

The conceptual framework of the sustainability of irrigation systems is shown in Figure 1.

A project's services are ranked in terms of sustained, sustained but at risk (sustained risk), and not sustained projects (Adhikari & Bhattarai 2010). The objective of this type of ranking is to help decisions for future investment. The assumption is no support is required for sustained projects, need some follow-up support for sustained but risky projects, and need significant project rehabilitation support to not sustained projects.

3. METHODOLOGY

3.1. Study area

The study area lies in the Saptari District of Madhesh Province, Southeastern Nepal. The study focused on two irrigation systems: (a) the Koshi Pump Irrigation System and (b) the Koshi Distributary Irrigation System. Both of these systems start off from the Western Koshi Canal. The Western Koshi Canal is the canal which takes 4,000 m^3/s of water from the Koshi Barrage to India. A total of 24,480 ha of command area lies in the study area. The study area is shown in Figure 2.

The Koshi Distributary Irrigation System has 13 branch canals (dividing into 195 sub-branches) to irrigate 11,300 ha of land in Nepal. Similarly, the Koshi Pump Irrigation System lifts the irrigation water benefiting an area of 13,180 ha of land in Nepal. The system has a 32.78 km main canal and 12 distributaries. Water is lifted to a total head of 50 ft in two stages from two different pump houses. There are a total of 12 pumps, eight pumps have a capacity of 2.75 m^3/s each and four pumps have a capacity 1.5 m^3/s each.

3.2. Data collection and analysis

Primary data were collected by key informant interviews, group discussions, and field observation. Multi-criteria analysis (MCA) was used for key sustainability dimension analysis. Sustainability dimensions are the most advanced level of monitoring indicators used in Nepal (Adhikari & Bhattarai 2010). It uses the technical, socio-environmental, cost recovery, and institutional monitoring components in the water industry. Numerous core elements and sub-factors play a vital role in influencing each sustainability component. For instance, the 'technical' aspect of irrigation water supply services is significantly influenced by five important factors: source

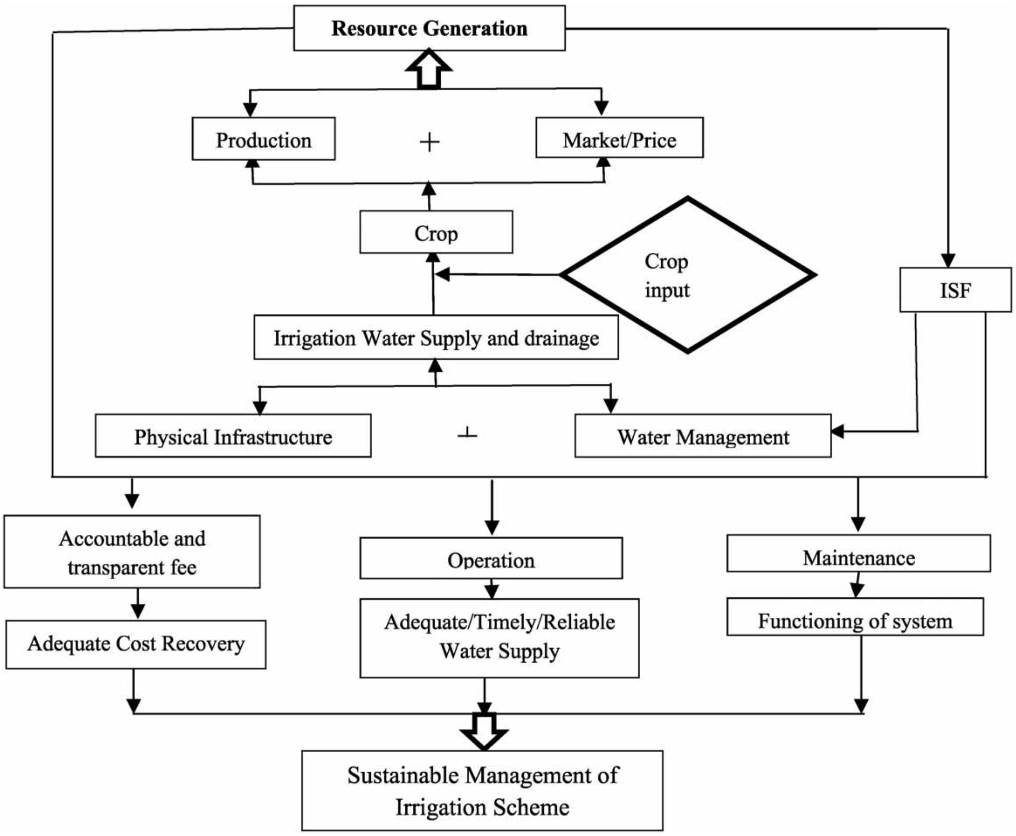

Figure 1 | Conceptual framework of sustainability of irrigation systems.

