






"Let's not allow a single drop of water to flow into the sea without being used for the benefit of mankind."

-King Parakramabahu the Great (1153-86 AD), Srilanka

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A view of Glacier-Lake in Annapurna Range in Nepal

Photo courtesy

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Recurrent Energy Crisis in Nepal: Why !

The continual shortage of energy during the dry season, 14 hours a day at present, termed as 'load shedding' has multiplier impacts on the national economy of Nepal and has upset the lives of its people. Electricity is the basic need and symbol of a modern society. Access to reliable and affordable energy is the prerequisite for any nation to prosper.

Since past 4.5 years, there has been an energy crisis in Nepal. The Government of Nepal has declared an Energy Emergency and put forward a 38 point plan to increase supply and alleviate the shortfall. However, no concrete outcome has been realized so far and the load shedding is likely to be continued for many years to come.

It has been a normal practice in Nepal that whenever there is energy crisis during the dry season, vigorous exercises take place to mitigate and manage the crisis by importing sufficient electricity from India, construction of cross border transmission line, giving priority to hydropower generation in Nepal, installation of diesel plants etc.

It is impractical to assume that imports of electricity from India will reduce the load shedding in Nepal. We should understand the fact that there is 15,000 MW shortfall of energy in India's northern grid.

Now, the time has come to act to turn the hydropower potentialities of Nepal into reality. In a country where there is an abundance of water resources and huge hydropower potential with geographical variation from the micro to mega capacity with the available proven technology; where donors, investors and promoters at international and local level are ready; and where there is a huge market available domestically and regionally; one must ask the questions to the policy makers and the political leadership why hydropower development in Nepal is not taking place?

It is high time to demonstrate commitment, honesty and formulate hydropower friendly policies with coordinating approaches among the line ministries for the judicious and sustainable exploitation of Nepal's abundant water resources and hydropower potential before it is too late.

Jeewan P. Thanju
Editor-in-Chief

World Bank's 2012 Ganges Strategic Basin Assessment: A View from Nepal

S.B. Pun

Abstract: The World Bank's 2012 Ganges Strategic Basin Assessment (GSBA) is an interesting but contentious document with a wealth of information. The basin has a population of 656 million; and 47 percent of Indians, 576 million, live in this basin. Nepal's three bordering States of Uttar Pradesh, Bihar and West Bengal with a population of 199, 104 and 91 million respectively have a staggering combined population of 385 million, far greater than that of the USA. The Ganges basin has the world's highest population density and, as a consequence, poverty level borders that of Sub-Sahara. This is India's Hindu cow belt where water is increasingly getting scarce.

With the strategic resource, water, getting scarce in the Ganges, the Bank's GSBA has some startling findings: storages in Nepal store '*significantly little*' water, so flood control in India is *'very limited'.* Storages in Nepal can '*double lean season flows*', but agricultural productivity in India is '*currently very low*' from such augmented flows. The Bank believes that '*hydropower and trade'* is *'significant*' and negotiation '*simpler than previously thought'*. The Bank recommends that Nepal push her hydropower development on a fast track. Many believe it is not the '*significant'* power trade that counts. What really counts is whether or not the traded Energy will be at a Significant Rate. By pushing Nepal's significant hydropower, the Bank is advocating a policy whereby India avail free lean season water stored in submerged in Nepal's fertile valleys submerged for perpetuity. In the Bank's opinion, as India's agricultural productivity is *currently very low* and flood control *very limited,* Nepal's downstream benefits are also very low. Nepal is, thus, very disappointed with the Bank's such Indo-centric GSBA report.

Key words: Ganges Strategic Basin Assessment (GSBA), World Bank, treaty, Nepal

Foreword

The Claudia Sadoff/Nagaraja Rao Harshadeep-led 2012 World Bank's 143 page Ganges Basin Strategic Assessment (GBSA) report has, to be fair, created an interesting '*knowledge base*' that is '*envisaged to encourage, rather than conclude, debate*' on the trans-boundary management issues of the Ganges. The Bank acknowledges it has utilized the inputs and information provided by various Institutes of India, Bangladesh and Nepal[1]. While the key SWAT model for the Ganges basin was developed in Delhi at the Indian Institute of Technology, the calibrated Ganges Basin Model[2] was developed in Dhaka by the Institute for Water Management (IWM). Except for IWM and CEGIS of Bangladesh and Nepal's ICIMOD (*if it could be called Nepal's*), inputs were predominantly from Indian Institutes. Inputs from India were a necessity as the major portion of the Ganga basin is in India. But this did not necessarily mean that the Bank, professing to be '*an honest* broker', should reflect biased Indian perceptions. If the Bank did concur with Indian views, it had the liberty to also reflect the other side of the coin of her other two[3] Ganges riparians, Bangladesh and Nepal. As far as the Ganges is concerned, geography has placed India in an uncomfortable position. But India, with two centuries of colonial British tutoring, has managed extremely well. While India, as the lower riparian to Nepal, wriggled out the '*without prejudice to their respective existing consumptive uses*' rights on the Mahakali river, she stuck to her guns on the Farakka by not conceding the '*historic use rights*' claim of her lower riparian, Bangladesh. This article attempts to reflect some of those Nepalese perceptions on the Bank's Indo-centric GBSA report.

Exclusion of Tibet from Ganges Basin Assessment

According to Dr. K. L. Rao's *India's Water Wealth*, 79% of the Ganga basin is in India, 13% in Nepal, 4% in Bangladesh and 4% in China's Tibet. But the multilateral Bank, whether by accident or design, has conveniently left out the population of Tibet which agreeably is tiny. The Ganges tributaries of the Karnali, Bhote Kosi and Arun in particular have a sizable basin in Tibet. This exclusion is puzzling because it was the very Bank that, as per its much-used OP 7.50 manual, notified[4] the upper riparian China when Nepal was wrestling with the run-of-river non-consumptive 201 MW Arun III Hydroelectric Project in the early 1990s.

Inclusion of Kalapani as Indian Territory

Interestingly, a close look on page 20 of the Bank's report showing the Ganges River Basin map indicates Nepal's Kalapani territory as being within India. The Mahakali River in the Himalayas is the border between Nepal and India. The Kalapani area, clearly shown in the map as being east of the Mahakali River, belongs to Nepal. But surprisingly the multilateral institution that is supposed to represent Nepal's interest as well has again, by design or accident, defaulted.

No Basin wide or Multilateral Treaties

In the last six decades, India has consistently pursued her bilateral policy on the Ganges, from the 1954 Kosi to the 1996 Mahakali and Farakka treaties. The *raison d'etre* for this is very simple. India used this bilateralism tool to achieve her objectives from both Nepal and Bangladesh, a lower riparian to one but upper riparian to another. It was in such a context that the '*bullied*' Bangladesh and Nepal requested India for a regional approach on the Ganges water resources development. But India interpreted[5] this as '*a gang up of sorts*' by Bangladesh and Nepal against her. Now that her eyes have moved on to the larger Brahmaputra waters and now that she is a lower riparian to a large China, it will be interesting to see whether India will continue to sing bilateralism or change her tune to regionalism.

The Bank has rightly pointed out '*Until now, there has been no basin wide knowledge base ….. to explore options and facilitate cooperative planning in the Ganges. Information and data are surprisingly scarce and difficult to obtain. In particular, very little information is available on hydrology and irrigation withdrawals in India*.' In fact, the Government of India is so secretive about hydrological data that even her own citizen, BG Verghese, puts on record[6] that India has been '*needlessly paranoid about classifying water resource data*.'

On the Ganges Basin Bilateral Treaties

The following are the four Ganges Basin bilateral treaties, three Indo-Nepal and one Indo-Bangladesh, so far concluded. The following are the World Bank's perceptions in its own words and the view from Nepal on those four Ganges Basin treaties:

i) 1954 Kosi Treaty, Revised 1966

World Bank's GSBA View: *The first treaty, on the Kosi River, was signed between India and Nepal in 1954. The treaty was developed to attenuate routine devastating floods in the Indian state of Bihar. Soon after its conclusion in 1954, however, the treaty came under criticism in Nepal where it was perceived as inequitable, in part because it called for the construction of embankments to contain the course of the Kosi, as well as the construction of the Kosi Barrage, both of which are entirely within Nepal. The land associated with the embankments and barrage (the built and inundated areas) was to be acquired by Nepal and then ceded to India. The Kosi Treaty was amended in 1966 so that the land would be leased to India rather than ceded, but many still felt the terms of that lease (199 years at a nominal annual rate) were inequitable and that it did not properly compensate the loss of fertile farmland in Nepal.*

View from Nepal: The Bank states "*The treaty was developed to attenuate routine devastating floods in the Indian state of Bihar*." The Bank mis-states the Treaty's very preamble "*……for the purpose of flood control, irrigation, generation of hydro-electric power and prevention of erosion in Nepal….*" So the Kosi treaty is not, as the Bank insinuates, for flood control alone. The Bank astutely refrains from mentioning that the Kosi Barrage irrigates a massive 9,69,100 ha[7] of land in Bihar while Nepal[8] gets a mere 11,300 ha through gravity flow from the western canal. The Bank does indicate that the Kosi Barrage and its associated embankments are all "*entirely within Nepal*". If one were to believe the scintillating logic of an Indian diplomat[9], this construction within Nepal was done solely for the purpose of providing irrigation benefits for Nepal; otherwise India could have built the Barrage downstream in her own territories. The Bank rightly mentions that the revised (not amended) 1966 Kosi Treaty leased, rather than ceded, the project land to India and many Nepalese felt the terms of the lease, 199 years at a nominal annual rate, were inequitable. The Bank has studiously failed to mention the 1966 Letters of Exchange that unequivocally stipulates '*…that the Government of India will be reasonably compensated in case the Project properties are taken over by His Majesty's Government at the end of the lease period….*' India, despite all her professed goodwill towards Nepal, had no bad conscience in demanding '*reasonable compensation*' from Nepal after using the Project facilities for 199 years!

ii) 1959 Gandak Treaty, Amended 1964

World Bank's GSBA View: *The second treaty between India and Nepal, the Gandaki Treaty, was signed in 1959 with a focus on flood control, irrigation, and power. The Gandaki River, like the Kosi, brought annual floods that damaged crops and property in both Nepal and India. This treaty is considered more favorable to Nepal than the Kosi Treaty. Nevertheless, it, too, was met with strong objection in Nepal. Unlike the Kosi Treaty, the Gandaki Treaty has not been amended.*

View from Nepal: To err is human, and the Bank badly erred in stating that the Gandak treaty has '*not been amended*'. The 1959 Gandak treaty was amended in 1964, two years earlier than the older Kosi Treaty. A perusal of the 1959 Gandak Treaty preamble states '*…. For the purposes of irrigation and development of power for Nepal and India….*' The preamble does not mention '*flood control*' but the Bank, in its esteemed opinion, deemed it necessary so that all its sundry readers will also mouth those words. In the Bank's exalted opinion that the Gandak treaty is '*more favorable to Nepal than the Kosi Treaty*.' This, unfortunately, is not the case at all. If one peruses Clause 9 of the 1959 Gandak treaty, so conveniently entitled '*Protection of Nepal's Riparian Rights*', it stipulates '*His Majesty's Government will continue to have the right to withdraw for irrigation or any other purpose from the river or its tributaries in Nepal … His Majesty's Government agree that they* ***shall not exercise this right*** *in such manner …* ***prejudicially to affect the water requirements of the Project as set out in the schedule annexed hereto***. This '*without prejudiced to the schedule annexed hereto*' was, in fact, protection of India's riparian rights and not Nepal's. Nepal would have no right to withdraw Gandak waters in her own territory upstream if it prejudicially affects India's Schedule of Water Requirements. India, in the annexed Schedule, allotted herself the entire flows (that of dry season) of the Gandak river for her use in the densely populated States of Bihar and UP. It was this very Clause 9 that was deleted in the 1964 amendment. In that amendment India, however, ensured that her concurrence was necessary '*for trans-Valley uses of Gandak waters…..in* *the months of February to April only*.' Yes, the Gandak treaty has more irrigation[10] for Nepal than the Kosi: 12,500 ha for Nawalparasi and 34,400 ha for Parsa and Bara. But unfortunately India has never provided Nepal the stipulated quantum of water from Gandak, in particular the 850 cusecs from Don Canal for Parsa and Bara districts.

iii) 1996 Treaty on Integrated Development of the Mahakali River

World Bank's GSBA View: *The third treaty between India and Nepal was the Mahakali Treaty that entered into force in 1997. The Mahakali River runs north to south along Nepal's western border with India. The Mahakali Treaty emphasized an integrated approach to water resources development, benefit sharing, and the need to revisit earlier activities and agreements based on present needs. It also included provision for the development of the Pancheshwar Dam (which remains un-built). It aimed to maximize the benefits for both countries, an approach that was absent in the Kosi and Gandaki treaties and is generally considered consistent with international good practice. But again, the treaty was met with widespread controversy in both India and Nepal.*

View from Nepal: The Bank mentions that the Mahakali Treaty aims '*to maximize the benefits*' for both countries and is '*generally considered consistent with international good practice*.' But the Bank does not elaborate why the Pancheshwar Dam, despite its aim to complete it in 8 years, remains un-built since 1996. While the treaty does mention '*equal sharing of the Mahakali waters*' to placate Nepalese ears, it does not, in the same breath, fail to stipulate '*without prejudice to their respective existing consumptive uses*'. Only later did it dawn on the Nepalese that '*without prejudice*' to India's existing consumptive uses meant not only the claim for the entire Sarda Canal capacity of 326 cumecs but also the flows of the Lower Sarda Canal, 160 km downstream. On the unutilized portion of waters (entirely Nepal's as her irrigation infrastructures are yet to be developed), Nepal's then politicians at the helm, meekly acquiesced to India's ruling '*... precludes the claim, in any form, by either Party on the unutilized portion of the shares of the waters...*' On equal sharing of the 6,480 MW hydropower, the story is no different. The Treaty's Letters of Exchange stipulate '*....net power benefit shall be assessed on the basis of, inter alia, saving in costs to the beneficiaries as compared with the relevant alternatives available.*' For Nepal the alternatives meant thermal plants (coal, oil and gas) but India has her own interpretation. It is precisely because of such obfuscation that the Pancheshwar dam remains un-built. And the Bank sanguinely wants Nepalese to believe that the Mahakali treaty is '*consistent with international good practice*'.

iv) 1996 Treaty on Sharing of Ganga/Ganges Waters at Farakka

World Bank's GSBA View: *India and Bangladesh entered into a number of successive agreements from 1975 through 1988. After prolonged negotiations, the two countries concluded a treaty on sharing the Ganges in 1996. The Ganges Treaty, whose provisions dictate inter alia the allocation of flows at Farakka Barrage (at the Ganges Strategic Basin* ***Assessment Indo-Bangladesh border),*** *has also raised equity concerns in some quarters. The Ganges Treaty, allocated the low dry-season flows at Farakka between India and Bangladesh, but did not specify how much water India could withdraw upstream from the Farakka Barrage, nor did it address high-flow (flood) issues.*

View from Nepal: To understand the Farakka barrage issue, one needs to delve earlier than the '*number of successive agreements from 1975....*' As early as 1854, Sir Arthur Cotton envisaged a barrage across the Ganges to augment the Bhagirathi-Hooghly flows and flush the sediments building up at the Calcutta port. Despite Pakistani protests, India implemented Sir Cotton's plan by unilaterally constructing in 1963 the Farakka barrage on the Ganges. After completing the barrage and by-pass feeder canal of 40,000 cusecs capacity in 1975, India officially notified Bangladesh that she wanted to '*test-run*' them. Bangladesh, hence, took this issue to the United Nations in 1976 arguing for continuation of the Ganges natural flows based on her '*historic right*' uses. India countered that the Farakka barrage was an '*intrinsically bilateral*' issue and Bangladesh should not question India's legitimate '*use of the water for its own reasonable requirements*'. As expected, when issues relating to '*budding*' Super Powers are concerned, the United Nation's Special Political Committee of the General Assembly issued a consensus agreement that the parties arrive at a '*fair and expeditious settlement*'. It is in such a contentious background that the 1996 Treaty on the Sharing of the Ganga/Ganges Waters at Farakka took birth. Naturally '*equity concerns*' in Bangladesh were bound to be raised. Such equity concerns, regarding the sharing of Teesta waters between these two countries, still resound.

Some Fundamental Questions: As part of the Ganges Strategic Basin Assessment study, the Bank has posed 10 fundamental questions stating the general perception on those questions and countering them with what the GSBA findings actually were. This article has picked up the Bank's only four Nepal-related fundamental questions and attempts to project the views as seen from Nepal:

Question 1. Is there substantial potential for upstream reservoir storage in the Himalayan headwaters of the basin?

General Perception: Yes

Much has been written about the potential for large water storage structures in the Himalaya. It is generally assumed that this potential could be harnessed through *large multipurpose dams to produce hydropower, deliver more timely irrigation water, and regulate the extreme flows of the Ganges River.*

Bank's Findings: Not Really

Although many sites are attractive for the development of multipurpose water storage infrastructure, the steep terrain and deep gorges allow surprisingly little water to be stored behind even very tall dams. Developing the full range of structures under consideration in this report would provide additional active system storage equivalent to only about 18 percent of annual average flow, which is not very significant on a basin wide scale.

View from Nepal: The Bank has very rightly cited the example '*In Egypt's flat terrain, the Aswan High Dam, with a height of 111 meters, can store 162 billion cubic meters of water, whereas the Andhi Khola Dam site on the Kali Gandaki River in Nepal, with a comparable height of 110 meters, would store only 0.9 billion cubic meters.*' Yes, with waters tumbling down the world's highest peaks into the flat Ganges basin within a short stretch, '*surprisingly little water…. equivalent to only about 18 percent of the basin's annual average flow*' can be stored in the Himalayan region. Yes, for such '*surprisingly little water*', it is time that our policy makers be selective and seriously vet only those projects of national interests? The 600 MW Budhigandaki for dire domestic energy needs or the 3,000 MW Kosi High Dam for India's dire irrigation and flood control needs should be vetted very much by Nepal. With tens of thousands of Nepalese to be displaced from their villages in perpetuity from these fertile river valleys, the social and environmental costs on the flora and fauna would be of immense unprecedented proportions. Yet, the two countries have not so far dared to vet these issues publicly. Sadly, the only issues that hog the media's limelight are the huge energy (*read for Nepal*) with some flood control and very little irrigation (*also read for both Nepal and India*) benefits. The question that has begun to raise its head in Nepal is "*Should Nepalese be submerged and displaced from their and their forefathers' homes for ever for the sole benefit of people across the border?*' This is the answer the Nepalese public want from the governments of Nepal and India before anything is done on the Kosi High Dam.

Question 2. Can upstream water storage control basin wide flooding?

General Perception: Yes

Himalayan storage reservoirs are commonly seen as the answer to the flooding that plagues the Ganges plains and delta, especially in areas of Bangladesh, Bihar, and eastern Uttar Pradesh.

Bank's Findings: Not Really

Although a moderate amount of flow could be stored at the sub-basin level, this storage is unlikely to significantly reduce flooding because it is generally not the level of peak flows in major (usually embanked) tributaries that causes flooding, but rather localized rainfall, high flows in smaller tributaries, and embankment failures.

View from Nepal: The Bank categorically concludes that flood control '*using upstream storage is very limited*' and goes on to state that the Kosi High Dam's '*impact on flooding would likely be modest…*'. Yet, after the Kosi river breached its eastern embankment in Nepal on August 18, 2008, India's Water Resources Minister, Saif Uddin Soz, is quoted[11] as saying '*We have already taken decisions…. Kosi is in focus this time in particular…Our main interest is flood control and irrigation. Those are our first and second priority. If we get hydroelectricity as a by-product, it will be a bonus for us.*' This means the Government of India has already decided to execute the Kosi High Dam irrespective of the findings of the World Bank's GSBA or her own Patna-based Ganga Flood Control Commission. What is enlightening for Nepal is the Bank's India-centric statement '*…almost all of the major tributaries in the basin are fully embanked. Lowering flood peaks within these embanked rivers is unlikely to have a significant effect on flooding events.*' This was exactly the Indian stand on flood control benefits during the Karnali Chisapani negotiation in the 1980s, and this still is India's stand on the Pancheshwar negotiation. When Indo-centric views are uttered verbatim by the World Bank, the so called honest broker, the GSBA is bound to be perceived by Nepal as skewed.

Question 3. Can upstream water storage augment low flows downstream?

General Perception: Yes

In addition to holding back floods, these reservoirs are expected to release water stored during the wet season for use in the dry season. This release would augment low flows for ecosystems, agriculture, and other uses across the basin, especially in the dry months preceding the monsoon.

Bank's Findings: Yes, but…

In physical terms, the modeling results confirm this expectation. ***Low-flow augmentation could indeed be significant*** *if all the large dams under consideration were built,* ***approximately doubling low flows in the driest months.*** *Storing even a minor portion of the flood flows until the dry season could significantly increase low flows especially in a very dry years….*

However, ***the economic value of this additional low-flow augmentation is unclear because of soil water logging and low agricultural productivity in India*** *and Bangladesh.* ***Water is not the crucial constraint to agricultural productivity*** *in the specific parts of the Ganges Basin that could receive additional flows…*

View from Nepal: This is where the World Bank with the '*Yes, but....*' statement has dealt the most deadly *'Et tu Brute?'* blow to Nepal. This is where Nepal finds the Bank's GSBA skewed and flawed. The Bank categorically concludes '*low-flow augmentation could indeed be significant*' due to upstream storages. In fact, if all the large dams (Pancheshwar, Sapta Kosi and Karnali) are built, then low flows in the dry season would '*approximately double*'. But the Bank, in the same breath, hastens to qualify '*the economic value of this low-flow augmentation is unclear because of low agricultural productivity and localize water logging. Water is not seen to be the crucial constraint to agricultural productivity...*' This is a deliberate attempt by the Bank to downplay the value of water. These are exactly the same arguments that India bandied on the Karnali Chisapani and Pancheshwar projects. A bad monsoon in the Indian subcontinent automatically means bad agricultural productivity. India, from British through her Republic times, invested massively in her irrigation infrastructures particularly in UP and Bihar – from the Sarda/Banbasa and Tanakpur, Ghagra/Girijapur, Saryu/Laxmanpur to the Gandak and Kosi barrages. With such infrastructures, the Bank itself mentions that UP alone has been able to irrigate about 9 million hectares at least partially with surface waters.

Now consider the demography and poverty of the Ganges basin that the Bank itself states '*The huge population of the Basin, combined with pervasive poverty and extreme population density, mark the Ganges Basin as a unique global challenge……poverty rates in the basin approach those of Sub-Saharan Africa*.' The Bank indicates that 655.5 million people (India 576.3 million, Bangladesh 50.7 million and Nepal 28.5 million) live within the Ganges basin. The population of Nepal's three bordering States of UP, Bihar and West Bengal (199.4 million, 103.7 million and 91.4 million respectively) means a staggering population of 384.5 million far exceeding that of the world's only superpower, USA. When 576 million Indians (47 percent of India's population) live in the Ganges basin, how can the Bank make the sweeping remark that '*low flow augmented*' Ganges waters is ***not crucial*** to India? What economic value does the Bank really want to peg for this low-flow augmentation? From the sill level controversies over the tiny Mahali Sagar (*UP/Kapilavastu border*) through the sill level of the Nepal intake at Tanakpur to the Mahakali treaty's '*without prejudice to their respective existing consumptive uses*' clause, water and lean season water has been India's one and only concern.

In fact, India believes[12] every drop of water is equivalent to a drop of blood. This led the Government of India to launch the controversial IC Rs 5,600 Billion River Linking Project (RLP) in 2002. The 220 meter Kosi High Dam *(live storage 9.4 BCM)*, 240 meter Karnali Chisapani *(live storage 16.2 BCM)* and 250 meter Pancheshwar[13] *(live storage 6.6 BCM)* in Nepal are the key critical players in the Himalayan component of the RLP for storing water during the wet season. During the dry season this 32.2 BCM of water stored by submerging Nepal in perpetuity is envisaged to be transferred to the drier west, India's bread basket, to augment the flows of the rivers along the way. The World Bank's GSBA has studiously uttered not a single word on India's River Linking Project. It is believed this loud ominous silence on the RLP definitely emanates a message. The Bank's findings that even augmented water is not '*a critical constraint to India's agricultural productivity*' means the '*honest broker*' is hand in glove with the Government of India.

Question 4. Is there substantial untapped hydropower potential in the Ganges basin?

General Perception: Yes

The Himalayas have enormous hydropower potential. This power is seen as a source of domestic energy supplies as well as a source of export revenues for Nepal where potential supplies far outstrip potential demand. It is also seen as an important source of clean energy in a region that is experiencing high growth.

Bank's Finding: Yes

In Nepal alone, it is estimated that more than 40,000 megawatts of economically feasible potential hydropower exists in the Himalayan headwaters of the Ganges. Less than 2 percent has been developed. The suite of dams examined in this report, the largest 23 in Nepal, would have an installed capacity of about 25,000 megawatts, producing an estimated 65-70 terawatt hours of power annually (and saving up to 52,000–56,000 tons of carbon equivalent per year (very low figure-Editor). The net value of this potential hydropower is estimated at some $5 billion annually, quite significant relative to Nepal's 2009 GDP of $12.5 billion.

View from Nepal: For the last six decades, Nepal has been singing hoarse this hymn on untapped hydropower potential. As part of that song, with load shedding exceeding 12 hours per day in the dry season, the Nepalese government recently rolled out two reports on 10,000 MW in 10 Years and 25,000 MW in 20 Years. It is, hence, no revelation that the Bank confirms Nepal's untapped hydropower potential. The Bank has estimated the economic value of hydropower as '*some US$ 5 billion annually*' in Nepal's 2009 GDP of US$ 12.6 billion. This is a substantial amount indeed. But the Bank has conveniently not delved into why this substantial hydropower remains untapped in Nepal.

Take the case of the celebrated 10,800 MW Karnali Chisapani where the Bank's President McNamara together with US President Carter and British Prime Minister Callaghan were very keen to implement it. India was not happy with the Bank's benefit assessment of: power 81%, irrigation 18.9% and flood control 0.1%. India argued that irrigation and flood control benefits were *negligible* to her and only power benefit *considerable*. India refused to be loaded with these *negligible* benefit costs and the project collapsed. While India's ex-Foreign Secretary, Jagat Mehta, lamented '*My greatest unfulfilled ambition was not to have been able to.....come to grips on eventual power supply from Karnali...*' Recently an ex-Indian diplomat[14] has been quoted as saying that India has no problems with any country (*read China*) developing hydropower in Nepal. But he stresses that the electricity rates for sale to India would have to be palatable to her. This is the crux of the matter, India's monopoly market.

The Bank in its report is at pains to explain that India's projected power shortfall by 2017 would be 100,000 MW and the Government of India has '*repeatedly stated its interest in importing Nepal's surplus, clean hydropower.' It goes on to add that 'power exports from Nepal to India could help correct Nepal's persistent balance-of-payments deficit with India.'* Such '*repeated and persistent*' statements are indeed very fine on paper. But why is it not happening? Is Nepal alone to be faulted? Take the case of the Bank cited '*cross-border transmission projects are now being implemented*'. Very few are aware that this long awaited 400 kV Muzaffarpur-Dhalkebar cross border transmission line is a One-Way power traffic. That is, the present arrangement[16] is meant only for importing Indian power! India is excessively paranoid about choreographing Nepal's '*huge hydropower*' access into India's so called '*hungry 100,000 MW*' market.

The Bank, no doubt, is hand in glove with India. Consider the Bank's following statement: '*Whereas most observers tend to focus on the installed capacity of a power plant (in megawatts) when discussing hydropower potential, it is, in fact, the actual power generation (e.g. in megawatt-hours) from the system that constitutes the economic benefits. Power generation reflects the hydrology of the river and the size of the reservoir. For example, as shown by the modeling analysis, the Kosi High Dam has an installed capacity of only 3,500 megawatts, but can produce more power than the Chisapani Dam with an installed capacity of more than 10,000 megawatts.*' This is a deliberate attempt by the Bank to fool Nepal's policy makers. The simple reason for Nepal opting for higher installed capacity (Megawatts) is the higher value of peaking energy she can obtain. This is what India's GMR Energy Ltd is doing by raising the 300 MW Upper Karnali to 900 MW and this is what the Government of India Undertaking, Satluj Jal Vidhyut Nigam *(former Nathpa Jhakri Power Corporation)*, has done with the 201 MW Arun III by upgrading it to 900 MW. Both GMR and Satluj have their eyes fixed on the peaking energy value that is getting more lucrative in the Indian power system. Yet, the honest broker wants Nepal to operate her hydropower on base load with lower energy value. The all underlying reason for this is that India prefers a continuous supply of water for her irrigation systems rather than in spurts (though there will be re-regulating dams) when plants are operated only for peaking purposes. This is the reason why India wants to lower the installed capacity of the 6,480 MW Pancheshwar project. And this is the reason why the India-designed Kosi High Dam has a mere 3,000 MW installed capacity. The Bank has also given non-factual data on Kosi High Dam and Karnali Chisapani energy generations. Reports[17] available to Nepal show that the 10,800 MW Karnali's annual energy generation at 20,842 million units is greater than that of 3,000 MW Kosi High Dam at 15,732 million units. This is, thus, the Bank's skewed and flawed attempt to make its GSBA report as Indo-centric as possible.

Final Word: Nepal's Right to say No

Inexplicably, the World Bank's Ganges Strategic Basin Assessment has excluded the Tibetan population from the Ganges basin but has not forgotten to include Nepal's Kalapani as an Indian territory. On the four bilateral treaties in the Ganges basin, the Bank has been at pains to reflect only those views that do not rub India the other way. That is why at a recent Kathmandu consultative workshop[18] on the Bank's GBSA report, the overwhelming commentators found the report too Indo-centric with some not hesitating to assess it as flawed.

On the potential for upstream storages in Nepal, due to steep gorges in the mountain '*significantly little water*' can be stored. The well-cited example is the 111 meter high Aswan Dam in Egypt that stores 162 billion cubic meters of water while the similarly high 110 meter Andhi Khola dam in Nepal can store a mere 0.9 billion cubic meters of water. Even the top prioritized 220 meter *(as given by GSBA)* high Kosi High Dam can store only 9.5 billion i.e a storage capacity of only one-sixteenth of Aswan Dam despite having a two times height. Similarly, the GSBA goes in length to describe why the potential to control floods through upstream storages in Nepal is '*very limited*' and that many of the Ganges tributaries are already well embanked. India would find this palatable as she has always been downplaying the flood control benefits. But what would indeed be far more palatable to India is the GSBA finding that though upstream storages can '*double the lean season flows*', the economic benefit to be derived from agriculture through augmented flows is '*currently quite low*'. This, of course, is not palatable to Nepal. However, the Bank finds the potential for hydropower development and trade 'significant' and that it is '*simpler to negotiate than previously thought*.' And this will be music to those groups of Nepalese who have been wailing at Nepal's '*apar khera gai rakheko pani*' *(enormous water going to waste).*

The World Bank's clear message, for Nepal, is go full speed ahead with hydropower of '*significant trade value*' and don't bother with the '*currently quite low*' irrigational benefits and flood control of '*very limited*' value. With such prescriptions, the multilateral institution is advocating a policy whereby India does to Nepal what Brazil did to Paraguay. In early 1970s Brazil and Paraguay implemented the 12,600 MW Itaipu bi-national hydropower project, till recently the world's largest. Despite selling half of Itaipu power to Brazil for a quarter of a century, Paraguay still remains the second poorest country in Latin America. It is not the '*significant*' power trade that counts. What actually counts is the *Energy Rate* at which that power trade is done with India. And the Bank's '*simpler to negotiate than previously thought*' means that Nepal should be far more cautious than she had been '*previously*' in her negotiation with India. By pushing Nepal's *significant* hydropower, the Bank is clearly advocating a policy whereby India, through Nepal's default, freely avail lean season water stored in submerged Nepal as, in the Bank's own opinion, agricultural productivity is *currently very low* and flood control *very limited* in India. Nepal, naturally, is very disappointed with the Bank's such Indo-centric assessment.

Are the Bank's findings really in Nepal's interests? Is this a win-win policy for Nepal? Many Nepalese believe that Nepal should not rush just because of '*significant*' power trade. Nepal should wait until the '*currently quite low*' irrigation and '*very limited*' flood control benefits also register a rise. Nepal, in the meantime, should implement projects that will cater to her own domestic water and energy needs. Nepal, as a member of the World Bank, has every right to reject the Bank's Indo-centric GSBA report. Nepal, similarly, has every right to say NO to large projects that submerge for perpetuity vast tracts of fertile lands and villages in Nepal until their '*accrued downstream benefits*' are also conceded by the World Bank to be '*significant*' !

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Notes

1. From India*: Integrated Natural Resource Management Consultants of Delhi, Indian Institute of Technology of Delhi, RMSI Pvt. Ltd. Delhi, Indian Statistical Institute, International Water Resources Management Institute (IWMI) in India;* from Bangladesh: *Institute for Water Management Dhaka, Center for Environmental and Geographic Information Services Dhaka and* from Nepal *International Centre for Integrated Mountain Development (ICIMOD) Kathmandu*. The report also acknowledges the inputs of Nepalese individuals like Dipak Gyawali, Ajaya Dixit, Mandira Shrestha, Shyam Ranjitkar and Rajib Upadhya.
2. It is reported that Bangladeshis, who worked on this Model, were surprised that the model the World Bank selected for Nepal was not the most appropriate one.
3. Actually, three riparians with China's Tibet.
4. The Bank notified China about the 201 MW Arun III project on November 14, 1993 and the Government of China gave its '*no objection*' concurrence on January 14, 1994. – *World Bank's Staff Appraisal Report on Arun III Hydroelectric Project dated August 29, 1994*. The Bank also used this notification on the classic Babai Irrigation Project that was aborted due to Indian objections.
5. Rasgotra, MK. 2004. *Discussion II, India-Nepal Relations: The Challenge Ahead*. Observer Research Foundation. New Delhi. Rupa & Co.
6. Verghese, BG. 1990. *Waters of Hope*. Centre for Policy Research. New Delhi. Oxford & IBH Publishing
7. Malla, SK. 1995. *Case Study of Kosi and Gandak Projects*. Thapa, BB & Pradhan, BB. *Water Resources Development*. Delhi. Konark Publishers.
8. Nepal gets another 13,800 ha through pumping from the western canal. The 66,000 ha upstream is not from the Kosi barrage.
9. Ambassador Dev Mukherjee at Face to Face Program of Reporters' Club, May 26, 2001 Kathmandu. *Partnership in Economic Development*. BP Koirala India-Nepal Foundation. Embassy of India, Lainchour, Kathmandu.
10. World Bank's Project Completion Report of Narayani Zone Irrigation Development Stage II Project, July 1, 1991.
11. *Nepali Times*, September 19-25, 2008 # 418
12. As told by Indian High Commissioner to Bangladesh, Muchkund Dubey, to Nepalese ambassador, Harka Bahadur Thapa, at Dhaka in the late 1970s during the height of Indo-Bangladesh Farakka barrage controversy.
13. The heights of these three dams are those as given in the Bank's GSBA report. One does not know where the Bank availed them. The height of Kosi High Dam according to Ministry of Irrigation/GOI (December 1983) is 269 meters, that of Karnali Chisapani according to Ministry of Water Resources/ HMGN (December 1989) is 270 meters and that of Pancheshwar Dam (Detailed Project Report, MOWR/HMGN, November, 1995) is 315 meters.
14. Verghese, BG. 1990. Waters of Hope. Centre for Policy Research. New Delhi. Oxford & IBH Publishing
15. Ex-ambassador and Foreign Secretary Shyam Saran to Kathmandu Post January 14, 2013.
16. The argument for this one way traffic is for importing 150 MW into Nepal. But 'if the spirit was willing' then this cross-border transmission line could easily have been provisioned for a two-way 150 MW power trade. Many foreign developers (read non-Indians) were keenly banking on this key 400 Kv cross-border transmission line to be a-two way traffic.
17. Karnali (Chisapani) Multipurpose Project, Feasibility Study, December 1989, HMGN/ Ministry of Water Resources. Comprehensive Plan of Flood Control for the Kosi Sub-Basin, December 1983, Ganga Flood Control Commission, GOI/Ministry of Irrigation.
18. Organized by Jalsrot Vikash Sanstha at Himalaya Hotel on July 20, 2012. The Chief Guest was Karna Dhoj Adhikari who incidentally was Chief Engineer/ Irrigation Department, Secretary/Water Resources Ministry, Chief Secretary and Nepal's Ambassador to India as well.

National River Linking Project of India

Naveen M. Joshi

Naveen M. Joshi

Abstract: India plans to transfer water from the water surplus region of the north-east to the water scarce regions of western and southern India. The plan is called the National River Linking Project (NRLP). Sixteen links in the Himalayan region and 14 links in the Peninsular region are proposed that will transfer annually about 174 Billion m^3 (Bm^3) of water through a canal network of 14,900 km. It will involve connecting 37 rivers and construction of dams/storages in 3,000 places. It is estimated to cost US$ 120 Billion (in 2000 price). The projected benefits are additional irrigation to 34 million hectares of land, generation of 34,000 MW of electricity, reduction of floods, and social upliftment.

