Water Resources of Nepal: Opportunities and Challenges

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ABSTRACT: The judicious utilization of the vast water resources of Nepal demands an overall understanding of hydrology and sediment related issues that are unique to the most dynamic river system in the world. The most conspicuous hydrological problem in the Himalayan region is that of erosion and sedimentation. The great spatial and temporal variation in river flows has posed a formidable challenge in the effective utilization of the water resources of the country. The long term and reliable quality data on precipitation, run-off and sediment are of prime importance for reliable resource assessment and to chart a road map for its development. The rapid development of Nepal's water resources has been constrained by several challenges such as geo-political, social, technological, economic, and financial factors. Nevertheless, the country must put in all the effort and tact at its disposal in order to unravel the intricate knot of water politics and pave the way for its all round development through the optimal utilization of the natural endowments available. In the larger perspective, a very proactive regional cooperation among the member countries for joint initiatives in the direction of regional/sub-regional water resource development is of paramount importance. This paper attempts to address the issue of hydrology and sediment of the rivers as a challenge for the sustainable development of water resources nationally and regionally.

1. INTRODUCTION

Nepal's water resources potential can be easily understood by the fact that about 2.27% of the world's fresh water resources is possessed by this landlocked country with an area of 147,181 km^2, the main source being precipitation, surface runoff, and groundwater. With this rich water regime of Nepal, under the backdrop of fragile geology, prominent mass wasting phenomena and extreme weather scenarios, the use of this resource in the form of domestic water use, irrigation, energy production and others has become very difficult. However, water use wise, 66% of the population has access to piped water supply. The current consumption of domestic water use is estimated to be 800 Million m^3 per year, which is estimated to grow to 1800 Million m^3 by 2027. Similarly, to feed the increased population, the agriculture production needs to be enhanced by providing year round irrigation facility for potential irrigable areas. It has been estimated that by the year 2027, irrigation demand will be around 37,000Million m^3 per year, which is 13,000 Million M^3 at present. In the same way, it is estimated that current consumption of industrial sector is about 80Milliom m^3 per year, which is expected to be 180 Million m^3 by 2027. Likewise, in the hydropower sector about 560 MW of hydropower plants have been installed at present against the techno-economically viable potential of around 40, 000 MW. By the year 2027, the demand is anticipated to grow to 22000 MW to cater to the need of electricity, both for domestic consumption as well as export. Exploitation of water resources for all these water products needs reliable long-term data on the availability of water. At the same time, extracting cleaner water from sediment-laden rivers of Nepal for most of the uses of water is of the first and foremost priority. This paper will focus on these two issues as the major technical challenges for water resource development in Nepal.

2. PRECIPITATION, RIVER BASINS AND HYDROLOGY OF NEPALESE RIVERS

About 80% of the annual mean precipitation of 1530 mm falls during the summer monsoon period (June-September) and the rest during the other eight months. Spatially, the mean annual precipitation ranges from more than 6000mm along the southern slopes of the Annapurna Range in central Nepal to less than 250mm along the rain shadow area near the Tibetan Plateau. During the rainy season about 64% of the rainfall goes immediately as surface runoff. Of the remaining 36 percent, some is retained as snow in the high Himalayas, some percolates through the ground as ground water acting as natural reservoirs which feeds the rivers to keep them flowing during the dry season. Nearly 8% of the country's area is estimated to be under permanent snow cover. Snowfall is estimated to contribute about 10% of the total precipitation.

There are more than 6000 rivers in Nepal with a total length exceeding 45000 kilometers. The average annual runoff from all the rivers is estimated to be over 220 billion m^3. Ground water resources in the country have been assessed tentatively at 12 billion m^3. The dominant feature of Nepal's water resources is that even though the country occupies only about 13 percent of the total drainage area of the catchment of the Ganges river, it contributes as much as 70 percent in the lean season and some 45 percent of its average annual flow to the Ganges river (IIDS, 1995). The climate and rainfall pattern of Nepal combined with the steep topography accounts for the great variability in water availability in time and space.

The rivers of Nepal have been classified into three grades depending upon their origin.

- Rivers originating from the High Himalayas – Grade I, Large
- Rivers originating from the Middle Mountains– Grade II, Medium
- Rivers originating from the Siwalik/ Churia Range or in Terai– Grade II, Small

Grade I rivers are the Mahakali, the Karnali, the Narayani and the Sapta Koshi originating in the Himalayan region's snow and glaciers.