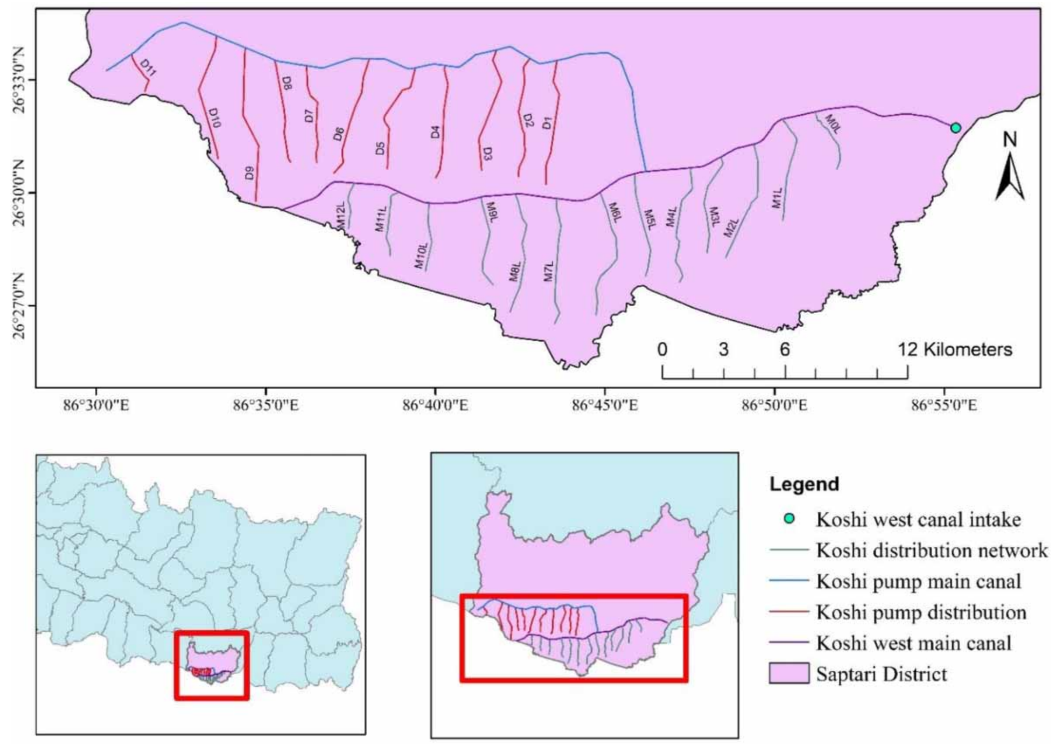

Figure 2 | Canal network of the Koshi Pump Irrigation System and Koshi Distributary Irrigation System.

yield, water quality, the physical state of engineering components, the operation of water points, and equity. Each set of criteria is graded in accordance with the MCA principles based on its potential contribution or significance in strengthening the case. The sustainability ranking was made using the following definition as presented by Adhikari & Bhattarai (2010) (Table 1).

Table 1 | Sustainability ranking

Sustained project	The project obtains a 70% (or more) score in all four sustainability dimensions individually
Sustained but at-risk project	The project obtains a 70% score in overall sustainability dimension but fails to obtain 70% (or obtain 30–69%) score in any of four sustainability dimensions
Not sustained project (poor project)	The project fails to obtain a 70% score in overall sustainability dimensions or get less than 30% score in any of the dimension

Source: Adhikari & Bhattarai (2010).

The indicator-wise weight distribution was done for the assessment of the sustainability of irrigation systems. The four sustainability dimensions (technical, socio-environmental, institutional, and economic) were equally weighted with a score of 25 for each. The core factors and sub-factors for each dimension were elaborated and weighted accordingly as shown in Table 2.

Table 2 | Indicator-wise weight distribution (service, criteria, factors, and sub-factor levels)