Many prominent experts and personalities have criticized the project claiming that it will be a financial, social and environmental disaster. Both the proponents and opponents think that India will be doomed depending on whether the NRLP is implemented or not (Amarsinghe 2009). The International Water Management Institute (IWMI) in collaboration with the Challenge Program for Water & Food (CPWF) undertook a three year Strategic Analysis of the NRLP to evaluate the NRLP concept with a detailed analysis.

This paper is a general description of the NRLP, and it summarizes the findings of the Strategic Analysis of this Project undertaken by IWMI-CPWF. Further, it explores the possible consequences to India's neighbors in general and Nepal in particular.

Key words: River Linking Project, Himalayan link, peninsular link, inter basin water transfer, Strategic Analysis, India

Background

India is planning a very ambitious and gigantic water transfer project called the National River Linking Project (NRLP) from the surplus region in the north-east with major rivers of the South Asian region i.e the Ganges and the Brahmaputra, to the water scarce areas of western and southern India. It will be in two parts- one is the Himalayan part involving 16 links and the other is the peninsular part involving 14 links. It will connect 37 rivers and will have 3,000 storages. In total 174 Bm^3 of water will be transferred through a network of 14,900 km of canals. It claims to be the largest infrastructure project in the world. It will cost US$ 120 Billion (at 2000 price) and is expected to provide enormous benefit with additional irrigation capacity of 34 million hectares (MHa) (24 MHa surface + 10 MHa ground water) of agricultural land, generation of 34,000 MW of hydropower, decreasing flooding in the eastern region etc. About 1.48 million people will be displaced by the proposed Project. The verdict of the Supreme Court of India which directed the Government of India to go ahead with the project in a time bound manner underscores the legal backing for the project.

Critics complain that the Indian Government has not undertaken sufficient detailed analyses for alternatives; whereas, the Indian Government reiterates that considering the magnitude of the crisis, the NRLP is the only option. Both the opponents and proponents of the enterprise think that India will be doomed depending on whether the NRLP is implemented or not. There are many opinions and assertions about the project; but has little analytical rigor (Amarsinghe 2009).

India faces severe flooding in several places and at the same time draught in other places. The non-homogeneity in the available water resources, both spatial and temporal, had given the impetus to undertake large scale water resources development in India. To boost the agricultural production, improve domestic water supply, and address the energy crisis as well as to ameliorate the socio-economic conditions in the water scarce regions, large inter-basin transfers have been suggested.

Previously, this project was scheduled to be completed by 2016. Now the completion date may be within 2050.

There is no debate about the requirement of additional water in coming decades due to increasing population and decreasing river flows aggravated by the climate change phenomenon. Yet, the critics claim that the project is planned without considering alternatives, and the said project will be an economic, social and environmental disaster.

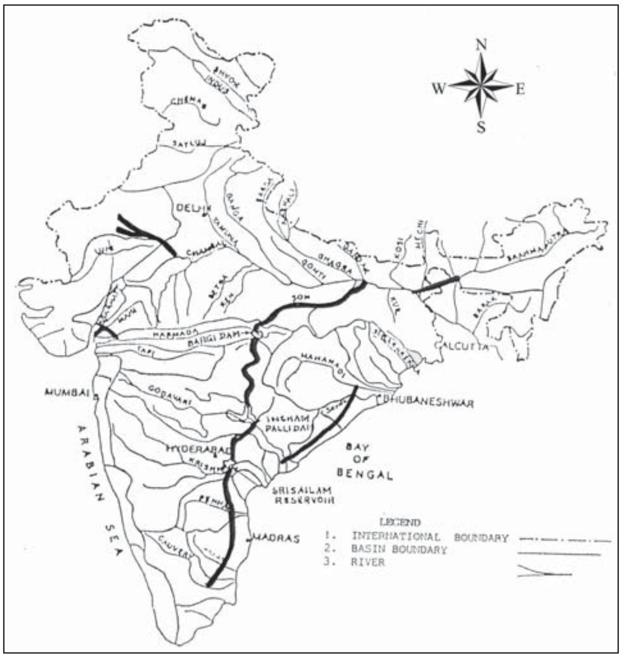
Capt. D.J.Dastur's Proposal

The Project History

In the nineteenth century, Sir Arthur Cotton had made a navigational plan for India from Assam to Mumbai primarily for the transportation of goods. Later in 1977, Captain D. J. Dastur had submitted a proposal to construct a high level canal to collect water from the rivers like Ravi, Sutlej, Yamuna, Ganga and Brahmaputra known as the Himalayan canal for transferring the harnessed waters down through the southern garland canals. The Himalayan canal would be about 2,400 km long and aligned along the southern slopes of the Himalayas and extending beyond the Brahmaputra towards the south by another canal 1,770 km long. The Central and Southern Garland canal would be around 9,332 km. Captain Dastur's proposal would cost Indian Rupees IRs. 120 trillion.

Another proposal, the National Water Grid, comprising the following components to interlink the major rivers was made by Dr. K. L. Rao in 1979. The National Water Grid comprised the following links:

- Ganga-Cauvery link connecting the Ganga with the Cauvery passing through the basins of Sone, Narmada, Tapi, Godavari, Krishna and Pennar,
- Brahmaputra Ganga link,
- Canal from Narmada to Gujarat, Western Rajasthan and Maharashtra, and
- Links from the rivers of the Western Ghats to the East.



K. L. Rao's Proposal

National Water Development Agency Plan

The Central Water Commission evaluated the proposal as a technically feasible but costing a huge amount. The proposal would also need a large block of power for lifting water in the Ganga-Cauvery section. As an alternative to the above mentioned two proposals, the National Perspectives Plans developed by the National Water Development Agency (NWDA) made a separate proposal for the inter-basin transfers. This proposal comprises two components, viz.

1. Himalayan Rivers Development and
2. Peninsular Rivers Development.

Components of the Proposed NRLP

The Himalayan component has been proposed to transfer 33 Bm^3 of water through 16 river links. It has two sub components linking the (Amarsinghe 2009):

1. Ganga and Brahmaputra to the Mahanadi Basin, and
2. Eastern Ganges tributaries and Chambal, Sabarmati river basins.

The Peninsular component has been proposed to transfer 141 Bm^3 water through 14 river links. It has four sub components linking the:

- Mahanadi and Godavari basins to the Krishna, Cauvery and Vaigai rivers;
- West flowing rivers south of Tapi to north of Mumbai;
- Ken river to the Betuwa river and Parbati, Kalisindh rivers to the Chambal rivers; and
- Some west flowing rivers to the eastern river.

It is very strange that only 33 Bm^3 of water is proposed to be transfered in Himalayan Component having 1154.1 Bm^3 of annual flows of Gangas and Brahmaputra; whereas 141 Bm^3 is proposed to be transferred in peninsular component having 177.4 Bm^3 annual flows of Godabari and Mahanadi

Project Benefits

The NRLP envisages to:

- provide additional irrigation to 34 million ha of cropped area and water supply to domestic and industrial sectors;
- add 34 GW of hydropower potential to the national grids;
- mitigate floods in the eastern India; and
- facilitate various other economic activities such as internal navigation, fisheries, groundwater recharge, environmental flows of water-scarce rivers.

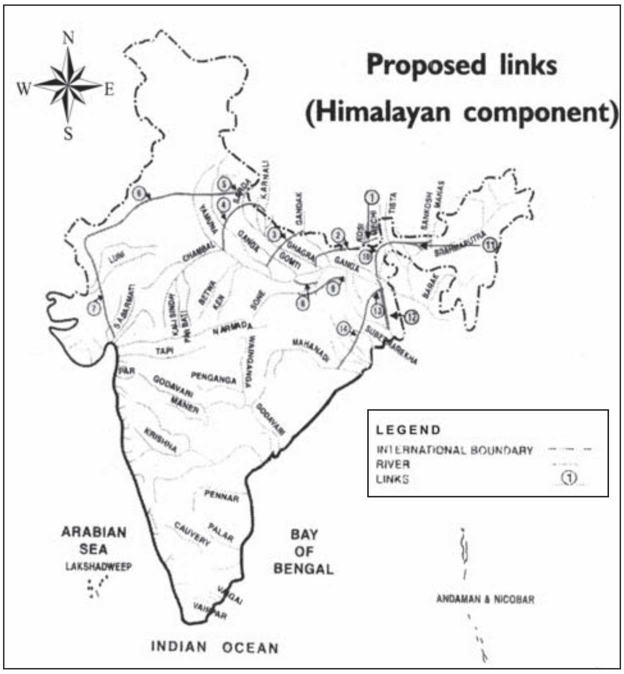
The project cost of the NRLP would be more than US$ 120 Billion (in 2000 prices) of which the:

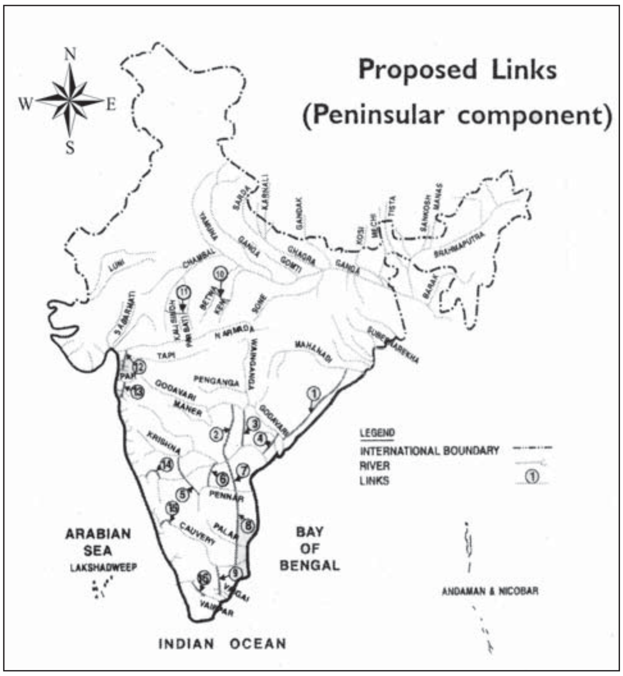
- Himalayan component cost would be US$ 23 billion;
- peninsular component cost would be US$ 40 Billion; and
- hydropower component cost would be US$ 58 Billion.

The NRLP, when completed, will increase India's utilizable water resources by 25%, and reduce inequality of water resources endowments in different regions (Amarsinghe 2009).

Himalayan Components

The Himalayan Rivers' component envisages the construction of storages on the main Ganga, and the Brahmaputra as well in principal tributaries both in India and Nepal so as to conserve the monsoon flows and acrue benefits from, hydropower generation, irrigation and flood control. An interlinking canal system will





be provided to transfer the surplus flows of the Kosi, Gandak and Ghagra to the west end of the Ganga and Yamuna to the Sutlej and Beas. Part supplies of the Beas and Ravi would be available for further transfer to the south in the drought prone areas of Haryana, Rajasthan and Gujarat. The Brahmaputra will be linked to the Ganga for augmenting the dry season flows of the Ganga in the downstream reaches.

Peninsular Component

The Peninsular Rivers' Development component is in four parts. The first part is the Mahanadi-Godavari-Krishna-Pennar-Cauvery link. It was considered that, among the peninsular rivers, the Mahanadi and Godavari have sizable surpluses after meeting the projected needs of the States within these basins. It was therefore, proposed to divert about 61 Bm^3 of surplus flows of the Mahanadi to and the Godavari system in eight links which will utlise 18.3 Bm^3 in en route that will help irrigate 2.9 Mha of culturable land and will supply 3 Bm^3 of domestic and industrial water. This would enable irrigation in the drought prone areas of Maharashtra, Karnataka, Andhra Pradesh and Tamil Nadu.

The second part consists of diverting surplus water of the west flowing rivers of Kerala and Karnataka to the east of the Western Ghats. The third part envisages to construct storages and to interlink the small rivers flowing along the west coast, north of Mumbai and south of Tapi. This will enable partial release of water from the Tapi and Narmada for extension of irrigation to Saurastra and Kutch areas. It will also enable the provision of extra water to meet the growing needs of the metropolitan area of Mumbai as well as providing irrigation to the coastal area of Maharashtra. The fourth part envisages the interlinking of the Southern tributaries of the Yamuna like the Ken and Chambal in addition to construction of small storages on intermediate tributaries and a dam on the Yamuna at Panchanad. This will provide irrigation in the Ujjain and Indore areas of Madhya Pradesh. It is estimated that the proposal of the Peninsular River Development will enable additional use of water to irrigate 13 Mha in the states of Orissa, Andhra Pradesh, Maharashtra, Karnataka, Tamilnadu and Madhya Pradesh besides generation of power.

Directions from the Supreme Court

Under the direction of the Supreme Court, a Task Force was established on December 13, 2002 with Mr. Suresh Prabhu as the Chairperson. Further, the Supreme Court on November 10, 2003 asked the Centre Government to give the status report detailing the progress made on the ambitious IRs. 5,600 billion (estimated about 2 decades ago) river networking project to link the major rivers by 2016. Further, the Supreme Court headed by Justice S. H. Kapadia on February 27, 2012 has asked the GOI to go ahead linking the rivers in India in the scheduled time frame.

Strategic Analysis of India's River Linking Project

In 2005, the International Water Management Institute (IWMI) and the Challenge Program on Water and Food (CPWF) started a three year research study on the "Strategic Analysis of India's River Linking Project (SAIRLP)". The primary focus of the IWMI-CPWF project was to provide the public and policy planners with a balanced analysis of the social benefits and costs of the NRLP. The project consisted of research in three phases. Phase-I analyzed India's water future scenarios to 2025/2050 and related issues. Phase-II analyzed how effective a response the NRLP is for meeting India's water future and its social costs and benefits. Phase-III contributed to an alternative water sector perspective plan for India as a fallback strategy for the NRLP (Amarsinghe 2009).

This was a vast study conducted by IWMI-CPWF. It involved 15 project partners. This analysis has generated several volumes of reports. The analysis of IWMI-CPWF was timely. This research project attempted to fill the void of analytical rigor in the discourse of the NRLP debate. This study resulted in the publication of five books and a series of related Reports and Proceedings of the workshops.

Summary of Findings of the SAIRLP

Phase I:

- Future water demand is projected to be increased by 22% and 30% in 2025 and 2050 respectively;
- Since last two decades ground water has been a major source of meeting the increasing demand for water, and in future also the same trend will continue creating severe ground water over-exploitation;
- The options are: rainwater harvesting, ground water recharge, water saving technologies, water markets to reduce ground water use, carefully crafted virtual water trade;
- Inter basin water transfer will increase ground water recharge; and
- At a time when there will be full impact of climate change, the NRLP will produce great benefits;

During the study, the share of the agriculture sector in the GDP was only 17% whereas 70% of the population in the rural areas was engaged in agriculture. Two thirds of the rain fed farm land produces only one third of farm products.

Phase II:

- Inadequate detailed planning in the proposed links;
- Water surplus availability forecast in a basin needs to be based on the detailed requirement in the basin including downstream riverine requirement. Monthly water availability needs to be considered, otherwise, it will show surpluses.
- The existing cropping pattern is of higher value than the proposed one. Rice, wheat is proposed to be increased; whereas rice planting is decreasing over the years.
- Conflict of interests among the stakeholders across the basin will be more complex than the hydraulic structures. Strong basin organizations will be required.
- Properly designed, disseminated, and implemented rehabilitation and relief packages for the project affected people will be necessary.
- Land acquisition must be handled with care as civil society organizations have been vocal and effective.

Phase III:

- Improving water productivity,
- Improving rain fed agriculture,
- Water demand management,
- Carefully crafted virtual water trade between states,
- Ground water recharge and water harvesting,
- Replacing long duration crops with short duration crops,
- Growing crops where yields are higher due to climatic advantages, better soil nutrient or lower ET demand,
- Changing the focus and priorities of the Master plan of Ground Water Recharge,
- Improving the quality of irrigation water supply, and
- Improving quality of power supply.

Review of the Irrigation Sector by the SAIRLP

After 1990, IRs. 1,000 Billion (US$ 24 Billion at 2006 price) spent on surface irrigation has produced hardly any additional increase in irrigated area. The economic performance of the surface irrigation system is declining. On the other hand, ground water has been extensively used since the last two decades and it continues to grow and reach an unsustainable level. It will be fruitful to plan for the over exploitation of ground water by recharging ground water aquifers by rainwater harvesting. It needs supply augmentation and irrigation demand management. Surface irrigation efficiency is projected to be 60% from the present 30-40%, which is unrealistic; whereas tubewell irrigation will have a 72% efficiency. Further, the major exports are from horticulture, dairy products, spices, and most of them are grown in dry land. Fodder or tree crops will increase trading opportunities.

In India two thirds of the farms are irrigated through ground water. Ground water is the source of irrigation in 90% of the command areas of the proposed Godavari-Krishna Link at present. Hence, the economic benefit from additional per cubic meter of proposed water transfer will be low.

The National Commission on Integrated Water Resource Development (NCIWRD)'s assumptions and predictions in respect to the NRLP planning has been proved to be unrealistic by the SAIRLP. In most cases, the situation has already changed. For example, the SAIRLP gave very different views on population growth, share of irrigation by surface irrigation, efficiency of surface irrigation, farm yield, food grains requirement etc.

The study has cited the case of the Sardar Sarovar Project of south India. Its estimated cost was IRs. 68,400 million in 1986/87. Till now IRs. 200,000 million has been spent producing 0.1 MHa of irrigated land out of the 1.8 Mha target, 200 MW of electricity generation out of 1,460 MW, and water supplies for 170 towns/cities. The project needs another IRs. 200,000 million and another 10 years for completion.

The SAIRLP has given great emphasis on ground water use, ground water recharge with rain water harvesting, and has questioned the effectiveness of surface irrigation systems.

The revised food grain demand is 380 Mt (reduced from 440 Mt of NCIWRD's estimate) by 2050 up from 200 Mt in 2000. If India's average yield is increased to 4 t/ha (China's present level) even over a 50 year period, there will be self sufficiency in food without any farming in additional land.

This (IWMI-CPWF) study has raised questions on what benefits this project will provide after spending such a colossal amount of money. Further, the study questions the investment capability of India, when the Government finds it hard to continue financing even the ongoing projects.

Progress till Date in the NRLP

The National Water Development Agency (NWDA) was established in 1982 for implementing the NRLP. The NWDA has already completed the Feasibility Study of a) the Ghagara - Yamuna Link, and b) the Sarada -Yamuna Link.

Further, the Bihar Government has completed a DPR in two following links which are approved by the Central Government. They will be part of the NRLP.

- Buri Gandak - Noon-Baya-Ganga
- Koshi - Mechi

Near the Nepal border, India has already constructed infrastructures to transfer water from the Ghagara, Babai and Rapti rivers.

Consequences of the Proposed Project

The ambitious project to transfer water from the surplus basin to the deficit basin could definitely be ideal in the sense of irrigating the barren land for more agricultural production, additional energy as well as navigation and other benefits. At the same time, it should also be kept in mind that modifying the behavior or courses of rivers is essentially geomorphic engineering, and naturally involves all the factors of geomorphology. A river is the most active element in a landscape, being the dominant factor shaping the landforms. The effects are erosion and deposition, in a complex pattern along the profile. In the lower reaches, the silt deposition is finer in grain size and the river follows a convoluted meandering course. The course of the river is always a shifting line, but the degree of mobility is more in the downstream reaches.

The entire valley of a river is sculpted by its water and is in a dynamic state. A river is an open system, as it constantly exchanges materials and energy with its environment. The study of a river needs to be taken as a system rather than a single water course. The river, unlike a canal, augments its flow all along its path, by additions from the tributaries and from rain in the lower catchment. The geomorphology is thoroughly stochastic, within a rough deterministic envelope. In one sense, the catchment is the envelope. Rivers are bounded by these domains and shaped by their domains. Breaking the envelope would unleash forces of uncontrolled change, and invite unintended consequences as mentioned below:

- The diversion of river would lessen the silt deposition in the river mouth or coastal area. This would result in erosion of the coastal area. The Akosombo Dam on the Volta River in Ghana has reduced the sediment to the coast, resulting in coastal erosion.
- Salt water intrusion into the land would occur as the river would have reduced discharge into the sea thus affecting the coastal agricultural production as well as the drinking water availability.
- Reduced discharge into the sea would affect the commercial fisheries. Dams and diversions have reduced the discharge of several rivers into the Caspian, Black and Azov Seas by 50 to 70 percent causing a reduction of commercial fisheries by over 90 percent.
- Prediction of surplus water would be a matter of question as the significant changes that are likely to take place in the hydrological flows due to climatic changes and glacial retreat.
- An artificially constructed river channel may not have the regime condition resulting in breaching of the channel. The Kosi River was breached in August 2008 affecting six million people in Nepal and India.
- It is doubtful whether the proposed river linking project is based on the understanding of the overall environment and ecosystem of the rivers?

Reactions from the Critics

Several experts and representatives from the society have raised their voices and concern against the proposed links. “India's river-linking project would be an economic, social and ecological disaster”, said Mr. Jairam Ramesh, Indian Minister for Rural Development, Drinking Water and Sanitation. “Large-scale inter-linking of rivers, which is the vision of some romantic engineers, is ecologically and even from the economic point of view quite a nightmare”, Mr. Ramesh said in an exclusive interview with The Daily Star (Karim 2012).

Mr. Som Pal, a former Minister of Agriculture and Water Resources, has argued: “The assumption that there is surplus water available for transfer to other basins is not correct. Most of the river basins of India are deficit ones. It may be argued that the flood waters during the monsoon can be transferred to deficit areas. But most of the existing dam reservoirs seldom get filled to cater to the given requirements of irrigation and power generation. The flooded rivers also carry a huge load of silt, which is likely to choke the channels (D'Monte 2012).”

Reactions from the Neighbors

Water transfer in the Himalayan component needs to consider the effects on the neighboring countries such as Nepal, Bangladesh and Bhutan. Bangladesh will be a downstream country regarding transfer from the Brahmaputra river. Bangaladesh strongly objects to transferring the Brahmaputra water to the Ganges. India - Bangaladesh Treaty of Dec. 1996, sharing of Ganges waters, India has undertaken to protect the flows arriving at Faraka, which is the sharing point. High dams with storages need to be constructed in Nepal and Bhutan. The neighboring countries have not been informed by India on the proposed NRLP. Not only there is the question of neighboring countries, there will be strong objections from within the country say, Bihar and West

Bengal and other southern Indian states. The plan needs to be beneficial for all stakeholders.

In the Himalayan links, excepting the Brahmaputra and other rivers in the flood seasons, there are no surplus flows in the rivers. The rivers flowing from Nepal contribute 40% of the mean annual flow and 70% of the dry season discharge to the River Ganges. This river basin, now home to nearly 600 million people, is one of the poorest regions in the world. Trans-boundary problems of water pollution, water sharing, and flooding and river channel changes affect all three countries, viz, Nepal, Bangladesh and India.

In the absence of political altruism, and if India unilaterally diverts water to her peninsular basins, Bangladesh would incur huge environmental losses. (Bhaduri and Barbier).

Storage projects within Nepal will highly complement lean season flows and assist the NRLP to achieve its goal. Regulated flows from the reservoir for hydropower generation also contribute to downstream benefits in terms of irrigation, flood control and even navigational use for the basin people. Despite the obvious potential benefits, the countries involved have not been able to get the benefit due to lack of an equitable framework. Further, storage projects come after a price of inundating fertile land, pristine forests, forced displacement of its habitats of human and other species. Till date India does not seem to be eager on paying the environmental service fees that is the rightful compensation to those affected by the storage projects. To make any meaningful regional cooperation, there needs to be a win-win situation for all the countries involved and also all states within India such as Bihar and West Bengal.

"While we recognise rivers as a trans-boundary issue, there has been no direct dialogue as far as building structures in Bhutan for the project (of India) is concerned," Bhutanese Minister for Agriculture and Forests Pema Gyamtsho told the BBC. Bhutan says it has not been appraised of the project idea (Khadka 2012).

Senior Nepalese water expert Santa B. Pun said, "There were concerns that politicians might not be able to secure a good deal for allowing India to build dams and reservoirs in Nepalese territory. That is because we hear our leaders talking only about the stereotype hydropower development; whereas they should be focusing on making India pay for the downstream benefits it would be getting from its river-linking infrastructures in Nepal. "Such concerns also stem from the fact that some think Nepalese politicians are too preoccupied with the prolonged peace process that India mediated after a 10-year Maoist insurgency (Khadka 2012).

Media reports and academic papers apart, little has come out officially about the inter-river linking project. Indian water resources ministry officials made no comment to the BBC's query on how India took its neighbors' reactions to the recent Supreme Court's order to implement the river linking project. Many of India's past water treaties and agreements with neighboring countries Bangladesh, Nepal and Pakistan have been mired in disputes (Khadka 2012).

Indian Strategy in Water Resources Development Areas close to the International Border

It is an established principle that trans-boundary countries honor international practice and norms in utilizing international rivers. To the contrary, the water resources development in South Asian region, especially in Indian states have been managed or developed with the diversion structures in the international rivers preemptively without any consultation with the riparian countries and, later on, forced the concerned riparian countries to come to negotiation. The following examples could be taken as the illustration:

- India unilaterally stopped water supply to Pakistan through Indus River in 1948;
- India constructed the Farakka Barrage without consultation with Bangladesh, the then East Pakistan.
- The Tanakpur Barrage was completed in 1988 on the Mahakali River, a river bordering Nepal and India. The Mahakali Integrated Treaty was forced on Nepal to be concluded in 1996 after the operation of the barrage was not feasible unless an afflux bund were connected onto the highland in the Nepal side;
- Again, India constructed the Laxmanpur Barrage in the Indian side of the Rapti River. The afflux so formed has been inundating human settlements and thousands of hectares of fertile land in Nepal.

Regional Cooperation

The cooperation of regional river basin partners is essential for the successful development of shared water resources to its full potential. Previous experiences with the regional/bilateral cooperation in water sharing indicate the need for more confident approach to eliminate the anomalities and in equity sharing. Little or almost no progress in this field would be achieved until the partner countries involved develop a better philosophy and framework of cooperation. To be successful, all riparian countries must accept that a nation's right to an equitable share of its own water resources is fundamental. Despite the obvious potential benefits, the basin countries have not been able to get the benefit due to lack of such a framework.

Mutual interest on increasing net benefits through development of projects are normally a prerequisite for cooperation. Benefits from water resources in this region are likely to be realized only by a well coordinated approach. Shared water resources present opportunities as well as problems.

If so, how should we deal with our conflicts over Water Resources?

"Come together, speak in concord, let your minds comprehend alike, let our efforts be united, let our hearts be in agreement, let our minds be united so that we all live in peace" – Riga Veda.

Conclusion

The proposed NRLIP, if completed, will be the biggest water transfer project in the world. It will have financial, social and environmental implications and repercussions on a gigantic scale. The proposal seems to be a conceptual one at present. As shown by the IWMI-CPWF's three years strategic analysis, there are many factors not considered, or the factors considered are not relevant and realistic. There is no debate that India needs increased water supply, especially to counter the effects of climate change.

Very detailed analyses need to be done including possible alternatives to the project. A win win situation needs to be formulated to gain the confidence of the neighboring countries such as Bangladesh, Bhutan and Nepal.

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Acknowledgements

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CALENDAR OF EVENTS - WATER AND WASTEWATER

5-6 March, 2013: International Research Conference on Environmental Issue and Waste Management (IRCEIWM). Location: Bangkok, Thailand. More info:http://allinternationalconferences.com/bangkok2013march/index.html

6-8 March, 2013: 5th Canadian Wastewater Management Conference and 48th Central Canadian Sympoasium on Water Quality Research. Location: Sheraton Hamilton, Hamilton, Ontario. More info: http://www.cwwa.ca/wastewaterconference_e.asp

15-26 April, 2013: Waste Management Course for Pacific Islanders. Location: Suva, Fiji. More info: http://www.sidsnet.org/events/waste-management-course-pacific-islanders

29-31 May, 2013: Save the PLANET: 4th Conference and Exhibition on Waste Management, Recycling, Environment for South-East Europe. Location: Sofia, Bulgaria. More info: http://www.eco.viaexpo.com/en/conference

27-28 June 2013: IWA Regional Conference on Waste and Wastewater Management, Science and Technology. Location: Limassol, Cyprus. More info: www.wwmst.org

Predicting Tunnel Squeezing: A Discussion based on Two Tunnel Projects

Krishna Kanta Panthi

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Abstract: Tunnel squeezing is a phenomenon, which is frequently confronted while tunneling through Himalayan rock mass. Weak and schistose rocks like mudstone, shale, slate, phyllite, schist, highly schistose mica gneiss and the rock mass of the tectonic fault zones are incapable of sustaining high stresses. A reliable and trustworthy prediction on the extent of squeezing is therefore essential. The reliable prediction results help to make strategy regarding stabilizing measures and optimization of tunnel rock support well in advance.

This paper is mainly focused in analyzing the tunnel squeezing that took place in connection with the two tunnel cases; i.e. Kali Gandaki 'A' and Middle Marsyangdi headrace tunnels. The main focus is given to look on the applicability of squeezing analysis using Hoek and Marinos approach in combination with the equation proposed by Panthi for the estimation of rock mass strength for highly schistose rocks of the Himalaya. The measured tunnel convergence (squeezing) and lab tested mechanical properties of the rocks from these two headrace tunnels have been used to verify the applicability of the proposed methods and also the uncertainty analysis approach on squeezing introduced by Panthi.

Key words: Tunnel squeezing, Kali Gandaki 'A' headrace tunnel, Middle Marsyangdi headrace tunnel, Nepal

Introduction

After the excavation is made, re-distribution of rock stresses occurs on the periphery of the tunnel contour. This re-distribution of stress leads to overloading in the rock mass surrounding a tunnel periphery, which results in deformation in the tunnel wall/periphery. If the rock mass strength is less than the induced (redistributed) magnitude of stresses, a failure in the rock mass occurs. The type of failure and extent of stress build up, however, depend on the type of rocks. There are mainly two forms of instability caused by induced stresses; i.e. rock burst/rock spalling in strong rock or tunnel squeezing (plastic deformation) in weak rock. It is noted here that the weak and highly schistose rock mass behave very differently from the isotropic, stronger and brittle rock mass when subjected to induced tangential stresses along the tunnel periphery.

The high degree of schistosity present in therock mass, more precisely, the extent of thin foliation is the dominating characteristic that leads to the formation of a viscoplastic zone of micro-fractured rock mass deep into the tunnel wall as shown in Figure 1. This leads to a time dependent inward movement of rock material and the applied support experiences a gradual build up of pressure. This time-dependent inward movement (plastic deformation) of the rock material towards the tunnel when subjected to tangential stress is defined as tunnel squeezing (Panthi 2012).

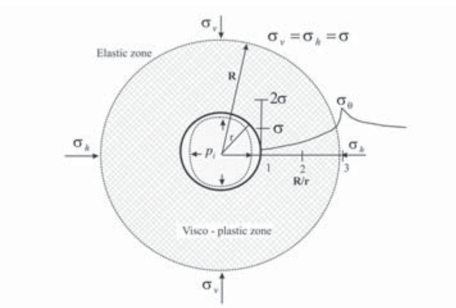

Figure 1. An Illustration of Plastic Deformation (Squeezing) in a Circular Tunnel (Panthi 2006; Panthi 2012).

The rock masses of the tectonically active Himalaya are highly directional concerning strength and deformability. Being highly schistose and weaker in their mechanical characteristics, the rocks such as slate, phyllite, phyllitic schist, schists, micagneiss and rock mass of the tectonic fault zones of the Himalaya lack sufficient bonding (confinement), and hence have considerably reduced self-supporting capability (Panthi 2006). Therefore, the main area of concern regarding tunnel stability in many oc-casions is related to tunnel squeezing (large plastic deformation).

The best way to deal with squeezing is to be able to predict and estimate the extent of squeezing so that a fairly good strategy can be made well in advance regarding stabilizing measures. Such effort helps to minimize stability problems and also helps to optimize tunnel rock support (2012). This means, predicting squeezing reliably is the key issue. Panthi (2006) has established an uncertainty analysis procedure for analyzing squeezing. The method focuses on the effect of variation on each input parameter and concludes that it is the most reliable way of predicting the extent of tunnel squeezing (Panthi and Nilsen 2010). The author used instrumented data from the Kali Gandaki 'A' headrace tunnel and lab tested strength and deformability charac-teristics for both Kali Gandaki 'A' and Middle Marsyangdi projects. The author also predicted tunnel squeezing along the headrace tunnel segment of the Middle Marsyangdi, which was under construction at that time (Panthi and Nilsen 2010).

The construction of the Middle Marsyangdi tunnel is now completed and instrumented tunnel convergence data are available. Therefore, the main aim of this paper is to check the accuracy of the prediction model and the equation proposed by the author (Panthi 2006) for estimating rock mass strength (Equation 3) and enhancing the applicability of tunnel squeezing prediction.

Kali Gandaki 'A' Headrace Tunnel

The Kali Gandaki 'A' Hydroelectric Project has an installed capacity of 144 MW. To produce energy, the project utilizes a 45 kilometer long loop of the relatively flat bedded Kali Gandaki river in a shortcut by diverting the water through a 5,950 metes long headrace tunnel. The tunnel has approximately 60 square meters of excavation crosssection and is a medium head scheme (net head 115 meters) with a rated design discharge of 141 m³/s.

Geologically, the project area lies in the lesser Himalayan highly deformed rock formations and is relatively close to the Main Boundary Thrust (MBT). The rocks in the project area are mainly comprised of Precambrian to lower Paleozoic shallow marine sediments. As shown in Figure 2, the headrace tunnel passes through highly deformed siliceous and graphitic phyllite that varies in mineral composition and degree of metamorphism. As the Himalayan region is still active in tectonic movement, the rock mass in the project has been also subjected to shearing, folding and faulting. The phyllite is of poor quality, thinly foliated and highly sheared (NEA 2002). The orientations and dips of the joints sets are scattered due to extreme folding and shearing giving no distinct joint system except for foliation joints.

As shown in Figure 2, the maximum rock cover above the tunnel reaches to approximately 620 meters, and more than 80 percent of the tunnel alignment has overburden exceeding 200 meters, which is critical in respect of tunnel squeezing.

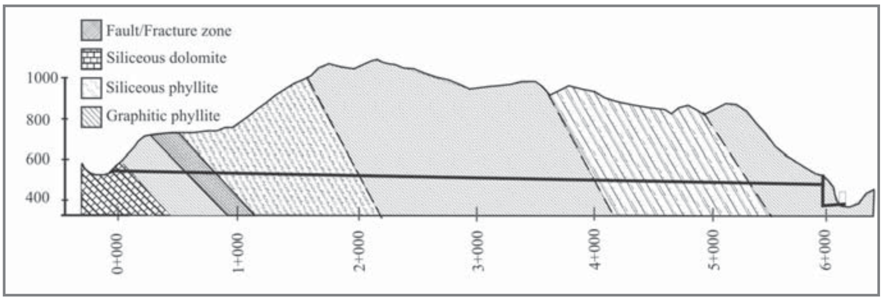

Figure 2. Longitudinal Profile of the Kali Gandaki 'A' Headrace Tunnel.

Middle Marsyangdi Headrace Tunnel

The Middle Marsyangdi Hydroelectric Project has an installed capacity of 69 MW. The project utilizes a gross head of approximately 110 meters and a design discharge of 80 m³/s to produce the maximum installed capacity. The project consists of a 5300 meter long headrace tunnel (Figure 3) and has a 6.4 meter excavation diameter (NEA 1998).

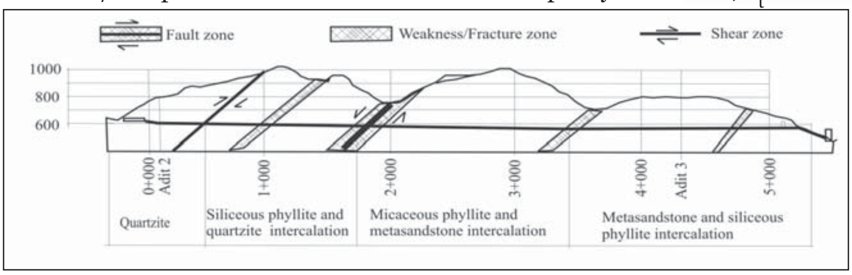

Figure 3. Profile of the Middle Marsyangdi Headrace Tunnel.

Geologically, this project also lies in the lesser Himalayan meta-sedimentary rock formations. As shown in Figure 3, the main rock types in the project area are quartzite, phyllite and meta-sandstone with intercalation features. The upstream short section of the headrace tunnel is located in highly to medium weathered, fractured and foliated quartzite of fair to good quality. The remaining downstream section is mostly passing through thinly foliated micaceous and siliceous phyllite. The phyllite of the area is intercalated with bands of quartzite and meta-sandstone. The micaceous phyllite is highly sheared, micro-folded and deformed, and is of extremely poor quality, whereas the siliceous phyllite is fractured (Panthi 2006) and (Panthi and Nilsen 2007). The maximum rock cover above the tunnel reaches approximately 450 meters, and more than 95 percent of the tunnel alignment has overburden (rock cover) exceeding 100 meters.

