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Optimal Management of a Climate Stressed Himalayan River Basin in Nepal

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Most rivers in Nepal originate in the high mountain glaciers and flow into the Ganges serving as the primary source of fresh water for the whole region. However, global warming-induced changes in temperature and rainfall patterns are accelerating the rate of deglaciation, the frequency of glacial lake outburst, massive flooding, and droughts. Moreover, the climate-induced changes in Nepalese river systems, which contribute more than 70 percent of the dry season river flow to the Ganges, is significantly affecting transboundary water supply and use in Nepal, India, and Bangladesh. In this light, this study uses a hydro-economic model to determine the optimal allocation of water in Fewa Lake watershed among four competing uses - irrigation, municipal use, power generation, and recreational use. Preliminary results show considerable opportunity to increase economic efficiency, equity, and sustainability. For example, construction of additional reservoir storage capacity and better use of available rainfall and river flow data in managing existing reservoir systems can substantially improve power generation capacity, ability to control flood, and increase irrigation productivity without significantly reducing downstream flow.

Keywords river basin, optimal allocation of water, competing uses

Introduction

The vast snow fields and ice caps deposited in the high mountains of the Hindu Kush Himalayan region are the primary sources of fresh water for many countries including Nepal. However, recent studies show that global warming-induced increase in average daily temperature, fluctuating rainfall patterns, and other climatic anomalies are accelerating the rate of deglaciation, the frequency of glacial lake outburst, the incidence of massive flooding, and the frequency and duration of droughts (Kang, Khan et al. 2009) (Kang, Khan et al. 2009, Manandhar, Vogt et al. 2011, Kurukulasuriya and Rosenthal 2013, Poudel and Kotani 2013, Nelson, Valin et al. 2014, Hussain, Rasul et al. 2016).

Moreover, increasing human encroachment to fragile mountain ecosystems have increased the incidence of landslides, soil erosion, gully formation, and excessive sediment collection in lakes, rivers, and other water bodies. For instance, rapid urbanization in the valley and unsustainable land use practices, particularly in surrounding hills, have substantially increased the siltation rate in feeder streams and sediment collection in the Phewa Lake. As a result, the size of the lake has decreased by more than fifty percent (from 10 square kilometers in 1956 to 4.4 square kilometer in 1998) in less than five decades (Devkota and Adhikali 2015).

On the other hand, the rapid increase in population in lakeside and surrounding region has substantially increased consumptive as well as non-consumptive demand for water. As a result, the Fewa Lake has become one of the main tourist attraction of the region for various recreational activities including boating, fishing, bird watching, and sightseeing. Moreover, the lake has also become a crucial source of water for municipal, power generation, and irrigation. Despite its central role in supporting multiple sectors of the economy and impending risk of permanently losing its access, there have been limited efforts to enhance its efficiency and longterm sustainability. This study aims to fill this gap in the literature by evaluating current water use patterns, identifying potential tradeoffs between competing uses, examining seasonal variability in recreational, agricultural, power, and municipal demands, and providing plausible policy recommendations to optimally allocate water among competing uses under different supply and demand scenarios. In particular, this study uses a hydro-economic model to determine the optimal allocation of water in Fewa Lake among four competing uses – recreation, irrigation, power generation, and municipal use.

The Herpan Khola and other small streams are the primary sources of water for the lake, and its overflow enters into the Seti River, which is one of the seven tributaries of the Gandaki River basin. Preliminary results show considerable opportunity to increase economic efficiency, equity, and sustainability. For example, increasing use of conservation practices in upstream farms and construction of siltation dams would substantially reduce sediment accumulation in the lake floor. Moreover, construction of additional reservoir storage capacity and better use of available rainfall and river flow data in managing existing reservoir systems can substantially improve power generation capacity, ability to control flood, and increase irrigation productivity without significantly reducing downstream flow.

Method and Data

The study aims to determine the optimal allocation of water in the Fewa Lake water basin between four competing uses – irrigation, municipal/industrial, power generation, and recreation. Since cost data are not available, the study focuses on total revenue generated by these sectors as a basis for determining the optimal allocation of water. Moreover, we use monthly data to account for season variation in water supply and demand. The data used in the study were obtained from various studies and research reports. The sectoral water demand, price, and revenue functions are developed in GAMS and solved using nonlinear programming routine of the program.