Sustainability dimension	S.No.	Core factor	Sub-factors to sustainability dimension	Weightage
Technical (25)	1	Source, yield and quality (9)	Reliability (availability of water per year), adequacy, depletion	6
			Water quality at source (silt)	1
			Accessibility, chance of contamination and conflict	2
	2	Physical condition of the system (7)	Design adequacy, site and technology	1
			Condition and functionality of the system	5
			Natural threat to physical system	1
	3	Water point functioning (5)	Water availability and cropping pattern	3
			Drainage system	2
	4	Equity (4)	Equity of water delivery	4
	Total weightage			25
Socio-environmental (25)	5	Social aspect (15)	Employment opportunity and living standard	10
			Community participation and decision-making	5
	6	Environmental aspect (5)	Occurrence of natural calamities	2.5
			Drainage	2.5
	7	Social inclusion and equity (5)	Gender role	2.5
			Inclusion (ethnic group), gender equity (woman role), rich and poor	2.5
	Total weightage			25
Economic/cost recovery (25)	8	Availability of funds (15)	ISF collection and establishment of O&M find	10
			Income through agriculture production	5
	9	Market availability (5)	Market condition and market price	5
	10	Use of funds and transparency (5)	Use of savings/surplus fund and transparency	5
	Total weightage			25
Institutional (25)	11	User's committee (15)	Existence, functioning and meetings	3
			Ownership and activities	2
			Water distribution practice	5
			Representation on user committee	2
			Existence, functioning of water guard	3
	12	Input use (5)	Crops variety, seed and fertilizer management	3
			Pest control	2
	13	Coordination and linkage (5)	With local authority and other agency	3
			Training (strength building) and external support	2
	Total weightage			25

Along with the technical and managerial parameters, gender and ethnic participation are also considered core factors, as their involvement is guided by the law of the land. Furthermore, social inclusion has proved to have positive impacts on the community-managed system.

4. RESULTS AND DISCUSSION

4.1. Situation of the Koshi Pump Irrigation System

The brick-lined 32.78-km long main canal of the Koshi Pump Irrigation System is deteriorating day by day. Thus, the seepage loss and canal bank erosion are increasing. Concrete lining and protection works are ongoing in selected sections but are not sufficient. The growth of weeds in the canals is also reducing the capacity of the system. At present, maintenance of the pumps is the major problem in the system and thus the pump operation is not throughout the year. Among the six pumps in each pump house, three pumps are operated at a time on a rotation basis so as to maintain the continuous flow in the canal. The design discharge capacity of the main canal is 11.25 m^3/s. The irrigation water in the main canal is distributed to the distributaries in a proportionate amount. The farmers from both head and tail reach confirmed that the water is sufficient for irrigation in both seasons.

The average annual volume of irrigation water conveyed through the canal system, calculated from the recent 3-year data, is shown in Table 3.

Table 3 | Canal operation details of the Koshi Pump Irrigation System

Season	Average canal operation, days	Volume of water (MCM)
Kharif	73	43.95
Rabi	27	16.33
Total	100	60.28

Rice, wheat, and potato are the major crops in the command area with productivity of 3.5, 2.5, and 25 metric tons per hectare (MT/ha), respectively. Pulses, oil seeds, and vegetables are the other crops grown. The cropping intensity in the Koshi Pump irrigation system is found to be 170%.

4.2. Situation of the Koshi Distributary Irrigation System

The Western Koshi Main Canal (India) takes off from the Koshi Barrage built across the Koshi River within the Nepal territory near the Indo-Nepal Border. The canal runs to 35.15 km along the head and reach within the Nepal territory before entering into India. The command area of 14,125 ha (gross command area) lying south of the canal is commanded by a gravity flow through 13 secondary canals, taking off from the Western Koshi Main Canal (Indian) to its left side. There are 195 water courses whose total length is 245.181 km.

Unfortunately, in 1988, only after 5 days of commissioning of pumps, heavy rainfall occurred (DOWRI 2020). This caused a flood that hit the system paralyzing all basic structures. The main equipments were damaged partially, but some equipment was completely out of function. This was not the end, subsequent heavy rainfall influenced the system time and again. The flood again hit the canal structure in July 1996, as well as pumping stations causing serious setbacks to the already paralyzed system. On the other side, no extra budget was allocated for reconstruction works. The general works of the canal system as well as the pump house were being done from the general O&M budget which was inadequate for such a heavy system. As a result, the whole system was in the process of decline. So, in 2013, a study was conducted about the status of the different structures and required different works to be done to rehabilitate the Western Koshi Main Canal Distribution system under the Large Government Irrigation Rehabilitation & Management Transfer Project and accordingly a report was prepared (KPCCIMD 2013). Based on that report, budgets are being allocated to complete the works along with general O&M works of the project. So, this general allocation of the normal budget is not sufficient for rehabilitation and general O&M of the project as almost all structures of the project are older and wear and tear is going on. So, an updated study was required about the present scenario of the different structures and other remaining works which were stipulated in the report to be completed in 2013 and are still not completed. The Koshi River basin is badly deteriorating mainly due to deforestation, and the problems of siltation are major in irrigation systems.

Rice, wheat, potato, and maize are the major crops in the command area with productivity of 3.5, 2.5, 15, and 3 MT/ha, respectively. Pulses, oil seeds, and vegetables are the other crops grown. The cropping intensity in the irrigation system is found to be 190%.

