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Impact of planned water resource development on current and future water demand in the Koshi River basin, Nepal

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The water resources of the Koshi Basin (87,311 km^2) are largely untapped, and while proposals for their development exist, their impacts on current and future water demand are not quantified. The current study is the first to evaluate the impacts of 11 proposed development projects for hydropower generation and water storage. We find that 29,733 GWh of hydropower could be generated annually and 8382 million m^3 of water could be stored. This could satisfy unmet demand in the current (660 million m^3) basin situation and in future scenarios – i.e. population, agricultural and industrial growth – that are projected to have 920, 970 and 1003 million m^3 of unmet demand, respectively, by 2050.

Keywords: Koshi River basin; WEAP; water demand; hydropower; Nepal; Bihar; India

Introduction

Water resources remains an under-developed sector in Nepal although it has been identified as a key resource for development and economic growth. Nepal receives 225 km^3 of surface water annually; however, less than 7% of this water has been utilized for economic growth (Government of Nepal Water and Energy Commission Secretariat [GoN-WECS], 2005, 2011). Only 72% of Nepal's population has access to potable water, and only 562 MW of hydropower capacity is exploited (out of an economically feasible potential of 42,000 MW). A major constraint in Nepal is that although the annual volume of water is great, the temporal and seasonal distribution is not even. Over 80% of the precipitation falls during the three monsoon months.

The Koshi River basin is a transboundary basin; it crosses China, Nepal and India. Even though the Koshi River flows with an abundance of water (average of 1564 m^3/s at the major outlet, Chatara Station in Nepal), as with other basins in the region, seasonality and variability in water availability is an important issue. Water is in surplus during monsoon months, with characteristic flooding in Nepal's Terai region and India's Bihar region, whereas there is shortage of water in the pre- and post-monsoon seasons (Bharati, Gurung, Jayakody, Smakhtin, & Bhattarai, 2014a; Reddy, Kumar, Saha, & Mandal,

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2008). As a result of this variability, domestic and agricultural water requirements are highly affected. Also, due to insufficient electricity, most of Nepal suffers power cuts lasting 10–16 hours per day (Nepal Electricity Authority [NEA], 2013). The power-cut period is seasonally variable: during dry periods (e.g. during pre-monsoon), the power-cut hours are longer than during monsoon months, as hydropower production is low during low-flow conditions.

Water resources development (WRD) projects (with storage) could buffer this variability by storing water during surplus periods and releasing it during drier periods. In addition, hydropower could be generated with WRD to aid in economic growth. Therefore, projects which store and distribute water both seasonally and spatially have the potential to alleviate Nepal's water and energy variability problems. However, WRD planning requires understanding as well as quantification of water availability, use and demand across different sectors and regions within a basin. Furthermore, WRD projects in the present context are only considered as single individual projects and not assessed and designed using an integrated basin approach that looks at upstream–downstream linkages as well as cross-sectorial issues.

Many agencies have evaluated the feasibility of WRD in the Koshi Basin (e.g. Canadian International Water Energy Consultant [CIWEC], 1998; Government of India [GoI], 1981; Japan International Cooperation Agency [JICA], 1985, 2014). The Japan International Cooperation Agency (JICA) has conducted the most recent and comprehensive study (JICA, 1985, 2014) and identified 11 potential sites for hydropower generation and water storage (Table 1 and Figure 1). Therefore, the present study used the JICA-recommended projects to analyze WRD impacts on basin water demand. Of the proposed projects, four (Dudh Koshi, Sapta Koshi High Dam, Sun Koshi and Tamor) are storage, while the others (Arun III, BhoteKoshi, Lower Arun, Sundarijal, SunKoshi (hydro-electric power, HEP), TamaKoshi and Upper Arun) are run-of-the-river (ROR) type (JICA, 1985, 2014). The National Electricity Authority (NEA) and the Canadian International Water and Energy Consultants conducted a feasibility study of the JICA-proposed projects and recommended the installation of the Dudh Koshi and Tamor projects (CIWEC, 1998). The Upper Tama Koshi hydropower project, which is currently

Table 1. Proposed hydroelectric power development projects in the Koshi Basin, as per the Japan International Cooperation Agency (JICA, 1985).

Project	Type	Catchment area (km^2)	Installed capacity (MW)	Available storage (MCM)
Dudh Koshi	Storage	4,100	118	162
Sapta Koshi High Dam	Storage	6,1000	3,489	4,420
Sun Koshi	Storage	16,200	1,357	3,040
Tamor	Storage	5,085	493	760
Arun III	ROR	32,332	240	–
Bhote Koshi	ROR	2,320	29	–
Lower Arun	ROR	32,881	239	–
Sundarijal	ROR	360	0.6	–
Sun Koshi (HEP)	ROR	5,520	536	–
Tama Koshi	ROR	27,533	130	–
Upper Arun	ROR	32,998	146	–
Total			6,777.6	8,382

Note. ROR = run of the river; S = storage.