Squeezing Prediction

The Hoek and Marinos (2000) approach for predicting tunnel squeezing given by Equation 1 and 2 and Equation 3 suggested by Panthi (2006) for estimating rock mass strength are used as a basis for the analysis below. Intact rock properties of the project cases are estimated based on lab testing carried out at the NTNU engineering geological laboratory and also by the project owner during project implementation phases (NEA 1998; NEA 2002). Tunnel convergence measured at both Kali Gandaki 'A' and Middle Marsyangdi headrace tunnels were key inputs for the uncertainty analysis.

$$\varepsilon_t = \left(0.2 - 0.25 \times \frac{p_i}{\sigma_v}\right) \times \left[\frac{\sigma_{cm}}{\sigma_v}\right]^{\left(2.4 \times \frac{p_i}{\sigma_v} - 2\right)} \quad (1)$$

$$\varepsilon_t = 0.2 \times \left(\frac{\sigma_{cm}}{\sigma_v}\right)^{-2} \quad (2)$$

$$\sigma_{cm} = \frac{\sigma_{ci}^{1.5}}{60} \quad (3)$$

Where; ε_t is tunnel strain in percentage, σ_v is overburden stress in MPa, σ_{cm} is rock mass strength in MPa and p_i is rock support pressure in MPa.

The tunnel strain (ε_t) defined by Equation 1 and 2 is considered as an uncertainty that is dependable mainly on three variable input parameters; i.e. rock mass strength (σ_{cm}), overburden stress (σ_v) and rock support pressure (p_i). This means that the main principle of predicting squeezing based on Hoek and Marinos (2000) approach is to define these variable input parameters. The tunnel strains (tunnel closure) is expressed in percentages and defined as:

$$\varepsilon_t = \frac{\delta_t}{B} \times 100 \quad (4)$$

Where, δ_t is horizontal convergence in meters and B is the excavation width or diam-eter of the tunnel in meters.

Since the uncertainties encompass natural variability and randomness, the best way to quantitatively analyze these uncertainties is to use the probability density (relative density) function (pdf). The probability density function (pdf) describes the relative likelihood that a random variable may have a particular value. The selection of such mathematical distribution models should always be based on numerical calculations, experimental or field measured results and logical judgment made by observation (Panthi and Nilsen 2010).

An uncertainty analysis model as suggested by Panthi (2006) is used for further squeezing analysis and comparison. Principally, the following four step procedure is applied for assessing the tunnel squeezing using Equations 1 to 3:

1. Representative mathematical probability distribution functions (pdf) for the different input variables associated with squeezing are defined.
2. Simulation is carried out by using the software program @Risk (PA 2002).
3. Probability distribution of the uncertainty in question, in this case squeezing expressed by Equation 1 and 2, is achieved from simulation.
4. Finally the results are interpreted and compared with the actually occurred squeezing.

Squeezing Analysis

A slightly more than two kilometer long tunnel segment between chainages 1964m and 4032m of the Kali Gandaki 'A' headrace tunnel was used by Panthi (2006) for the uncertainty analysis of tunnel squeezing. At this section, the headrace tunnel passes through highly schistose and sheared graphitic phyllite and the rock cover (rock overburden) ranges from 425 to 620 meters (Figure 2). Since actually measured tunnel convergences (deformations) were available for this tunnel section, main emphasis was given to verify the reliability of Equation 1, 2 and 3. Based on this verification, the degree of tunnel squeezing at the Middle Marsyangdi headrace tunnel was predicted for a section between Jamitri and Khahare Khola (between chainage 2000 -3400m) (Figure 3). At this section, the rock mass is dominated mainly by very weak, micro-folded micaceous phyllite with intercalations of meta-sandstone (Panthi and Nilsen 2007).

The estimated statistical ranges of input variables and values calculated according to Equation 1, 2 and 3 are given in Table 1. The table highlights the minimum, maximum and mean values of input variables and the respective tunnel strain (ε_t).

According to Panthi (2006) an exponential probability density function (pdf) is rele-vant for the inverse of overburden pressure ($1/\gamma h$). In fact, the higher the overburden (h), the smaller the value of $1/\gamma h$, but the more likely squeezing is to occur. Similarly, the lower the overburden (h), the higher the value of $1/\gamma h$, but the less likely squeezing is to occur. This is why an exponential probability density function is considered to be the most representative distribution model for $1/\gamma h$.

Similarly, as for a laboratory tested population of intact rock strength, most of the values of rock mass strength should in general cluster towards its mean value and with certain dispersion from it, representing the standard deviation. Therefore, the normal probability density function is considered to be the most representative distribution model for rock mass strength (σ_{cm}). Similar will be the case, i.e. a normal distribution, for support pressure p_i.

The @Risk uncertainty analysis model was run

Description of input variables	Kali Gandaki 'A' tunnel segment					Middle Marsyangdi tunnel segment					
	Min.	Max.	Mean	St.dev.	@Risk values	Min.	Max.	Mean	St.dev.	@Risk values	Selected pdf
$1/\sigma_v = 1/\gamma h$	0.060	0.087	0.073	0.011	0.076	0.087	0.198	0.121	0.013	0.134	Exponential
σ_{cm} (Eq. 3)	2.47	5.89	4.05	1.21	4.28	1.49	5.89	3.45	1.45	3.59	Normal
p_i	0.46	1.27	0.71	0.3	0.75	0.46	1.27	0.71	0.30	0.75	Normal
$\sigma_{cm} / \gamma h$	0.148	0.51	0.29		0.34	0.13	1.17	0.38		0.50	
ε_t (Eq. 1)	7.85	0.54	1.82		1.43	9.27	0.11	1.03		0.59	
ε_t (Eq. 2)	9.20	0.76	2.26		1.75	11.87	0.15	1.36		0.81	

Table 1. Statistical Ranges of Input Variables for Graphitic Phyllite for Kali Gandaki 'A' and for the Schistose Phyllite at Middle Marsyangdi Headrace Tunnels (Panthi 2006; Panthi and Nilsen 2007).

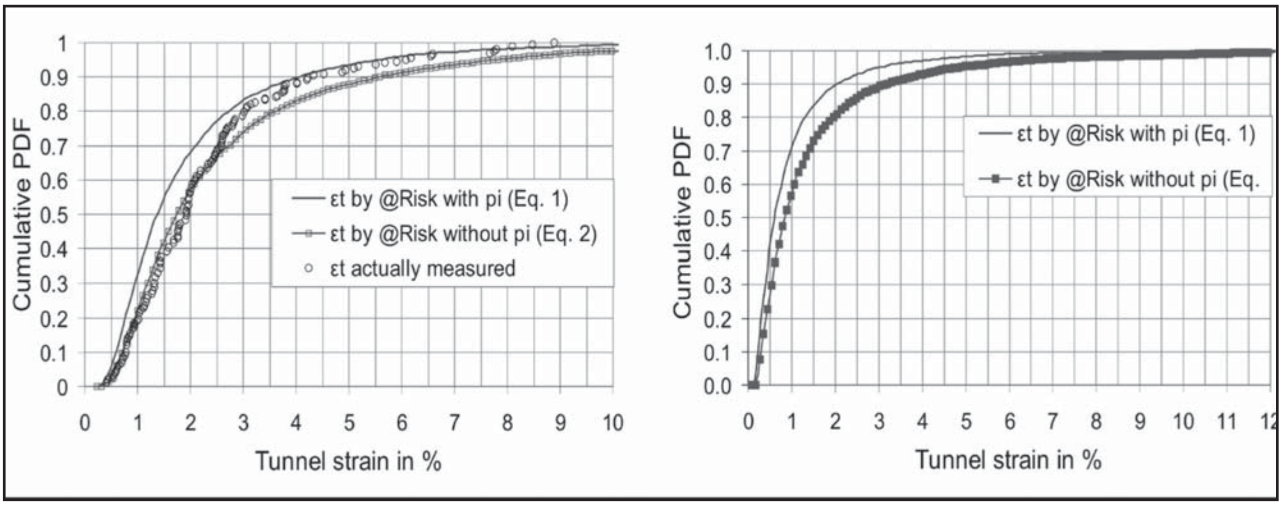

Figure 4. Cumulative Distribution of Tunnel Strains between Chainage 1964-4032 of the Kali Gandaki 'A' Headrace Tunnel (left) and Predicted Cumulative Distribution of Tunnel Strain for Chainage 2000-3400 of Middle Marsyangdi Headrace Tunnel (Panthi 2006; Panthi and Nilsen 2007).

based on the probability density functions (pdf) of each input variable as given in Table 1. The results achieved by simulation regarding pseudorandomly distributed cumulative tunnel strain (ε_t) based on equation 1, 2 and 3 are shown in Figure 4 (see also Table 1).

As shown in Figure 4, the cumulative probability distribution of the pseudorandomly calculated tunnel strains based on the Hoek and Marinos (2000) approach using the tool @Risk and the calculated cumulative distribution of tunnel strains based on actually measured horizontal convergence are found to be in very close agreement. This indicates that the assigned probability density functions for the input variables are realistic. As highlighted by Panthi (2006), the most important aspect of this uncertainty analysis was, of course, to verify the applicability of Equation 3 with the Hoek and Marinos (2000) approach of squeezing analysis (Equation 1 and 2).

As seen in Figure 4-left, the correlations achieved for the Kali Gandaki 'A' are considered to be quite good and a similar approach was hence used in predicting the squeezing at the Middle Marsyangdi headrace tunnel (Panthi 2006; Panthi and Nilsen 2007). Hence, a similar approach was used to predict the degree of tunnel squeezing in the tunnel segment between chainage 2,000 – 3,400 of the Marsyangdi headrace tunnel (Figure 3). The results of the uncertainty analysis are shown in Figure 4.

Based on Figure 4-right, Panthi (2006) predicted that out of the 1,400 meter long headrace tunnel between Jamitri and Khahare Khola, 70 percent of the tunnel length (approximately 980 meters) had a probability of tunnel squeezing with a magnitude of less than one percent, 25 percent (approximately 350 meters) had a probability of tunnel squeezing with a magnitude between 1 and 2.5 percent and 5 percent (approximately 70 meters) had a probability of tunnel squeezing with a magnitude exceeding 2.5 percent. The author also highlighted that due to intercalation of meta-sandstone within micaceous phyllite, a positive effect on the extent of squeezing will most likely be achieved. Therefore, the author concluded that the risk of exceeding tunnel strains with a magnitude higher than 5 percent was considered low (Panthi and Nilsen 2007; Panthi 2012).

Recorded Tunnel Strains along Predicted Tunnel Segment

During tunnel excavation, a convergence (deformation) monitoring plan was imple-mented at the Middle Marsyangdi headrace tunnel, which also experienced

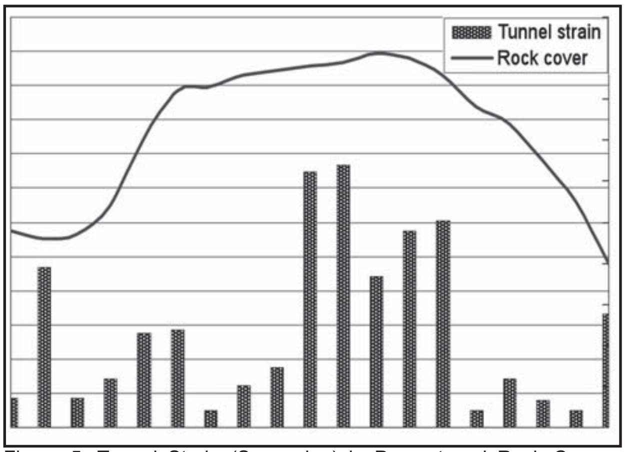

Figure 5. Tunnel Strain (Squeezing) in Percent and Rock Cover above Tunnel in Meters from Chainage 1,974 to 3,449 at the Middle Marsyangdi Headrace.

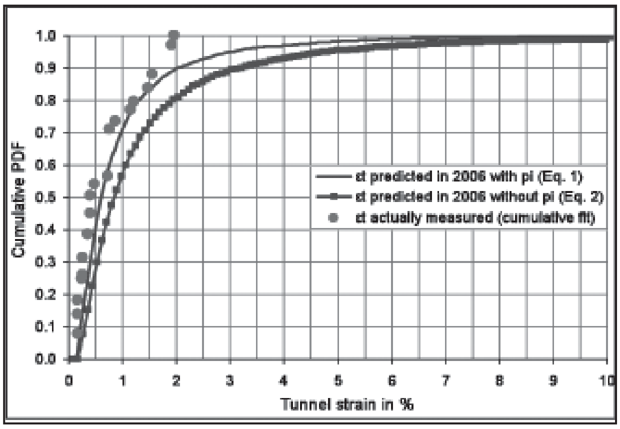

Figure 6. Cumulative Distribution of Actually Measured and Predicted Tunnel Strains between Chainage 2,000-3,400 of the Middle Marsyangdi Headrace Tunnel.

consider-able amount of tunnel squeezing. The measured horizontal convergences between chainage 1,974 to 3,449 are converted to tunnel strains (ε_t) using Equation 4 and the results are presented in Figure 5.

As seen in Figure 5, the magnitudes of horizontal tunnel strains vary considerably within this section of the headrace tunnel. The figure also illustrates that even within similar overburden heights there are considerable differences in the degree of tunnel squeezing. This suggests that the quality of rock mass, and in particular rock mass strength, varies greatly within short tunnel distances.

Comparison between Predicted and Actual Squeezing

The information provided by Figure 4-right was used as a basis in predicting the degree of tunnel squeezing in a tabular form (see predicted part of Table 2) by Panthi (2006). Since the actually measured squeezing results are available now, it is of great interest to compare these results with the predicted ones. This can be done by fitting the actually measured tunnel strains shown in Figure 5 within the predicted cumulative distribution of tunnel strains presented in Figure 4-right. Figure 6 is the result in this endeavor, which includes predicted cumulative distribution of tunnel strains by Panthi (2006) and the calculated cumulative distribution of tunnel strains of the actually registered (measured) ones presented in Figure 5.

Figure 6 indicates that most of the tunnel strains actually measured fit quite well with the predicted cumulative distribution curve of the tunnel strains calculated using Equation 1, i.e. with support pressure (p_i), which is in fact very logical. Because, the tunnel convergence measurement was carried out only after the scaling and application of rock support consisting of steel ribs at one meter spacing, 20 – 25 cm thick reinforced shotcrete and systematic radial bolting. The predicted and actually measured tunnel strains are shown in Table 2.

Table 2. Predicted (Panthi 2006) and Actually Measured Squeezing Tunnel Length Based on Tunnel Data (NEA 2007) at Middle Marsyangdi Headrace Tunnel between Chainage 2000 and 3400m.

As seen in Table 2, the deviation between the predicted and actually measured tunnel length with tunnel strains below 2.5 percent is below 6 percent, which is considered to be extremely good. The same can be seen in Figure 6 with a quite good fit between the actually measured and predicted (in 2006) tunnel strains for the magnitudes of less than 2.5 percent. However, Table 2 also indicates that about a 70 meter length of this headrace tunnel segment was predicted to experience tunnel strains exceeding 2.5 percent. However, as seen in Figure 5 and 6, no measured tunnel strains were recorded with a value exceeding this limit along this tunnel segment.

Discussions

The accuracy in predicting tunnel squeezing depends on the reliability of the estimated input variables and equations that are used for such analysis. The selection of the representative probability distribution functions (pdf), the input variables related to equations used and reliability of the equations in use for such predictions are key factors. The possible reasons for the deviation in the tunnel strain results exceeding 2.5 percent in the above uncertainty analysis may, therefore, be explained as described below:

1. Firstly, tunnel excavation is a routine work that involves mucking, scaling and application of rock support. Considerable time is already spent between excavation and completion of the support work during which instantaneous deformation already takes place in the rock mass surrounding the tunnel periphery. On the other hand, the convergence monitoring, in general, only starts after this routine work is completed.
2. Secondly, the support resistance achieved by the applied rock support consisting of steel ribs at one meter spacing, 20–25 cm thick steel reinforced shotcrete and radial bolting might have been stiff

Degree of difficulties	Tunnel strain, %	Horizontal convergence, cm	Predicted length in 2006, m	Length based on actually meas-ured data	Deviation (%)	Possible consequences on applied rock support
Insignificant squeezing	< 1	<7	980	1036	6	No or very minor impact on aplied support
Minor squeezing		1 – 2.5		7 - 16		Cracks on applied shotcrete, slight yielding on rock bolts.
Severe squeezing		2.5 - 5		16 - 32		Slight buckling on steel ribs, cracks on applied shotcrete and yielding on rock bolts.
Very severe squeezing	5 - 10		32 - 64	-		
Extreme squeezing	> 10		> 64	-		

Table 2. Predicted (Panthi 2006) and Actually Measured Squeezing Tunnel Length Based on Tunnel Data (NEA 2007) at Middle Marsyangdi Headrace Tunnel between Chainage 2000 and 3400m.

enough to limit the deformation. Unfortunately, no instrumentation was carried out to register the rock support pressure (p_i) at the Middle Marsyangdi. Therefore, it makes verification a difficult task.

3. Thirdly, the intercalation of the relatively strong metasandstone bands within the highly schistose phyllite may have helped in achieving a slabing (arching) effect surrounding the tunnel periphery of the rock mass, which might have a positive influence for the large deformations to take place.
4. Fourthly, the uncertainty analysis tools such as @ Risk may also result in some degree of discrepancies. In particular, the lower five percent and higher five percent values of the cumulative curve may be considered as outliers due to the pseudorandom distribution.
5. Finally, the deviation may also be explained by the fact that the rock mass strength calculated by Equation 3 (Panthi 2006) and tunnel strain calculated by Equation 1 and 2 (Panthi 2012) cannot be expected to give results with hundred percent accuracy.

Conclusion

The most important aspect of this uncertainty analysis was to verify the applicability of Equation 1, 2 proposed by Hoek and Marinos (2000) and Equation 3 proposed by Panthi (2006). In addition, verification of the applicability of the suggested methodology in predicting tunnel squeezing by Panthi (2006) and the applicability of assigned probability distributions were also the key issues. The correlations achieved from both the Kali Gandaki 'A' and Middle Marsyangdi are considered to be quite good. Hence, the suggested methodology of the probabilistic approach of uncertainty analysis in predicting tunnel squeezing is a relevant tool. It is therefore, recommended to be used in the planning of tunnel projects passing through schistose and deformable rock mass.

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CALENDAR OF EVENTS - DRINKING WATER

5-7 February, 2013: GEOGEN 2013: Towards Sustainable Safe Drinking Water Supply in Developing Countries- The Challenges of Geogenic Contaminants and Mitigation Measures. Location: Addis Ababa, Ethiopia. Contact Email: geogen2013@eawag.ch. More info: http://www.eawag.ch/medien/veranstaltungen/events/geogen2013/index_EN

9-12 October, 2013: International Conference on Drinking Water Safety, Security and Sustainability. Location: Hangzhou, China. More info: http://drinkingwater.zju.edu.cn/

21-24 October, 2013: 15th Canadian National Conference and 6th Policy Forum on Drinking Water. Location: Delta Grand Okanagan Hotel and Conference Center, Kelowna, BC, Canada. More info: http://www.cwwa.ca/DrinkingWaterConference_e.asp

Water Quality Assessment of Sukhna Lake of Chandigarh City of India

P. Chaudhry, M.P. Sharma, R. Bhargave, S. Kumar and P.J.S.Dadhwal

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Abstract: The Sukhna Lake of Chandigarh City is a man-made lake situated in the foothills of the Shivalik range in the north-east corner of the city. This urban lake is one of the prime tourist places of the 'City Beautiful' and is mainly used for recreational purposes like boating, morning and evening strolls, exercises, food plaza and sightseeing. The catchment of the lake is mainly hilly and erosion prone, with the Sukhna wildlife sanctuary comprising a major portion of it. The water quality index of the lake water and its dependence on catchment characteristics has been studied. By using the National Sanitation Foundation Water Quality Index (NSFWQI) and Overall Index of Pollution (OIP), the results of the water quality assessment have found the lake water as having 'good' and 'acceptable' quality respectively based on past seven years' data. During the last few years, construction activities in the catchment area have speeded up and a few invasive alien plant species have come up in the lake. Inflow of untreated domestic waste water from nearby villages in the catchment, particularly during the rainy season, seems to be the main reason for the weed problem in the lake. Strict enforcement of ban on new construction activities and preventing the release of untreated domestic waste water from the villages located in the catchment are the absolute necessary steps for maintaining and improving the lake water quality.

Key words: Lake catchment characteristics, market and non-market benefits, Shivalik hills, water quality index, water quality parameters, India

Introduction

The lakes, rivers and wetlands provide a number of environmental, social and educational benefits to mankind. The quality and quantity of these resources is an indicator of sustainable development of a country. Water bodies like lakes and rivers located in urban cities provide market and non-market benefits like boating, recreation, nature viewing, climate amelioration, water flow regulation, carbon sequestration etc. The world scientific community is presently unanimous about such non-market/intangible benefits provided by lakes/ rivers/wetlands. Efforts were made by Costanza, d'Arge et al (1997) to quantify and value the benefits provided by natural capital like oceans, forests, grasslands, wetlands and lakes/rivers. It was found that non-market services in the form of water regulation, water supply, waste treatment and recreational aspects constitute the major portion of overall benefits/services provided by lakes/ rivers.

A lake is the most beautiful and expressive feature of a landscape. In India, there are relatively few natural lakes in the Himalaya region and in the floodplains of the Indus, Ganga and Brahamaputra. A number of artificial water bodies were constructed during the last 1,000 years in western and peninsular India (Gopal, Sengupta et al 2010). Lakes are classified on the basis of the salinity level of water like freshwater, brackish or saline lakes. On the basis of their nutrient content, these are also categorized as Oligotrophic (low nutrients), Mesotrophic (medium nutrients), and Eutrophic (high nutrients) lakes. The vast majority of lakes in India are either Eutrophic or Mesotrophic on account of receiving nutrients from their catchments. Literature reveals that a number of studies have been conducted in India on water quality assessment of water bodies like Halai, Koloroi, Kalyani, Salim Ali, Dahi-Khura, Ramgarh, Kalakho and Dalvoy Lake (Jain, Sharma and Thakur 1996; Sreenivasan Venkatanarasimha and Franklin 1997; Srinivasa and Kotaiah 2000; Thorat and Masaraat 2000; Shastri and Pendse, 2001; Moundiotiya, Sisodia et al 2004; Sisodia and Moundiotiya 2006; Mahesha and Balasubramanian 2010). Padmanabha and Belagali (2005) monitored the water quality of four lakes in Mysore city during November 2004 to April 2005. Based on pH, total alkalinity, total hardness, chloride, calcium, magnesium, total dissolved solids, dissolved oxygen and BOD, it was found that the water of these lakes was severely polluted and unfit for human consumption. Mahesha and Balasubramanian (2010) found the Dalvoy Lake of Mysore city as having poor water quality. Sisodia and Moundiotiya (2006) found that the Kalakho Lake of Rajasthan has poor water quality due to lack of proper sanitation, flow of untreated municipal sewage and agricultural runoffs. In both cases, the lake water was found unfit for drinking and propagation of wild life and fish culture. Further, Moundiotiya, Sisodia et al (2004) studied the physicochemical parameters of the Jamwa Ramgarh wetland and advocated habitat conservation and ecological restoration as the measures to prevent the wetland from becoming ecologically inactive.

The present paper deals with the water quality assessment of the Sukhna Lake of Chandigarh City of India and its pollutional status. The Chandigarh administration is already undertaking suitable conservation measures to maintain its recreational and aesthetic status for the residents of the city and tourists coming to the city. This Lake of Chandigarh City has the potential of providing tangible and intangible benefits to the people of the region, though no scientific study has yet been reported on this aspect of the lake. Suggestive conservation measures are also covered in the paper.

About the Sukhna Lake

The Sukhna Lake was created artificially in 1958 by constructing an earthen dam of about 3 kms length and 14m height on the Sukhna choe (seasonal rivulet). The lake is located in the north east corner of Chandigarh City; the location map is given in Figure 1. Presently, the lake is fed mainly by two hilly torrents, the Kansal and Nepli choes. Total catchment area of the lake is about 42 km², of which 33 km² falls in the Shivalik hills and rest in a few villages of Punjab, Haryana and Union Territory (UT) of Chandigarh. The width of the top dam is 23m and the length of walk way is about 3 km.

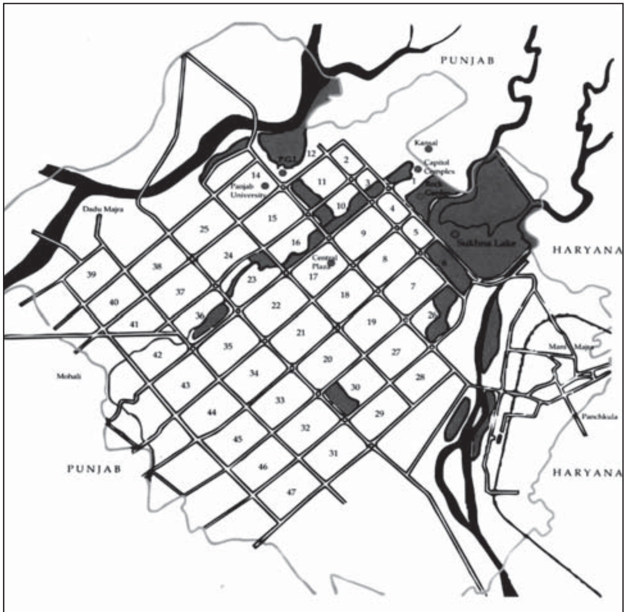

Figure 1. Location of Lake and Different Sectors of Chandigarh City. (Source: Wattas and Gandhi 2009)

The lake is the main tourist attraction for Indian and foreign tourists. About 1,000 to 1,500 tourists visit the lake on weekdays and 2,500 to 3,000 on weekends for boating. The Chandigarh Industrial and Tourism Development Corporation (CITCO), which looks after boating arrangements in the lake, is generating between IRs. 60,000 to 70,000/- per day from boating. Residents of the city, irrespective of age, use the lake site for morning/evening walks and recreational purposes. Chandigarh city has some famous tourist spots like Nek Chand's Rock Garden, Zakir Rose Garden, Leisure Valley, Bougainvillea Garden etc., but the Sukhna Lake is considered as the top most tourist spot by the people of the city (Chaudhry, Singh and Tewari 2007). Apart from this, three Asian and six National level rowing competitions were organized at the lake during the last three decades. A large number of winged guests from Siberia and other European countries are also visiting the lake, particularly during the winter season, when the lake has sufficient water. These migratory birds include Coots, Pochards, Mallards, Geese, Eagrets, Teals, Herons, Ducks etc. but lower rainfall during the last few years and detrimental catchment activities have resulted in accumulation of silt and excessive growth of weed indicating the onset of the eutrophication process in the lake.

Characteristics of Lake Catchment

The climate of the area is semi-arid with a maximum mean temperature of 41.80°C in June and minimum temperature of 5.10°C in January. Average annual rainfall is 1,120 mm, 80% of which is received during the monsoon season from July to September. The Shivalik foot-hills are one of the seven most degraded ecosystems of India. These low hills of recent origin are made up of one of the most erodible soils of the world. In the last 400 years, the vegetative cover of the hills has been destroyed by human activities resulting in significant mass soil erosion in the monsoon period. Low productivity, poor vegetative cover, high run-offs, soil loss and presence of deep and wide network of gullies are the main characteristics in the upper catchment of the lake. All these factors are responsible for the heavy siltation of the Sukhna Lake (SPACE 2008). Different parent material, namely sand stone and shale occur side by side, their differential hydro-thermal properties and erosional behavior give rise to lack of cohesion causing heavy runoffs from the bare hill slopes (Grewal and Juneja 1984).

Types of Vegetation

There are wide varieties of trees, shrubs, herbs, grasses and climbers in the catchment. The prominent tree species in the catchment area include Khair (*Acacia catechu*), Kikar (*Acacia nilotica*), Shisham (*Dalbergia sissoo*), Eucalyptus species and Muscat (*Prosopis juliflora*). The Sukhna wildlife sanctuary is also rich in other tree species like Chhal (*Anogeissus latifolia*), Neem (*Azadirachta indica*), Semal (*Bombax ceiba*), Dhak (*Butea frondosa*), Kachnar (*Bauhinia racemosa*), Amla (*Emblica officinalis*), Tut (*Morus alba*) Amaltas (*Cassia fistula*) etc. The overall tree density is around 500 trees per ha in the sanctuary area. Important shrubs in the area include Basuti (*Adatoda vasica*), Lantana (*Lantana camara*), Karipatta (*Murraya koenigii*), Beri (*Zizyphus mauritiana*) and Karonda (*Carissa spinarum*). During 2002-08, the Forest Department removed Lantana from the sanctuary area as it is an aggressive Invasive Alien Species (IAS) and does not allow other favorable species to come up nearby. Considerable success has been achieved as evidence from the natural regeneration of favorable species in the sanctuary.

Water Quality Status of the Lake

For the purpose of continuous monitoring of lake water quality, water samples were collected from the centre of the lake using local boats by the 'Pollution Control Committee' of the Chandigarh administration once every month from the year 2006-2012. The monthly data were averaged to get the annual data as reported in Table 1. The analysis of samples for water quality parameters was carried out as per standard methods of

Parameters	Unit	2006	2007	2008	2009	2010	2011	2012
Temperature	^{O}C	26	27	25	24	26	25	25
pH	Std unit	7.6	8.1	8.0	7.9	7.4	7.4	8.1
Turbidity	NTU	88	80	64	92	95	44	42
TS	mg/l	381	262	270	267	136	173	218
DO	mg/l	8.1	6.4	6.9	7.9	7.0	10.3	6.8
BOD	mg/l	2.5	1.6	1.4	2.0	2.5	2.0	3.0
TP	mg/l	0.4	BDL*	BDL*	0.05	0.16	BDL*	0.6
Nitrate	mg/l	3.25	BDL*	1.32	BDL*	0.59	0.04	0.16
NSFWQI		**72**	**73**	**76**	**79**	**76**	**85**	**77**
Water quality as per NSFWQI		Good	Good	Good	Good	Good	Good	Good
OIP		1.71	1.66	1.50	1.66	1.80	1.25	1.58
Water quality as per OIP		Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable	Acceptable

Table 1. Water Quality Parameters of Lake Water (Annual Average). BDL* - Beyond Detectable Limit

analysis (APHA 1989).

Water quality assessment is a tool that provides valuable information for the policy and decision makers. The Water Quality Index (WQI) is a single number that expresses the overall water quality at a certain location and turns complex water quality data into information that is understandable and usable by the general public. It is one of the most effective tools to communicate information on the quality of water to the concerned citizens and policy makers. Horton (1965) proposed the first WQI followed by other indices including National Sanitation Foundation (NSF) of USA which is accepted as a more convenient WQI based on expert or panelist's opinion (Brown, McClelland et al 1970). Besides the National Sanitation Foundation Water Quality Index (NSFWQI), some other water quality indices used worldwide in practice include the Canadian Council of Ministers of the Environment Water Quality Index (CCMEWQI) (Lumb 2006), British Columbia Water Quality Index (BCWQI) and Oregon Water Quality Index (OWQI) (Debels, Figueroa et al 2005; Kannel, Lee et al 2007; Abbasi 2002). In the Indian context, Sargaonkar and Deshpande (2003) developed the 'Overall Index of Pollution' (OIP) for Indian rivers based on measurements of pH, turbidity, dissolved oxygen, BOD, hardness, total dissolved solids, total coliforms, arsenic and fluoride. Each water quality observation was scored as Excellent, Acceptable, Slightly polluted, Polluted and Heavily polluted according to the Indian standards/ guidelines and standards of WHO. After categorization, each observation was assigned a pollution index value. The 'Overall Index of Pollution' (OIP) is calculated as the average of each index value given by the following mathematical expression:

$$\mathrm{OIP} = \sum_{i=1}^{n} Pi/n$$

Where Pi = pollution index for ith parameter, n = number of parameters

To recognize a unique WQI for assessing surface water quality of a particular area or country with a definite solution is very difficult (Bharti and Katyal 2011). However, The NSFWQI seems to be one of the most comprehensive forms of WQI based on expert opinion whereas OIP has been developed in the context of Indian conditions. These two methods i.e. OIP and NSFWQI have been used for estimating the WQI of Sukhna lake water. Water quality of the lake is found in 'acceptable' range using the OIP method as given in Table 1.

The NSFWQI used for estimating the quality of Sukhna lake water is mathematically expressed as follows:

$$WQI = \sum_{i=1}^{n} W_i Q_i$$

where Q_i = Sub index for ith water quality parameter
W_i = Weight (in terms of importance) associated with water quality parameter
n = Number of water quality parameters

NSFWQI has been calculated using the standard software (Oram 2012) and the results are reported in Table 1 and graphically shown in Figure 2. It can be seen that the lake water quality is found to be in the 'good' quality range during 2006-12. The water quality is found suitable for bathing purpose with designated best use of outdoor bathing (CPCB 2008) as the DO is found > 5 mg/l, BOD < 3 mg/l and pH between 6.5 to 8.5 during the measurement period. The water quality is also suitable for supporting the fish population in the lake and for migratory birds as well.

The U.S. Environmental Protection Agency (USEPA) has specified a turbidity limit of 5 NTU for any lake to be used for swimming and recreational purposes (EPA 2006) but the Sukhna Lake fails on this account as the turbidity is rather high (Table 1) but no standards are provided by the Government of India on the turbidity limit acceptable for swimming and recreational purposes.

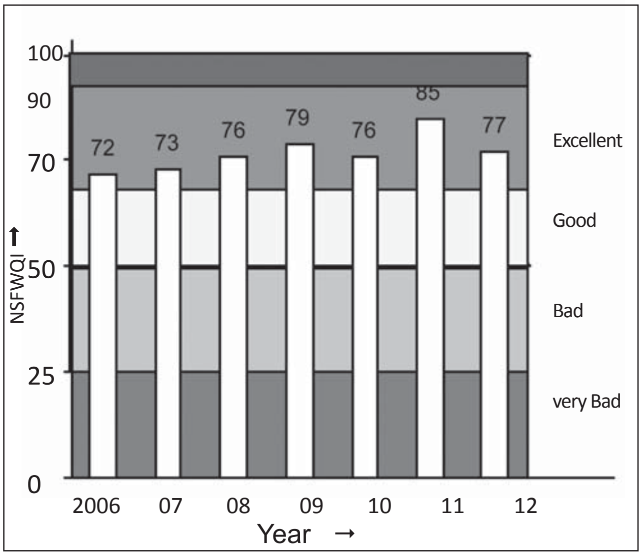

Figure 2. Water Quality Index for 2006-2012.

The reasons for the high turbidity and corrective steps taken by the Chandigarh administration to control this parameter are discussed in the next section.

Results and Discussion

Soil erosion by water is the most serious land degradation problem worldwide (Eswaran, Lal and Reich 2001). It affects not only the agricultural production and other infrastructure but water quality also (Lal 1998; Pimentel, Harvey et al 1995). As is evident from the above water quality data, turbidity is found as the main stressor in the Sukhna Lake due to receiving of silt and dissolved minerals from the catchment. Since the creation of the lake in 1958 up to 1988, the rate of siltation in the lake was more than 150 t/ha/year. It is due to the prevailing edaphic and biotic factors in the Shivalik hills, the youngest of all mountains in India, which are ecologically sensitive and geologically very unstable and so highly prone to soil erosion during rains. More than one-third of the catchment area of the watershed of the lake falls in 'high to very high erosion' category due to steep hill slopes, which are prone to more soil and water erosion (Shrimali 1999; Shrimali et al 2001). Though the catchment treatment of such slopes is difficult in terms of establishment of vegetation, the Department of Forest and Wildlife, Chandigarh administration has considerably succeeded in greening most of the catchment area falling in the sanctuary during the last eight years. The preventive measures (vegetative and engineering) were undertaken by the Chandigarh administration in the forest area falling mainly in the hilly portion of the catchment. Massive plantations were undertaken in the Kansal and Nepli reserved forests of the catchment, which were declared as the "Sukhna Wild Life Sanctuary" in 1977. Engineering structures like check dams, silt retention dams, mechanical spurs, and revetments were also created. All these measures have reduced the rate of siltation to around 5-6 t/ha/yr during last few years (Sohal 2000; SPACE 2008), and this is the main reason for maintaining the water quality as 'good' during 2006-2012 as shown in Figure 2. It is observed that, broadly, the water quality is improving from 2006 onwards except in 2010 and 2012. Turbidity is declining during 2011 and 2012 in comparison to earlier years (Table 1) but increase in BOD and Total Phosphorus (TP) level in 2012 is a matter of concern and responsible for the resultant decline in the water quality index from 85 (in 2011) to 77 (in 2012). Sewage and waste water from cattle and poultry sheds from the catchment villages seem to be the main reason for this decline.

As stated elsewhere, about 20% of the lake catchment area is in the plains which include villages located in UT Chandigarh and Punjab. These villages are Kaimbwala, Khuda Alisher and Kansal. Untreated sewage and other domestic wastes like run offs from cattle sheds of the villages find their way to the lake during the rainy season. The lake is likely to become rich in nutrients N, P and K etc that have led to the growth of aquatic weeds during the last 3-4 years and have comparatively higher evapo-transpiration rate of water in comparison to other plants, causing rapid loss of lake water during summer season. The National Botanical Research Institute (NBRI), Lucknow, India has identified the following weeds in the lake: *Hydrilla verticillata, Vallisneria spiralis, Typha species, Potamogeton crispus, and Zannichellia palustris*.