4.3. Sustainability of the irrigations systems

The overall sustainability of the Koshi Pump Irrigation System is scored as *70.35%* but *cost recovery dimension* has scored less than 70% (i.e. 58%). It means the system is found to be *Sustained but at-Risk project*. The cost recovery dimension of the system seems to be crucial as the system is dependent upon the operation of pumps. The frequent repair and maintenance of the electric pump makes the system costlier.

Similarly, the overall sustainability of the Koshi Distributary System is scored as *65.33%* which means that the system is *not sustained project*. However, every individual dimension has scored greater than 30% which reflects that certain improvement can upgrade the sustainability ranking of the system. The unsustainability of this irrigation system mainly relies on the siltation during flooding and not reaching enough water at tail reach.

A comparative study of both systems shows that the Koshi Pump System is more reliable due to its proper design and functioning of physical infrastructure but as the Koshi Distributary System runs along the Western Koshi Main canal it has a problem of huge siltation during high flooding. Therefore, the improvement in the functionality, i.e. ensuring water to the tail reach users, is essential in the Koshi Distributary System. However, the end life of the Koshi Barrage is a major threat to the sustainability of these irrigation systems. Appropriate alternatives should be planned timely for the operation of these irrigation systems, before any catastrophe happens.

The irrigation management in both systems is said to be under the joint management of government agencies and water users. The Irrigation Management Office (IMO) of the federal government is responsible for the major repair and operational works while the WUAs are limited to the maintenance of distributary canals. However, the coordination between the IMO and WUA is very weak and most of the committees at the distributary level are not functional. The actual participation of the water users in irrigation management is lacking. Rather the involvement of the private sector, as envisaged in the irrigation policy, would be an option for better management of the systems to increase the command area reach by improving the canal conveying efficiency.

5. CONCLUSION

Nepal receives irrigation facilities for a total of 24,480 ha of land from the Koshi Barrage. The irrigation systems would be dysfunctional if the said barrage fails as its service life is already over. The average annual amount of water available in the Koshi Pump System and Koshi Distributary System is found to be 60.28 and 136.97 MCM, and the existing cropping intensity of these two systems are 170 and 190%, respectively. The Koshi Pump Irrigation System is found to be *sustained but at-risk project*. The Koshi Distributary Irrigation System is found to be *not sustained project*. These systems have low crop productivity and the existing infrastructures are in poor conditions. From the sustainability assessment, it is concluded that the regular maintenance of the physical infrastructures and the managerial aspects of the systems are more important for these irrigation systems. Decision-making with the real participation of the irrigators, regular and proper collection of ISF, maintenance of the systems, and ensuring the irrigation water in the tail reach can increase the sustainability of these systems. In the meantime, alternative plans should be made for the operation of these systems to supply water from intake, in case the Koshi Barrage becomes dysfunctional.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

CONFLICT OF INTEREST

The authors declare there is no conflict.

REFERENCES

Adhikari, B. K. & Bhattarai, S. 2010 *Long Term Sustainability Monitoring: WaterAid's Experience in Nepal*. WaterAid in Nepal, Lalitpur.

Bagale, D. R. 2020 Nepal–India water cooperation: consequences of mutuality or hegemony? *Water Policy* **22**(6), 1098–1108.

Bisht, M. 2008 *Revisiting the Kosi Agreement: Lessons for Indo-Nepal Water Diplomacy*. Available from: https://idsa.in/idsastrategiccomments/RevisitingtheKosiAgreement_Medha%20Bisht_220908 (accessed 3 August 2022).

Cai, X., McKinney, D. C. & Rosegrant, M. W. 2001 *Sustainability Analysis For Irrigation Water Management:Concepts, Methodology and Application to the Aral Sea Region*. International Food Policy Research Institute, Washington, DC, USA.

Dhakal, T. R., Davidson, B. & Farquharson, B. 2018 Factors affecting collective actions in farmer-Managed irrigation systems of Nepal. *Agriculture* **8**(6), 77.

DOWRI 2020 *Annual Report on Water Resource & Irrigation*. Department of Water Resource & Irrigation, Lalitpur.

KPCCIMD 2013 *Proposal for Koshi Pump Chandra Canal System Under Large Government Irrigation Rehabilitation & Management Transfer Project*. Koshi Pump Chandra Canal Irrigation Management Division No 2, Rajbiraj.

Norton, R. D. 2004 *Agricultural Development Policy: Concepts and Experiences*. Jhon Wiley & Sons Ltd, West Sussex, England.

Pradhan, B. K. 2021 *Telegraphnepal.com*. Available from: https://www.telegraphnepal.com/nepals-water-resources-and-its-development-strategy-2/ (accessed 12 December 2022).

Wichelens, D. & Oster, J. 2006 Sustainable irrigation is necessary and achievable, but direct costs and environmental impacts can be substantial. *Agricultrual and Water Management* **88**(1–2), 114–127.

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