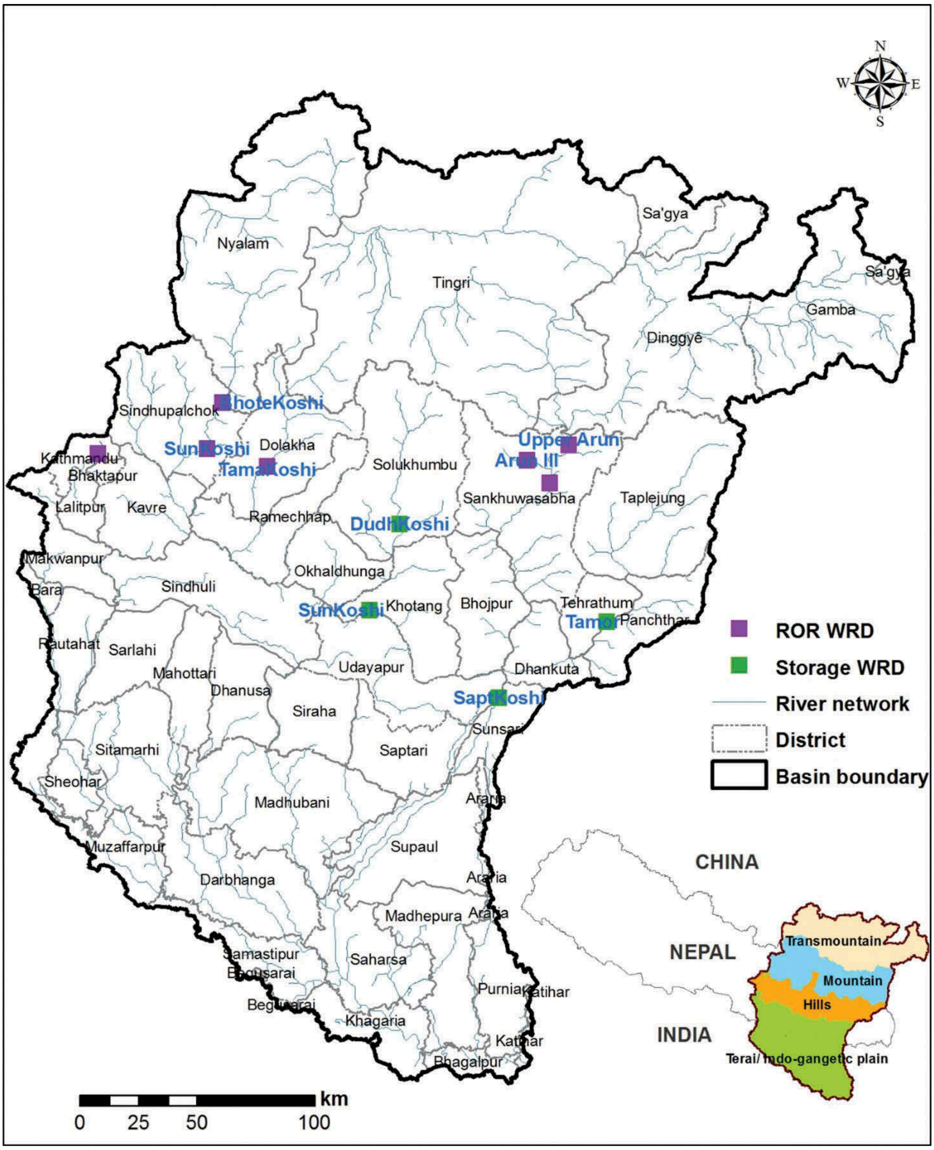

Figure 1. Koshi River, basin, districts and the location of hydropower stations as proposed by the Japan International Cooperation Agency report (JICA 1985, 2014). Inset shows Koshi with respect to Nepal and the four dominant physiographical regions.

under construction, was also based on the JICA report. One of the limitations of the JICA's assessment, however, is that the evaluation did not take an integrated basin perspective, looking also at current and future water user demand, but focused only on individual projects.

Integrated water system models can increase the understanding of WRD impacts on sectoral water users, and can predict the role of WRD with scenarios of situations encompassing expected future changes in key water-use sectors, especially agricultural, domestic and industrial. The present article used the Water Evaluation and Planning (WEAP) model to investigate proposed WRD in the Koshi River basin. In addition to analyzing the current basin situation (baseline), agricultural growth, population growth and industrial growth scenarios were simulated to quantify future water demand and investigate whether WRD can satisfy them.

WEAP is widely used to assess basin-level water supply and demand. Example applications include studies for British Columbia's Okanagan Basin (Harma, Johnson, & Cohen, 2012) to predict future water demand, the Volta Basin (De Condappa, Chaponnière, & Lemoalle, 2009) to test the impact on downstream communities of the introduction of many small reservoirs, Ghana (Amisigo, McCluskey, & Swanson, 2014) to assess impacts of projected climate change on water availability and crop production, Ethiopia (Alemayehu, McCartney, & Kebede, 2010) to assess the impact of hydropower development on Lake Tana water levels, and the Upper Ganges (Sapkota, Bharati, Gurung, Kaushal, & Smakhtinm, 2013) to assess the impact on agricultural water use by including environmental flow releases. Given the wide and successful use of the WEAP model in investigating WRD projects, the current study used the WEAP model in the Koshi Basin.

The objectives of the present study are (1) to estimate sectoral water demand in the Koshi Basin; (2) to assess the potential of proposed water infrastructure in effectively managing water demand under current and future conditions, including future population, agriculture and industrial growth; and (3) to quantify the hydropower generation potential of the proposed infrastructure. Such estimates of water surplus, water shortage, water storage and hydropower generation could inform basin planning, help ease water shortage stress, increase agricultural and hydropower yield, and lead to economic development in the Koshi Basin. This study is the first-ever attempt to estimate basin-wide water demand in the Koshi Basin and compare it against proposed water storage estimates.

Study site

Of the Himalayan rivers that flow into the Ganges, the Koshi is the largest, with a total catchment area of 87,311 km^2, of which 33% (28,300 km^2) is in China, 45% (39,407 km^2) in Nepal and 22% (19,604 km^2) in India (Figure 1). The Koshi Basin encompasses 5 counties in China, 27 districts in Nepal and 16 districts in India. The Koshi River generally flows south, along a length of 255 km. The Koshi Basin in Nepal has a huge elevation drop, from 8848 m (Mt Everest) to 60 m (in the alluvial plains). Based on variations in elevation and topography, the basin is broadly divided into four physiographical regions (Figure 1). The Terai region extends from 60 m to 200 m in elevation; above this are the hill regions (200–4000 m) and mountain regions (above 4000 m); the trans-mountain region lies north of the Himalaya Mountains and extends into Tibet (Bharati et al., 2014a). Due to the varying climate and topography, the precipitation is unevenly distributed, from 1755 mm in the central mountain to 210 mm in the trans-mountain region annually. The eastern mountain regions receive 1418 mm on average, and the southern part of the basin is on average wetter than the northern parts (Bharati et al., 2014a; Chen et al., 2013). Koshi's climate varies from a frigid north to a tropical south and has four major seasons: pre-monsoon (March–May), monsoon (June–September), post-monsoon (October–November) and winter (December–February) (Bharati et al., 2014a; Chen et al., 2013). It is to be noted that, for the current study, the confluence point of the Koshi River with the Ganges at Kursela in Katihar District (Bihar, India) was used in delineating the watershed boundary of the Koshi Basin.