Grade II rivers are the Babai, West Rapti, Tinau, Bagmati, Kamala, Kankai and Mechi, fed by ground water and springs. Grade III rivers originate in the Siwalik range and are called the southern rivers flowing directly to India.

The large rivers are snow fed and carry a significant and more sustained discharge even in the dry season. The medium rivers are also perennial but possess a wide seasonal fluctuation in water availability. The small rivers are either seasonal or ephemeral with little or no flow during the dry season.

The hydrology of Nepalese rivers closely follows the rainfall pattern. The flow is high during the months of July to September followed by a period of recession during the month of October to November. Flow becomes low during the months of Decembe augmenting the summer monsoon flow. The type of basin where the river originates governs the hydrology. Rivers in the Himalayan basins have sustained dry season flow due to snowmelt. The Mahabharat rivers are rain fed and get supplemented by the recharge r to April. Pre monsoon rains, thunder and squalls, generally increase the flow in May and early June from the springs, runoff, and ground water recession. As a result, the hydrology of these rivers is characterized by low dry season flow and high flow during the monsoon. The Siwalik rivers are rain-fed and because they have small drainage area and are flashy, with very low dry season flow. In several streams, during the dry season flow, the flow becomes almost zero.

The total volume of Nepal's water supply far surpasses the scale of expected water uses. A number of factors, however, limit the spatial and temporal availability of water in Nepal and exemplify the challenges the country has to face in harnessing its water resources for optimal use and maximum benefits. The factors include:

- The volume of runoff in to the country's streams and rivers varies greatly from place to place due to large variations in climate and topography
- The seasonal variation is very large. In an average year, 82% of the annual river flows occur from June to November. Even in large rivers, the dry season flow in an average year is only 12.5% of the annual flow.
- The locations where water can be usefully tapped do not always coincide with the locations where water is easily available.
- The patterns of desired water use in terms of times of day and seasons of the year may or may not be compatible with the natural supply patterns.

3. SEDIMENT AND RIVERS OF NEPAL

Sedimentation in the rivers of Nepal is a continuing natural phenomenon. As a natural consequence of water flow within the hydrological cycle, sediment is derived from various sources in the land surface. Most of the Nepalese rivers carry heavy sediment load in the rainy season and the sediments come from Glacial Lake Outburst Flood (GLOF) in the Himalayan rivers or bank erosion or landslides in others. **Nepal's suspended** sediment load varies from 1000 to 100,000 parts per million (PPM) in discharges of 10 to 100 m^3/s respectively. In the event of GLOF, at a flow of 10,000 m^3/s, the sediment load was as much as 10000mg/litre in the Tamur river (Sharma, 1997). Carson (1985) indicated that sediment load is in the order of 25,000ppm recorded regularly in the Narayani river. Sediment loads of the Narayani river at Bhainsa Lotan and Koshi at Barahachettra are 170 and 177 million tons per annum, respectively. The above sediment load is roughly equivalent to the removal of 1mm of top soil per year (Sharma,1997).

The magnitude of sedimentation in the rivers of Nepal is influenced by topography, geology, climatic conditions, intensity, duration, and distribution of rainfall, seismicity, and anthropogenic factors. Each year large quantities of sediment from the highlands are transferred by the river system to the low land areas. In recent times, the natural rate and extent of the sediment process has aggravated the sediment transfer rate by increased human and development interventions on nature. Sedimentation affects all types of irrigation, water supply, hydropower systems, and all forms of water uses. Sediment yield is of the utmost importance in assessing the sedimentation rates in reservoirs, in water supply, irrigation and hydropower projects of all sizes. In storage projects, the major concern is the inflow of sediment mass and depletion of storage volume whereas in the Run of the River type of projects (Diversion Head Works), the major concern is the amount of suspended sediments suitable for the particular water use.

4. HYDROLOGICAL AND SEDIMENT DATA ACQUISITION

The records of precipitation data in Nepal date back to the year 1921 AD. The first rain gauge station in Nepal was established in 1921 within the Indian Embassy premises in Kathmandu. Thereafter, between 1948 to 1965, one hundred rain gauges and four climatological stations were established and operated by the Indian Meteorological Department. It was only after 1965 that HMG/ N observed the rain gauge stations and other meteorological parameters with the establishment of Department of Hydrology and Meteorology (DHM).

Stream flow data, however, was not measured and very little was done in this field before 1960. In 1961, under the special UN funded program, flow measurement of the Karnali river was started for the feasibility study of Chisapani hydropower project. A program to establish nationwide network of river flow measurement stations in Nepal was started in 1961 with UNDP cooperation. Similarly, DHM initiated suspended load sampling in 1966 in twenty-four gauging stations for the collection of the suspended sediments covering all the important river basins.