The charm of living near the lake and the capital city of Chandigarh has led to rapid urbanization of the catchment area, especially, in the Kansal village of Punjab. During the survey, it was found that agricultural land was being sold in the village at prices between IRs. 40-50 million/acre. In 2011, a multistoried Tata Group housing project was initiated in this part of the catchment area due to political and other influences. Recently, the Punjab and Haryana High Court has stopped all sort of construction activities in the catchment and has asked the Chandigarh administration, Punjab and Haryana governments to publicize the boundaries of the catchment area in local newspapers to prevent any new construction. There is, therefore, a need for proper coordination among the States of Punjab, Haryana and U.T of Chandigarh to conserve the lake, which is lacking at present, as observed by the Punjab and Haryana High Court at times. To protect the lake, soil conservation and plantation activities in the catchment area need to be strengthened in terms of regular maintenance and desilting of 190 silt detention dams. In addition, providing sewage treatment plant facility and safe disposal of solid wastes in the catchment area should be taken up immediately.

Conclusion

The Sukhna Lake is known as a famous spot for outdoor recreation and tourism in north India. The Chandigarh administration is spending a significant portion of the annual budget on its maintenance and upkeep. Construction activities in the catchment have increased during last few years and due to inflow of untreated sewage from nearby villages, mainly during the rainy season, invasive alien species of weeds have come up in the lake. Setting up a sewage treatment plant or diversion of waste water away from the lake in nearby villages and imposing a ban on new construction in the catchment area is a must for maintaining the good health of the water body along with regular de-weeding and silt removal. All the above measures would help not only in improving the water quality but also increasing the recreational and aesthetic value of the Sukhna Lake.

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CALENDAR OF EVENTS - IRRIGATION

19-20 February, 2013: Landscape Irrigation Auditor Course. Location: Denver, Colo. Contact Email: trainingservices@rainbird.com. More info: http://www.irrigation.org/calendar.aspx?calid=175&id=496

11-12 March, 2013: Irrigation Contractor Course - Chicago, Ill. Contact Email: trainingservices@rainbird.com. More info: http://www.irrigation.org/calendar.aspx?calid=175&id=496

29-30 May, 2013: IAL (Irrigation Australia) Conference. Location: Griffith, NSW. Theme for the conference is "Better knowledge sharing for better irrigation outcomes". More info: http://www.irrigation.org.au/index.cfm?/events/2013-conference

29 September-3 October, 2013: First World Irrigation Forum (WIF). Location: Mardin, Turkey. More info: http://www.icid.org/wif/

14-20 September, 2014: 22nd International Congress on Irrigation and Drainage. location: Gwangju Metropolitan City, Republic of Korea. More info: http://www.icid2014.org

Local Response to Conservation Practices in Use for the Protection of Tinau River, Nepal

Khet Raj Dahal and Hari Prasad Guragain

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Hari Prasad Guragain

Abstract: A study was undertaken to identify the pressing problems in the Tinau River and to suggest ways to overcome the various problems such as pollution, riverbed extraction, bank erosion and threats to the foundation of bridges, etc. The study showed several problems responsible for deteriorating the health of the Tinau River. The Study suggests that the agencies and stakeholders should work together to counter the various negative problems. A Commission involving the concerned representatives from the Government, Municipality, DDC, VDC and the stakeholders such as WUAs of irrigation, water supply and others has been proposed to be established. All the river conservation practices from the Government and funding agencies have to be implemented with the active participation of the beneficiaries. It must be started as early as possible. The effective way of river conservation would be the active participation of the local inhabitants with meaningful Government support.

Key words: Tinau River, conservation, riverbed materials, extraction, river health, participatory approach, Nepal

Introduction

Tinau river originates in Palpa district and flows through the mountain, gorge and plains of Palpa and Rupandehi districts of Nepal. It is a class-II, perennial and third order stream (Guragain 2012; Kharel 2002). The Tinau River bifurcates into the Dano and Tinau just downstream of East-West Highway, which again meet at about 13 km upstream from the Indian border, and is named as Dano (JICA 1999).

The Basin area at the Nepal-India border of the Tinau River is 1,081 km^2. The catchment area up to *Kanyadhunga* at intake point of 16/36 Irrigation System is 560 km^2 The river has maximum flow during July-August and minimum flow in March-April. About 75 % of the annual flow of the river drains within the months of monsoon.

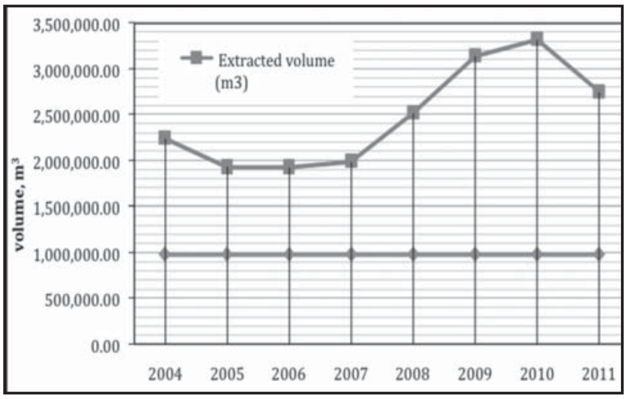

Figure 2. River-bed Extraction during Past Eight Years (2004-2011). (Source: DDC records, 2012)

There are several problems associated with the health of the Tinau River. However, the major problems associated with the Tinau are: river-bed extraction, landslides, rock-falls, mass-wasting, deforestation in the upstream catchment, over extraction of bed material downstream, river incision, flood-plain encroachment, change in geomorphology, non-regulated waste disposal, habitat destruction, effects on the intake/hydraulic structures like Bridges at Butwal and Bethari of Tinau Rivers (Dahal et al 2012). The well foundation of the Bridge of the East-West Highway (EWH) at Butwal has been exposed by about 3m in height; consequently, the diversion structure built on the Tinau river near Gadi Muhan by the Water Users' Association (WUAs) of Chaar Tapaha Irrigation System has been defunct, and similarly, the diversion structure of the SorahChhattis (16/36) Irrigation System built by WUA near *Itiya Bhod* also has become defunct. Earlier, the Barrage (Hattisundhe) constructed near Devinagar under the Indian Government assistance has been washed away sometime in the 1960s. Several other irrigation systems downstream managed by the farmers on either banks of the Tinau River have been defunct due to river degradation. Several electric poles erected by the Nepal Electricity Authority (NEA) along the banks of the Tinau River have deteriorated and are just hanging. Also the water level, in the substantial numbers of existing shallow tube-wells along the river banks on either side, has gone

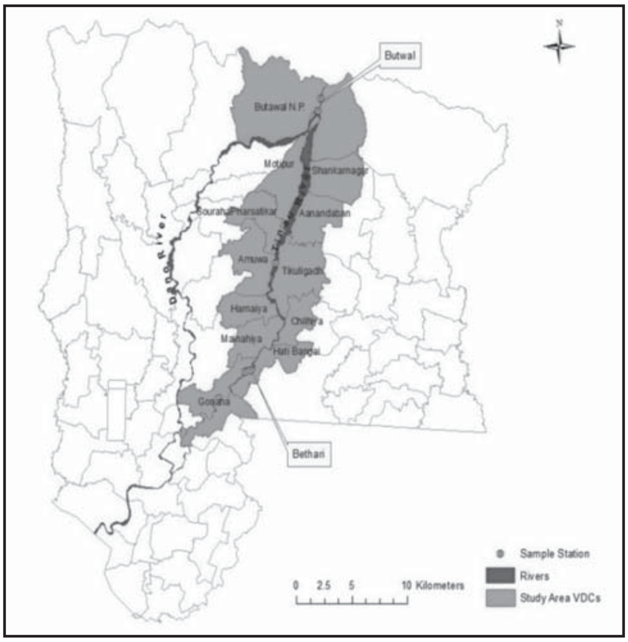

Figure 1. Map of Study Area.

down affecting the productivity of the agricultural land (Guragain 2012).

River bed materials have been excessively extracted in the Tinau River over the last several years. The extraction activities of the past eight years have been presented in Figure 2. It clearly indicates that the river-bed materials were over extracted during the years 2004 to 2011.

Due to the erratic distribution of monsoon rainfall combined with the young geological formations, flash-floods are common in the basin. Moreover, human activities such as cultivation of marginal land, mining of river-bed materials, large-scale deforestation, unplanned systems of construction of physical infrastructures like roads in the hazardous mountain regions and cultivation on steep slopes have increased the incidence of landslides, increased silt in the river water causing floods in various places (PEP-5, 2009). Sedimentation, bank erosion, flooding over farm land and washout of settlements are the common features of disasters in the Tinau Basin. Every year, sand, silt and flood water covers on an average about 3,000 hectares of land of which 580 ha is covered with sand and soil (JICA 1999). With appropriate flood mitigation measures, such land could be reclaimed and soil/sand inundation could be reduced (DWIDP 2011). Because of the weak geology and unstable nature of the Churia hills, landslides in the upper catchment are frequent. During the heavy rains, the river transports high sediment load, which is deposited in its inland delta, and the gradient of the river is reduced. The sediment carrying capacity decreases upon reaching the plains, which is one of the causes of river-bank erosion and inundation.

Hence, an integrated but immediate conservation approaches are needed to conserve the health of the Tinau River. Locally, if the people are united to save the health of the river, they can raise their voice up to the top level of the government, and development can be made sustainable.

This study aims to find the most suitable conservation and protection strategies. The combined approach (government plus local effort) has been found to be the most effective at maintaining watershed and river integrity as well. Legal formation of local water conservation groups with a network of upstream and downstream groups are essential. This study is done in the same way. The study area has been selected from the source to the Indian border at Marchawar (Figure 1).

Materials and Methods

The study has been done on the basis of field observation from Butwal to Bethari, interview with key stakeholders, community people residing on the banks of the Tinau river and an interaction cum workshop with various people on "How to conserve the health of the Tinau River ?". The study was carried out during the period of November to December, 2012. A structured questionnaire was developed and interviewed with 52 persons upstream and downstream of the Tinau River. In addition to this, 10 river specialists who have already worked with the Tinau River and two from crusher industries were selected for further interview and discussion. Local social activists to conserve the health of river including journalists and local leaders were also selected for interview to know the fact of degradation of the health of the Tinau. An one day workshop cum interaction program was held at Butwal to find the overall gist associated with the health of the Tinau River. In the program, altogether 62 participants participated. Among them 4 were journalists, 5 engineers, 2 were from crusher industry, and remaining were from local water users residing on the bank of the Tinau River. In the workshop, the whole participants were divided into three groups, and they were given a set of questions based on the conservation practices. They had to find the prevailing problems and the solutions for the same.

Based on the works of the groups and their presentation, conclusion was derived from the workshop/ interaction for conservation of the health of Tinau River.

Results and Discussions

The first part of this research is quantitative research; whereas the second part is qualitative. The qualitative part of this research includes what the respondents have perceived about the devastation and conservation of the Tinau. Both results have been presented in a systematic manner as given below.

Quantitative Analysis

The local self Governance Act and Rules (1999) has provided the authority to use the local resources for development works and revenue generation. Therefore, after the enforcement of this act and rules, local bodies like the DDC, Municipalities and VDCs are extracting river-bed materials in huge quantities. However, the extraction has been indiscriminate and haphazard. Uncontrolled river-bed extraction causes change in the river morphology, downstream degradation, disturbs the natural habitat and affects aquatic animals like fishes (Kondolf 1993, 1994, 1997, 1998). There are many such symptoms observed in the Tinau River as mentioned above. The river channel is incised. The average degradation of the river channel is 3.67 m in a stretch of 25.54 km. However, there is no local river conservation network. If there were a local participatory network to conserve the health of the river, the extraction could be done in a balanced way and the health of the Tinau River could be preserved.

There can be various methods of river conservation. During the survey, some of the options selected were bio-engineering practices, cement masonries, gabion walls, reinforced cement concrete (RCC) structures, composite structures, etc., for the protection works to conserve the health of the Tinau River.

Among various protection works, the majority of respondents (71%) opined that the construction of composite structures is more effective to conserve the health of the Tinau River. The health of the Tinau River

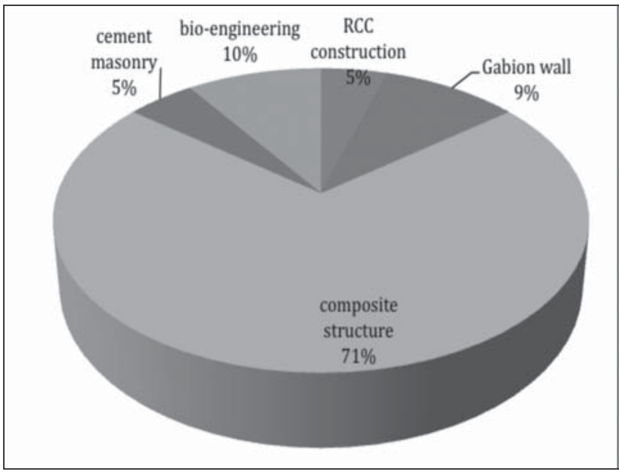

Figure 3: Practices in River Protection. (Source: Field survey, 2012)

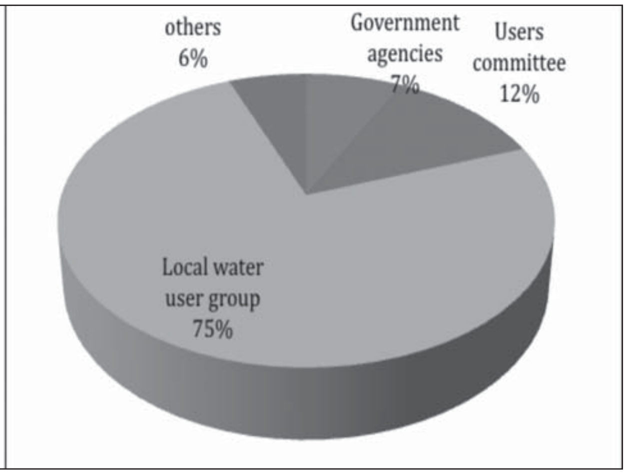

Figure 5. Agencies Involved in the Tinau Conservation. (Source: Field survey, 2012)

has been regarded as highly damaged due to various causes. The Government has initiated the construction of new headworks and bed-bars so as to conserve the farmer managed irrigation systems of the Sorha- Chhatis and Chaar Tapaha (DoI 2010).

Numerous landslides are prevailing in the Tinau corridor. The remedial measures for landslide protection works could be gabion wall construction, plantation, bio-engineering practices and others. However, during the survey at site, the majority of respondents (56%) selected the bio-engineering practices for landslides protection in the Tinau corridor (Figure 4).

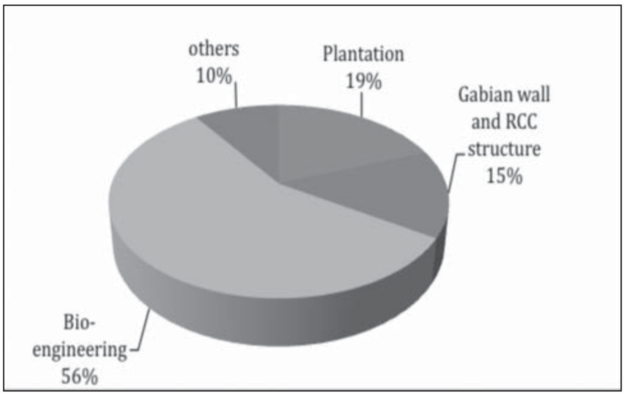

Figure 4. Structures Preferred for Landslide Protection. (Source: Field survey, 2012)

Preventive measures for river control can be done through the government, local users' committees and in a combined way (government agency and local water users groups (Figure 5). During the survey of the site, the majority of respondents opted that the implementation works for protection should be done through the local water users' groups (75%).

River protection works undertaken last year in the Tinau with gabion filled with boulders were not properly designed and, as a result 150m of the newly constructed gabion structures (costing Rs. 150 million) were washed out by the first flood of the Tinau. Hence, the local people have the least preferance on the gabion structure options. Further, there are substantial failure cases of such walls throughout the length of the river. The majority of respondents supported the composite structure option for protection works. Structures that are made by more than one material and technology are called composite structures. The composite structures in the case of the Tinau can be plantation plus cement

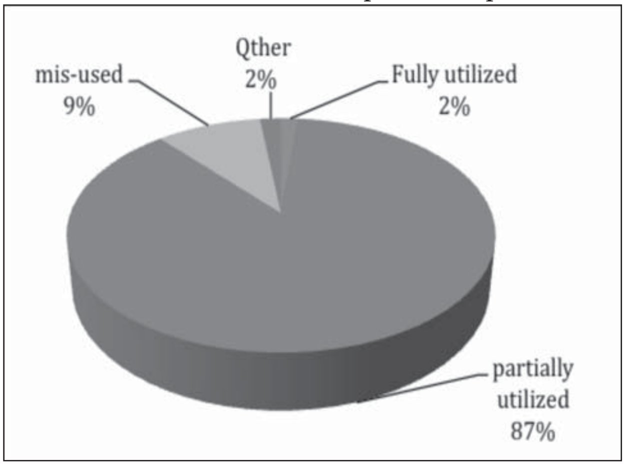

Figure 6. Utilization of Investment for the Protection Works. (Source: Field survey, 2012)

masonry, plantation plus dry masonry, plantation plus reinforced cement concrete (RCC) and so on. During the survey, the team observed the Bagmati protection works

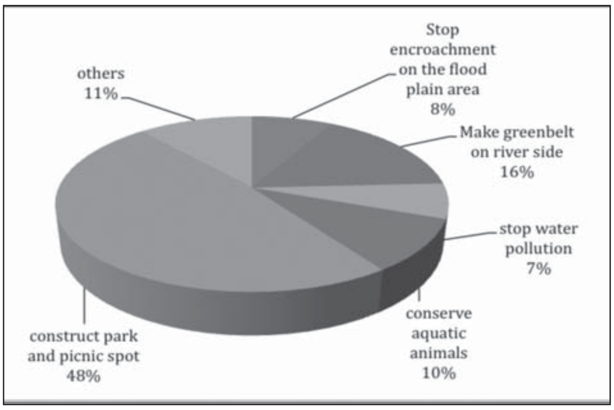

Figure 7. Infrastructure for Tourism Development. (Source: Field survey, 2012).

at Karmaiya, Sarlahi and suggested to adopt the same method for the Tinau River as well.

People have a feeling that the water discharge in the Tinau River has been decreasing year after year. During the survey, the respondents raised serious concerns saying that that the effects of climate change, deforestation of upstream catchment, diversion of water for drinking and irrigation purposes are the major causes of declining discharge downstream.

There are several agencies investing millions of rupees year after year for protection works on the river. However, the investment has not been properly utilized (Figure 7). During the survey, the majority of respondents reported that the investment was not effectively utilized (87%).

The river is one of the prime spots for entertainment. There is a possibility of tourism development in the Tinau corridor. During the field survey, the respondents were given several choices like prohibiting encroachment, making green belt on either side of the river, conserving aquatic animals and plants, and constructing parks and picnic spots. About 48% of the respondents selected the construction of parks and picnic spots on the floodplains (Figure 7).

Qualitative Analysis

The general rule of river conservation is to start from the source itself. During the survey at site, almost all the respondents were agreeing to conserve the health of the river from its source to the tail-end through local WUGs. The conservation practices needs an extensive study and master plan. It must mention the short-term, mid–term and long-term preventive works to conserve the health of the Tinau through a network of local WUGs. Millions of rupees have been invested for years through the government agencies (Department of Irrigation, Department of water induced disaster prevention, Peoples Embankment Program, Butwal Municipality, District Development Committees, Village Development Committees, etc.) for the preservation and control of the Tinau River. However, the investment has not been effectively utilized due to the limited participation of local WUGs during construction. During the survey of the area, cent-percent of the respondents agreed with the need of the collaborative practices (Govt. + People). The protection works must be done with the network of local WUGs for the effective utilization of the investment. The active involvement of local WUGs and other stakeholders associated with the River in conserving the health of the Tinau can make the development activities more sustainable. However, the budget must be mobilized by the Government agency and monitoring role should be taken by the local people together with the Government implementing agency in a participatory manner. The joint participatory planning paradigm has been widely acclaimed as an important factor for the conservational practices. Development must be people centered. Thus, the local WUGs and other stakeholders must be compulsorily involved in all the phases of development from planning to implementation and thereafter for operation and maintenance, to make it sustainable. There is a lack of data generating and maintaining system in the Tinau basin. The hydro-meteorological data must be kept in a scientific manner so as to design the hydraulic structures and to know the actual situation of the river. Hence, the hydro-meteorological database system must be developed as suggested during the survey at site. The quality of river water also is not good. Furthermore, the respondents suggested that the water quality monitoring mechanism also has to be established.

Open defecation is polluting the river upstream of the intake of 16/36 Irrigation System which is also a serious problem. The local bodies like VDCs, and municipality have started to stop open defecation; however, the problem is not solved. There is a lack of awareness and people's involvement in implementing the program. Thus, the anthropogenic disturbances like open defecation is still in existence. Construction and operation of public toilets may help reduce the problems.

Illegal fishing upstream and downstream of the river is rampant. Most people use poison and electric current for fishing. Thus, such type of activities must be banned and made punishable.

Similarly, there is a lack of an extensive network of local water users' groups. According to the respondents, the need of the network is an urgent task to save the health of the river. To establish a network is not a difficult task but to keep it sustainable, constant support of the Government is indispensable.

There is an urgent need of water diversion from the Kaligandaki River into the Tinau to augment water flow, wash out the pollution, irrigate the dry areas of Terai districts (Nawalparasi, Rupandehi and Kapilvastu) and generate hydro-power including other uses. As it is a mega project, at present, it is only a vision and it may take decades to implement this project.

The channel bar deposits and river terraces are major sources of riverbed material and distributed throughout the river channel under the study stretch. They were formed when the entire valley was inundated and the streams carried much of the debris as bed load material. The flood, carrying heavy sediment from the catchment area, drops down the sediments when it comes out of the gorges to the plains at nearby Butwal city (Sharma 1997).

The People's Embankment Program (PEP 2009) prepared a Detailed Project Report (DPR) in 2009 from Butwal to Marchawar for the conservation of the Tinau River. The study focused mainly on general information of the river hydrology, socio-economic condition of the area, existing condition of the river and proposed remedial measures. However, it could not be implemented in a proper way.

The construction materials extracted from the Tinau River are being exported to India. The undulated river-bed along the course or many man-made ditches, which do not fill up after the main flood, show that there is a clear deficit in sediment deposition as compared to the present mining rate. If the situation continues, there could be a problem of river-bed lowering, which affects riverbank erosion causing damage to the bridges, embankment protection, and intake of the canal in the upstream side. It can also damage all man-made structures (especially hydraulic structures) (Butwal Municipality 2001). People living in the periphery of Butwal city raised their voice to protect the river and a case was filed in the Supreme Court. The court ordered to stop the extraction activity in the Tinau. The delegation from the house of representatives visited the site and made a report concerning the degradation of river environment (Parliament 2010).

An Environmental Impact Assessment (EIA) study report was prepared by the DDC (Rupandehi) to continue the extraction activities in the Tinau River. The report mentions that the environment of the Tinau River is continuously deteriorating due to water pollution and deforestation.

Human activity is one of the main causes for such adverse impacts on the aquatic ecosystem. The extraction has caused a lot of loss of aquatic lives. Thus, the Tinau needs rehabilitation measures such as establishment of predestined areas for extraction of boulders, sand and aggregates from the river (DDC 2011).

Fresh water bodies like the Tinau and others are also sources of drinking water. Many people of Butwal municipality are taking drinking water from the Tinau River. There is a need of water quality monitoring in the River. The biological water quality monitoring is considered one of the best methods for the rivers like the Tinau (Sharma 1996).

River processes refer to the interaction between water and sediment. The capability of the water in the river to transport the sediment supplied to it determines the dominant river processes for a specific reach of river. If there is an imbalance between the supply and transport capacity, the river will adjust its hydraulic characteristics of width, depth, slope, and pattern by the process of aggradation (deposition), degradation and/or lateral shifting (WECS 1987).

Establishing appropriate natural resources management institutions and strengthening the capacity of these institutions could help in the efficient and equitable distribution of these resources to the beneficiaries (Guragain 2012). Such institutions would contribute to increase the economic status of the nation. These institutions are also important to avoid and manage conflicts and ensure the participation of targeted people.

Conclusion

The Tinau River needs extensive planning to restore and conserve its health. The conservation approaches are of various types. However, the local initiative to conserve the health of the river is felt effective in case of the Tinau. The combined efforts of the agency and related stakeholders and water users' groups could be the best way of river conservation. If the local initiatives were commenced in a proper manner and government provided the necessary support to them, the river conservation practices could be made sustainable.

The Workshop attended by the related stakeholders shows a clear determination to counteract the negative aspects and make Tinau River a healthy river. Even though, the workshop has not come up with a methodology of creating a River Commission, it could be a starting point to move forward. Such workshops and interaction programs are needed in the future too.

The main suggestions for the conservation of the health of the Tinau given by the participants of the Workshop are summarized as follows:

- Stop encroachment on the flood plain area,
- Make green-belt on both sides of the Tinau river,
- Stop water pollution,
- Conserve aquatic plants and animals,
- Construct embankments on either side of the Tinau river and make a motorable road,
- Prepare proper waste management plan and stop waste disposal into the Tinau river channel and flood-plains, construct electric incinerator for the cremation of dead bodies,
- Restrict uncontrolled river-bed extraction,
- Regulate river-bed material export to India, and
- Establish a network of local water users' groups for river conservation and establish powerful Commission which will include Govt. agencies also on for the conservation of the River.
- Construct parks and picnic spots,
- Demarcate the actual river width in the topographic map,
- provide compensation to who are already settled on the bank and flood plains of the Tinau and resettle them,
- Undertake Initial Environmental Examination (IEE) or Environmental Impact Assessment (EIA),
- However, the holistic conservation techniques through participatory approaches are lacking. Therefore, there is an urgent need of local initiatives to conserve the health of the Tinau River and make its development sustainable.

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PHOTOGRAPHS OF THE SITE

Figure 8. Electric pole hanging

Figure 9. Bank breaching

Figure.10. Protection failure

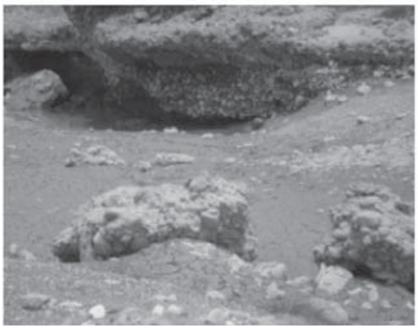


Figure11. Cave formation

Figure 12. Habitat destruction

Figure 13. Protection work

Figure 14. Interaction with locals

Figure 15. Explanation by River Expert

Figure 16. Presentation by the Leader

(Source of above photos: Field Survey, 2012)

CALENDAR OF EVENTS - ENVIRONMENT

20-21 February, 2013: UNECE Meeting of the Core Group of Pilot Projects on Climate Change. Location: Geneva, Switzerland. More info: http://www.unece.org/env/water/core_group_pilot_projects_climate_chang...

20-22 February, 2013: Regional Workshop on Payment for Ecosystem Services in the HKH region. Location: ICIMOD Headquarters. http://www.icimod.org. Contact Person Laxman Joshi.

24-25 February, 2013: 3rd International Conference on Future Environment and Energy (ICFEE) Conference. Location: Rome, Italy. More info: http://www.icfee.org/

24-27 February, 2013: International Conference on Natural Resources Management in a Changing World. Location: Al-Ain, United Arab Emirates. Contact Email: NRMConference@uaeu.ac.ae. More info: http://www.fos.uaeu.ac.ae/conference/nrm/

6-8 March, 2013: Expert Consultation on Knowledge and Capacity Needs for Sustainable Development in Post-Rio+20 Era. Location: Incheon, Republic of Korea. More info: http://www.unosd.org/index.php?page=view&type=13&nr=9&menu=229

14-16 March, 2013: International Conference on Global Scenario in Environment and Energy. Location: Bhopal, Madhya Pradesh, India. More info: http://www.icgsee2013.com

19-22 March, 2013: World Environmental and Water Resoureces Congress 2013. Location: Cincinnati, USA. Contact Email: lking@asce.org. More info: http://content.asce.org/conferences/ewri2013/

Monte Carlo Simulation for Economic Analysis of Hydropower Pumped Storage Project in Nepal


Kaspar Vereide


Leif Lia


Lars Ødegård

Kaspar Vereide, Leif Lia and Lars Ødegård

Abstract: Investments in hydropower pumped storage projects (PSP) are subjected to a high degree of uncertainty. In addition to normal uncertainties in hydropower schemes, the profit of a pumped storage scheme is dependent on the margin between power prices for buying and selling, which is difficult to predict without a power purchase agreement (PPA).

A PSP without a PPA and without known construction costs requires quantification of the uncertainties in order to make qualified decisions before investing in such projects. This article demonstrates the advantages of using Monte Carlo (MC) simulations as a tool in the economic analysis of PSPs. The method has been tested on a case study, namely the Tamakoshi-3 Hydropower Project (HPP) in Nepal.

The MC method is used to calculate the probability distribution of the net present value of installing reversible units in the Tamakoshi-3 HPP. The calculations show that PSPs may be profitable in Nepal, given a beneficial development of the power market.

The MC method is considered to be a useful tool for economic analysis of PSPs. In this case study of installing reversible units in the Tamakoshi-3 HPP, there are many uncertainties, which the MC simulation method is able to quantify.

Key words: Hydropower, pumped storage, reversible turbines, Monte Carlo, Tamakoshi-3, Nepal

Introduction

All over the world, except in regions with many regulated reservoirs such as Norway, hydropower pumped storage projects (PSP) are commonly used to supply the grid with peaking power and power in periods with scarce power production (Deane et al 2010). PSPs are most frequently used in regions where the thermal power is dominating in the supply system. So far no PSPs are commissioned or under construction in Nepal. A PSP may be designed for several purposes:

- Seasonal pumping of water from low level reservoirs to high level reservoirs in periods with high run off. The stored water may be used in dry seasons.
- Daily peaking operation by subsequently producing in peak periods and pumping in off peak periods.
- Controlling frequency and voltage in the grid.

Regarding to the different purposes listed above, a PSP will be designed accordingly. In many countries such as Germany, Austria, Switzerland and Norway, new PSPs are developed and constructed. It is one of the most promising technologies to handle the future challenges in the electricity supply system.

Due to the deficit of electrical power in Nepal, numerous new hydropower projects (HPP) have to be commissioned in order to meet the demand (NEA 2012). For HPPs with reservoirs in both the upstream and downstream end, there is an opportunity to install one or more units for pumping. The most recent technology available is reversible turbines, which eliminate the need for separate units for pumping and generation.

Investments in PSPs are subject to a high degree of uncertainty. In addition to normal uncertainties in hydropower schemes, the profit of a pumped storage scheme is dependent on the margin between power prices for buying and selling, which is difficult to predict without a power purchase agreement (PPA). This margin is often referred to as the spread. Compensation for auxiliary services such as stabilizing the frequency and voltage introduce additional uncertainties but these are disregarded in this article due to lack of a commercial market for such services in Nepal.

A PSP without a PPA and without known construction costs requires quantification of the uncertainties in order to make qualified decisions before investing in such projects. This article demonstrates the advantages of using Monte Carlo (MC) simulations as a tool in the economic analysis of PSPs. The method has been tested on a case study, namely the Tamakoshi-3 HPP in Nepal. The MC simulation method is used to calculate the probability distribution of the net present value (NPV) of installing reversible units in the Tamakoshi-3 HPP.

The NPV is a frequently used parameter for evaluating the economic feasibility of hydropower projects. It is calculated as the sum of each annual cash flow, discounted for required rate of return. The following equation presents the calculation where i = rate of return, N = economical lifetime, Rt = annual net cash flow, t = year number (Khan et al 1993):

$$NPV(i,N) = \sum_{t=0}^{N} \frac{R_t}{(1+i)^t}$$

This article is written to highlight the possibility of using MC simulations for economic analysis of PSPs, and the reader needs to be aware that the performed calculations are based on beneficial prerequisites. The downstream reservoir is assumed to be available without cost. Tamakoshi-3 HPP has been shown to be most profitable with only one reservoir, one power plant and construction of a longer headrace tunnel (SN Power 2010). This will eliminate the possibility of having reservoirs both in the upstream and downstream end, and thus eliminating the possibility of installing reversible units.

The main reason for considering two power plants and two reservoirs is to reduce risk in the project. The project is still economically feasible, but will be constructed in smaller steps. The performed calculations evaluate whether reversible units should be included in the design if two reservoirs are available.

Case Study - Tamakoshi-3 Hydropower Project

Tamakoshi-3 is one of the future HPPs in Nepal, and is currently being considered as a potential investment for the Norwegian Power Company SN Power. With the design presented in Figure 1 and Figure 2 (edited from SN Power, 2010), reversible units can be implemented. If reversible units prove to be profitable for the Tamakoshi-3 HPP, this may imply profitability also for other projects.

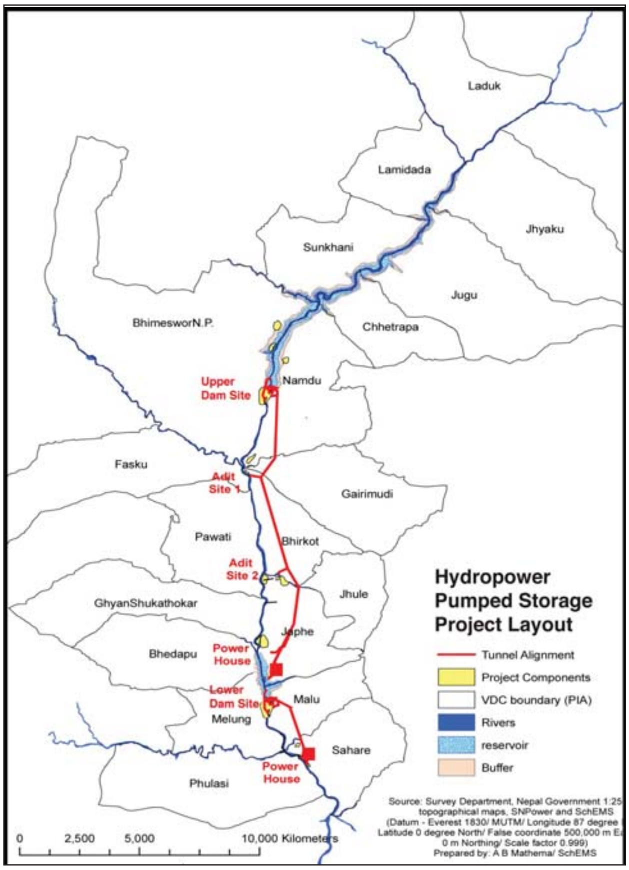


Figure 1. Tamakoshi-3 HPP Layout (Edited from SN Power 2010).

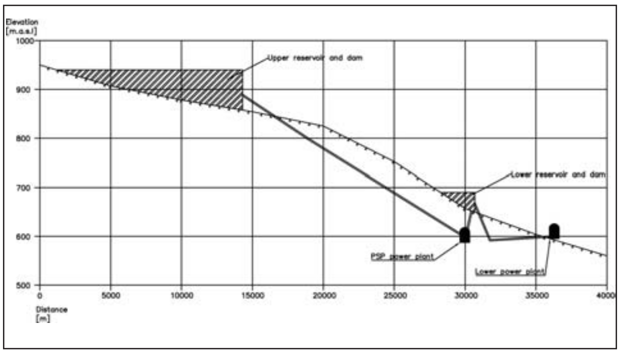


Figure 2. Profile Plot of Tamakoshi-3 HPP.

Data on the Nepalese power market and power supply system has been given by the Nepalese Department of Electricity Development (DOED). Data on the Tamakoshi -3 HPP has been given by SN Power.

SN Power has been considering several project layouts for the Tamakoshi-3 HPP. In the layout presented in this article, the project design includes two reservoirs and two power plants. Reversible units are implemented in the upstream power plant. Key features for the upstream power plant of the Tamakoshi-3 HPP are presented in Table 1 (SN Power 2010).

Upstream Reservoir		
HRW	940	m.a.s.l.
LRW	890	m.a.s.l.
Live storage	137	mill. m^3
Downstream Reservoir		
HRW	690	m.a.s.l.
LRW	670	m.a.s.l.
Live storage	14	mill. m^3
Waterway		
Total tunnel length	13 000	m
Tunnel cross section area	74	m^2
Gross headloss	16	m
Power station		
Gross head	250	m
Maximum discharge	305	m^3/s
Number of units	3	
Turbine unit rating	206	MW

Table 1. Upstream Power Plant.

The reservoir volumes are too small for seasonal storage and the PSP will be used uniquely for daily peaking operation, based on the spread between peak and off peak power price. Auxiliary services such as regulation of frequency and voltage have been disregarded in this article, since there is no commercial market for these.