Methods

WEAP model application

The WEAP model was developed by the Stockholm Environment Institute for assessing water demand and to evaluate WRD projects, climate change impacts and water management scenarios (SEI, 2011). WEAP is unique in its integrated manner for evaluating water systems by its policy orientation (SEI, 2011). WEAP can act as a database to maintain water demand and supply information, and as a forecasting tool to estimate water resources (e.g. surface water, groundwater, water transfer, and storage), demand (e.g. user-defined sectoral demand, irrigation, domestic and industrial supply), and storage (SEI, 2011). Typically, WEAP conducts a water mass balance of flow sequentially from upstream to downstream in a river system, considering water abstractions and water inflows. As part of the model setup, the parameters of water supply and demand systems, and their spatiotemporal variations and priority of access, are characterized. The model then optimizes water use in the basin using a linear programming algorithm to allocate water to the various demand sites, as per the demand priorities that range from 1 to 99, with 1 being the highest priority. For more information on the WEAP model, readers are directed to SEI (2011). In the present study, the model was set up for the baseline year (2000) and also for the future year of 2050, as 2050 coincides with many climate change studies (e.g. Bharati et al., 2014a; Gosain, Sandhya, & Mani, 2011) and thus enables comparisons between current and future agricultural water demand. In the current setup, even though WEAP can model the hydrology, Soil and Water Assessment Tool (SWAT) hydrological outputs based on studies by Bharati et al. (2014a, 2014b) and International Water Management Institute (IWMI, 2015) were used, as the SWAT model was already calibrated and validated for the Koshi Basin.

Hydrological inputs from the SWAT model

Bharati et al. (2014a, 2014b) used SWAT to simulate the hydrology of the basin under current and future climate trends. The Koshi basin was divided into 127 sub-basins to predict water yield at the sub-basin level. Climate data (e.g. rainfall, air temperature, wind speed) were obtained from the Department of Hydrology and Meteorology, Nepal, EVK2CNR, TRMM, Reanalysis and Indian Meteorological Department. Topographic elevation data were obtained from the Shuttle Radar Topography Mission, while soil data were obtained from the Soil and Terrain Database (SOTER). The land use / land cover map (Figure 2) was received from the International Centre for Integrated Mountain Development. The SWAT model was calibrated using daily discharge data for a period of 4 years (1999–2002) and validated for a period of 4 years (2003–2006). The Department of Hydrology and Meteorology stations used for model calibration were Turkeghat (604.5), Majhitar (684), Pachuwarghat (630), Padherodovan (589) and Chatara (695). The overall SWAT model performance was deemed satisfactory. Specifics on hydrological inputs, model setup, calibration and validation can be found in Bharati et al. (2014a, 2014b) and IWMI (2015).

Similar to the SWAT setup, the WEAP model was set up with 127 catchment demand nodes to represent 127 agricultural demand sites (sub-basins) and 48 demand sites to represent district-wise domestic and industrial demand (Figure 2). Each sub-basin had a river network to incorporate water supply in the form of headflow. Headflows were estimated from the water yield outputs of the SWAT model.

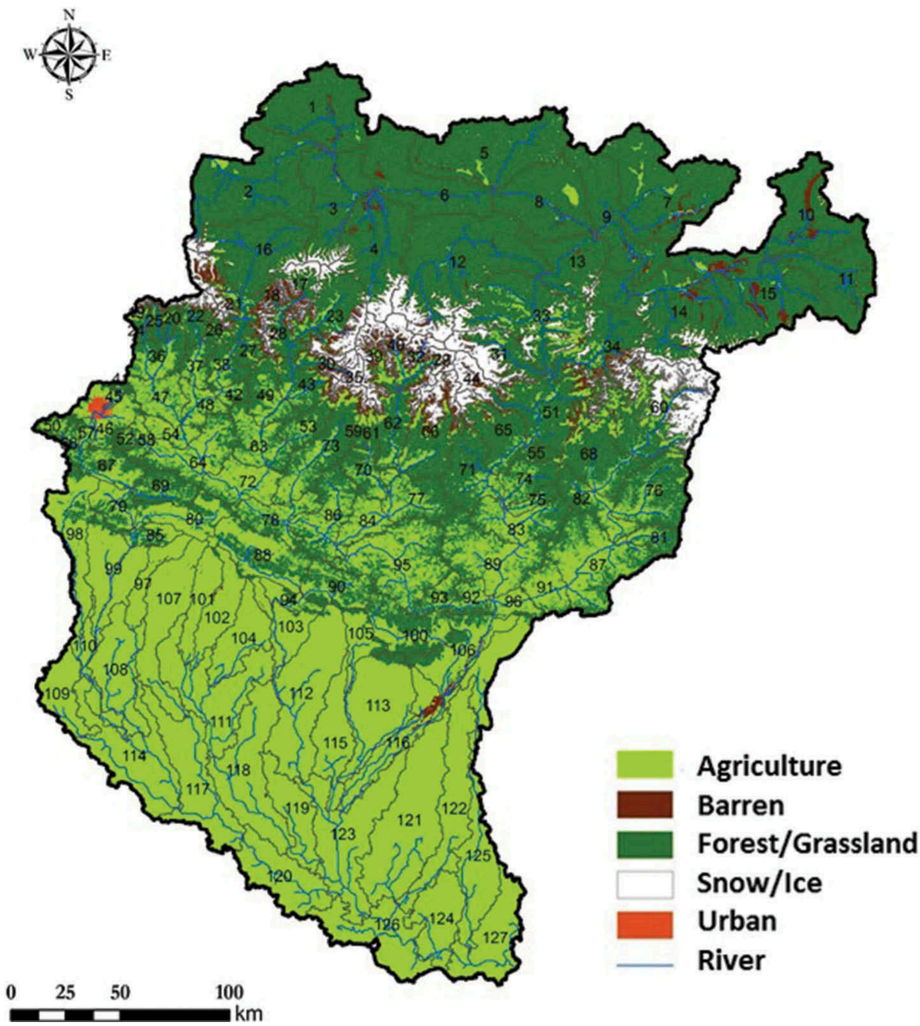

Figure 2. Land use and land cover in the Koshi Basin. Numbers refer to sub-basins.