The DHM today maintains about 252 meteorological stations established over different periods amounting to a density of 580 km^2/gauge on an average which is inadequate as per the norms for minimum network recommended by the World Meteorological Organization (WMO). According to WMO norms, the coverage has to be in the order of 100km^2 to 25km^2 per station in mountainous area requiring the number of stations to be between 1472 and 589 in Nepal. The orographic effects are more pronounced in high mountains than in lower mountains. Locations of stations do not seem to have properly addressed this factor. Moreover, the network is biased giving greater density in the southern and middle mountain regions. The network is most sparse in the high mountain regions consisting of 9 stations only within 3000 to 45ooo m of elevation and none in the high Himalayan region.

Likewise, WMO has standardized a minimum of 300 to 1000 km^2 per stream gauging station. Presently, there are only 43 stations equipped with automatic water level devices requiring a total of 147 to 491 stations to meet the stream gauging station density. Meeting the bottom line limit of minimum density of stream gauging station network will require at least another 104 gauging stations. As far as sediment sampling stations are concerned, there are only 13 suspended sediment sampling stations, which is very few in comparison to the number of river basins and severity of sediment flow. The present hydrological station network seems to be established mostly for the assessment of the potentials of major rivers and main tributaries only. There are very few rivers with drainage area of 200 to 300 km^2 and below, which are measured regularly and gauged. These types of rivers are used mostly for small irrigation and hydropower projects. But the flow characteristics of such rivers are not known due to the lack of systematic data collection. The hydrological behavior of rivers originating from the Siwalik and other rivers crossing the Siwalik range is very special due to the presence of highly pervious debris fan known as the Bhabar zone between the Churia hills and the Terai plain. There are no gauging stations on the Terai rivers or the rivers originating from Siwalik Hills.

5. ISSUES

The technical constraint for the optimal use and allocation of the abundant water resource for different needs should be looked within the context of history of monitoring and management of hydrological and sediment database. Long term and reliable hydro-meteorological and sediment data are a prerequisite to ensure the sound analysis of hydro-meteorological and sediment characteristics of all rivers for the proper assessment, evaluation, and planning of national water resources development projects and management of river discharges. Among many, the following are some of the reasons that pose inherent uncertainties on the systematic and sustainable development of water resources projects.

5.1 Network Size and Management

Hydrological data are vital for the planning, design and operation of water resources development projects. Adequate database enable optimal and sound engineering design. The cost effectiveness of the designed structures would be suspect in the absence of sufficient database. On a national scale, the density of hydrological stations and rainfall stations is very poor, not anywhere near to the WMO standard. The DHM, the principal data collector and disseminator, has not been able to improve the network density. With the increased demand for water resources data from the relevant public developers as well as private developers, it has become very urgent to optimize and upgrade the entire hydrometeorological network system.

Development of regional models, which simulate rainfall runoff processes, is necessary for estimating discharges from ungauged catchments. A commensurate increase in data collection will be required, in terms of both length of record and the range of variables. The requirement of data for a particular region will be even higher if the model is of regression type. The present distribution of network is insufficient to develop such models.

Sediment plays a big role in the operation and maintenance of water resources projects. Heavy siltation chokes the conveyance system, lowers the efficiency of settling basins and affects the performances of pumps and hydraulic machinery. Due to the high drainage density of the rivers with fragile geological conditions and effect of heavy rain, there are serious consequences of land erosion and landslides resulting in the high sediment load in the rivers. Continuous records of sediment loads of the rivers do not exist and, as a result, estimates of detailed sediment load distribution are not available for the majority of the rivers.

Nepal possesses substantial reservoirs of water stored in the form of snow and glaciers. The main rivers originate from the great Himalayas and are fed by melt water from snow and glaciers. The melt water from snow and ice contributes significantly to the sustained base flow in the dry season. But there is no systematic snow measurement performed at present except for the six stations under the Snow and Glacier Hydrology Project.

Despite the fact that DHM is undertaking a relatively small network of stations, effort is ongoing to improve the data generation and management. The generation, analysis, and distribution of quality and reliable data have become imperative, as the success of any water resource project is dependent on those data.

5.2 Limited Understanding of some natural phenomena

Rainfall: Rainfall is influenced by topography and altitude differences where orographic effect is high. Even during the monsoon the nature of precipitation is variable. Throughout the hills, pockets exist where precipitation characteristics, volume, duration, and intensity are variable. While one station may be recording high rainfall, the other side of the hill may receive very little or no rainfall. The inadequate number of rain gauges, and monitoring of rainfall intensity and poor understanding of time and space variability lead to the use of ambiguous data in long term planning of water resources projects.