Monte Carlo Simulation Model

The MC simulation model presented in this paper is based on the works presented by Rubinstein (2008). Monte Carlo simulations for economic risk assessment for wind power are documented by Montes, Martin et al (2011) and Li, Lu and Wu (2012), but similar calculations for PSPs have to the authors' knowledge not been documented earlier. The principle of the MC simulation model is:

1. The model variables are selected based on the specific influence on the profit. The numbers of variables (X) are chosen based on preferred complexity and accuracy of the analysis.
2. Each of the variables is described with a probability distribution, with a maximum, minimum and expected value.
3. In a MC simulation with X variables, N values are randomly drawn from each of the variables. This gives N sets of X variables.
4. These N sets are used to calculate construction cost

and power production, producing N possible costs and N possible productions.

5. The N possible costs and productions result in N possible NPVs.
6. These N possible NPVs are analyzed statistically and used to describe the probability distribution of the NPV.

The result is a probability distribution of the NPV, which is used to evaluate the profitability of the PSP. In comparison to the traditional deterministic method, one number is calculated as expected NPV; the MC simulation method will provide more details for an investment decision.

It is important to have a high enough number N, to ensure convergence of the result. However, the main challenge in MC simulation is to find the probability distributions for each of the variables. For the Tamakoshi-3 Hydropower Project in Nepal, the probability distributions are based on available data provided by the DOED and SN Power.

The transformation of the data into probability distribution is subject to individual interpretation, which may introduce inaccuracies in the result. The accuracy of this interpretation will have a direct impact on the accuracy of the result.

Model Input

In order to evaluate the NPV of installing reversible aggregates in the Tamakoshi-3 HPP, the following input variables are used:

- Future amount of peak price hours
- Future power price in Nepal
- Future power price in India
- Future electricity demand in Nepal
- Future electricity production in Nepal
- Reversible unit costs

The input variables are based on the following data received from DOED and SN Power:

- Time series of the electricity production and demand in Nepal;
- Predictions of the future production and demand in Nepal;
- Historical and current power prices in Nepal and India;
- Predictions of future electricity prices in Nepal and India;
- Power grid capacity in Nepal and India; and
- Project layout of the Tamakoshi-3 HPP.

Based on this data, the selected input variables are described with probability distributions as presented in the following sections. The probability distributions are based on the theory as presented by Walpole (2007).

The characteristics of the probability distributions such as maximum, minimum and expected values are limited by the knowledge of the authors.

Peak Price Hours

The number of hours per day when the power price is high will impact on the profit of a PSP, and has been selected as a variable in the model. In this simulation, the power price is assumed to change directly from peak to off peak without an intermittent zone. The key data of the probability distributions are presented in Table 2.

Parameter	Peak price hours
Minimum	0
Maximum	12
Expected value	5
Distribution	Discrete

Table 2. Number of Peak Price Hours.

A probability for zero peak price hours has been included, to account for the probability that the future power market does not have peak price hours. The maximum number of peak price hours is chosen as twelve due to the possibility of having twelve peak hours and twelve off peak hours. Figure 4 presents the probability distribution.

The probability distribution used to describe the number of peak price hours is discrete. This is chosen since the number is assumed to be in whole hours, and not minutes.

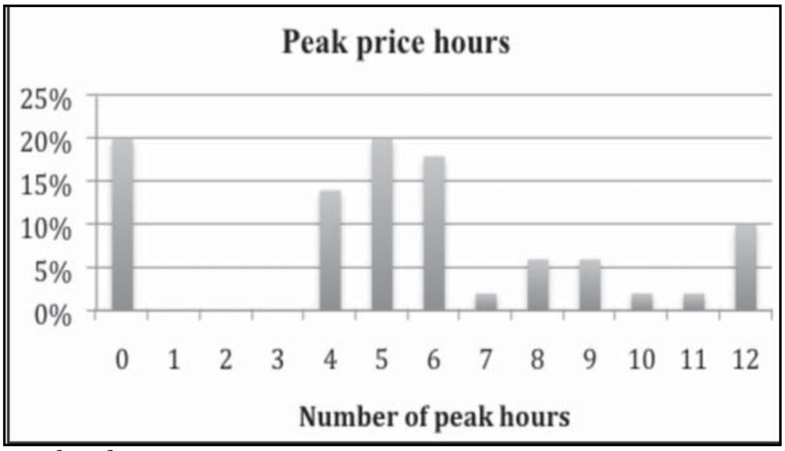


Figure 3. Probability Distribution Peak Price Hours.

Future Power Price in Nepal

The variable for future power price in Nepal is the price the owner of the power plant receives per produced MWh. The future power price has been separated into three components to describe the daily and seasonal variation:

- The base power price (wet season off peak period)
- Additional fee during dry season
- Additional fee during daily peak period

The price during the peak period in the dry season is equal to the added sum of base power price, the dry season fee and the peak period fee. The formula and key data of the probability distributions are presented in Table 3.

Future Power Price in India

The future power price in India is predicted as monthly

Parameter	Wet off peak period price USD/MWh	Additional Dry season fee USD/MWh	Additional Peak period fee USD/MWh
Minimum	55	41	27
Maximum	96	96	110
Expected value	68	48	55
Distribution	Chi squared	Exponential	Chi squared
f(x)	232Γ(32)(x−4000250)32 −1e−x−4000500	17310.7e−x1000+30.7	173125Γ(5)(x−2000200)4e−x2

Table 3. Future Power Price in Nepal.

averages by the Spanish consultancy firm AF Mercados EMI (2011). The variable is separated in two components, deviation from the prediction and the spread. Table 4 presents the formula and key data of the probability distributions.

Parameter	Deviation from prediction %	Spread USD/MWh
Minimum	- 60%	0
Maximum	+ 60%	137
Expected value	0 %	48
Distribution	Normal	Chi squared
f(x)	1182πe−(x)22∗182	173129Γ(9)(x200)8e−x400

Table 4. Future Power Price in India.

Future Power Production and Demand

The future production and demand of electricity in Nepal will determine whether there is surplus or de in the system. This will influence whether there is power available for pumping. A prediction of future annual production and demand is supplied by the DOED.

To estimate the future production and demand, the following parameters are used:

Parameter	Future production	Future demand
Minimum	-100%	0%
Maximum	-20%	90%
Expected value	-60%	50%
Distribution	Modified normal	Normal
f(x)	0.9192πe−(x−60)22∗92+0.1142πe−(x−90)22∗42	1232πe−(x−50)22∗232

Table 5. Future Power Production and Demand.

- Deviation from the predicted annual production growth
- Deviation from the predicted annual demand growth

The key data of the probability distributions is presented in Table 5.

Parameter	Cost	
Turbines	8	mill. USD
Generators/ control gear	16	mill. USD
Sum	24	mill. USD

Table 6. Expected Cost of Three Reversible Units.

The future production depends on the amount of new power plants constructed. Today, the rate of constructing new power plants is slow, but the rate is expected to increase in the future if projects can be made more feasible. The future production is therefore described with a modified normal distribution in order to account for both slow development and fast development.

Reversible Unit Cost

It is only the isolated cost of the reversible units that are studied in this article. The cost and profit of the original project without reversible units is disregarded. This is chosen in order to isolate the NPV of installing reversible units. Table 6 and Table 7 present the expected cost and key data of the probability distributions.

The cost for the reversible units is based on a cost estimate produced by the Norwegian Water Resources and Energy Directorate (2010). It is assumed that all the three units will be reversible.

Parameter	Reversible unit cost
Minimum	-20%
Maximum	+20%
Expected value	0%
Distribution	Normal
f(x)	1102πe−(x)22∗102

Table 7. Probability Distribution of Reversible Unit Cost.

Simulation of PSP Operation

The random selection of N sets of X variables is performed with the Matlab software. These N sets are then used in a PSP operation model to calculate how the PSP plant will operate under the different conditions, and the resulting profit. Compared with the production simulation for regular hydropower plants, the PSP model needs to be programmed with a criterion for when to pump, and when to produce. The simulation model has been programmed with the Visual Basic software on an hourly resolution and is based on the following assumptions:

- No limitations in transmission capacity (only valid for limited amount of MW);
- Power may be sold in both the Nepalese and the Indian market;
- Power will be bought where it is least expensive, and sold where it is most expensive;
- No limits in the amount of energy that can be bought or sold in the Indian market;
- Pumping mode cannot operate in the wet season (4 months) due to full reservoir.

The output of the operation model is the profit from operating the reversible units. Next, the cost of the reversible units is included and the NPV of the project may be calculated.

A flow chart of the power production/pump routine in the operation model is presented in Figure 5 (PP = power price). This routine is implemented in a normal production simulation model, which calculates the operation of regular HPPs based on hydrological data and operational strategy. Hydrological data and operational strategy for the Tamakoshi-3 HPP is described in SN Power (2010).

Due to the head loss in the waterway, limited efficiency of the units and transmission losses, only approximately 65% of the energy that is used for

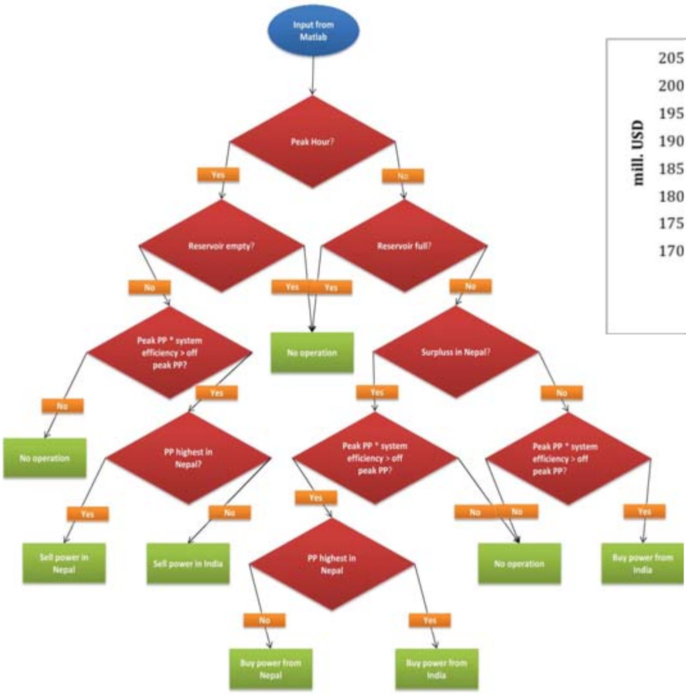


Figure 4. PSP Routine Flow Chart.

pumping will be returned when the same water is used for power production. The head loss, unit efficiency and transmission losses are defined as system efficiency in the routine, and will vary with the unit discharge. In order to profit from the operation of reversible units, the spread in the power price needs to be sufficiently high. The routine accounts for this with the requirement that the peak price multiplied with system efficiency must be higher than the off peak price in order to run the reversible units.

Result

The principle of Monte Carlo simulation relies on a high enough number of simulations in order to converge the result. Figure 6 presents a convergence test for the MC model.

Due to the computing time, it is chosen to use N=15,000 as satisfying the convergence criteria. However, the convergence test shows that the solution has not fully converged at this number of simulations, and that there is some inaccuracy in the result. For the purpose of demonstrating the method, the convergence is regarded as sufficient.

The resulting probability distribution of the NPV is presented in Figure 7. A discount rate of 11.5% has been used. As can be seen, installation of reversible units is likely to be profitable, but there is a high standard deviance. The expected value of the NPV is 192 million USD, with a standard deviance of 201 million USD.

The output domain of the NPV is in the range e [24, 1475 million USD]. The theoretical maximum has a probability of approximately 0.00005%, and is sensitive to the chosen maximum of the input parameters.

There is a large probability of negative NPV from the project. This is mainly due to the probability of zero peak price hours in Nepal, as presented in Figure 4. In addition there is a probability that the spread is too small

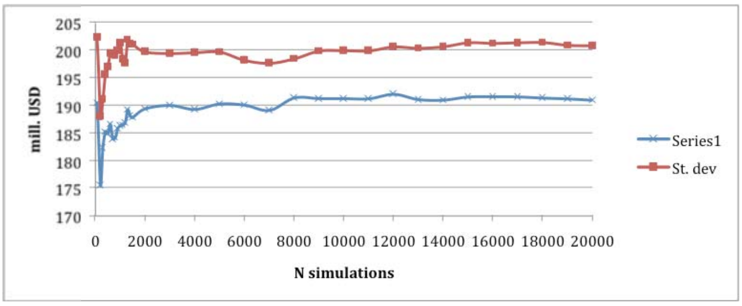
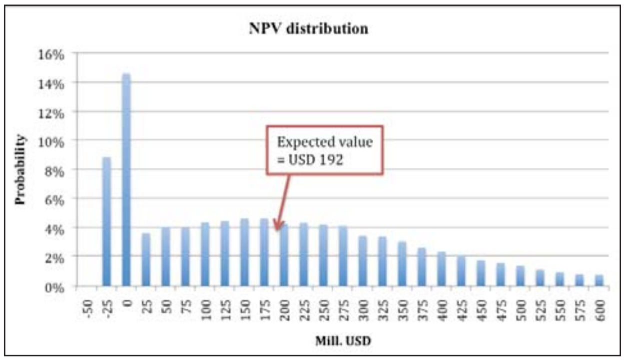


Figure 5. Convergence Test.

to operate the PSP. In this case there will be no income, and the NPV will be equal to the cost of the reversible aggregates.



Figur 6. NPV Distribution.

Discussion

The results presented in this article are regarded as optimistic. The input data and many of the assumptions may provide unrealistically beneficial conditions for the PSP. However, the results prove that there may be a potential profitable market for reversible units in Nepal, given the possibility of operating under beneficial conditions in a combined Nepalese and Indian power market.

Considering the MC method, the negative aspect is the difficulty of accurately transforming the input data into probability distributions. In case of limited input data, personal interpretation may cause unrealistic results. Limited input data and personal interpretation are normally the main sources of error in the economic analysis. However, given accurate input data, the MC method will provide an accurate probability distribution of the output, which presents the entire output domain and gives a better understating of the possible economic scenarios of the project.

The MC method is considered to be a useful tool for economic analysis of PSPs. In the case study of a potential PSP in Nepal, there are many uncertainties, which the MC simulation is able to quantify.

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CALENDAR OF EVENTS - ENERGY

13-15 February, 2013: Solar Power-gen Conference and Exhibition. Location: San Diego Convention Center, San Diego, CA, USA. More info: http://www.solar-powergen.com/index.html

25-26 February, 2013: Wind Power Summit Conference. Location: Dallas, TX, United States of America. More info: http://www.windpower-summit.com/el

25-26 February, 2013: 2nd Annual International Conference on Sustainable Energy and Environmental Sciences. Location: Singapore. More info: http://www.env-energy.org/

27 February-1 March, 2013: Micro Perspectives for Decentralized Energy Supply Conference. Location: Berlin, Germany. More info: http://www.microenergysystems.tu-berlin.de/conference

27 February - 1 March, 2013: World Sustainable Energy Days. Location: Wels, Austria. Contact Email: office@esv.or.at. More info: www.wsed.at

7-9 March, 2013: International Renewable and Sustainable Energy Conference. Location: Ouarzazate, Morocco. More info: http://www.med-space.org/irsec

30 March, 2013: National Conference on Green Energy - (NCGE13). Location: Chennai, Tamilnadu, India. More info: http://www.rmd.ac.in/NCGE13/contact.html

8 - 12 April, 2013: IEA Energy Training Week 2013. Location: Paris, France. More info: http://www.iea.org/training/etw2013/#d.en.15745

10-12 April, 2013: Power and Energy Systems - AsiaPES Conference. Location: Phuket, Thailand. More info: http://www.iasted.org/conferences/home-800.html

17-18 April, 2013: Fourth Clean Energy Ministerial. Location: New Delhi, India. More info: http://www.cleanenergyministerial.org/events/cem4/index.html

23-25 April, 2013: The 6th Energy Storage Forum – Europe 2013 Conference. Location: Berlin, Germany. More info: http://www.energystorageforum.com/

24-26 April 2013: Asset Management for Enhancing Energy Efficiency in Water and Wastewater Systems. Location: Marbella, Spain. More info: http://iceam2013.es/

25-27 April, 2013: The 7th International Energy Trade Fair, RENEXPO Central Europe. Location: Budapest, Hungary. Contact: REECO Hungary Kft. Contact Email: hungary@reeco.hu. More info: www.renexpo.hu

26 April, 2013: Clean Energy Financing Forum for Central America and the Caribbean. Location: San Pedro Sula, Honduras. More info: http://cti-pfan.net/events_detail.php?eventsid=43

9-10 May, 2013: Energy and Environment: bringing together Economics and Engineering Conference. Location: Porto, Portugal. More info: http://www.fep.up.pt/conferences/icee/

23-25 May, 2013: The 10th International Symposium on Power of Green Energy. Location: Toruń, Poland. More info: http://gape2012.umk.pl

27 - 30 May, 2013: The Asian and Pacific Energy Forum (APEF 2013). Location: Vladivostok, Russian Federation. More info: http://www.greengrowth.org/?q=event/asian-and-pacific-energy-forum-apef-2013

29-31 May, 2013: 9th See Congress and Exhibition on Energy Efficiency and Renewable Energy (EE & RE). Location: Sofia, Bulgaria. More info: http://www.eeandres.viaexpo.com/en/congress

30-31 May, 2013: International Conference on Alternative Energy in Developing Countries and Emerging Economies. Location: Bangkok, Thailand. More info: http://www.sci.tsu.ac.th/2013aedcee/

6-9 June, 2013: ACSEE 2013 - The Third Asian Conference on Sustainability, Energy and the Environment Conference. Location: Osaka, Japan. More info: http://acsee.iafor.org

19-21 June, 2013: Energy and Sustainability 2013 Conference. Location: Bucharest, Romania. More info: http://www.wessex.ac.uk/13-conferences/energy-and-sustainability-2013.html

4-7 July, 2013: ECSEE 2013 - The European Conference on Sustainability, Energy and the Environment Conference. Location: Brighton, United Kingdom. More info: http://ecsee.iafor.org/

14-18 July, 2013: World Renewable Energy Congress-Australia 2013. Location: Perth, Western Australia, Australia. More info: http://www.promaco.com.au/events/WREC_2013/index.html

Technical Guidelines for Installation of Rainwater Harvesting System and its Operation

Binod Shakya and Jeewan P. Thanju

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Abstract: Rainwater harvesting (RWH) systems have been in use since ancient times, and these days its use is increasing. However, due to improper planning and design, problems are seen and the collected water is polluted.

The major reason for water contamination is attributed to the toxic materials used for the rain harvesting system, faulty operation, improper rain filtration system and improper disinfection methods. The reason for diseases arising from drinking rainwater is the consumption of contaminated rainwater. Clean raindrops comprising rainwater will become contaminated as they pass through the atmosphere, flow over the roof surface, flow along the gutter, and upon collection and storage.

This paper focuses on the technical guidelines for the installation of RWH components, its operation and maintenance, and rainwater quality improvement for household use.

Key words: Rainwater harvesting, first flush for RWH, disinfection of rainwater, catchment, guidelines for RWH

Background

Rainwater harvesting (RWH) is being practiced in many countries both with good rainfall and also where rainfall is scanty. In countries with good and frequent rainfall such as Myanmar, Thailand, Sri Lanka, Maldives, Pacific islands etc. RWH is practiced. In dry areas with scanty rainfall such as Rajasthan, India and Gansu Province of China, RWH is also being widely used.

The Department for Water Supply and Sewerage (DWSS), Government of Nepal has produced Draft Technical Guidance (TG) on the application and construction of rainwater systems (IDI 2010). The Department of Urban Development and Building Construction has been working since early 2006 on the promotion of rainwater harvesting in the urban areas. The Department has produced a final draft of the RWH Guidelines which are to be used to guide municipal authorities and those engaged in the building trade.

In Nepal the TG prepared by the DWSS has not yet been finalized even after two years of its preparation. As this TG is bulky, it will fruitful to prepare a brief TG after review by related experts.

Why Technical Guidelines is Required

The performances of the existing RWH system in many places are not satisfactory due to faulty design and installation. It is expected that a TG will help/assist in the smooth construction and operation/maintenance of a RWH system. Further, the rainwater collected have shown the presence of e coliform in large percentages of samples tested.

Evaluation of RWHS

RWH implemented by the DWSS in 18 districts were evaluated, and the following table 1 is the result (Udaya 2004).

Description	Excellent	Good	Poor
Technical Aspect	13%	57%	30%
Institutional Aspect	4%	35%	61%
Social/environmental	0	43%	57%
Financial Aspect	14%	46%	40%

Table 1. Evaluation of RWH Systems

The major reason for the poor quality is due to the toxic material used for the rain harvesting system, its bad operation, improper rain filtration system and disinfection methods. But it is noted that in ancient rainwater harvesting systems, there was no provision of purifying rain water and ensuring uniformity of the materials used for the harvesting system. Nowadays, rainwater harvesting with a proper health care system is gaining popularity in many developing countries due to shortage of other clean water resources. But still in many countries, particularly the least developed countries, the harvester still ignores the health risk from rainwater.

The main aim of this paper is to give some guidelines for the installation of system components and disinfection of the rainwater mostly for household use.

Water Requirement

The following criteria were developed for water scarce rural areas of Nepal:

Water Demand Criteria (IDI 2010):

a. Generally 5-10 litres/capita/day
b. In school, the water demand may be taken as 2-3 litres/student/ per day
c. Alternative water source but far in distance: potable only source-adopt 5 litres/capacity/day
d. Contaminated water source not suitable for drinking purpose without considerable treatment: consider potable only source-adopt 5 litres/capita/day
e. No water source nearby or source is very far (>1 km) from settlement-Consider adaptive water source - adopt 10 litres/capita/day
f. Availability of seasonal water source but the condition prevails at all other periods as above - adopt provision of b, c, and d

Calculation of Required Water and Available Water

For accuracy, it is required to acquire monthly rainfall data of the site for about 15 years. The average monthly data should be used to derive 10 day average rainfall. In very small showers, most of the water goes to evaporation/first flush etc. and the recoverable water is almost nil. Hence, small showers should be neglected in the calculation. The 10 day rainfall multiplied by the roof (catchment) area (horizontal) and the runoff coefficient gives the available water. The water balance should be calculated for the water used by the numbers of the family members of the household. In the monsoon season, there may be periods of spill water, if the storage tank is not of sufficient capacity.

A Sample Calculation is shown as follows:

For quick calculation, available annual water = average annual rainfall (less small winter showers) x runoff coefficient x roof area (catchment area)

If annual rainfall is 1500 mm, runoff coeff. for the CGI roof is 0.85, and factor for reducing small showers is 0.85%, roof area = 40 sq.m,

Then, water available = 1500mm x 40 sqm x 0.85 x 0.85 = 1.5 x 40 x 0.85 x 0.85 = 43.35 cubic metres

It is advised to use a simple Excel sheet for water balance calculation based on 10 days water availability and water use.

Sample Water required in a rural area:

Considering a 7 month water scarce period, per capita consumption of 10 lit/per capita/day for 6 member family and one big cattle head = 7 x 30 (6 x 10+30) = 18,900 litres =18.9 cu.m.

Basic Components of Rainwater Harvesting System

RWH system is a simple system that collects direct water from rain and is stored in a tank. Rooftop RWH consists of three major components: a catchment area (roof); a delivery system of gutters, down pipes, filters and any first flush device and a storage system (tank). The basic components are:

- ***Catchment surface (Roof):*** The rainfall collection surface or simply rain collecting roof,
- ***Gutters and downpipes:*** horizontal and vertical rain water channel that helps water run from the roof to the storage tank,
- ***Leaf Screen, first flush diverters, and roof washer:*** Components which remove dust, debris and other vegetations before water goes to the storage tank,
- ***Cisterns:*** One or more storage tank, and
- ***Delivery system:*** Pumped to the end user

a. Catchment (Roof)

The Roof is an important component in the rainwater harvesting system. It controls the water both quantitatively and qualitatively as the collection of rainwater depends on the roof size and roof material. The quality and quantity of rainwater from different roofs is a function of the roof material, climatic conditions, and the surrounding environment. Generally, a smoother surface is good for both quantity and quality. Therefore, in the rainwater harvesting system component design, the roof material of the building or house is the first choice of the system component. The common materials of interest are metal sheets, ceramic tiles, rock slate and Ferro cement. In recent days, the most suitable and widely used material is corrugated galvanized steel sheets. Galvanizing protects the steel from corroding by coating with zinc compounds. Some remarks are given in Table 2.

Recommended run off coefficient from the catchment is given in Table.1

These days most of the CGI sheets used for roofing come in color. The paints used for coloring the CGI sheets normally contain lead that is very harmful to human health. This point has not been researched yet. Hence, it is better to use non-colored galvanized CGI sheets.

b. Gutter Sizing

The correct installation of gutters is most important so that there are no flat areas where debris and water may pool, as these may provide sites for mosquitoes to breed. Standing water can collect insects, attract animals, and catch organic materials, such as leaves. Decaying organic material can ruin the taste and color of the water and cause health problems.

Roof Material	Remarks
Metal	Easily available and less fitting problem. Lead fitting should be avoided
Clay/concrete tile	To reduce water loss, tiles can be painted or coated with a sealant
Slate	sealant must be nontoxic
Asbestos	Cancer from ingested asbestos is very slight (Campbell 1993). Inhaling asbestos dust however has sufficiently high risk for getting cancer.

Table 2. Roof Material.

The required gutter width and downpipe size adapted from Still and Thomas 2003, Davis and Lambert 2002 is tabulated in Table 3.

Slope of Gutter: Recommended slope is 0.5% for 2/3 length and 1% slope for remaining 1/3 length. Increasing the slope lets through the same size of gutter greater volume of water (IDI 2010).

CGI roofing	Concrete	Cement tile	Cement ground	Plastic film covered with sand	Hand made tile	Bituminous road	Natural slope (soil)
85	80	75	53	46	40	68	10-18

Table 1. Runoff Index in Different Surfaces (in percentage) (Except first and last, the data is from Fuxue, Junlan and Yufeng 1999)

Roof area m^e^	Gutter width, mm	Downpipe, mm
17	60	40
25	70	50
34	80	50
46	90	63
66	100	63
128	125	75
208	150	90

Table 3. Guideline for Gutter and Downpipes.

C. First Flush Diverter

The amount of rainwater that needs to be removed through first flush diverters varies between different studies. Yaziz, Gunting et al (1989) have noticed 0.5 mm of rain is needed to wash thermo tolerant coli form (case study in two Malaysian Campus) (WHO 2004), and Coombes, Kuczera and Kalma (2002) found thermo tolerant coli form flushed in 2mm rain in Australia. For different roof size the required water to be diverted by first flush is presented in Table 4 (Coombes, Kuczera and Kalma 2002; Yaziz, Gunting et al 1989). Amount of first flush required for flat roof will be considerably more than for the sloping roofing.

Roof-Catchment size, m^e^	Water flushing, litres Coombes, Kuczera and Kalma (2002)	Water flushing, litres (Yaziz, Gunting et al 1989)
25	50	12.5
35	70	17.5
45	90	22.5
55	110	27.5
65	130	32.5
75	150	37.5
85	170	42.5
95	190	47.5
105	210	52.5
115	230	57.5
125	250	62.5
135	270	67.5
145	290	72.5

Table 4. Water Flushing from First Flush Diverter.

d. Storage Tank

In rainwater harvesting systems, the storage tank is usually the most expensive part. A question is which Tank? It is a question that does not have one right answer because there are many different rainwater tanks used in rainwater harvesting. Some of the most popular tanks used in rainwater harvesting are Polyethylene rainwater tanks. These tanks are much-liked because of the various advantages they have. Firstly, they can be used above the ground, are easily movable and can be kept even below the ground. Polyethylene rainwater tanks are also UV resistant, and rather than being heavy and bulky, are very light in weight and easy to carry around. Fibreglass rainwater tanks are another popular type of rainwater storage tank. The biggest advantage they have is that they are resistant to rust and chemical corrosion. Fibreglass rainwater tanks can also withstand extreme temperatures.

The durability, with some remarks on the different types of tank, is shown in Table 5.

In countries with frequent rainfall for more than one monsoon season, the required storage container is normally small and in the case of dry areas with scanty rainfall, the storage size required is large. In Nepal, more than 80% of the rain falls in the 3.5-months monsoon period. Storing water for dry seasons will require a substantial tank size which is an expensive item. In Nepal, a large number of 2000 litre capacity ferro-cement tanks were constructed earlier. In recent years, the tank size has been increased to 6,500 litres capacity (one number for one household).

Where there is ground water table at a reasonable depth such as in Kathmandu, it is fruitful to have a small storage tank say 3,000- 4,000 litres capacity, and the spill is sent to recharge the ground water aquifer after filtering.

Contaminants in Rainwater Harvesting System

The raindrop as it falls from the cloud is very soft and considered to be cleanest of water in nature. Clean raindrop will become contaminated as it passes through the atmosphere, as it flows over the roof surface, as it flows from the gutter, while it is being stored, during collection from storage and during maintenance.

Faecal coli form, viruses, protozoa, algae and helminths are microorganisms more related to disease. All biological pathogens are not harmful to humans; however, most pathogens can be eliminated by chlorination. The most harmful bacteria are faecal coliforms generally found in bird, animal and human faeces. The positive coli form hints that the water is dirty and, with this, it is difficult to say about the presence of harmful pathogens in water. Only a few of the 20,000 species of protozoans cause disease. Some protozoans produce a cyst which allows the organism to survive for a long time. It is a problem for rainwater harvesting systems because the cysts of some species survive after chlorination. Cysts such as Cryptosporidum are very small in size, 4 to 6 microns, and can easily pass through the normal filter. The absolute 1 micron filter only can stop such cysts.

Many of the researchers have been ignoring the effects of lead poisoning. This does not figure in chemical tests of the water samples. Chemical risk is mainly from the roof and other fitting materials. The degree of risk however also depends on maintenance of the RWH system. Source of contamination, illness and some precautions to be taken are shown from Tables 6 through 8.

Treatment of Rainwater

The frequently asked questions by rural and urban rainwater harvesters are: Do I need to filter my water? Do I need to disinfect my water? How do I disinfect my water? Regarding these questions no single answer is available for rainwater treatment. Generally, the harvester determines which problem their system has and find /choose the cost effective and health friendly method for treatment.

In many cases, rainwater is generally free from chemical contamination if the roof is installed properly and cleaned regularly. The overhanging trees, bushes and wire that allow birds a resting place must be kept away from the roof to minimize the microbiological contamination. However, it is difficult to make a roof completely free from contamination; regular cleaning of the roof and gutter will give less microbiologically contaminated water and one can disinfect by a simple disinfection process. Due to some atmospheric causes, the rainwater pH may be a little acidic (less than 7). A slight buffering half table spoon of baking soda per 2000 litres of water in the tank will neutralize the acid, if desired.

a. Chlorination

When chlorine is treated in water, it reacts with compounds in the water. The amount should be enough for a significant amount of chlorine to remain in the water for disinfection. Chlorine must be present in a concentration of 1 ppm (1mg/L) to disinfect the water. The maximum amount of chlorine one can use is 5 mg/L (WHO).

b. Boiling Rainwater or Solar Treatment

Boiling of water for at least 5 minutes before drinking is a suitable alternative to get safe drinking water. Boiling water will kill pathogenic viruses, fungi, and bacteria. This method is impractical for large scale boiling and expensive as well.

Solar disinfection or solar distillation is practically possible for treating small amounts of drinking water which are considered to be inexpensive methods. Solar Water Disinfection (SODIS) improves the microbiological quality of drinking water, using solar UV radiation and temperature to eradicate pathogens causing diarrhoea.

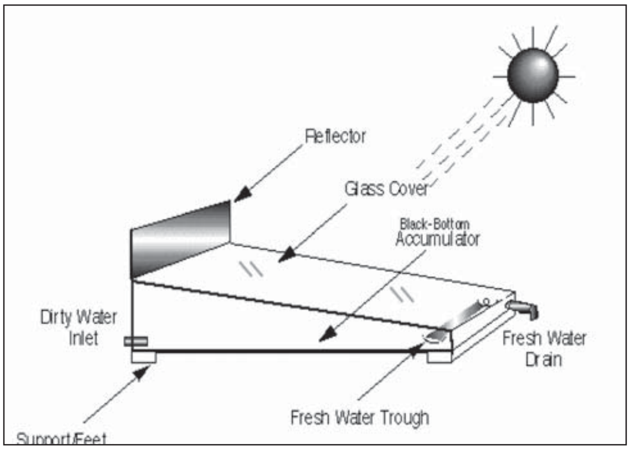

Figure 1. Solar Distiller Model.

Distillation is one of the many processes that can be used for water purification. This requires an energy input,

Tank Type	Life expectancy	Remarks
Fibreglass	Minimum 25 years claimed by manufacturer	Tank must be complete with inlet, outlet and overflow
Concrete	If well built with good quality materials and properly maintained regularly, it can go more than 50 years.	High time consuming in installation and needs open space. Unmovable and leakage problem may happen.
Corrugated galvanized steel	Can be less than 2 years in corrosive environment. If well maintained can pull 20 years of tank life.	Corrosion is the main problem. Inside painting is necessary to extend tank life.
Plastic/HDPE	Generally 15 to 20 years	Probability of leakage can be neglected since there will be no joint in the tank. Light weight
Ferro cement	If well built with good quality materials and properly maintained regularly, it can go 50 years.	High time consuming in installation and needs open space. Unmovable and leakage problem may happen.

Table 5. Life expectancy of Storage Tank (SOPAC 2004).

Source	Reason
Contamination from the Atmosphere	Rain absorbs pollutants from air. In Maldives most of the islands are far from islands that have industries.
Contamination from the roof	Wind-blown dust, birds, can carry faecal pathogens. Cats and birds also can deposit their own faeces. Other contaminants such as dust and leaves can be deposited on roofs by wind and birds.
Contamination from Gutter	Both PVC and galvanized steel can be used for gutters. Pollutants may deposit if fitted flat or with insufficient slope. Providing slope in the gutter is necessary to run the water smoothly. Generally an inclined gutter holds less contaminants.
Contamination during storage	The storage tank must be with good quality cover and all openings should be screened. Generally water quality improves with storage as bacteria and other pathogens gradually die off and other suspended particles settle in the bottom.
Contamination during maintenance	The rainwater system may get contaminated by human contact during storage, tank cleaning, screen cleaning, roof and gutter cleaning. Further, the equipment itself used for cleaning the tanks need to be clean.

Table 6. Causes of Rainwater Contamination (Krishna 2005).

Contaminants	Precaution
Dust, ash and other particles	Can be minimized by regular roof and gutter maintenance and use of proper first flush diverters.
Pathogenic Bacteria	Can be minimized using first flush diverters and good roof and regular tank cleaning.
Heavy metals	Unless wind blows from industrial area, heavy metal contamination in water is minimal. Very acidic rain may corrode the toxic material of the roof. Roof and gutter should not be fitted with lead material.
Mosquito larvae	If tank inlet is well screened, the contaminant risk will be low.

Table 7. Precaution.

as heat, solar radiation can be the source of energy. In this process, water is evaporated, thus separating water vapour from dissolved matter, which is condensed as pure water.

c. UV Treatment

Ultra Violet (UV) treatment is the disinfection process of passing water by a special light source that emits UV waves to inactivate harmful micro-organisms. The UV rays alter the nucleic acid (DNA) of viruses, bacteria, or parasites, so that they cannot reproduce and are considered eliminated. UV treatment does not add chemicals or change the chemical composition of the water. But UV treatment does not remove dirt and particles, metals such as lead or iron, or hard minerals such as calcium. Prolonged storage of water after UV treatment is not recommended.

d. Ozone Treatment

In general, an ozonation system includes passing dry, clean air through a high voltage electric discharge, i.e., corona discharge, which creates ozone concentration of approximately 1% or 10,000 mg/L.

Ozone is effective over a wide pH range and rapidly reacts with bacteria, viruses, and protozoans and has stronger germicidal properties than chlorination but the operational cost of ozone treatment is high, and it may be more difficult to find a professional proficient in ozone treatment and system maintenance.

e. Reverse Osmosis (RO) System

The RO system acts as high pressure water filtration technique. Special membranes are used to remove suspended or dissolved bacterial and chemical impurities up to 1 micron (1 micron=1/1000mm). Generally, it consists of five stages of filtration to provide clean and micro-organism free soft water for drinking purpose.

The chemical impurities like chlorine are filtered through a Granular Carbon Pre-filter; the suspended impurities present in the inlet water are removed by 5 microns sediment Pre-filter. The extruded Carbon Pre-filter also removes bad taste and odor. RO membrane clears the water of bacteria, virus and hardness thus making it safer for drinking. It enhances the taste of water by removing undesirable salts and water.

f. Filtration

A filter is a type of screen that stops particles when water passes through it. No single filter can disinfect the rain water. Filters with smaller pores trap more debris but such filters slow down the water flow. Most filters do not stop microorganisms. Filters of 1 micron size can stop protozoan cysts. Coarse filters range from 20-30 microns in pore diameter and are generally used to catch larger particles. Coarse filters are not designed to filter out chemicals or pathogens but water filtered from a coarse filter holds less pathogens and could be easily removed through less chlorine or UV treatment.

Some Case Studies

Rainwater Harvesting in Maldives

The Maldives comprises of very small, flat and low-lying coral islands. The highest elevation in the islands is just 2 meters above sea level. Family size in a household consists of about 7.3 people.