Water demand

- *Agricultural water demand*. Crop type and crop area were determined from district-level census data (Central Bureau of Statistics, 2000; China Statistical Bureau, 2000; Registrar General of India, 2001). The dominant crops in the Koshi Basin are paddy, wheat, maize, cereal, vegetable, oil, orchards, sugar-cane, tobacco and jute. Crop coefficients were obtained from the Food and Agriculture Organization (FAO) (Allen et al., 1998). Precipitation and reference evapotranspiration at sub-basin level were imported from the SWAT model (Bharati et al., 2014a), while cropping calendars were used to estimate crop growing periods (Table 2). The WEAP model then calculated the monthly agricultural demand using the Simplified Coefficient Method (Allen et al., 1998).

  Once agricultural water demand was estimated, the model withdrew the water needed for agriculture from the headflow via the withdrawal nodes. Agriculture was

Table 2. Cropping calendar for the dominant crops in the Koshi Basin.

Crop	Months
Paddy	May–October
Wheat	November–April
Maize	March–September
Cereals	August–January
Vegetables	February–June
Oil	October–February
Orchards	January–December
Sugarcane	March–August
Tobacco	September–January
Jute	March–August

given higher priority than industrial demand, but lower than domestic demand. Hence, as soon as domestic water demand was satisfied, water was supplied to satisfy agricultural water demand.

- *Domestic water demand*. District population data were obtained from census reports. Use-rate data, i.e. litres per capita per day (LPCD), were obtained from the census reports separately for rural and urban locations. The use rates were then multiplied by the population to estimate daily and monthly domestic water demand for rural and urban regions. The WEAP model then withdrew water from the sub-basin headflow (supply) at monthly intervals to satisfy domestic water demand, which had the highest priority.
- *Industrial water demand*. The number of industries and average water use per industry type were obtained from census reports. It was found that the Chinese regions did not have any industries, while India had the highest number of industries in the basin. The reported annual water use for each district was converted to monthly industrial water demand by WEAP. Industrial demand was given the lowest priority; it was satisfied only after domestic and agricultural demand was satisfied.

Description of scenarios

To understand water demand in the basin, five scenarios were simulated, as follows.

Scenario 1: *Baseline*. Current water use was estimated under current water supply and demand estimates from census data for the year 2000. The reference scenario had three types of sectoral demand: domestic, agricultural and industrial. The year 2000 was taken as the baseline year as the 2000 demand data and hydrological outputs were easily available from the SWAT model.

Scenario 2: *Population growth*. Population increase rate, as assessed from the past three census reports (1991, 2001 and 2011), was used to estimate the population for 2050. For this scenario, only the population was changed in the WEAP, while all the other model setup was similar to the baseline scenario.

Scenario 3: *Agricultural growth*. District-wise agricultural statistics from three reports over the years 1991, 2001 and 2011 were used to assess 2050 cropped area. The rate of change of crop area per crop type per census year (i.e. once in 10 years) was calculated. This rate was then used to estimate the crop area per crop type for the year 2050. Trend analysis of the census statistics indicated a decreasing trend in some crops (e.g. cereals, vegetables and oilseeds), while other crops had an increasing trend (e.g. paddy, sugar-cane, tobacco and jute). The WEAP model was then run with the updated cropped type and area, under baseline conditions.

Scenario 4: *Industrial growth*. District census reports were used to generate industrial growth trends across the basin. While the Chinese regions have no increase in industries, Nepal and India have a 30% and 40% increase in industrial units, respectively, by 2050. As in the above scenarios, baseline water supply and domestic and agricultural demand are the same, with only the industrial demand altered.

Scenario 5: *Planned WRD projects*. Table 1 presents the list of WRD projects assessed in this study. Of the proposed projects, the Sapta Koshi High Dam, across the Koshi River near Chatara, is highly recommended by JICA (1985) as there is potential to build large storage: 8500 million cubic metres (MCM). According to the report, the excess power produced annually by this project could be exported to India, and thus promote healthy transboundary relationships, leading to economic growth for both countries. The Sapta Koshi High Dam project was initially identified in 1956 by the government of India (GoI, 1981), with a 239-metre-high dam and a hydropower station located immediately downstream. The Sun Koshi Dam, proposed across the Sun Koshi River, was also initially identified in the GoI (1981) report. A site was selected near the confluence of Sun Koshi and Dudh Koshi for a proposed 147-metre-high dam. The Tamor project was proposed across the Tamor River near the confluence of Tamor and Sapta Koshi Rivers. A 153-metre-high dam was proposed with a hydropower station location directly down-stream of the dam. The Dudh Koshi project was planned as a pondage type (low storage compared to the other storage dams) across the Dudh Koshi River, 28 km upstream of the confluence of the Sun Koshi and Dudh Koshi Rivers. Details on the aforementioned projects – storage type, catchment area, installed capacity and storage volume – are listed in Table 1.