Despite our utmost effort to obtain and use observed data on river flow, sectoral water demand, and resource prices, we were not able to obtain them for some variables. The missing data were generated by combining available information with plausible assumptions and other subsidiary information. The lake inflow data are imputed based on the estimates reported by Devkota and Adhikari (2015) for two locations in the Herpan Khola and assuming that other streams would supply additional twenty percent of flow (see Table 1 for details).

The agriculture sector is assumed to have about 500 hectares of irrigated rice production in the basin (both upstream as well as downstream). We assume that rice is the primary crop grown in the area. The average rice yield is assumed to be 2.5 tons/hectare. The average price of raw paddy is assumed to be $400/ton. Recreational, power, and municipal water revenues are estimated using tourist visits and city population data. The Fewa Lake watershed schematic conceptualized for developing the optimization model is shown in Figure 1.

Method of Analysis

Let, Z_t = City's population, I_t =head inflow, PD_t =power demand, PP_t =Power Price, and PC_t =Power Coefficient. The t refers to months from $n = 1, \ldots, 12$. Given these notations, the electricity price, head release (H), and energy production (E) equations can be expressed as

$$(1)\ PP_t = \sum_{t=1}^{n} (PC_t * Z_t * PD_t),\ n = 1, \ldots, 12$$

$$(2)\ H_t = B_0 + B_1 * SS + B_2 * (SS)^2 E_t = D * G * H_t * V_t$$

where SS is starting storage of the reservoir, MX is maximum reservoir capacity, and $B_0, B_1,$ *and* B_2 are head function intercept and slopes. E is power generated per unit of head release (H), D is water density, G is gravitational constant (10 m^2/s), and V is water flow at period t (measured in million cubic meters/month). Similar functions were developed for other competing water uses and solved as nonlinear systems of equations to maximize total revenue from all four sectors.

Result

The preliminary results show that agriculture, which requires irrigation water primarily during the summer months (July to September) generates about $1.2 million revenue mostly from rice production. The municipal sector generates about $3.9 million. The agricultural and municipal water use is mainly concentrated on summer months when the water supply is at peak (i.e., July to October). Because of higher return from tourism throughout the year (a total contribution of $4.8 million), the model tends to maintain minimum lake level required for boating and other recreational activities. Although the total contribution of the power sector is highest among all four sectors ($8.1 million), actual power generation is highest during summer months because of higher river flows (see Table 2 for detailed breakdown of revenue).

The overall contribution of the four sectors analyzed in the study is about $17.97 million per year. In recent years, tourism has emerged as one of the primary sectors of the local economy in Pokhara, and the simulated results reflect this trend is emphasizing the importance of maintaining minimum lake levels throughout the year and allocating water to other sectors during monsoon when river flows peak.

Conclusions

A nonlinear optimization model is used to determine the optimal allocation of water in Phewa Lake among four competing uses. Results show that tourism is becoming one of the most stable sectors of the economy generating consistent return throughout the year. Among four sectors analyzed in the study, power sector generates the most revenue, but its contribution is highest during summer months when the water supply is abundant.

The existing literature shows that increasing adoption of conservation practices in upstream agriculture and construction of siltation dams would substantially reduce sediment collection in the lake flower and enhance water use efficiency and ensure sustainability of water resources in the basin. Moreover, construction of a second reservoir to store water during monsoon season when there is abundant water supply could substantially increase power production and help reduce power shortage in the region.

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Table 1. Total Monthly Flows for Harpan and Khahare Khola and Total Inflow to Phewa Lake

Month	Khahare Khola (Million Cubic Meter)	Harpan Khola (Million Cubic Meter)	Total Inflow to Phewa Lake (Million Cubic Meter)
January	0.65	0.93	1.90
February	0.44	0.60	1.24
March	0.57	0.80	1.65
April	0.49	0.73	1.46
May	0.75	1.06	2.18
June	3.27	4.61	9.46
July	13.97	19.75	40.47
August	8.45	11.95	24.48
September	8.94	12.65	25.91
October	1.94	2.77	5.66
November	1.66	2.36	4.82
December	1.50	2.13	4.35