Snowfall: High mountain hydrology, dealing with the processes of snow and ice, has received only limited attention. Poor understanding of snowmelt and runoff processes leads to limitations in the estimate of the contribution by snowmelt.

Runoff: As only a small percentage of the rivers has flow monitoring stations, the network is inadequate to represent the full hydrological regime of the river systems. As a result, the hydrological assessment of total runoff from the country in itself has some limitations and the same is true for individual river systems. Variation in the runoff is contributed by factors like infiltration, percolation, and ground water flow processes, which are site specific, depending on the topography and geology. This has made the prediction of floods unreliable.

Sediment: Though there are several empirical and semi empirical equations for estimating sediment transport rates and yield for analytical purposes; they provide only preliminary order of magnitude since the sediment processes in Nepal are dynamic, complex and random.

6. REGIONAL COOPERATION

Some 70 billion cubic metres of water can be stored behind Nepal's identified dam sites. In view of the acute water and power scarcity that Nepal's co-riparian countries are likely to face in the course of this century, in contrast to the low domestic demand compared to its enormous potential, the surplus of regulated water and power could substantially make up for the deficit in the neighbouring countries. Therefore, the judicious harnessing of Nepal's water resources is very much in the interest of its co-riparian neighbours. There is thus a very valid and convincing argument in favour of regional or sub-regional cooperation in developing Nepal's bountiful water resources, which is going to waste in the form of unregulated run off day by day. As a foremost step toward the realization of harnessing this huge water potential for a geo-climatically fragile country like Nepal, more research into Himalayan eco-hydrology in collaboration with neighboring countries supported by exchange of data and technical expertise should be promoted for sustainable and integrated water resources management. This is the one area where collaborative efforts at the regional and sub-regional levels amongst countries of South Asia could prove most beneficial in view of the fact that many of them share the Himalayan rivers. Similarly, the creation of a joint funding institution and joint committees between and among the member countries for driving the process of integrated water resource management would be helpful for regional cooperation.

Floods constitute the major natural disaster aggravating the poverty of millions of people residing in the Ganges-Brahmaputra-Meghna basin (GBM). Serious flooding in the Ganges basin is frequently associated with heavy torrential rains in Nepal. Hence, heavy precipitation over Nepalese catchments are of great concern to both India as well as Bangladesh not only in terms of flood water only but also the enormous amounts of sediment associated with it, aggravated by heavy soil erosion, and the numerous landslides and debris flows triggered in Nepal. Similarly, an anomalously thick blanket of snow over the Chinese (Tibetan) catchment could have repercussions on the monsoon precipitation over Nepal, and also India and Bangladesh. As hydro-meteorological phenomena transcend national borders, there is a great interdependence among the regional and sub-regional countries embraced by the Hindu-Kush- Himalaya (HKH) chain. Moreover, the wide diversity in the capabilities of the countries of the region in flood forecasting and management offers tremendous opportunities for flood forecasting and management including bilateral and regional technical cooperation. In this respect, even though, certain arrangements for the exchange of historical hydro-meteorological data in a limited manner do exist at the bilateral level, achievements with regard to sharing of real-time data and information on a regional/sub-regional scale, so vital for flood management, have been very limited. In this context, the Hindu Kush-Himalayan Hydrological Cycle Observing System (HKH – HYCOS) Project, as a regional component of the World Hydrological Cycle Observing System (WHYCOS), proposed by the World Meteorological Organization (WMO) and the International Centre for Integrated Mountain Development (ICIMOD) is a positive initiative that is anticipated to provide the operational concepts and tools for improving integrated river basin management, specifically by managing floods and contributing to the reduction of poverty and economic development of the region.

7. CONCLUSION

The overall development of Nepal's water resources is indeed a great challenge with great opportunities not only for Nepal but also its co-basin neighbours. The undertaking is also fraught with the many uncertainties inherent in our present understanding of Himalayan eco-hydrology compounded by phenomena like global climate change. Nevertheless, it is a most worthy undertaking that must be underpinned by regional cooperative efforts at improving the hydro-meteorological information system, and more proactive initiatives in the sustainable development of joint water projects, the benefits of which can be shared amongst Nepal and her neighbouring countries. This indeed is the thrust envisaged by the country's Water Resources Strategy, 2002 and the National Water Plan in the course of formulation.

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