Of the RORs, Upper Arun, Lower Arun and Arun III were placed along the Arun River, while the Sun Koshi HEP was placed along the Sun Koshi River. Also, the Tama Koshi River and the Bhote Koshi River each had one ROR. The capacity of each of the RORs is listed in Table 1, and the locations are indicated in Figure 1. Further information on the construction and operation of the RORs can be obtained from JICA (1985, 2014) and NEA (2013). The characteristics of the projects (e.g. gross storage, hydropower capacity, volume-elevation curve) were input into the WEAP model and run using the baseline hydrological setup. The domestic, agricultural and industrial demand were the same as in the baseline scenario.

Results and discussion

Baseline scenario

Spatiotemporal variations in water demand and unmet demand

Spatiotemporal variations exist in the water supply across the sub-basins in the Koshi. In general, the sub-basins in the trans-mountain region have the lowest water yield, followed by the plains. The sub-basins in the hills and mountain regions have the highest water yields. Annual total water demand results indicate spatial variations across the basin, mostly due to variations in sectoral water demand; e.g. agricultural and urban areas

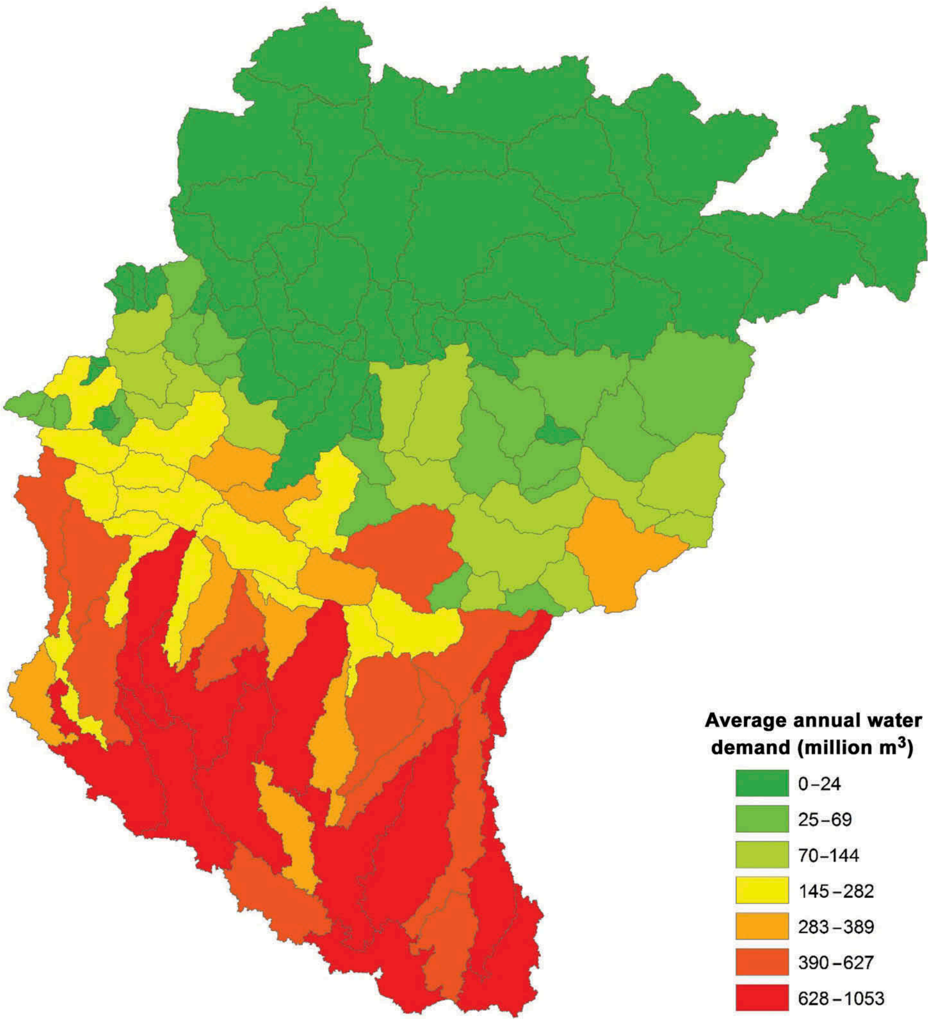

Figure 3. Sub-basin-level average annual water demand for the baseline scenario.

had higher demand (Figure 3). Of the three regions, the trans-mountain region had the least total water demand, ranging from negligible to 10 MCM, followed by the mountain region, ranging from 5 to 100 MCM. The hill region had demand in the range from 20 to 300 MCM, while the Indo-Gangetic Plain had the highest demand, with values from 300 to 1050 MCM. As agriculture is the highest water user in the basin, the Indo-Gangetic Plain had the highest water demand due to its higher agricultural activity, while the trans-mountain region had the lowest agricultural activity (Figure 2) and hence the least water demand. Of the Indo-Gangetic Plain, the lower Terai districts of Nepal (Sarlahi, Mahottari, Morang, Siraha and Sapatari) and the Bihar districts of India (Sitamarahi, Madhubani, Dharbanga and Saharsa) had higher water demand due to higher agricultural water use. Hence, due to the spatial variations in agricultural activity, there is considerable spatial variation in water demand. In addition, regions with higher population (e.g. Kathmandu) also had higher demand due to high domestic water demand.

The unmet demand was estimated by the difference between the water demand and the water supply delivered (Figure 4). The baseline results indicate temporal variations in water demand and unmet water demand across the basin (Table 3). The monsoon season had no unmet demand owing to high water availability, while winter, pre-monsoon and