Table 2. Preliminary Results: Optimal Revenue Generated from the System

Month	Power	Tourism	Agriculture	Municipal	Total
January		155,871			155,871
February	17,226	185,966			203,192
March	17,226	467,690			484,916
April	13,781	547,205			560,985
May	10,336	383,072			393,407
June	9,187	146,027			155,214
July	2,000,000	150,563	400,000	1,000,000	3,550,563
August	2,000,000	194,878	400,000	1,000,000	3,594,878
September	2,000,000	648,309	400,000	1,000,000	4,048,309
October	2,000,000	1,059,705		928,053	4,187,758
November	9,187	527,194			536,381
December	10,336	285,856			296,191
Total Revenue					18,167,666

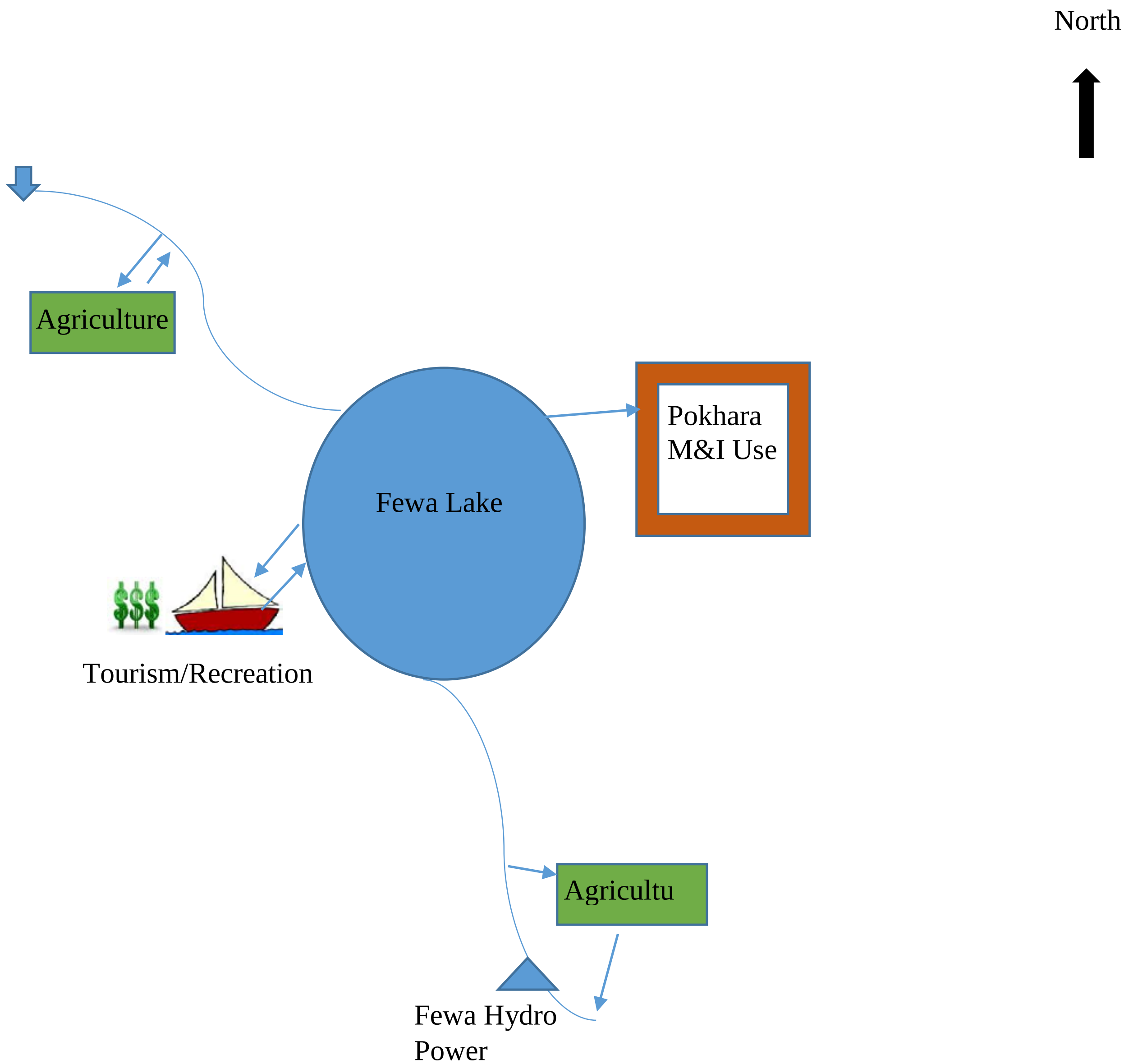

Figure 1. Fewa Lake Water Basin Schematic