The Maldives does not have any surface water such as rivers or lakes; thus, freshwater is a scarce resource for a Maldivian. Nevertheless, almost all the islands of the Maldives do have thin groundwater aquifers. Rain water harvesting is practiced in the Maldives since a long time.

Some Bacteria Caused Diseases Associated with Water			
Illness	**Sources**	**Average duration days**	**Possible Complication**
Listeriosis	Faecal matter of infected animals	3-7	Listeric meningitis; headache, stiff neck, Convulsion; miscarriage.
Leptospirosis	Urine of infected mamals	2-5	Jaundice, kidney failure, death
Campylobacteriosis	Faecal matter of animals (birds, domestic and wild)	2-5	Arthritis, Guillan-Barre Syndrome
Diarrhea	Faecal matter of all animals	1	Hemolytic uremic syndrome which causes kidney failure
Enteritis necroticans	Faecal matters of animals	few	Necrotic enteritis
Salmonellosis	Faecal maters of animals including bird and reptiles	5-7	Septicemia, death;mostly in infants and old
Some Protozoan Diseases Associated with Water			
Giardiasis	Faecal matter of infected animals	Several weeks or months	Chronic diarrhea with significant weight loss
Toxoplasmosis	Cat, rodent and other animal Faeces	A few days to several weeks	Damage to eye or brain
Cryptosporidiosis	Faeces matter of animal	2 days to 4 weeks	Sever symptoms lasting for months
Some other Diseases Associated with Water			
Hantavirus pulmonary syndrome	Water contamination from faeces, urine or saliva from infected species	Onset-2-3 weeks after exposure	Severe respiratory failure; even death
Alveolar hydatid	Ingesting the tapeworm egg	Surgical removal and continuous medication	Liver and others

Table 8. Microbial Contamination and Diseases (Macomber 2004).

Figure 2. RO Equipment.

Normally, 1000-2000 litre capacity tank size is used in each house for storing rainwater. The Govt. distributes 1000 litres capacity HDPE tanks.

The average annual rainfall is approximately 1900 mm. The Central, Southern and Northern parts of the Maldives receive annual average rainfall of 1924mm, 2277mm, and 1786mm, respectively. Rainfall is evenly distributed throughout the year, except between January and March when dry periods of three months are common (Shakya, Limbu et al 2007).

Collected rain water is mainly used for drinking. As people do not like the taste of chlorine; most of the people use rain water for drinking without any disinfection.

Photo 1. RWH System in the Maldives.

Case Study of Nepal

In Makawanpur District, Plan Nepal has installed about 609 ferro cement jars of 6,500 liters capacity each. A household is provided with one jar. A performance evaluation was undertaken which shows that about 96% of households used the collected rainwater for drinking without treatment. Only 2% practiced boiling before drinking. It was found that 22% of the samples (2011) and 76.3% (2009 and 2010) were contaminated with e-coli (NDRI 2011).

The RWH system constructed/promoted by the DWSS in various 18 districts show an unacceptable quality of water (contamination of e-coli) in 90% of the samples indicating that the first flush systems were not performing well (WETC 2012).

In Nepal, many of the researchers have been ignoring the effects of lead poisoning. This does not figure in the chemical tests of the water samples.

Conclusion

RWH must be undertaken to augment water supplies wherever feasible. Planning and design should be based on TG. As large percentages of the collected water samples are seen to be polluted with e coli form; proper disinfection is of the utmost necessity.

In Nepal the TG prepared by the DWSS has not yet been finalized even after two years of its preparation. It needs to be finalized after review by the related experts at the earliest.

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Further, the second author's writing is based on the experiences in Nepal and the water quality test data used are from the projects of Plan Nepal and DWSS implemented projects.

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CALENDAR OF EVENTS - RAINWATER HARVESTING

September/October, 2013: International Rainwater Catchment Systems Association Conference. Location: Nanjing, China. More info: http://www.ircsa.org

Satellite-Based Precipitation Estimation for Hydropower Development

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Knut Alferdsen

Abstract: Runoff is one of the major factors that govern the capacity of a hydropower project. Precipitation data are needed for estimation of runoff through runoff simulation using a hydrological model. Dense setup of rain gauge network in a mountainous topography is difficult and expensive. An alternative for this problem is the use of Satellite precipitation data with high spatial and temporal resolution. They have an additional advantage that they represent areal precipitation. But, these data should be duly evaluated before using them. In this study, Tropical Rainfall Measuring Mission (TRMM 3B42) precipitation data are evaluated using ground based precipitation stations over Nepal and fed in a rainfall-runoff model to estimate monthly discharge through four of the major basins of Nepal. A simple water balance model has been used, initially developed by Thornthwaite. Statistical parameters showed significant under-estimation of precipitation over major areas of Nepal. The results from the water balance model presented quiet a good estimation of discharge through basins with an average Nash Sutcliffe Efficiency (R^2) value of 0.8. This implies that TRMM data can be used for runoff simulations over Nepal. The TRMM satellite data can be used during the planning stage of hydropower projects as well as on ungauged catchments.

Key words: TRMM, satellite precipitation, rainfall-runoff model, Thornthwaite water balance, Nepal

Introduction

Discharge and head are the major factors that govern the capacity of the hydropower plant. Head is dependent on topography and discharge depends on catchment characteristics and precipitation falling over the area. Discharge simulation over an area requires measurement of precipitation and feeding data in a hydrological model. The study of spatial and temporal distribution of rainfall is the first step for the planning and development of water resources of the catchment (Islam 2009). A conventional way of measurement of precipitation is done by point measurement from ground based station which is converted to an areal precipitation using different approaches. This needs adequate number of stations spread over the catchment to understand the spatial and temporal variations of precipitation.

Regarding the study of precipitation in case of Nepal, there is a huge change in precipitation pattern even in a small region due to highly undulating surface topography with high hills, mountains and valleys. Moreover, it is rather difficult and expensive to arrange a dense setup of rain gauge network and their periodical maintenance for the study of the spatial variation of precipitation (Islam 2009). In Nepal, though the elevation ranges from 60m to 8,848m, there are only 9 rain gauge stations above 3,300 masl and no gauge stations above 3,900 masl. Most of the river basins remain ungauged. Taking an example, the Lapche Hydropower Project has been identified with a gross head of 1,000m and intake at an elevation of 3,000m. There had been difficulty in understanding the hydrology of the catchment of this project since there were no any recorded data in the catchment of this project. No rain gauge stations have been installed in this elevation range. This could probably be due to difficulty in setup and periodic maintenance of the gauge station as it needs three days of walk from serviceable road to reach the project area.

So, an alternative method for estimating precipitation and thus the discharge through the catchment is required. During the last decade, satellite sensing technologies have been introduced for the estimation of global precipitation. Satellite precipitation maps are derived from satellite observations of infrared, passive microwave and space borne precipitation radar. They also have an advantage over the conventional method as they provide areal estimation instead of point measurement.

In recent years, a number of precipitation products have been developed. The present study undertakes the evaluation and validation of TRMM satellite product relative to precipitation measured in gauges over major basins of Nepal and investigates their application for the determination of monthly water balance over major basins of Nepal, which is presented in Figure 1. The detailed study of TRMM precipitation has been restricted only to the Trishuli catchment (Barros 2000), Narayani Basin (Ghaju 2010) and Bagmati Basin (Shrestha 2008) of the country.

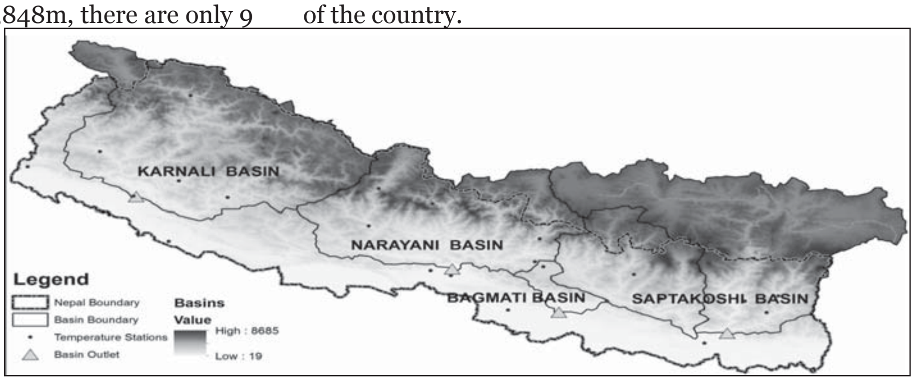

Figure 1. Major Basins of Nepal.

Data Source and Methodology

TRMM Satellite Data

TRMM is a joint mission between National Aeronautics and Space Administration (NASA) of USA and National Space Development Agency (NASDA) (now merged into Japan Aerospace Exploring Agency (JAEA)) of Japan. The satellite estimates rainfall and energy exchange on tropical and subtropical regions of the world based on the characteristics of cloud tops, cloud cover and temperature. TRMM satellite data are available with different levels of calibration and resolution. Among them, TRMM 3B42 version 6 has been used for the study as this product has high temporal resolution and is calibrated and produced after different levels of processing. The principal characteristics of this product are presented in Table 1.

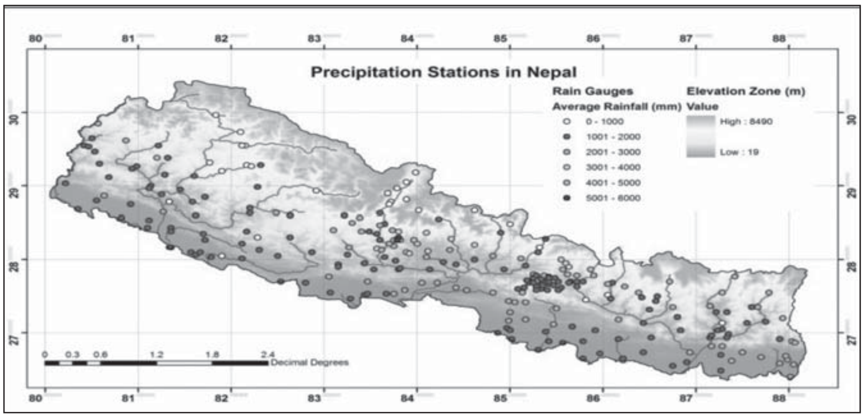

Figure 2. Precipitation Stations over Nepal.

Description	
Data Extent	1998 to present
Geographic Coverage	Latitude: 50°S to 50°N Longitude: 180°W to 180°E
Temporal Resolution	3 – Hours
Spatial Resolution	0.25° x 0.25°
Grid Size	400 x 1440 pixels
Average File Size	Compressed: ~285 KB; Original: ~4.5 MB
Projection	Geographic WGS 1984
Data Format	HDF
Precipitation measurement	mm/hr.
Missing value	-999.9

Table 1. Characteristics of TRMM Satellite Data.

Rain Gauge Data

Rain gauge data are needed for statistical comparison of satellite data for evaluation. Daily rainfall data are collected from 2001 to 2008 for 272 gauge stations spread all over the country. The data are collected from the Department of Hydrology and Meteorology (DHM), Ministry of Environment, Science and Technology, Government of Nepal. The data quality was also checked for individual stations.

Methodology

The raw TRMM data are in HDF format. These data need to undertake a series of processing steps before they could be used to compare with measurements from rain gauges. The steps include format conversion, rotation, clipping, filling of missing data and temporal aggregation. The aggregation is done from 3:00 UTC to 03:00 UTC of the next day. Since large numbers of three hourly TRMM maps are involved, it seems impractical to carry out data processing manually. So, a series of scripts are prepared in Python programming language to automate the processing of TRMM precipitation data. The scripts were initially developed at NTNU (Abdella and Alfredsen 2010; Ghaju 2010) and modified during this study.

The first step includes the conversion of HDF5 files to ASCII grid using external translator library as HDF5 format is not supported by ArcGIS. ASCII grids are rotated counter clockwise to get them in exact grid. These grids are clipped to an area of study to ease handling of data file. The 3-hourly precipitation data are then accumulated as daily, monthly and yearly precipitation maps. The pixel values are then extracted at the gauge locations from these precipitation maps based on gauge coordinates and elevation. Quantitative precipitation estimates from the TRMM satellite data are compared with the available gauge precipitation measurements using different statistical parameters like scatter plot, Nash-Sutcliffe coefficient of efficiency (R^2), coefficient of correlation (RR), Normalized Accumulated Difference (NAD), Root Mean Square Difference (RMSD), Mean Absolute Difference (MAD), Mean Relative Absolute Difference (MRAD), Estimation Bias (EB), Satellite Conditional Probability of Detection (CPOD_S), Gauge Conditional Probability of Detection (CPOD_D).

The Nash-Sutcliffe coefficient is given as (Nash and Sutcliffe 1970):

$$R^2 = 1 - \frac{\sum_1^N (SP_i - GP_i)^2}{\sum_1^N (GP_i - Avg.GP)^2}$$

The range of the index is 1 (perfect fit) to negative infinity.

Estimation Bias (EB) is the normalized difference between the satellite and gauge precipitation data sets evaluated over a long period of time. It is calculated in percentage and is defined as:

$$EB = \frac{\sum_1^N SP_i - \sum_1^N GP_i}{\sum_1^N GP_i} \times 100$$

Satellite conditional probability of detection (CPOD_S) is the measure of probability that precipitation recorded by a gauge is detected by the satellite (Wang 2008). The following equation is used to compute this probability:

$$CPOD\_S = \frac{No.of\ days\ when\ (GP > 0.1\ and\ SP > 0)}{No.of\ days\ when\ (GP > 0.1\ and\ SP \geq 0)}$$

Similarly, Gauge conditional probability of detection (CPOD_G) is the measure of probability that precipitation recorded in a satellite is recorded in a gauge (Wang 2008). The following equation is used to find this probability:

$$CPOD\_G = \frac{No.of\ days\ when\ (SP > 0.1\ and\ GP > 0)}{No.of\ days\ when\ (SP > 0.1\ and\ GP \geq 0)}$$

Where, GP represents gauge precipitation and SP represents the satellite precipitation.

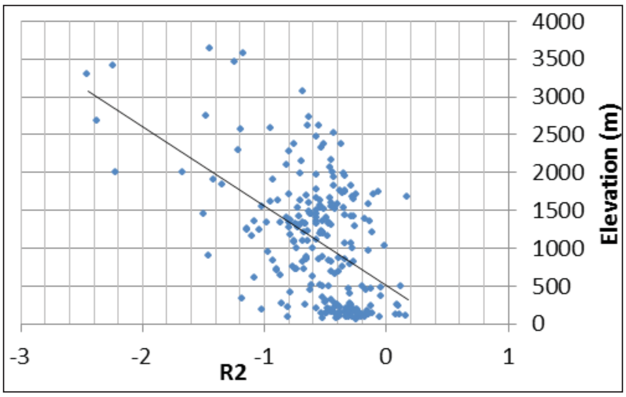

Figure 3. Nash-Sutcliffe, R^2 vs. Elevation for Daily Data Comparison.

Results of Comparison

For comparison, gauge stations with lots of missing data are rejected from analysis; the rejection criteria being ratio of gauge precipitation days and satellite precipitation days are less than 0.8. Additionally, precipitation days with zero recordings on both gauge and satellite are also excluded.

Point to Pixel Comparison

The point measurement of gauge station is compared with the pixel value of satellite derived precipitation at same location. The degree of accuracy depends on pixel resolution. Pixel to pixel method of comparison is not adopted since precipitation stations are not uniformly distributed over Nepal. If stations are scattered and the distance between points are more, there is less influence on the output value of the cell. Nepal has very few precipitation stations at higher elevations. So, this method would provide the precipitation value for a pixel with high error. The accumulated daily, monthly and yearly precipitation TRMM maps are evaluated using Gauge Precipitation data from 2001 to 2008. The results of comparison are summarized in Table 2.

The results show that the TRMM satellite data is deviated from the observed precipitation over most of the gauge stations as the R^2 value is low and negative in most cases. Also, there is a significant ($p<0.01$) decreasing trend of R^2 with elevation that depicts less accuracy with increase in elevation as shown in Figure 3. An average of -10 % of Estimation Bias shows an underestimation. An overall average of CPOD_S of 0.7 reflects good detection of precipitation by TRMM.

Monthly accumulated TRMM data represent better estimation of precipitation as R^2 values for most of the gauge stations lie between 0.5 to 1. This could have resulted due to accumulation of positive and negative errors in the estimation of precipitation by TRMM satellite data. The spatial variability of R^2 over gauge locations is presented in Figure 4.

During comparison, it is observed that some gauge stations (Samargaon (St 624), Sanda (St 625), Manangbhot (St 820)) recorded very low precipitations during the monsoon season although these stations are in a rain shadow zone. As these stations lie in a very remote areaand unskilled local person are employed, there could be error due to lack of proper maintenance, precipitation loss or false reading. The scattered plot for Samargaon (St 624) for the average monthly precipitation is shown in Figure 5. This underlines that there could also be potential errors in gauge data, and it is also worth mentioning that no correction is applied for catch deficiency in any of the data.

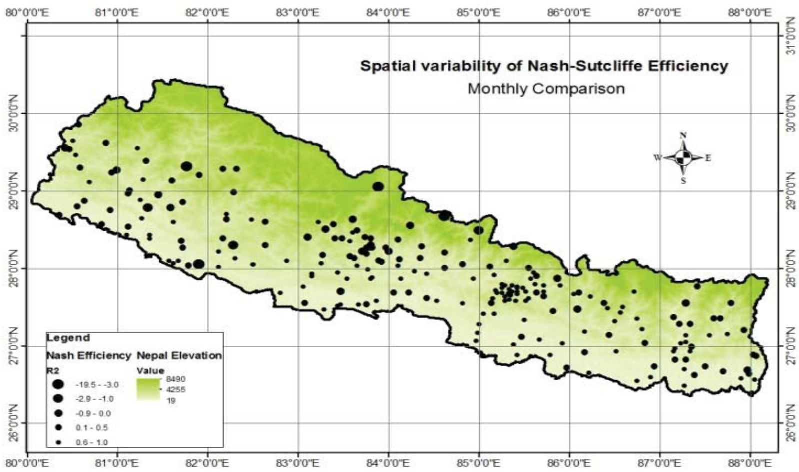

Figure 4. Spatial Distribution of R^2 over Nepal.

Statistical Parameters	Daily		Monthly		Yearly	
	Max	Min	Max	Min	Max	Min
R^2	0.18	-5.42	0.88	-19.47	0.48	-51.82
RR	0.60	-0.06	0.95	0.81	0.80	-0.86
RMSD	56.54	8.05	519.41	42.90	3914.97	167.99
MAD	32.83	4.85	346.67	29.94	3851.18	145.29
NAD	53.23	-75.95	164.08	-78.68	359.67	-78.90
MRAD	11.61	0.74	7.98	0.38	6.15	0.15
CPOD_S	0.89	0.47	1.00	0.91	1.00	1.00
CPOD_G	0.89	0.14	0.99	0.55	1.00	0.83
EB	332.03	-78.44	233.44	-78.65	359.67	-78.90

Table 2. Comparison Results.

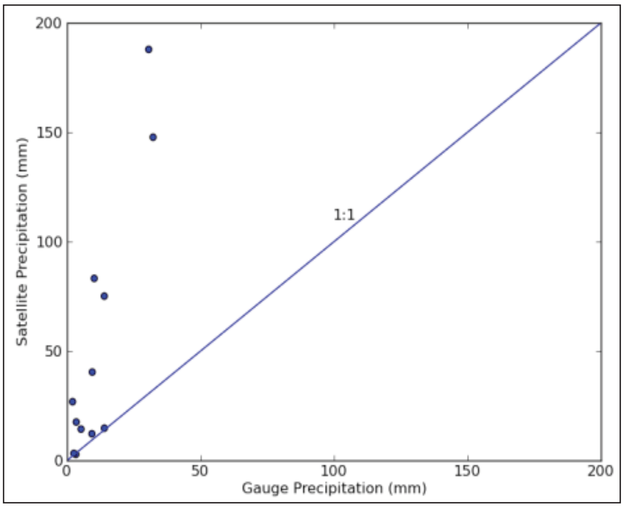

Figure 5. Scatter Plot for Monthly Average Precipitation (Samargaon, St 624).

Spatial Variability within a Single Pixel

The pixel resolution of TRMM 3B42 map is 0.25° x 0.25° which is nearly equal to an area of 27.5 km x 27.5 km. So, the precipitation for this area will share a single value. A comparison is also made between a single pixel and gauge station lying within same pixel. A pixel between 85°15´E to 85°30´E and 27°30´N to 27°45´N is considered in which 11 stations lie within same pixel.

Table 3 depicts that there is a high spatial variability even within a small area.

The correlation between rainfall stations is very low despite of the elevation difference. The comparison between TRMM pixel value and gauge station are made from 2001 to 2008 for daily, monthly, yearly and average monthly precipitations.

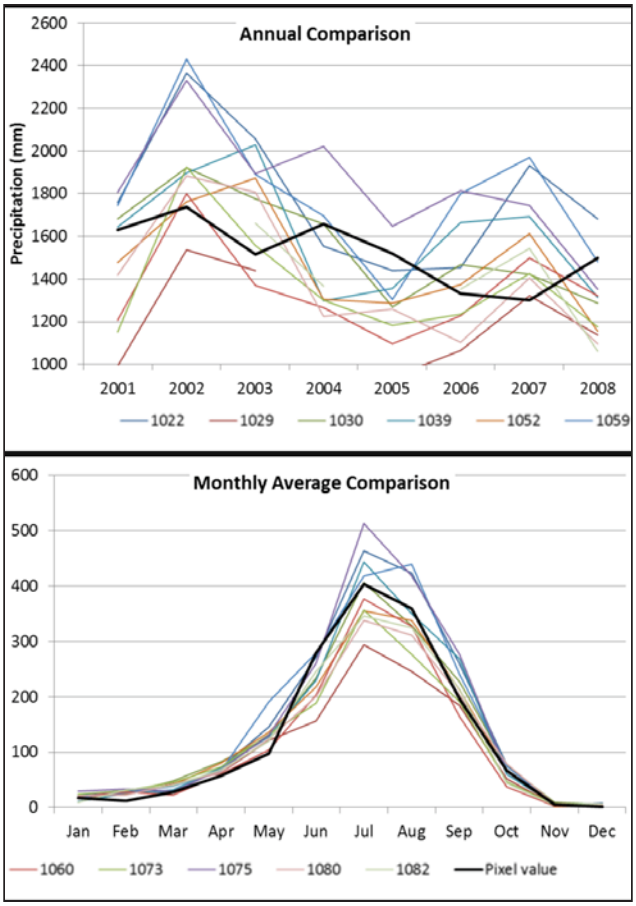

Figure 6. Variation of Precipitation within the Same Pixel.

S. No	Station Pair	Elevation diff. (m)	RR
1	1030 vs. 1039	2	0.27
2	1052 vs. 1080	11	0.23
3	1029 vs. 1030	13	0.26
4	1029 vs. 1039	15	0.19
5	1022 vs. 1029	50	0.38
6	1052 vs. 1082	98	0.44
7	1060 vs. 1075	142	0.18
8	1073 vs. 1082	216	0.35
9	1060 vs. 1073	236	0.22

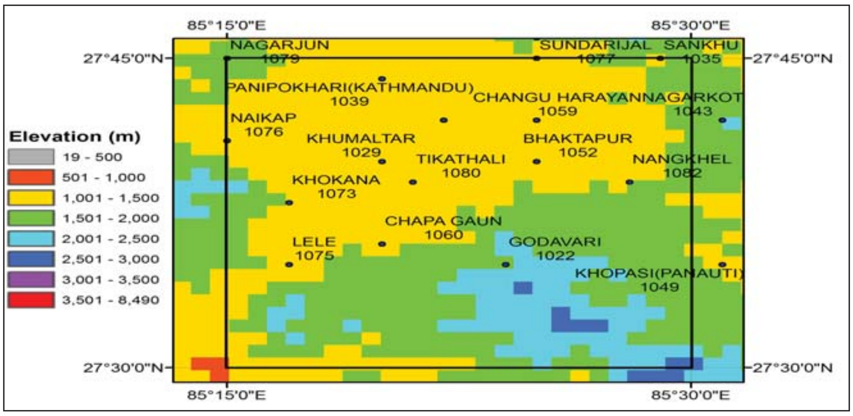

Table 3. Variation of RR within same Pixel for Daily Precipitation Data.

A comparative graph of the annual and mean monthly precipitation recorded by gauge station and TRMM for the pixel is presented in Figure 6. It can be seen from the comparison that the annual precipitation recorded in the gauge stations in 2004 varies from 1100 to 1800 mm even within a single pixel whereas TRMM refers to a value of 1600 mm. This states that TRMM is estimating an average value for the pixel. Similar findings can be derived from the mean monthly precipitation comparison as shown in Figure 6. This states that the error in TRMM data might have resulted due to averaging of the precipitation value for the pixel.

Monthly Water Balance Model

One of the applications of the precipitation study is for its use as an input for rainfall-runoff modeling. The model predicts surface runoff from the catchment. A monthly Water Balance model has been widely employed for long term forecasting of water resources distribution. Though a wide range of complicated water balance models with many catchment parameters have been developed, a simple monthly water balance model can still be efficient and useful in terms of runoff simulation.

The model used for the study was initially developed by Thornthwaite (Thornthwaite, 1948). The study used

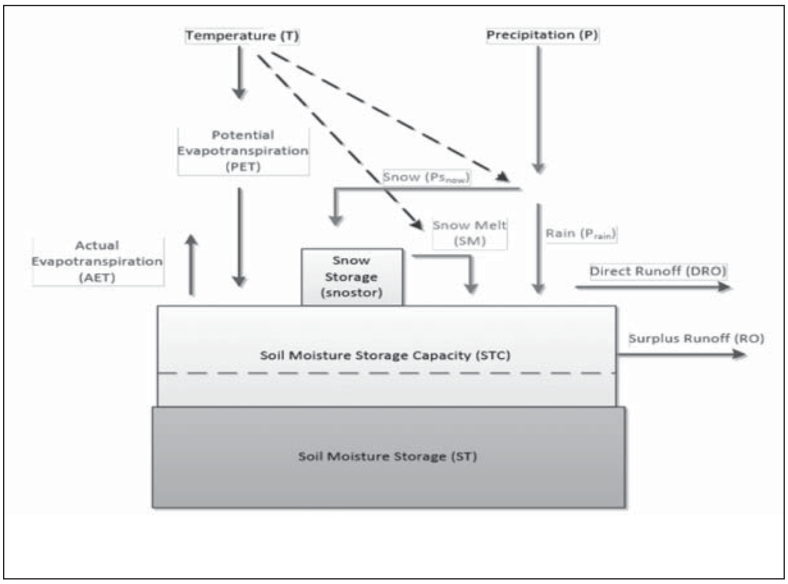

Figure 7. Thornthwaite Monthly Water Balance Model.

the 3 parameter monthly water balance model for 4 major basins of Nepal. The scripts were prepared in R software by Emmannuel Jjunju (NTNU, PhD) to handle the distributed simulation.

The model consist of two storage parameters: soil moisture capacity and storage constant. The model assumes that some fraction of the precipitation is immediately transformed to direct runoff. Inputs to the model are mean monthly temperature and total monthly precipitation. The potential Evapo-transpiration is calculated with respect to the latitude of the location. The framework of the model structure is presented in Figure 7.

The form of precipitation over the catchment (either snow, rain or both) is determined by the threshold temperature for rain and snow. If the temperature is below the threshold temperature for snow (T_{Snow}), all precipitation will be snow. When the temperature is greater than the threshold for rain (T_{Snow}), all precipitation is considered as rain. If the temperature is in between T_{Snow} and T_{rain}, the amount of accumulated snow and rain varies inearly with temperature. The threshold temperature for rain (T_{rain}) is taken as 3.3°C and that for snow (T_{Snow}) depends on elevation which is equal to -10°C for elevation below 1,000m and -1°C for above 1,000m. The amount of snow that melts from the accumulated snow depends on the mean monthly temperature and maximum melt rate.

For this model, the monthly Potential Evapotranspiration (PET) is estimated using Hamon's equation (Hamon, 1961). Hamon's equation assumes that there is abundant water in the catchment. Actual evapotranspiration is then derived from this PET, total precipitation (PTotal), soil moisture storage (ST) and soil moisture storage withdrawal (STW). When PTotal exceeds PET, the excess water replenishes soil moisture storage and when ST becomes greater than STC, surplus water flows as runoff. Soil moisture storage withdrawal decreases linearly with decreasing Soil moisture storage (ST). The total runoff from the catchment is then calculated as the sum of direct runoff and surplus runoff.

Data Preparation

The model has been simulated over 4 major basins of Nepal namely Karnali, Narayani, Bagmati and Saptakoshi. The hydro 1k DEM model of the basins is presented in Figure 1.

The elevation of the basins range from 60m to 8,848m, the higher elevations being in the northern part and low lands on the southern part. Thus, snow/ice has a major contribution on the discharge through the

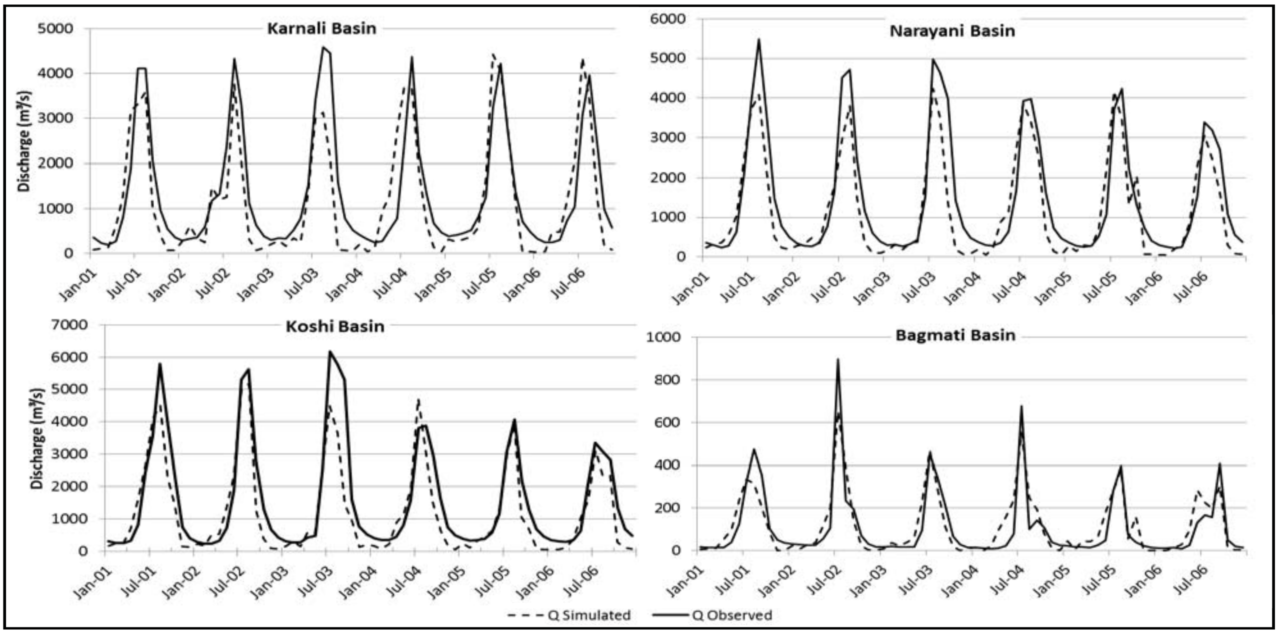

Figure 8. Simulated and Gauge Discharge for Major Basin.

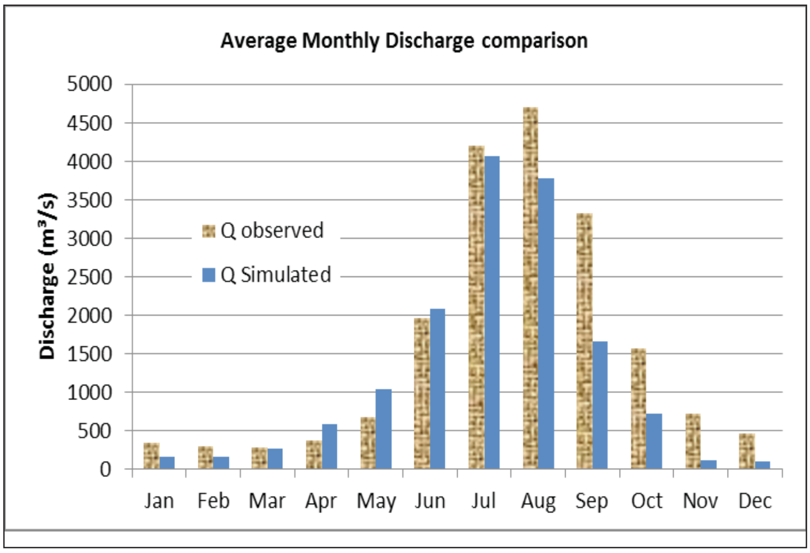

Figure 9. Mean Monthly Discharge for Saptakoshi Basin.

for the Narayani basin is presented in Figure 10. The R^2 values obtained for the Karnali, Narayani, Bagmati, Saptakoshi and Sunkoshi basins are respectively 0.745, 0.826, 0.803, 0.816 and 0.802. This shows quite a good estimation of discharge for big basins using a simple rainfall-runoff model.

An average runoff map is created using the monthly discharge computed by the model for each cell. The pixel size is 0.25° x 0.25°. The map can be used for initial planning of water resource projects like hydropower project to estimate the discharge through a point, e.g. as a tool in scaling the observed discharge to study sites.

basin. Temperature data from each basin were collected to prepare a monthly temperature map with an adiabatic lapse rate of -0.005°C/m. TRMM satellite maps were used to feed monthly precipitation data for the model. Since the spatial resolution of TRMM data is 0.25° x 0.25°, temperature maps were also prepared of the same resolution.

River discharge data is used for the calibration of parameters for the model and comparison. The data are collected from the DHM.

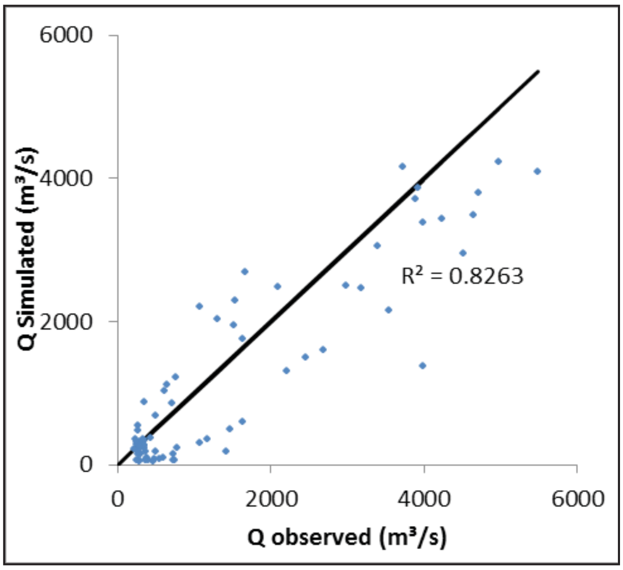

Figure 10. Scatter Plot for Narayani Basin with Coefficient of Correlation.

Simulation and Results

The Thornthwaite water balance model was calibrated for 4 major basins of Nepal using TRMM precipitation data. The parameters have been adjusted for the best fit of the simulated discharge curve. The parameters possess similar values for all of the basins. High direct runoff factor indicates that 90 % of the rainfall is drained immediately by rivers resulting in flash floods.

The mean monthly observed and simulated discharges were plotted from 2001 to 2006 for each basin as shown in Figure 8. The figure shows quite a good match between the observed and simulated values except for the fact that the model is not able to represent the falling limb in some years, but this should not influence the computation of annual runoff value used in the runoff map.

The average observed and simulated discharges for each month are also compared. The comparison shows that the model has a good estimation of the rising limb, but the recession limb is not yet estimated perfectly. The graph for the Saptakoshi basin is presented in Figure 9.

A scattered plot is also prepared to observe the variation in the gauge and simulated discharge. The plot

Conclusion

The study results showed a clear indication of the underestimation of precipitation by TRMM satellite data. The conclusions derived from this work seem to be in good agreement with the results from Barros

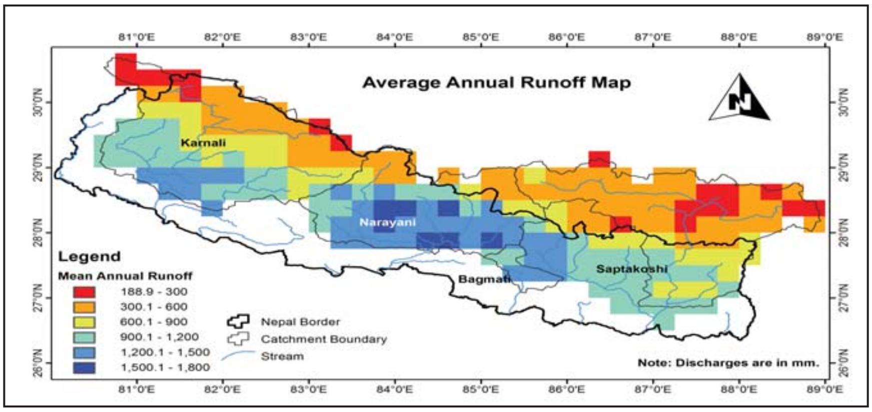

Figure 11. Average Runoff Map of Nepal.