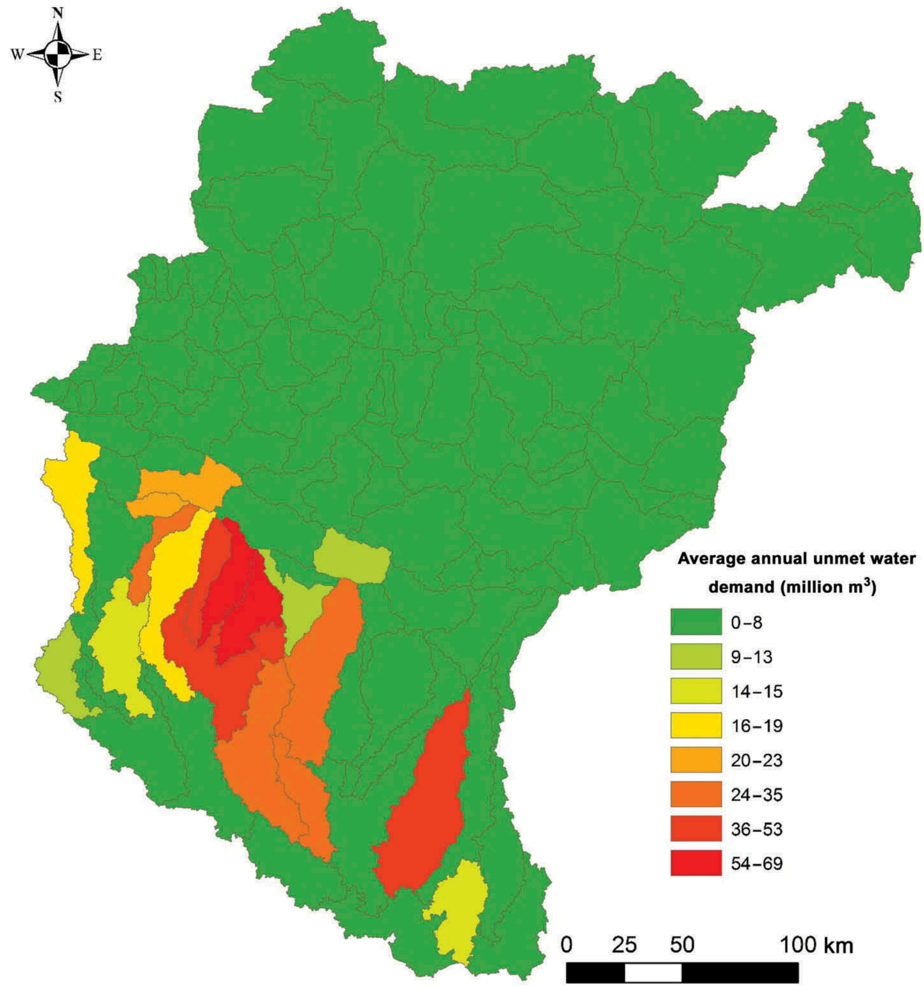

Figure 4. Sub-basin-level average annual unmet water demand for the baseline scenario.

Table 3. Water flow and demand under baseline scenario with water resources development.

	Winter	Pre-monsoon	Monsoon	Post-monsoon	Annual
Flow (m^3/s)	39	166	699	144	262
Domestic demand (MCM)	386	395	524	262	1,566
Agricultural demand (MCM)	1,890	6,608	13,489	2,009	23,996
Industrial demand (MCM)	105	107	142	71	424
Demand (MCM)	2,380	7,110	14,154	2,342	25,986
Unmet demand (MCM)	273	370	0	17	660

Note. MCM = million cubic metres.

post-monsoon had 11%, 5% and 0.7% of demand unmet, respectively, resulting in an annual average of 660 MCM unmet water demand. The temporal variation in unmet demand indicates differences in water availability (wet versus dry periods) and water use (agriculturally active periods and regions). In addition, the unmet demand trend captures the variability in water availability across the basin (with regions near rivers having lower unmet demand than other regions), and thus identifies the need to employ water storage and distribution practices to alleviate water scarcity in non-monsoon periods, especially in regions away from the main channel. For example, regions along the Koshi and Sun Koshi Rivers (i.e. Udayapur, Sunsari, Saptari) were not affected by high water demand. These regions also coincided with the proposed location of the hydropower storage type projects (e.g. Sapta Koshi and Sun Koshi); however, neighbouring regions had unmet demand. Hence, even with the construction of the WRD projects, water distribution would have to extend to areas away from the main channel to ease unmet demand. Distribution channels from the proposed projects could alleviate the unmet demand in many neighbouring sub-basins. For example, within 100 km of the storage structures, the sub-basins have unmet demand of 0–40 MCM. This unmet demand could easily be met with the new stored water (8382 MCM post-monsoon storage).

Sectoral water demand

In the baseline scenario, agricultural demand is the highest, with 92% (23,996 MCM) of the total demand (25,986 MCM), followed by domestic (6% of total) and industrial (2% of total), reflecting the high agricultural water use and low industrial presence in the basin (Table 3). The trans-mountain region has low agricultural water demand (0–24 MCM/y) owing to the low suitability of climate and land for agricultural production. The mountain regions also have low agricultural water demand (20–144 MCM/y). The hill regions have moderate agricultural demand (70–283 MCM/y), while the fertile Indo-Gangetic Plain has the highest agricultural water demand (72–283 MCM/y). In addition, the Indo-Gangetic Plain grows more high-water-demand crops (especially paddy) and does more crop rotations when compared to the other regions, and hence has higher agricultural water demand (Figures 2 and 3).

Population growth scenario

Under this scenario, results indicated a 16% increase in total water demand and an increase of 39% (from 660 to 920 MCM) in water unmet demand in comparison to the baseline scenario (Table 4). With the current increasing trend in the basin population, domestic water scarcity is high and can lead to socio-economic stress. Hence, policy makers need to incorporate and integrate water storage options, while formulating management plans to sustain the population growth in the basin.

Agricultural growth scenario

The results indicated higher water demand and unmet demand for all seasons under this scenario (Table 4). Post-monsoon had 41 MCM more unmet demand, while pre-monsoon and winter had 47% and 36% higher unmet demand, compared to baseline. On an annual average basis, the basin's unmet demand is set to increase by 310 MCM. Hence, to

Table 4. Seasonal variation in water demand and unmet demand under five scenarios.

SWater Demand	Winter	Pre-monsoon	Monsoon	Post-monsoon	Annual
Scenario 1: Baseline					
Demand (MCM)	2,380	7,110	14,154	2,342	25,986
Unmet (MCM)	273	370	0	17	660
Scenario 2: Population growth					
Demand (MCM)	2,727	9,356	15,521	2,576	30,180
Unmet (MCM)	337	555	0	27	920
Unmet percentage change	23	50	0	60	39
Scenario 3: Agricultural growth					
Demand (MCM)	2,406	8,795	15,215	2,506	28,922
Unmet (MCM)	370	543	0	58	970
Unmet percentage change	36	47	0	241	47
Scenario 4: Industrial growth					
Demand (MCM)	2,788	9,419	15,604	2,618	30,429
Unmet (MCM)	386	575	7	35	1,003
Unmet percentage change	41	55	0	106	52

Note. Unmet percentage change is the change in unmet demand between baseline and the given scenario.

incorporate future cropping area trends, there is a need to increase water storage in the basin by at least 310 MCM per year.

Industrial growth scenario

Of all the scenarios, this scenario had the highest water demand and increase in unmet demand (52%), owing to an average of 10% potential increase in the number of industries over a 10-year period. The annual unmet demand is 1003 MCM, which is 443 MCM more than the baseline scenario. Hence, for sustainable industrial growth, the basin needs to introduce cost-effective methods to store water over the year, and to increase the water efficiency of industrial processes. As in the previous scenarios, the aforementioned increase in unmet demand is small (only 12%) when compared to the total stored volume in the basin, and hence WRD could satisfy this demand.

Planned water resource developments

Water storage under WRD and impact on current demand

With the introduction of the WRD projects, as explained under Scenario 2 (four storage and seven ROR projects), the agricultural, domestic and industrial demand remain the same, as the projects do not consume water and as water loss was assumed to be negligible (Tables 4 and 5). Hence, the total demand remains the same as under the baseline scenario (2380 MCM). All storage projects filled up by May (i.e. four months to fill from the start of simulation). This water storage (8382 MCM) in the current scenario is more than 12 times the annual unmet demand (660 MCM). By the end of the monsoon, the Sapta Koshi High Dam had the highest storage, with 4420 MCM, followed by Sun Koshi, Tamor and Dudh Koshi with 3040, 760 and 162 MCM, respectively.

This stored water can be distributed to regions with high unmet water demand and alleviate water supply shortage during deficit periods. Especially, the current dry-season unmet demand (290 MCM) could be easily satisfied using the water stored by WRD

Table 5. Hydropower generation and water storage with introduction of water resources development.

Project	Type	Available storage (MCM)	Hydropower generation (GWh)				
			Winter	Pre-monsoon	Monsoon	Post-monsoon	Annual
Arun III	ROR	–	8	33	60	8	109
Bhote Koshi	ROR	–	47	100	187	72	406
Lower Arun	ROR	–	364	524	695	348	1,931
Sundarijal	ROR	–	27	61	113	21	222
Sun Koshi (HEP)	ROR	–	25	54	94	38	210
Tama Koshi	ROR	–	38	161	372	63	634
Upper Arun	ROR	–	169	279	451	225	1,124
Dudh Koshi	S	162	25	34	209	47	315
Sapta Koshi High Dam	S	4,420	761	2,375	10,716	2,695	16,547
Sun Koshi	S	3,040	242	501	3,627	784	5,154
Tamor	S	760	81	553	2,189	258	3,081
Total		8,382	1,787	4,676	18,712	4,558	29,733

Note. ROR = run of the river; S = storage.

projects over the monsoon period (post-monsoon unmet demand is only 3% of the total water stored). With the presence of a storage-type WRD, there is a possibility of expanding agricultural area or introducing new industrial units, which were investigated in the future growth scenarios.

Impact of WRD on future water demand

In the population growth scenario, the unmet demand is only 10% of the water storage potential in the basin and hence the WRD projects could easily satisfy this increase in future unmet demand. Similarly, the unmet demand increase in the agricultural growth scenario is only 12% of the total WRD storage, and hence could easily be satisfied. Also, the 1003 MCM unmet demand due to increased industrialization is only a fraction of the total WRD water storage potential.

With all the growth scenarios run together for the 2050 year, the unmet demand increases from 660 to 1573 MCM (138% increase from baseline unmet demand). However, this is only 19% of the total water that could be stored in the projects, hence establishment of WRD should be considered in the basin to satisfy current and projected future water demand in the basin. In the extreme case, even if the current water demand is tripled (i.e. increased to 1980 MCM) in the future, it will still be only 24% of the total WRD storage volume, and hence future basin growth should be encouraged with the establishment of WRD projects.

Hydropower generation under water resource development

The WEAP estimated hydropower generation for the Koshi Basin (Table 5) is comparable to (within 8% of) the hydropower generation estimates of the JICA (1985) report (Figure 5). With the installation of the WRD projects, the total hydropower production in the basin would be 29,733 GWh. Due to the variation in discharge, there would be

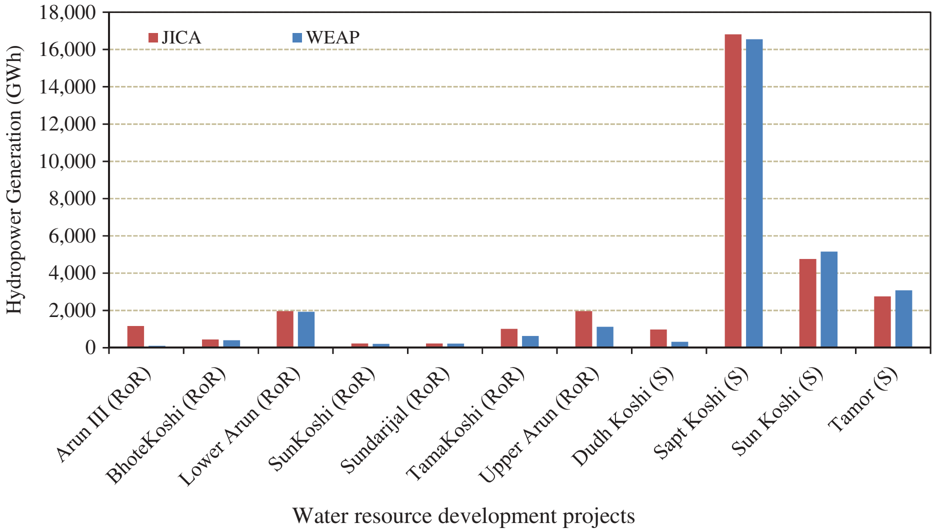

Figure 5. Hydropower generation comparison: as modelled in Water Evaluation And Planning (WEAP) tool and as reported by the Japan International Cooperation Agency (JICA, 1985).