(2000), Shrestha (2008) and Ghaju (2010). Yet, the results also suggest that TRMM could be applied for runoff simulation to the catchments where there is no precipitation station for early investigations.

The study used a very simple rainfall-runoff model for runoff simulation. A better model can be employed to observe the detailed characteristics of TRMM data. An extensive study and research should be done for investigation on the use of TRMM data over the country before making a concrete conclusion.

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CALENDAR OF EVENTS - HYDROPOWER AND DAMS

5-6 March, 2013: HydroVision Russia. Location: Moscow, Russia. More info: http://www.hydrovision-russia.com/en_GB/index.html

16-18 April, 2013: Water Storage and Hydropower Development for Africa. Location: Addis Ababa, Ethopia. Contact Email: mb@hydropower-dams.com. More info: http://www.hydropower-dams.com.

22-24 April, 2013: National Hydropower Association Annual Conference. Location: Capital Hilton, Washington D.C., USA. More info: http://www.nationalhydroconference.com/index.html

6-8 May, 2013: HydroVision India 2013. Location: Bombay Exhibition Centre. Location: Goregaon, Mumbai, India . More info: http://www.hydrovisionindia.com/index.html

21-24 May, 2013: IHA World Congress on Advancing Sustainable Hydropower. Location: Kuching, Malaysia. More info: http://www.ich.no/

4-6 June, 2013: POWER-GEN Europe Conference and Exhibition. Location: Vienna, Austria. More info: http://www.powergeneurope.com/index.html

23 - 26 July, 2013: HydroVision International 2013. Location: Colorado Convention Center Denver, Colorado, USA. More info: http://www.hydroevent.com/index.html

9-11 September, 2013: 4th Australasian Hydropower Conference 2013, Synergies with other renewables-wind and irrigation. Location: Rotorua, New Zealand. More info: http://www.hydroconference.co.nz/

24-26 September, 2013: HydroVision Brasil. Location: Transamerica Expo Center, Sao Paulo, Brasil. More info: http://www.hydrovisionbrasil.com/en/index.html

24-26 September, 2013: Power-gen Brasil. Location: Transamerica Expo Center, Sao Paulo, Brasil. More info: http://www.powergenbrasil.com/en/index.html

Flooding and Inundation in Nepal Terai: Issues and Concerns

Basistha Raj Adhikari

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Abstract: During the monsoon months from June to September, all the rivers in Terai are in spate with bank-full discharges and cause flooding and inundation. The problems of flooding and inundation in the Terai are more critical due to change in climate in general and change in rainfall pattern/intensity in particular. This article tries to highlight the issues and concerns of flooding and inundation in the Terai and suggests measures to mitigate these issues in light of climate change adaptation.

Key words: Flooding, inundation, River Training Works, Terai, Nepal

Introduction

The Terai region of Nepal occupies about 17 percent of the land area (25,000 km^2) and forms the northern edge of the Indo-Gangetic plain. The Terai area is popularly known as the granary of the nation. The topography of the Terai is almost flat with gentle slope towards the south. The elevation of the Terai ranges from 65m to 300m from mean sea level with varying width of 20 km to 45 km. The climate of the Terai is subtropical with average temperature of 25^{o}C. The rainfall of the Terai varies from 1,200 mm to 3,000 mm per annum with occasional showers and cloudbursts. All the rivers of Nepal debouch into the Terai plain at the foot hills of the Churia and Siwalik ranges and provide water for livelihood of the Terai. During the monsoon months from June to September, all these rivers are in spate with bank-full discharges and cause flooding and inundation in several parts of the Terai. The problems of flooding and inundation in the Terai are more critical due to change in climate in general and change in the rainfall pattern/ intensity in particular. This article tries to highlight the issues and concerns of flooding and inundation in the Terai and suggests measures to mitigate these issues in light of climate change adaptation.

River Systems of Nepal

According to the origin, size and nature of the flow, Nepal's rivers are grouped into three categories:

- Large rivers originating from the Higher Himalayas,
- Medium rivers originating from the Mahabharat Hills, and
- Small rivers originating from the Siwalik and Churia Hills.

The largest four rivers of Nepal, i.e. the Koshi, the Gandaki, the Karnali and the Mahakali originate from the high Himalayas and carry large discharges. These rivers are incised in the hills and mountains and are comparatively less vulnerable until they debouch into the Terai plain. The average discharge of the Koshi, Gandaki and Karnali range between 1,350 m^3/s to 1,600 m^3/s while the average discharge of the Mahakali River is 726 m^3/s. In the Terai these rivers often cause flooding and inundation over large stretches of land adjoining their banks.

The medium rivers that originate from the Mahabharat hills experience monsoon discharge of 2,000 m^3/s to 8,000 m^3/s and create havoc of flooding and inundation in the Terai. These rivers transport significant amounts of sediment while flowing through the Churia range and exhibit lateral shifting. These rivers are wide as they enter into the Terai plain and start meandering after the Bhabar zone. These rivers are the Kankai in Jhapa, Kamala in Siraha and Dhanusha, Bagmati in Sarlahi and Rautahat, Tinau in Rupandehi, West Rapti in Dang and Banke, and Babai in Bardiya districts.

The small rivers originating from the southern slope of the Churia hills are named as Churia rivers. The length of these rivers up to the Nepal-India border ranges between 25 km to 85 km. These rivers are numerous and cause local erosion and deposition in the Terai belt. These rivers have special morphological characteristics that aggravate the flooding and inundation in the Terai of Nepal. The most vulnerable Churia Rivers are the Biring and Ratuwa in Jhapa, Bakraha and Lohendra in Morang, Sunsari in Sunsari, Khando in Saptari, Balan and Gagan in Siraha, Rato in Mahottari, Jhim and Lakhandehi in Sarlahi, Lal Bakaiya in Rautahat, Pashaha in Bara, Rohini in Rupandehi, Banganga in Kapilvastu, Khutiya in Kailali and Dhondha in Kanchanpur districts. These Churia rivers have special characteristics that are described in their proper context below.

River Morphology in the Terai

The river morphology in the Terai depends upon the origin, flow magnitude and sediment load of the river. The rivers originating from the Churia hills are characterized as flashy with negligible or low flow during the dry season. In addition, the large rivers also change their morphology as they debouch into the Terai plain with flatter slopes and wide widths. The morphological characteristics of the rivers flowing through the Terai are briefly described hereunder:

Severe Erosion in the Hill Slopes: The Churia hills are the youngest hills in the Himalayas formed about 2 million years ago (Neocene period). Their composition is made of sedimentary rocks such as mud-stones, sand-stones, and conglomerates. The Terai areas of

Nepal experience relatively higher rainfall intensity (Carson 1985) which contributes to higher soil erosion in the slopes of the Churia hills. The rivers that originate from the Churia hills bring a lot of sediment thereby eroding the hill slopes as well as river banks (Photo 1).

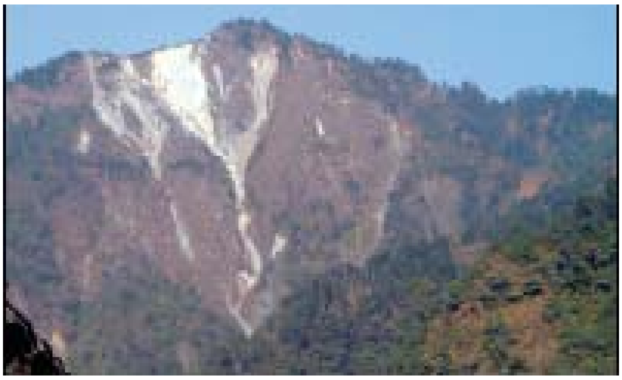

Photo 1. Degradation of Catchment in the Churia Hills.

Excessive Sediment Load: The Churia range contributes maximum sediment load to the rivers originating from the southern face (Sharma 1977). According to a JICA study, the annual sediment yield of the Lakhandehi river is estimated as high as 178,000 m^3 per year. In some stretches of the Churia rivers, almost two meters of sediment has been deposited in the last 45 years (Dixit 1995). Due to the higher sediment load, the bed level of several rivers are rising significantly. The case of the Lothar river in Chitwan District is typical of this phenomenon (Photo 2).

Photo 2. Sediment Accumulation under the Lother High Bridge.

Wide and Braided Channels: Most rivers in the Terai are braided at the Bhabar zone and prone to change their course frequently. In many cases, these rivers find a new path and enter into the cultivated lands leaving the old course. This is also evident in some medium sized rivers. For example, the bifurcation of the Tinau River into the Tinau and Dano rivers just downstream of the East-West Highway Bridge after 1978 flood is a typical example of the Terai river characteristics.

High Peak Floods: Runoff in Churia Rivers concentrates only in the monsoon months from June to September. Factors like short steep slope, overgrazing, deforestation, and short time of concentration produce high peak flood during the monsoon. In general, the runoff duration is less than one day and the flood hydrograph is very sharp with high peak discharge.

Photo 3. Flood in Mahakali River in 2009.

Narrow Width at Nepal-India Border: Most of the Churia Rivers have relatively narrow width at the Nepal-India border. During heavy rainfall these rivers spill over the banks and flooding and inundation occur for some time depending on the topography, slope of the river and the waterway. A typical example of a narrowing river width is the Rato River in Mahottari District. The Rato and Jangha rivers in Mahottari District lie 6 km apart at the East-West Highway. The span of the Highway Bridge at the Rato River is 204m. After joining the Jangha and Ankushi rivers, the span of the bridge over the Rato River at the Bardibas-Jaleshwor road narrows down to about 100m. Further downstream near the Nepal-India border at the Jaleshwor-Bhirttamod road, the span of the bridge is narrowed again to only 30m.

Topographical Depressions: Some of the Churia Rivers form topographical depressions such as marshy lands, swampy lands and oxbow lakes in the lower reaches of the Terai. These depressions have formed due to excessive meandering, abandoning of the old course, and avulsion of the rivers or their part. The Sunsari River at Maria Dhar, old course of the Kankai River are some of such examples. The medium sized river Babai in Bardiya District had also changed its course and formed topographical depressions in the west of Gularia some 80 years ago.

Rainfall-Runoff Process in the Terai

Past experience shows that flooding and inundation occur following high intensity rainfall in the Churia hills and Terai. A rainfall intensity of 350 mm for consecutive 48 hours is considered as high intensity rainfall (Sharma 1988). In addition, rainfall exceeding 70 mm per hour is considered as cloudburst rainfall (Gyawali 2011) which disrupts both the slopes and channel equilibrium at the local as well as regional scales. Precipitation events exceeding 375 mm in 24 hours have been recorded in different parts of the Terai between 1959-1993 and maximum rainfall data is shown in Table 1.

S. No.	Station Code	Station Name	District	Mean Annual Rainfall (mm)	Max Mean Monthly Rainfall (mm)	
1	0215	Godavari	Kailali	2,279	700	July
2	0416	Nepalgunj	Banke	1,338	426	July
3	0705	Bhairahawa	Rupandehi	1,609	509	July
4	0906	Hetauda	Makwanpur	2,283	566	Aug
5	1121	Karmaiya	Sarlahi	1,718	443	Aug
6	1421	Gainde	Jhapa	2,853	683	Aug

Table 1. Maximum Rainfall Records in the Terai.
Source: Department of Hydrology and Meteorology (DHM) Data

Past Flood Events in the Terai

Historical evidence shows that the floods of 1785, 1787, 1793, 1806, 1867, and 1871 in the 19th century were major ones. During the 1871 floods, rainfall of 483 mm in 36 hours was recorded causing heavy loss of lives and property in Nepal's Terai and India. In 1883, about 2,300 km^2 of area situated at the northern part of the railway line in India was flooded severely. Thousands of houses collapsed and crops of some 1,000 villages were almost ruined.

In 1902, excessive rainfall along the lower reaches of the Himalaya had caused heavy floods in the Nepal Terai. In 1926, heavy floods occurred in the Bagmati River in the Terai and 75 percent of Bhadai (harvested at mid September) crops and 50 percent of Aghani (harvested in late November) crops were damaged completely in the Terai and adjoining Indian Territory. In 1934, the floods of the Bagmati River had caused it to shift its course towards the right in India. In 1935, severe floods and inundation again occurred in the Terai and India. The Sitamani railway embankment in India was breached by flood. In recent times, heavy floods were observed in the Nepal Terai and northern India. The floods of 1954, 1956, 1958, 1960, 1962, 1981, 1987, 1993, 1998, 2002, 2004, and 2008 are vividly imprinted in the memories of the people. The details of some flood events are briefed hereunder:

Floods of 1978 in Butwal: With the intense rainfall in the Churia hills, a landslide occurred in the Butwal area in September 1978. The landslide had blocked the river Tinau, and upon burst of the landslide dam, the high surge of water had washed away the newly constructed bridge over the river along the East-West highway, diversion weir of the Tinau Irrigation Project and other public property. This flood had not only damaged the infrastructure and property adjacent to the river bank but also had changed the flow pattern of the river. A rainfall of 125 mm within a few hours had been experienced in Butwal (Sharma 1988).

Floods of 1987 in the Eastern region: In August 1987, an intense rainfall of 200 mm had caused flooding and inundation in the Eastern Terai. The East-West Highway was damaged in several places. In some locations, 50 cm deep water was flowing over the road pavement causing submergence of agricultural lands adjacent to the highway (Sharma 1988). The most flood affected districts then were Jhapa, Morang, Sunsari, Saptari and Udayapur.

Floods of 1993 in Central Nepal: The floods of 1993 were one of the worst in the history of Nepal which had resulted in the deaths of 1,336 persons. The maximum daily rainfall of 540 mm was recorded in Tistung of Makawanpur District on 19 July 1993. This was the highest daily maximum rainfall ever recorded in Nepal. The floods had also inundated sixty thousand ha of agricultural land in the Terai and washed way 67 irrigation systems. The peak flood of the Bagmati River is a typical example of a highly disastrous flood in the history of the country, which had washed away part of the Bagmati Barrage and inundated vast areas in Sarlahi and Rautahat districts.

Koshi Flood of 2008: The devastating Koshi flood disaster occurred on 18th August, 2008 near Kushaha village of Sunsari District due to a breach of the eastern embankment of the Koshi barrage. The barrage and embankments were constructed in the 1960s under the Nepal-India Koshi Project Agreement. Four VDCs of West Kushaha, Haripur, Shripur and Narsingha of Sunsari district were severely affected from the flood disaster. At the time of the breach, the Koshi river had only 4,700 m^3/s of water flowing through the barrage. The flood flow was minimal of August flow against the highest flood of 26,990 m^3/s (Dixit 2008) recorded in 1968.

Photo 5. Forced Migration due to Flood.

Photo 6. Koshi Flood 2008.

Photo 7. Damage of Crops in Far-West Flood, 2008.

Far-West Flood of 2008: One month after the devastating flood of the Koshi, downpour generated by cloudbursts occurred in the Far-western region. Most of the mountain districts were affected by a series of landslides while the Terai districts were affected by floods. All the rivers that originate from the Churia hills swelled with bankful discharges, spilled over their banks, eroded adjacent agricultural lands, deposited sands and silt on nearby houses, and inundated settlements for days. The East-West highway was eroded in two-three places in Kailali and Kanchanpur districts along with damages to irrigation projects, transmission lines, and other public and private infrastructure.

Barriers as Drainage Congestion in Terai

Drainage congestion is one of the reasons causing flooding and inundation in the Terai. Some of the examples of drainage congestion are briefed hereunder:

East-West Highway: The East-West highway connects all Terai districts by a single strategic road network and is considered as a backbone of national economic development. It traverses mostly along the foot hills of the Churia range and acts as a barrier embankment especially for rivers and streams that originate from the Churia hills. In 2007 September, a small culvert near Chormara in Nawalparasi district was washed out by flood water due to drainage congestion.

Bridges and Culverts: The waterway opening of the bridges and culverts constructed in the Terai area seem to be on the non conservative side to address the floods from upstream catchments. There are several examples of damages to the bridges and culverts due to drainage congestion. In 2007 September, a highway bridge over the Dhanshar River in Rautahat District collapsed by flooding, and traffic movement was interrupted for days. Two causeways needed to be replaced in Nawalparasi district on the Danda Khola and Janga Khola. The over flanking of the East-Rapti river from its left bank upstream of the highway bridge near Hetauda by the flood of 2007 had also interrupted traffic for many days.

Urban Settlements: Most of the urban settlements in the Terai are prone to inundation after intense rainfall events due to improper drainage provisions. The inundation of Nepalgunj in 2007 July is an example of drainage congestion owing to deficient urban planning and management. The inundation lasted for a week in most of the city centers including New Road, Gharbari Tole, and Surkhet Road. A maximum rainfall of 205 mm was recorded in Nepalgunj on July 27, 2007 which caused flooding and inundation in Nepalgunj (KC 2008). Similarly, Biratnagar, Bhairahawa, Narayanghat and Janakpur are also prone to inundation time and again due to drainage congestion. The inundation of Gaur Bazar is a different case as it becomes inundated due to congestion of sheet flow over the entire area from the Lalbakeya River on the West and Bagmati River on the East. The main cause of this inundation is the construction of the Bargenia Ring Bund in Indian Territory which blocks the flow path of natural drainage from Gaur Bazar.

Hulaki Sadak: The cross-country postal road or *Hulaki Sadak* is being implemented under Indian assistance in the Nepal Terai. The proposed length of the road is

Photo 8. Mahali Sagar of Kapilvastu District.

1,446 km which is aligned mostly within 10 km of the Nepal-India border from Mechi to Mahakali. It passes through flat Terai terrain and acts a barrier to sheet flow. The confinement of the road at the location of bridges

S. No.	Name of river	Span of bridges (m)		Remarks
		E-W Highway	*Hulaki Sadak*	
1	Gagan	128	46	In Siraha district
2	Rato	204	102	In Mahottari district
3	Lakhandehi	250	100	In Sarlahi district
4	Lalbakeya	361	120	In Rautahat district
5	Aurahi	319	50	Aurahi and Basai form Bighi river in Dhanusha district

Table 2. Typical Bridge-spans in E-W Highway and *Hulaki Sadak*. Source: Field Survey, 2009

may aggravate the drainage congestion. The alignment of the postal road starts from Chandragadi, Jhapa to Dewanganj, Sunsari through Rangeli in Morang District and joins the E-W highway to cross the Koshi river. In Siraha District, the *Hulaki Sadak* is just a few hundred meters north of the Nepal-India border where the Gagan River crosses it. In Nawalparasi and Rupandehi districts, it joins Bhairahawa town with Parasi and after Bhairahawa follows the Lumbini Road up to Taulihawa. The waterways provided to pass the flood under the bridges of the *Hulaki Sadak* are significantly narrow and cause flooding and inundation in several locations. In addition, the comparison of waterways of the bridges along the E-W Highway and *Hulaki Sadak* shows significant deviation (Table 2) in respect to the same river.

Inundation at Southern Border Points: All the rivers of Nepal drain to the Ganges basin crossing the Nepal- India border in the Terai plain. The total length of the border with India is estimated as 1,808 km, of which rivers act as the border between Nepal and India for about 595 km of length (Shrestha 2009). The infrastructures constructed just downstream of the border across the contour have congested the drainage passage of the natural water bodies and have caused inundation in upstream areas adjacent to the border. India has constructed dozens of the embankments, dams water control structures just at the boarder inundating Nepalese territory/farmland. Nepal's request to alleviate the problems have not been considered by India. The major structures constructed at the border points in India that cause flooding and inundation in Nepalese territory are:

- Girijapuri barrage on the Karnali river (Ghaghra in India),
- Saryu barrage on the Babai river (Saryu in India),
- Laxmanpur barrage on the Rapti river,
- Banganga barrage on the Banganga river,
- Goabari weir on the Lalbakaiya river, and
- Dheng bridge on the Bagmati river

The main canals that pass along the contour under the Koshi and Gandak Project agreements between Nepal and India have also created drainage congestions time and again. The Gandak Western Main Canal and associated structures are causing flooding and inundation in Nawalparasi District due to drainage congestion of these structures. Similarly, the Koshi Western Main Canal also adversely affects the area in Saptari District of Nepal. In addition, embankments constructed in India near the Nepal-India border block the sheet flow as well as natural drainage passage causing flooding and inundation in Nepalese territory. The major embankments constructed in India adjacent to the border are:

- Kalkalawa Bund in the Rapti river (right afflux bund of Laxmanpur barrage),
- Khurd-Rasiwal Bund (K-G Bund) in the Danav river (Kunha in India),
- Bargenia Ring Bund near Gaur Bazar in Rautahat District,
- Kunauli embankment in the Khando river near Trilathe in Rajbiraj District, and
- Mechi embankment in the Mechi river near Kakarbitta in Jhapa District

Furthermore, the implications of these embankment bunds are many. Lack of proper maintenance of drainage flow paths under the cross-drainage structures of irrigation canals in India also aggravates the flooding and inundation in the Nepal Terai. Drainage congestions on the Ghorasain branch canal of Gandak Project are the typical examples in this respect.

In addition, there are several isolated irrigation projects and small embankments in India near the Nepal-India border that cause flooding and inundation in the Nepal Terai. Some of the minor irrigation structures are:

- Mahali Sagar, Bajha Sagar, Siswa Sagar and Marthi Sagar in Kapilvastu District,
- Danda Barrage on the Danda river near Sunauli in Rupandehi District,
- Masauliya barrage on the Rohini river in Rupandehi District and,
- Kantawa Irrigation in the Maraha river in Siraha District

The Sagars in Kapilvastu District are the typical examples of pond irrigation. These Sagars provide irrigation to the bordering area of India at the cost of inundation in Nepal territories. More than 60 percent of the reservoir area of these Sagars lies in Nepal at normal water level. The situation aggravates during the heavy monsoon rainfall and delay in gate operation by the Indian authority who live far away from the location of these gates.

Initiatives to Cope with Floods and Inundation

People of the Terai area have been compelled to live with floods and inundation since time immemorial. People have adopted indigenous local coping measures to survive the floods and inundation. The Government has also been implementing several flood protection and rehabilitation measures. In addition to the humanitarian support to the victims of the floods, there are institutional efforts of the Government towards mitigating flooding and inundation in the Terai, which are briefed hereunder:

Department of Water Induced Disaster Prevention (DWIDP): The DWIDP is the leading Government agency to deal with the water induced disasters in general and floods in particular. In 1991, the Disaster Prevention Technical Center (DPTC) was established to address the water induced disasters in a coordinated way under JICA assistance. Considering the positive impacts of DPTC, the Government has converted it into the DWIDP since 2000. To cope with ever increasing demands of disaster mitigation at the local level, the GON has expanded the DWIDP through divisions and sub-divisions along with the inclusion of River Training Projects known as Peoples embankment. In addition to the structural measures of river training, the DWIDP also imparts awareness and training activities to the concerned persons and institutions. The river training works carried out so far are in the Bakra River in Morang, East-Rapti River in Chitwan, and Mahakali River in Kanchanpur districts.

JICA Study on Flood Mitigation Plan: In 1999, JICA carried out the study on flood mitigation plan for selected rivers in the Terai plain. These rivers are the Khutiya in Kailali, Babai in Bardiya, West Rapti in Banke and Dang, Tinau in Rupandehi, Narayani in Chitwan and Nawalparasi, Lakhandehi in Sarlahi, Lohendra in Morang and Ratuwa in Jhapa. The study also carried out the detailed feasibility of two most vulnerable rivers, Babai and Lakhandehi, on a priority basis and suggested to implement the flood mitigation plan as soon as possible. The flood mitigation plan suggests three components for its sustainability: watershed management, river control measures and community development activities.

Extension of Embankments and Indian Cooperation

Realizing the seriousness of the flooding and inundation problems in the vicinity of the Nepal- India border, it was agreed to extend the embankments from the border along both banks of the vulnerable rivers. Since 2002, embankment constructions are being carried out in the Bagmati, Lalbakeya and Kamala rivers with grant assistance from the Government of India. Adjoining areas of these rivers in Rautahat, Sarlahi, Dhanusha and Siraha districts have been protected from the recurrent floods and inundations. However, many trans-boundary rivers are awaiting a positive response from the Indian side towards mitigating floods and inundation along the southern border.

Apart from the Governmental initiatives, there are several Non-Governmental Organizations (NGOs) working in the field of floods and inundation in the Terai.

Suggestions to Mitigate Flooding and Inundation in the Terai

Floods are natural process and we can only reduce the impacts of the floods. Following are some of the issues and concerns to be addressed to reduce the floods impacts.

- **Discourage the Tendency to Encroach Upon Marginal Lands at the River Banks:** Many poor people take shelter at the banks of the river due to the availability of jobs and free fertile land in the river valley. Many marginal people are maintaining their livelihoods through cultivation of steep sloppy lands and river banks which are susceptible to flooding and inundation. This tendency is increasing day by day. The case of settlements along the Tinau River is an example.

- **Manage River Bed Mining:** The increasing trend of river bed mining and its un-planned management is one of the most notorious activities responsible for flooding and inundation. On the one hand, thousands of people do find their jobs in collecting, screening and transporting river bed materials, and on the other hand, severe environmental consequences arise due to the extraction of boulders and gravel from the river bed thereby lowering its level. The problem has been aggravated due to issuance of export permits to the neighboring country by the District Development Committees (DDCs). Almost all Terai DDCs are generating revenues by exporting the river bed material and consequently inviting flooding and inundation at the homes of poor people. It is very high time to manage river bed mining in a planned, judicious and limited manner so as to sustain the environment and reduce the vulnerability to flooding and inundation.

- **Enforce Land Use Rules and Regulations:** Proper land use based on topographic and agronomic considerations is key to a planned development approach. The settlement area should be at a higher elevation than the cultivation area. Due to absence of land use regulations, several houses are constructed in the most fertile lands of the Terai. Hence, proper land use regulation and its enforcement are essential to reduce the vulnerability to flooding and inundation in the Nepal Terai.

- **Provide Adequate Drainage Passage in Road and Embankment Construction:** As mentioned earlier, development activities, mainly construction of physical infrastructure, are the major barriers to the passage of flood water. Roads in urban areas have less drainage passage way to allow the escape of incoming sheet flow. In addition, due to lack of sufficient information on hydrology, several bridges and culverts are constructed with constricted water-ways. It is necessary to provide adequate drainage passage to safely allow the the flood flows to pass.

- **Conserve the Churia Hills:** The Churia hills are the major source of sediments in the Terai Rivers. Due to degraded catchment, these hills are susceptible to erosion, landslides and mass wasting. The Churia conservation activities are being implemented on project basis since the 1990s. However, the process of degradation of catchment is not prevented. Hence, emphasis must be given to conserve the Churia hills in the long term with watershed management with peoples participation.

Conclusion

The Terai is the bread basket of the country which needs to be well safeguarded from flooding and inundation impacts. Several development initiatives need to be coordinated properly so as to provide adequate waterways for the floods. An integrated water resources management approach is the key tool to address the flood and inundation problems. Apart from watershed management in the Churia hills, land use regulations need to be promulgated and enforced to dovetail with integrated water resources management interventions.

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CALENDAR OF EVENTS - WATER RESOURCES

12-14 February, 2013: WATECHASIA: International Exhibition and Conference on Water Technologies. Location: Mumbai, India. Contact Email: watechasia@radeecal.com. More info: http://www.biztradeshows.com/trade-events/watechasia-expo-mumbai.html

12-14 February, 2013: Second International Conference on Water Resources and Environmental Management (ICWRE 2013): Water, Food, Energy Security and Climate Change. Location: Marrakesh, Morocco. Contact Email: info@icwre.com. More info: http://www.icwre.com/index.php

19-21 February, 2013: WEX 2013: The Water and Energy Exchange. Location: Lisbon, Portugal. Contact Email: info@w-e-x.com. More info: http://www.w-e-x.com/index/articles.php?id=44&navi_cat=47&page=HOME

24-25 February, 2013: 5th International Conference on Water Resources and Sustainable Development. Location: Algeries, Algeria. Contact Email: ciredd2013@ensh.dz. More info: http://www.water.tallyfox.com/event/5th-international-conference-water-resources-and-sustainable-development-2013

28 February-2 March, 2013: 10th Everything about Water Expo 2013: International Exhibition & Conference on Water & Wastewater Management. Location: Chennai, India. Contact Email: intlenquiry@eawater.com. More info: http://www.eawater.com/expo/

6-7 March, 2013: 2nd World Water-Tech Investment Summit. Location: London. Contact Email: abigail.ryder@rethinkevents.com. More info: http://www.worldwater.rethinkevents.com

11 March, 2013: CGIAR Research Program on Water, Land and Ecosystems Management Committee Meeting. Location: Colombo, Sri Lanka. More info: http://wle.cgiar.org/events/wle-management-committee-meeting-colombo/

13-15 March, 2013: Asia Water Week 2013. Location: ADB headquarters, Manila, Philippines. More info: http://www.adb.org/news/events/asia-water-week-2013

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An Integrated Approach for Long Term Solutions of Flooding: A Study of the Eastern Chitwan Valley

Achyut Man Singh

Achyut Man Singh

Abstract: A timeline study since 1976-2010 with satellite imagery maps on the flooding problems of Eastern Chitwan has revealed that due to the rapid degradation of the vegetative cover in the upper catchments of its rivers, increased flooding events had occurred. The conditions of the catchment environment depend on the behavior and activities of the people residing in the area. Infrastructure construction for the flood control in the river banks are short term solutions only effective for a few years. For a long term solution, the people of the area need to be sensitive for the river training works and good watershed management. The study has emphasized social and institutional aspect along with awareness campaign with the populations to achieve good impacts in the long term.

Key words: Flood control, watershed management, dykes, spurs, catchments, flood plains, Nepal

Introduction

The Eastern Chitwan valley is located in the Central Region of Nepal (Figure 1) and has the most ideal environmental friendly surroundings for water and agriculture development if properly protected and conserved. Primary threats to the valley are the aggradations of the streams including the Rapti River due to the changing catchment environment.

The Eastern Chitwan valley has experienced a series of high flood events in the past recalling from 1954 AD (2011 BS), 1971 AD (2028 BS), 1975 AD (2032 BS) and the most damaging flood event of 1993 AD (2050 BS) with loss of 24 lives and 2,206 houses and large scale of properties. After this event, the local communities, and the Government of Nepal (GoN) with the financial assistances of donors such as the Asian Development Bank (ADB), and Swiss Agency for Development and Cooperation (SDC), are taking active lead roles in preventing such disaster by constructing and maintaining the dykes and spurs in the Lothar and Rapti River.

The Chitwan Valley as a whole is ideally set up environmentally by Mother Nature having a National Park in the south, reserve and protected forest cover in the middle, and mixed forest cover in the northern and eastern mountain region.

The study has focused on two aspects: (i) watershed management with livelihood enhancement plan for the hilly catchment of the valley having poor and deprived communities to discourage deforestation and degradation of the watershed and (ii) to prepare a river training master plan for protecting the flood plain area against the flood disaster from the Lothar, Rapti and other streams.

The field works were carried out with intensive consultation with the local communities, including engineering survey works of the rivers and streams. The experts on GIS, Hydrology and Meteorology, Geology, Sociology, and river training have carried out intensive analysis of the field and secondary data from DHM, Survey Department, and Satellite imagery from ICIMOD. GIS and HECRAS software applications were applied from the available satellite imagery, maps and data available from the related agencies in order to prepare distinct workable maps, and to investigate the probable flood prone areas.

Historical Flooding Events and Impacts

Mustering the time line experiences of the inhabitants of the flood plain areas of the eastern Chitwan Valley it has clearly been revealed that the effect of vegetative environments has a direct impact on the flooding and thus on the settlements with the loss of life and properties. An old man having witnessed the 1993 flood event had told the author that the largest flood event in the Chitwan valley occurred in 1954 AD (2011 BS), when the Rapti and Lothar rivers inundated the whole valley. However, the flood disaster was negligible compared to the 1993 event. He also recalled that the settlements of population were scarce and the environments were covered with thick forest then. During the flooding, water level increased gradually and subsided slowly with mild velocity of flow. But the 1993 flood disaster occurred due to breach of the dyke of the Rapti River, which had swept away large parts of Bhandara, Kumaroj, and Kathar Village Development Committee (VDC) areas adjoining the Dhungre stream taking a death toll of 24 persons and 5,880 no. of livestock, washed out 741 ha, and inundated 2,321 ha of land. The affected households were 5,293 and damaged houses were 2,206 (DWIDP 2009, 2011).

The Kayar Khola stream is the second largest stream in the valley next to the Lothar Khola. The sedimentation problem in this stream also is high, as its river bed up to 7 km stretch from the foot hill has been covered with debris carried by the stream. Before 1975 AD, the stream banks were covered fully with dense forest and bushes in which the stream was flowing with a stable single channel; while at present, it is covered with sediments and the width of the river bed also has increased to more than 200m at places. The local people recall the visible changes in the characteristic of the stream. They said that in the year 1971 AD (2028 BS), a large flood event occurred with debris flow and deposited the sediments in the foothill area. Another high flooding event occurred again in 1975 (2032 BS),

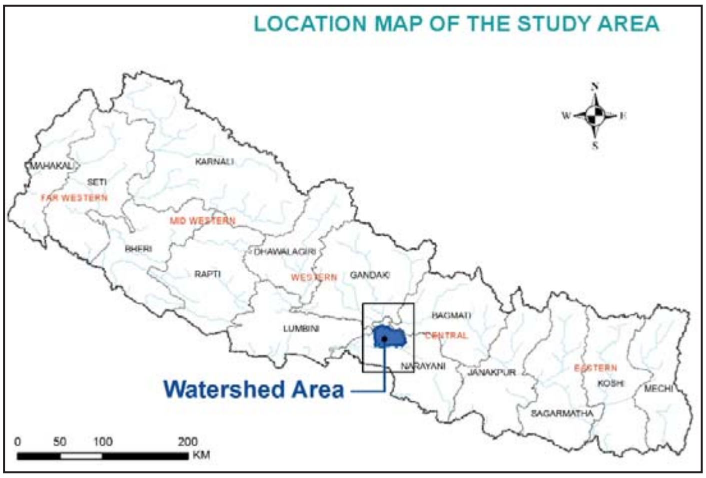


Figure 1. Location Map of the Study Area.

which increased the sediment deposition further and inundated the adjacent agricultural lands. The other similar streams such as the Ladara, Chatrang, and Pampa have been subjected to similar changes in their regimes (Please see Figure 3 of Google map for its evidence).

Presently, the Lothar Khola has been identified as one of the most rapidly aggrading rivers in the Terai region of Nepal threatening the East West Highway Bridge, and inundation to the adjacent lands and property. The Department of Water Induced Disaster Prevention (DWIDP) has carried out a detailed study of the watershed conditions to investigate the real cause of the aggradations, which is reported to be in average more than 5 to 7m at different reaches. The primary causes of the aggradations are uncontrolled deforestation and consequent instability of the prevailing geological formations. Near the Lothar Bridge site of the East West Highway, the river bed has aggraded to more than 5m from its base level[1].

All these events point towards the degradation of the environment and its impacts on the flooding effects. The degradation of the vegetative cover not only causes transportation of large quantity of sediment and debris by rainfall, but also has a direct impact on the volume of the flooding. The effects of such phenomena have been experimentally proved in the USA. Therefore, long term solution of flooding and its disastrous impacts could be reached only if the watershed problems are also addressed and taken care of by restoring/adding to the vegetation cover and improving the environment.

Theoretical Aspects of Flooding and its Origin

The term 'Runoff' is defined as that part of the precipitation that makes its way towards the natural channels, lakes, or oceans as surface or sub-surface flow. It means generally surface water flow in the dictionary. The large flow of water in a stream or rivers due to high precipitation or snowmelt is called 'Flood'. In our sub-continent, the flood events occur during the monsoon season when more than 80% of the annual precipitation falls. The factors affecting the 'Runoff' or 'flooding' could be grouped into two kinds of physical activities related to: (i) rainfall or precipitation, and (ii) watershed condition.

The factors associated with 'Rainfall' are; Rainfall duration, Intensity, and Areal distribution.

A rainfall of small duration with the same intensity will not produce 'Runoff', but for longer duration it will produce 'Runoff'. As for smaller duration rainfall, it will be absorbed by infiltration into the groundwater table. Usually intensity of rainfall greater than 37mm/hr produces greater percentage of runoff.