temporal variation in hydropower generation. The monsoon season would generate the most energy (18,712 GWh), and winter the least. The excess hydropower and water in monsoon could be used to increase industrial output and provide more power and water for domestic use. According to the NEA report (2013), current annual power use is 6404 GWh, which is only 21% of the total power that could be generated with the projects. Furthermore, the projected annual power demand in 2028 (estimated by NEA, 2013) is 17,404 GWh for the entire country, which is only 58% of the power that would be produced by the proposed projects in the Koshi Basin. Therefore, even in 2028 the surplus hydropower (12,329 GWh) could be used for future growth within Nepal as well as exported to downstream countries, i.e. India and Bangladesh.

The surplus hydropower could also aid Koshi Basin farmers by allowing the use of cost-effective electric pumps, leading to increase in use of groundwater for cash crops (as in Gujarat's agricultural boom – see Shah, Gulati, Hemant, Shreedhar, & Jain, 2009). In addition, if needed, the hydropower could be exported across transboundary countries during periods of excess hydropower production (e.g. monsoon), with the agreement to import power during low-production months (e.g. winter). Currently, Nepal imports 746 GWh from India and exports only 4 GWh to India annually (NEA, 2013). As a result, Nepal pays India a net amount of USD 54 million annually for power. Hence, if the power were generated within the Koshi Basin, Nepal could sustain its power requirements and also export/sell power to India. The possibility of generating hydropower with the WRD projects is of utmost importance to Nepal, where every day more than twelve hours of cut power is experienced even in urban areas, and power import costs are increasing (NEA, 2013).

Conclusions

Considerable potential for WRD exists between India and Nepal, but limited cooperation between the nations has considerably impacted the development of new projects (Salman

& Uprety, 2003). In a review of the conflicts on the Koshi, Mahakali and Gandaki Rivers, Salman and Uprety (2003) discuss the various historic treaties between India and Nepal, their influence on political relations and how they impacted the development of WRD projects. The authors note that the initiation of development projects suffered as neither nation is fully content due to differences in priorities and perspectives. The smaller nations are always under fear of being outsmarted by their partner, while the larger nations feel they are more generous, and thus without amicable agreements the projects are delayed significantly.

For example, discussions on the Koshi project started as early as 1896, and resurfaced again in 1930s and 1950s, with an agreement finally signed in 1954 (Rawat, 1974; Salman & Uprety, 2003). Political instability and changing governments have added to the delays. To avoid delays in installing transboundary WRD projects, it is essential to examine the pros and cons of the proposed projects from the perspective of each nation. For example, compensation for land submergence in the upstream nation should be considered while estimating hydropower profit for downstream nations – thus striking a balance for both nations involved. Salman and Uprety recommend an integrated approach to water resources assessment and management in any WRD involving India and Nepal, with particular emphasis on extensive cooperation throughout treaty preparation and increased sensitivity to the benefits and losses for each nation involved.

The present study provides the first-ever assessment of baseline and future water demand for the Koshi Basin and compares it against proposed WRD as such investments are necessary in the Koshi Basin to alleviate current and future water stress. This study is the first-ever attempt to integrate and assess basin-wide water demand with planned WRD in the Koshi Basin. The study utilized a water demand assessment model, WEAP, to estimate water storage and hydropower generation potential for the Koshi Basin. Out of the 11 proposed projects studied, 4 were storage type, while the other 7 were run-of the-river type. The WEAP was successful in modelling the hydropower generation potential in the Koshi Basin within 8% of reported values. In addition, WEAP simulated future water demand associated with estimated population growth, agricultural growth and industrial growth for the basin in the year 2050. With the introduction of the WRD projects, 8382 MCM of water could be stored, which would easily satisfy the unmet demand in the current scenario (660 MCM) and for all the future scenarios (population growth, agricultural growth and industrial growth are projected to have 920, 970 and 1003 MCM unmet demand, respectively).

Of the scenarios tested, the population growth and industrial growth scenarios had the most water demand and unmet demand, while the baseline had the least. All scenarios had seasonal variability in unmet demand owing to seasonal variability in water supply and sectoral water demand. Even if the basin's current unmet demand triples in the future, it will only be 24% of the total water storage potential in the basin. Results also indicate that the projects could store water during monsoon periods and release water during low flow-periods (during post-monsoon and winter months) and thus alleviate water stress during the dry season. Future studies need to investigate the operational impacts of the projects on downstream communities, for which the current study can provide valuable baseline information.

In addition, results reveale that the introduction of WRD would lead to hydropower generation of 37 times the power that Nepal imports from India, for a price of USD 54 million. With such capacity of hydropower production, Nepal could not only sustain its growing power demand but also export power to neighbouring countries (especially

India, which depends primarily on coal for power production). This power sharing would also lead to further collaborations with India, leading to growth in other sectors such as industry, agriculture and science and technology.

Thus the surplus water storage and hydropower from WRD projects introduced in the Koshi Basin could promote significant economic, agricultural and industrial growth and improve the quality of livelihoods of the basin's population. The surplus hydropower could encourage transboundary cooperation with neighbouring countries for power sharing and joint industrial growth. It is thus important that policy makers, international donors and investment agencies take into account the present study's results that indicate high potential for water storage and hydropower productivity in the Koshi Basin.

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