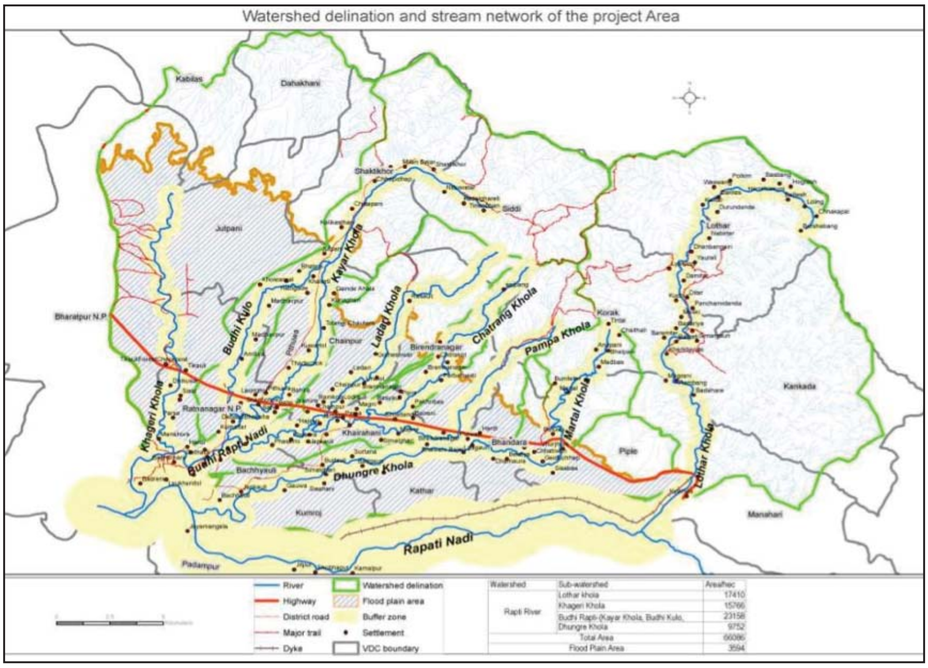


Figure 2. Watersheds in Hills and Flood plain Delineation of Eastern Chitwan Valley.

Another main group is 'Watershed' which has also

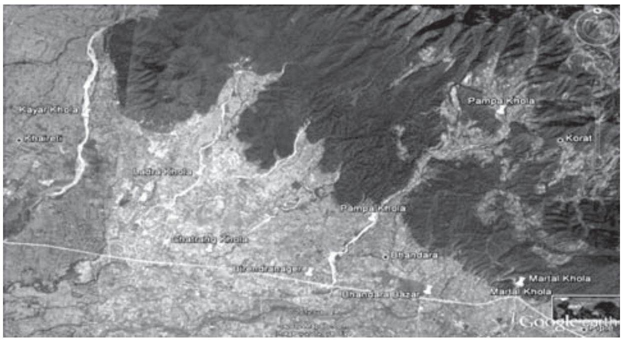


Figure 3. Sediment Deposition by Kayar Khola, Ladari Khola, Chatrang, and Pampa Khola in the Flood Plain. (Source: Google)

a direct contribution in the runoff volumes. The factors affecting the runoff associated with 'Watershed' are: Size, Shape, Orientation, Topography, and Geology (Soil).

The first group 'Rainfall' related factors are beyond the control of humankind; however, the watershed group can be controlled effectively to reduce or prevent flooding event to some extent only. The experiments conducted in the USA's Iowa and Mississippi watersheds indicated that the runoff occurring from heavy soil is three times larger than in loess soil with the same intensity of rainfall. The effect of land management practices also indicated that the discharge volume varies with the vegetative covers from 2 to 2.5 times with the same amount of rainfall intensity, as indicated in Figure 4. In another experiment, land management in a small watershed of the White Hollow River of 700 ha area was undertaken which has indicated a drastic reduction of runoff to about 15% only compared to its previous bare soil covered catchment. The effect of land management in small to medium size catchment on runoff is more pronounced, than in larger watershed of rivers

Therefore, vegetative cover of the landscapes is a prominent factor affecting and producing flooding effect.

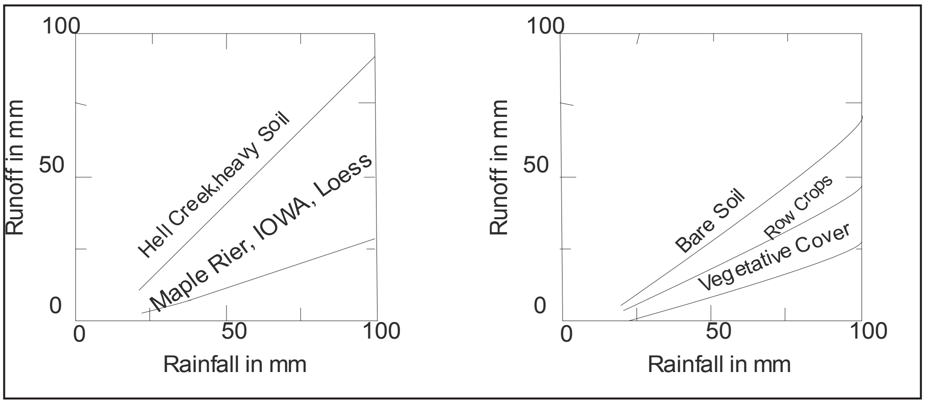


Figure 4. Effect of Vegetative Cover on the Runoff or Flood Volumes.
(Source: Soil Conservation and Watershed Management Engineering)

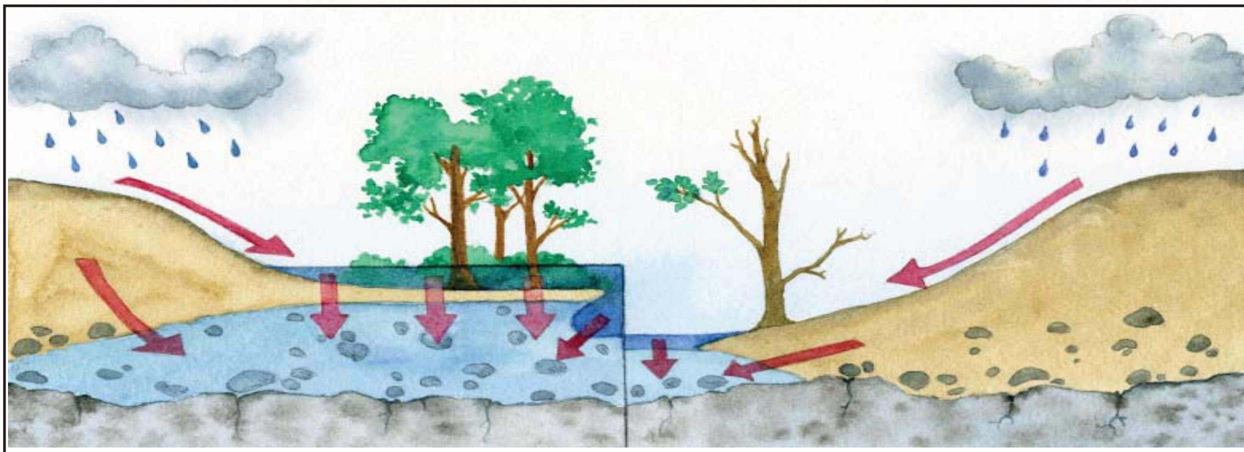
Rationale for the Study of Flooding

The event of flooding is an imminent natural phenomenon, which occurs in all the rivers when high intensity rainfall generates surface runoff in the watershed areas. If the flood water confines itself within the active floodplain of the river, it does not have any impact on the settlement and agriculture lands adjacent to its bank. However, the rivers are always prone to outflank the banks as the rainfall patterns are unpredictable; the geological events like earthquakes, landslides, debris flow, and others cause changes in the river regime itself. One has to be prepared for the flood events with preparedness of flood warning system and safe evacuation in case of such events especially during monsoon period in the prevailing climatic set up.

High intensity rainfalls occur frequently in the foothills of the Mahabharat range like Hetauda, Bharatpur, Dharan, Butwal, and also the study area. So, the flood events of unpredictable volume are sometimes imminent and beyond the control of any engineering solution. However, they could be confined to some extent within the flood plain boundary by constructing dykes and other protective measures. One has to accept this fact and should be prepared for its eventuality.

Objectives of the Study

Overall objective of the study was to find long term solutions to the flooding problems of the Eastern Chitwan Valley and to propose an Integrated Watershed Management Plan incorporating the catchment development with a conservation plan and river training plan for the flood plain with engineering solutions.



Healthy floodplains, which are well-vegetated, slow the flow of water, allow it to spread and soak in effectively.

Water speeds over flood plains with poor vegetation health, with channelized portions or cutoffs, and does not linger long enough to fill the underground "sponge".

Box 1. Effects of Vegetative and Non-vegetative Catchment Coverage on Environment
Source: Integrated Watershed Management Planning (IWMP), Manitoba Water Stewardship, USA

Scope of the Study

The scope of works were envisaged to have in depth analysis of the hydro-metrological conditions, and the land use changes in the watersheds to come up with the long term solutions by collecting available secondary data and the satellite imageries. In brief, the following aspects were covered in the scope of the study.

a. *Hydro-Meteorological Study;*
b. *River System Study;*

The river system study was carried out to assess: (i) the flood protection measures along the banks of the rivers and streams, probable vulnerable spots and preventive measures, (ii) watershed Management of the rivers which included the assessment of the catchment conditions, geological events as active slide zone, degradation of the soil cover by deforestation, land use patterns, soil conditions, social structures of the settlements and their cultivation practices such as '*Khoria*[2]'.

Methodology Applied

The planning of the study has been conceived to delineate the Eastern Chitwan Valley into two parts as (i) flood plain and (ii) watershed areas in the hills. The flood protection measures will be generally concentrated on the plain areas, whereas soil conservation and protection works in the watershed areas of the hills. The detailed tasks were grouped into sub-tasks as Preparatory works, Field works, Desk works, Interaction and Information Dissemination Works, and Report Finalization and Submission.

The activities as mentioned above were conducted with the team consultation first in the initial stage with literature review and then conceptualizing the details of the works regarding flood management and watershed management. Secondary data analyses of the previous studies were used for modeling the study activities. Geographical Information System (GIS) and Hydro-meteorological analysis were conducted using the prevailing software such as ArcGIS 9.3, EDRASII, and HECRAS to investigate the changes in land use in timeline and flood volume and inundation coverage. The analysis of rivers was conducted using the River Analysis System developed by US Army Corps of Engineers named as HECRAS.

The Study Area

The study area is bordered in the east by the catchment of the Lothar River, south by the Rapti River, west by the Khageri catchment, and north by the ridge of the Mahabharat mountain range. The study area is comprised of hilly catchment and plain valley as its flood plain having a total area of 661 square kilometre; the plain valley part constitutes 251 square kilometre area of fertile agricultural land, and watershed areas in the hills constitute 410 square kilometre. The Mahendra Reserve Forest and Chitwan National Park covers the valley in the west and south. The study area is composed of one municipality and 16 Village Development Committee (VDC) political boundaries. It constitutes the watershed areas of the adjoining streams – the Lothar, Mardar, Pampa, Chatrang, Ladra, Kayer, Bhudhi Kulo, Khageri and Dhungre Kholas. The proposed study area can be divided in to two parts, as (i) Flood Plain areas and (ii) Catchment areas in the Hills (see Figure 2).

The major land use cover is still the forest lands constituting 54 percent, with cultivation lands of 38 percent as calculated from the topographic map of 1992 imagery (released in 1995). The remaining land cover comprises of bushes, water body and sandy area, and built up areas (SDC 2012).

The Chitwan National Park protects and conserves the forest areas on the left bank of the Rapti River and also its vicinity along the Lothar Rapti Dyke and at Kumaroj VDC at its right bank which are covered with reserve forest as Buffer Zone. The Harda River joins the Rapti River on the left bank just near the confluence of the Lothar River.

The flood plain is a relatively populated area having fertile flat agriculture lands incised by the drains of the rivers and streams, whereas the catchments in the hills are sparsely populated with indigenous tribes and deprived communities.

Climate

The climate of the Chitwan Valley is classified as sub-tropical monsoon type with micro-thermal effects in the Mahabharat and Siwalik Hills. The monsoon season (June - September) experiences almost 80-90 percent of the annual rainfall occurrences, which is the main characteristic of the Monsoonal type of climates in the Indian Sub-continent. Orographic effects due to the mountain ranges in the north side of the study area is visibly prevalent in this region as the intensity of rainfall is high compared to other parts of the country.

The annual average rainfall of the study area is about 2,000 mm. The annual mean temperature is about 24^{o}C with the highest temperatures occurring in April and May reaching up to 40^{o}C. The coldest time of the area lies from December to January having lowest value up to 5^{o}C.

Demography of the Study Area

The study area of eastern Chitwan is comprised of 16 VDCs and Ratnanagar municipality. Broadly, the study area is divided into watershed area and flood plain area. The total population of the study area is 173,779 (Female 88,163 and Male 85,616) which is approximately 40% of the district population. The ethnic composition of the study area indicates Brahmin, Tharu, Chhetri, Tamang, Gurung, Newar, Chepang, Kami, Magar, Damai, Kumal, Darai, and other ethnic groups inhabiting the area by maintaining harmonious relationships and engaging in agriculture as well as industrial, and tourism development activities. The ethnic composition of the study area is much more similar to the district except for the localization of the Chepang community found largely in Siddi VDC (approx. 90%) of study area.

Key Findings

Changing Land Use Pattern

Classification of the land use and land cover of the Rapti Watershed of the project area has been assessed using GIS on the topographical map and LRMP map. The calculations of the forest land and cultivation land use with their corresponding VDC are assessed. The findings are given in Table 1. Figure 5 below shows that the forest area has significantly changed during the period 1976 to 1992. The figures indicate that forest land has been encroached for cultivation (SDC 2012).

The land use changes are further analyzed by VDC wise to see which VDC has larger impact of forest encroachment. The forest land in the watershed area particularly in Siddi VDC, Korak VDC, Piple VDC, Lothar VDC, Shaktikhor VDC and Jutpani VDC are observed major encroachment. These VDC are the prime watershed area of Kayer Khola, Pampa Khola, Ladari, and Chhatrang Khola (Table 2).

Land use LRMP 1976 image			Land use Topo 1992 image		Changes in 1976-1992	
Land use type	**Area / Sq.Km**	**Area in Pecent-age**	**Area / SqKm**	**Area in Pecent-age**	**Area / SqKm**	**Area in Pecent-age**
Cultivation	196.9	33.8%	223.4	38.3%	26.6	4.6%
Forest	341.0	58.5%	315.1	54.0%	-26.0	-4.5%
Grasslands	20.1	3.4%	4.0	0.7%	-16.1	-2.8%
Bush	11.1	1.9%	12.4	2.1%	1.3	0.2%
Water body and Sandy area	14.1	2.4%	25.9	4.4%	11.8	2.0%
Built Up	0.5	0.1%	0.7	0.1%	0.2	0.0%
Total	583.0	100.0%	583.0	100.0%	82.0	14%

Table 1. Changes in Land Use Coverage of the Watershed from 1976-1992.

Land Use Changes in 13 VDCs of Chitwan and Makwanpur Districts from 1992 to 2010

This study carried out a comprehensive analysis of forest area encroachment within the flood plains and watershed boundaries of; namely Kankada, Piple, Manahari, Lothar, Korak, Siddi, Birendranagar, Bhandara, Shaktikhor, Jutpani, Dahakhani, Chainpur and Kabilas VDCs of Chitawan and Makwanpur Districts. In order to calculate the forest encroachment area, the change of forest coverage area of tree and shrub is a fundamental measure over the studied period of time. For this analysis, Landsat TM imagery of 2010, acquired from the ICIMOD, Nepal and Topographic land use digital map, 1992 imagery from the Survey Department, has been used to calculate the encroachment of forest area. The analysis revealed that Jutpani has the highest encroachment area with 16 sq. km followed by Kankada and Siddi with 13.6 sq. km and 12.6 sq. km of forest encroachment areas respectively. As shown in the land classification imagery, forest encroachment in Jutpani VDC is distinctly seen near to the former Maoist cantonment area. Altogether, nearly 109 sq. km of forest land has been encroached over a period of 18 years within the flood plain boundary of watershed area (Table 2, Figure 6 and 7).

The above analysis made on Landsat TM imagery of 2010, acquired from the ICIMOD, Nepal and Topographic land use digital map, 1992 imagery from survey department, revealed that Jutpani has the highest encroachment area with 16 sq. km followed by Kankada and Siddi with 13.6 sq.km and 12.6 sq.km forest encroachment area respectively. As shown in

Village Development Committee (VDC)	Forest Coverage in timeline in the 13 VDCs (Sq. Km)				
	LRMP-1976	**TOPO-1992**	**Landsat 2010 Imagery**	**Change 1976-1992 (16 Yrs)**	**Change 1992 - 2010 (8 Yrs)**
Siddi	42.8	36.9	24.3	5.9	12.6
Shaktikhor43.4	38.4	27.3	5	11.1	
Piple	28.9	24.6	15.1	4.3	9.5
Lothar	49.1	44.8	32.9	4.3	11.9
Korak	42.4	34.2	25.8	8.2	8.4
Kabilas	16.6	16.3	9.2	0.3	7.1
Jutpani39.5	33.5	17.5	6	16	
Dahakhani	21.52	0.1	13.7	1.4	6.4
Chainpur9.5	9.4	7.9	0.1	1.5	
Birendranagar	19.5	19	13.9	0.5	5.1
Bhandara7.6	5.1	3.8	2.5	1.3	
KankadaNA	38.3	24.7	NA	13.6	
ManahariNA	8.8	4.4	NA	4.4	
Total	320.8	329.4	220.5	38.5	108.9

Table 2. Changes in Forest Coverage in the VDCs of the Eastern Chitwan Watershed from 1976 to 1992 and 2010.

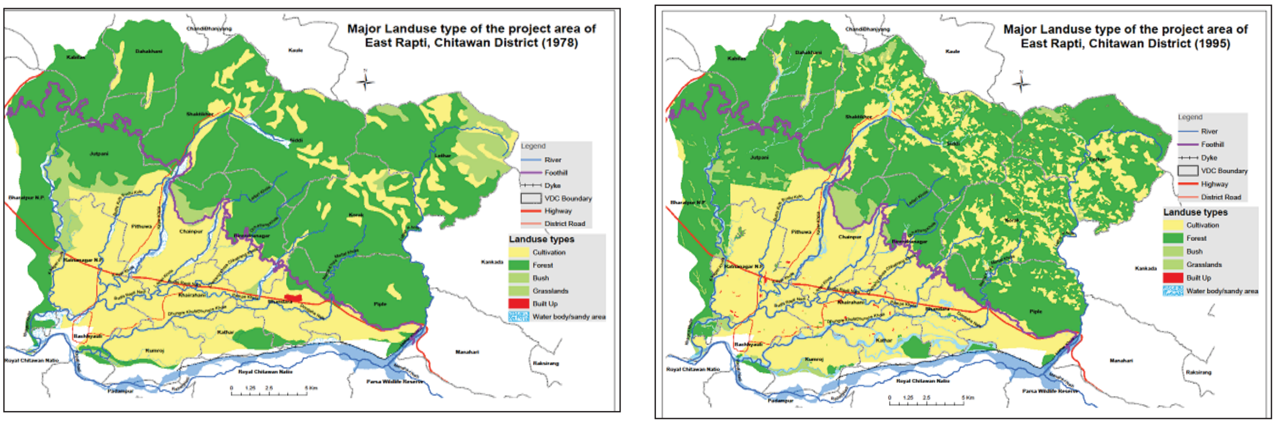


Figure 5. Land Use Type based on the LRMP 1976 Map and 1992 Topographic Map.

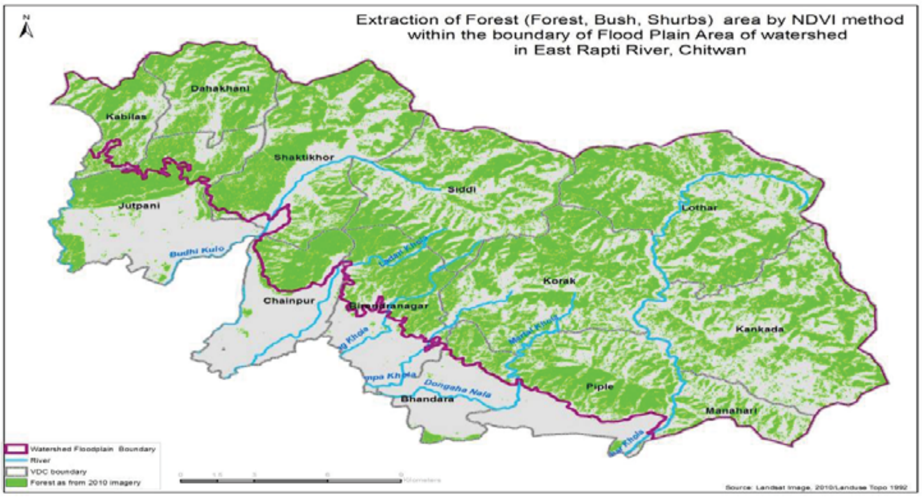


Figure 6. Forest coverage based on the 1992 Imagery.

classification imagery, the forest encroachment in Jutpani VDC is distinctly seen. Altogether, nearly 109 sq. km of forest land has been encroached over the period of 18 years (1992-2010 AD) within the boundary of the watershed area. The very facts indicate the degradation of the environments, as also in the regime and flooding characteristics of the streams and rivers.

Most Vulnerable Areas from Flood Disaster

Analysis of Flood Coverage

The hydrological analysis using HECRAS has revealed that the Rapti River will, most likely, outflank the banks near the Kumroj and Sauraha area. It has also indicated that some portions of the existing dyke are vulnerable to outflanking by a 100 year return flood; so it has been advised that the Rapti dyke be raised at places. Cases with a similar analysis are adopted in the other streams too, which revealed that adjoining lands are prone to inundation during 50 and 100 year flood volumes (see Figure 8).

Reviewing the landscape and topography of the lower flood plain, **Piple, Bhandara, Kathar, Kumaroj, and Bachhauli VDCs are most vulnerable to flood disaster from the Rapti River**, as the landforms of these VDCs are sloping from east to west, and lower than the Rapti river bed from the Lothar confluence to the end of the dyke (SDC 2012).

The Lothar-Rapti Dyke is the sole protection measure against flooding in these spots. During monsoon period there is always a high probability that unprecedented rainfall in the Rapti catchment might trigger a high flood and breaching of the embankment. So vigilance and proper preparedness must be taken by the communities to fight against such disaster as in the event of the

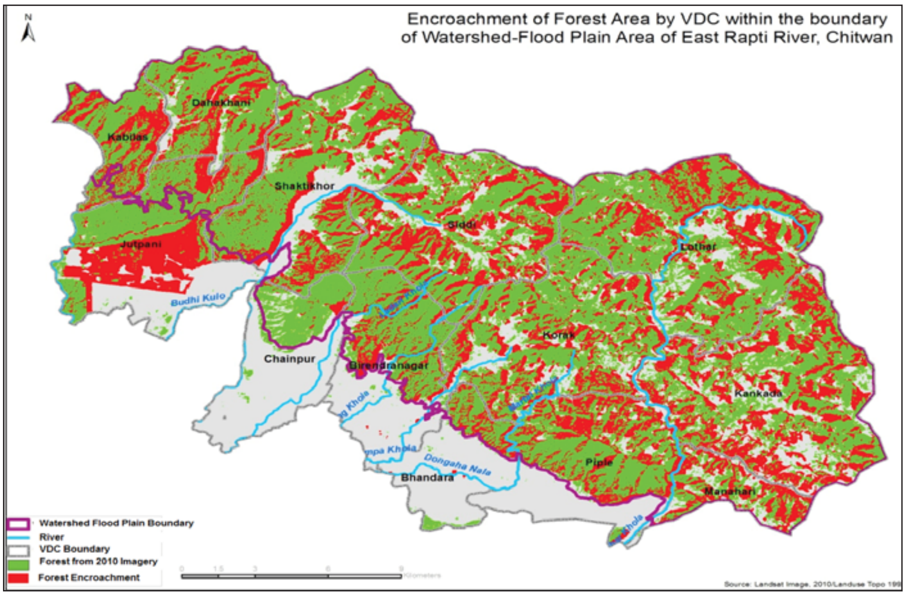


Figure 7. Forest Coverage based on the Landsat TM Imagery 2010.

Figure 8. Flood Extent for the Return Period of 50 yrs (Red Color) and 100 years (Blue Color).

1993 flood. The study also has identified that the river is aggrading by 1 to 2 metres on average since the last decade, which will make it most vulnerable to outflanking the existing dyke.

Socio-economic and Institutional Aspects

Eastern Chitwan Valley has a diversity of ethnic groups, castes, languages and religions, and they have co-existed peacefully since 1956 when the government carried out settlements in the Valley with the Hill migrants to start a better livelihood. It is believed that the Tharus are the oldest ethnic group in the floodplain area; on the other hand, the Chepang, Gurung, Tamang, Magar ethnic groups are the local residents in the hilly areas. The average land holding size in the watershed area is less than 0.5 hectare and the average land holding size in the flood plain is 0.5-1.0 hectare as reported by key informants (SDC 2012).

The DDC Chitwan carried out a study on food sufficiency as a major indicator of poverty in 21 VDCs (total HH 21678) in 2007/08. As per the study, 29% of households seem to be vulnerable. During a discussion in February 2012, the key informants of the DDC and VDCs revealed that in the study area approximately 17-20% of HH may belong to the below the absolute poverty level as compared to the Per Capita Income level of NRs 15,162 (national level). Further, they expressed that the Hilly VDCs like Lothar, Korak and Siddi etc have the majority of households having to cope with food deficiency, as they can hardly hardly feed themselves for more than 6 months with their regular income.

In the case of the Eastern Chitwan valley, the institution “Lothar Rapti Dyke Protection Committee (LRDPC)” has been active and successful in undertaking protection and maintenance works of the Lothar Rapti Dyke with funding assistance from the SDC. The LRDPC was founded by the flood affected victims who had terrible experiences in the past (1993 Flood), which made them united out of dire necessity to protect their belongings in the future. A common cause holds them together united to form a committee for the welfare of the affected population by irrespective of the ethnic groups and political affiliations. The study has thus proposed the strengthening and reforming of the LRDPC to act as the institution on behalf of the local communities. So, the team has proposed the up-gradation of the LRDPC to assume an active role in the implementation of civil and other works on behalf of the communities as a monitoring body.

Geological Findings

The rivers, rivulets and streams of the Eastern Chitwan valley originate from the Siwalik and Mahabharat ranges, and traverse through terrain composed basically of sandstone, mudstone and conglomerates of the Siwaliks. The rocks are very fragile in nature. The Mahabharat ranges are comprised of meta-sedimentary rock and sedimentary rocks like phyllite, slate quartzite and dolomite. The MBT and other thrusts pass too straddle this area. *Very few numbers of land slides are seen in the Siwaliks and Mahabharat ranges. There are no conspicuous landslides in Eastern Chitwan valley (SDC 2012).*

The River System Analysis

The Eastern Chitwan Valley is a flood plain being charecherized by the alluvial deposits of the Rapti River and its tributaries like the Lothar, Martal, Pampa, Chatrang, Ladari, Kayar, Khageri, Budhi Rapti Nadi, and Dhongre. The Rapti River flows from the east to west direction at the edge of the study area dissecting the whole Chitwan valley in almost half section. The Rapti River channel is confined in the mountainous area up to say, Hetauda Bazar, braided in the middle reach, and becomes confined into a deep channel

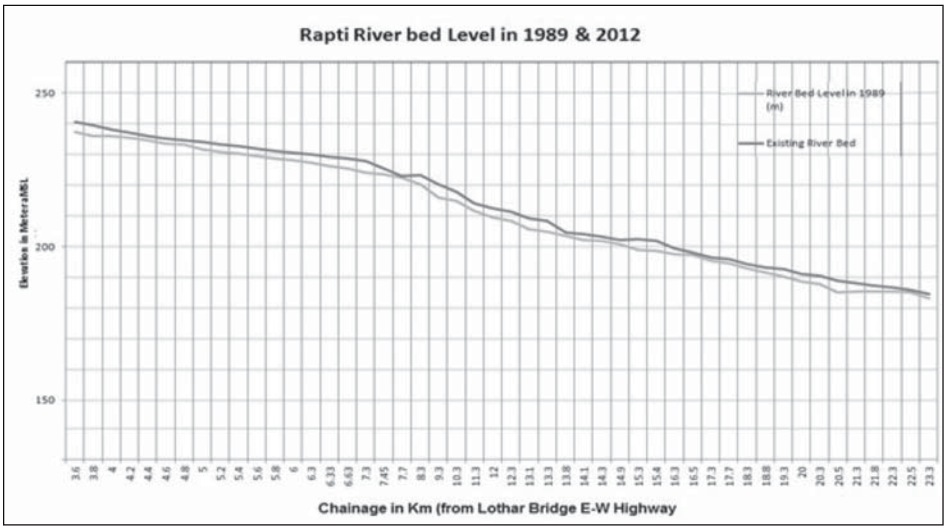


Figure 9. Rapti River Profile Changes from 1989 to 2012.

probable such disaster. Its continuous maintenance and strengthening with raising of the embankment height is crucial to prevent breaching in case the anticipated design flood volume is surpassed.

But there remains always the probability that a higher order flood event might occur if unprecedentedly high rainfall events and degradation of its catchment area prevails in future. So both watershed management and river training aspects are important for the long term safety and sustained stability in the valley (Galay 1994).

meandering at the lower reaches, and in meeting its parent channel of the Narayani. The major tributaries are the Manohari, Lothar, Budhi Rapti Nadi, Khageri, and Dhungre streams. Other small tributaries are the Martal, Pampa, Ladari, Chatrang, and Kayar Khola. The major contributors of sediment in the Rapti River are from the tributary streams in Makawanpur district, the Monohari, and Lothar. The channel slope varies from 1 in 240 to 1 in 1240 gradient, and the width of waterway varies from 50m to more than 1000m depending on the local physiographic set up.

The analysis also has indicated that the Rapti River bed has aggraded from 2 to 3m since 1989 to the present study in 2012 (see Figure 9). The aggrading nature of the rivers always threatens to outflank the bank and flooding in the vicinities (Nippon Koie Co. 1989, 1990).

Irrigation Potential in the Valley

The lower portion of the Eastern Chtwan valley has networks of irrigation systems from the Lothar river, Rapti, Dhongre, Lower Budhi Rapti streams. The irrigation systems are operated and maintained by the farmers with occasional funding from donors or GON. It is noted in the flood plain that the flood control and irrigation systems built in the rivers are interlinked, as water is attracted towards the bank for irrigation purpose, whereas for flood control the rivers are repelled away from the bank.

Effectiveness of the Past and Existing River Training Measures

The river training works carried out by various agencies, especially the East Rapti Irrigation Project under ADB assistance and LRDPC under SDC assistance, have been most effective in protecting the valley against flood disaster as in 1993.

Among other protection measures in the smaller streams, the Lothar Dyke, and its continuation up to the Rapti Dyke to an extent of 18 km near Kumroj is most vital and effective against flooding and a cushion of any future

Recommendations

Integrated Approach

For a long term solution of the flooding problem, nurturing and proliferating vegetation in the catchment area is a major factor apart from outside human control factors such as rainfall intensity and duration. The local communities should realize this fact and adopt appropriate measures to upgrade the watershed in future, for which the local communities of the watershed have an important role to play. The communities of the flood plain and the watersheds must share and campaign to implement a plan for the preservation of the forests and carry out measures to reduce soil erosion and changing cultivation practices. The study has recommended some plans to develop the institutional set up along with a with livelihood plan for the upper watershed communities.

The condition of the watershed of the Eastern Chitwan valley is at the stage of rapid degradation due to rampant deforestation as the findings of the GIS study reveal. The watershed has been converted to cultivated lands exposing the soil surface, thus triggering high soil erosion and sediment transport in the streams. During interactions and workshops conducted with the communities of the flood plain, these facts have been clearly explained, and they have expressed their commitments to support the communities of the watersheds. The foremost steps for them now are to find a means to stop logging of the forest area, which is in increasing trend.

Watershed Management Aspects

- Investigation and monitoring of the landslide, debris flow and flood should be carried out on a regular basis especially after the occurrence of events like heavy rain falls, landslides and floods.
- Afforestation in the Churia region and control of deforestation in the Mahabharat region will protect the region from further environmental degradation.

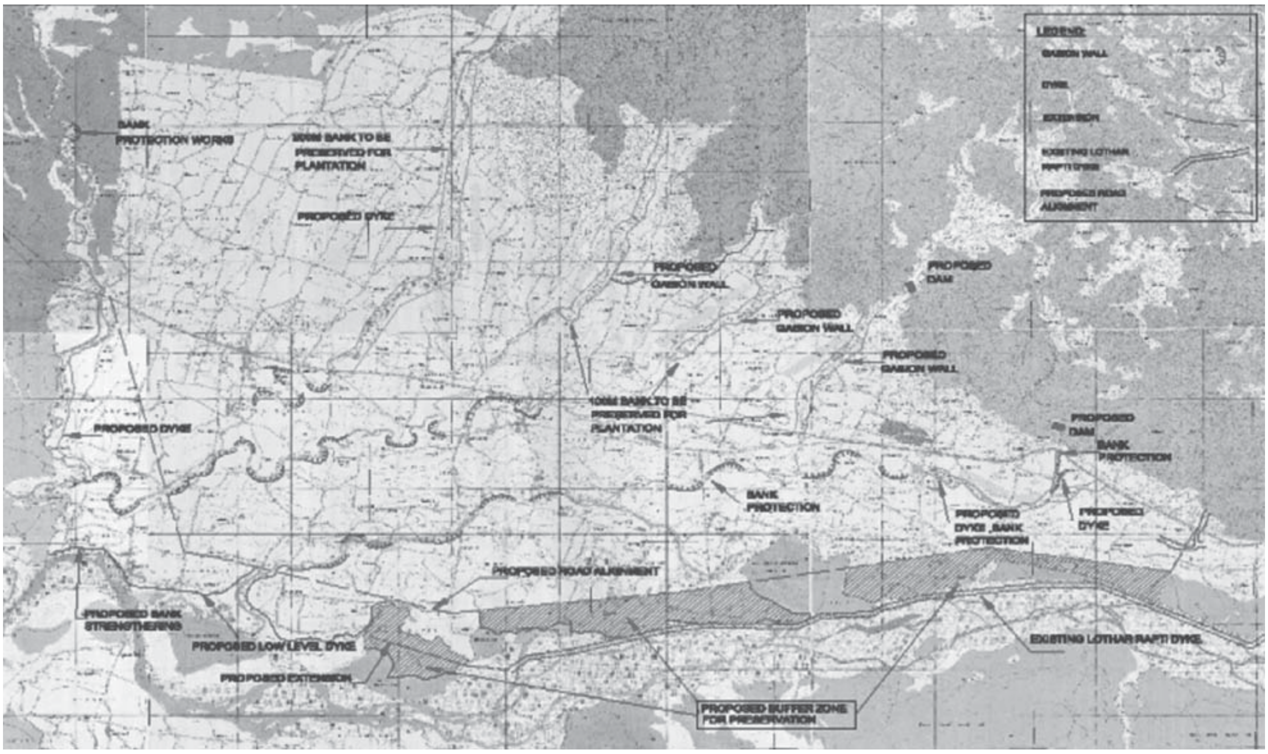


Figure 10. Proposed Medium and Long Term Plan for the Flood Plain of the Eastern Chitwan Valley

A sustainable energy resource management strategy along with diversification of domestic energy from firewood to non-forest products and plantation of trees for fodder and fuelwood will greatly help in protecting the forests in the catchment.

- A public awareness program should be launched in order to disseminate and advocate the causes of disaster occurrence, importance of forest resources and methods to mitigate/protect against disaster.
- Check dams should be made as soon as possible in the riverbed, for instance in the wide valley (e.g., Tangi, Damar, Kuchur, Bangshiling Khola, Ganwarchok Khola sections of the Lothar watershed; Chisapani Khola, Mandu Khola, Khani Khola of the East Rapti River watershed.

Socio-economic Aspects

- At present the LRDPC is active and functioning well since its establishment and has successfully implemented the river training and irrigation system rehabilitation works in the flood plain under SDC's funding and participatory mode with the communities. The study team has proposed to *upgrade and strengthen community institutions in order to enable them to undertake extended responsibilities regarding maintenance of river training and also the watershed management works.*
- In order to uplift the living standard of the population of the hilly catchment, a livelihood enhancement plan has been proposed to sensitize and elevate peoples's awareness on the importance of forest cover and guide them towards alternative income generating activities.

Engineering Aspects and Proposed Implementation Plan

A river training master plan needs to be implemented as a solution to the flooding problem for all the streams/ rivers in the valley by delineating its implementation period as: (i) Short Term (0–5 Yrs), (ii) Medium Term (3–12 Yrs), and (iii) Long Term (5 – 20 Yrs). The proposed engineering protection measures were prepared to address its vulnerability in its site specific situation with its prioritization. *The socio-economic and watershed management activities would be carried out in all terms, side by side independently to achieve the impacts on the river behavior (SDC 2012).*

Short Term

The river training works of: (i) Lothar and Rapti Rivers, (ii) SABO dams in Lothar, Martal, Kayar and Pampa, and (iii) low level dyke around Kumaroj and Sauraha areas, are proposed at most vulnerable spots against flooding from the Rapti and Lothar rivers.

Medium Term

The proposed river training works under this category includes; (i) Kayer Khola (I), (ii) Pampa/Budhi Rapti Nadi (I), (iii) Martal/Dhungre Khola (I), (iv) Construction of Ring Road from Gadaulli to Kathar, Kumroj, Saurah, and Tikauli and (v) plantation in the river/stream banks.

Long Term

Less vulnerable spots but prone to probable river attacks in future are categorized under this term which would be a guide for future planning. The proposed river training works proposed under this category are; (i) Kayer (II), (ii)

Pampa/Budhi Rapti Nadi (II), (iii) Martal/Dhungre Khola (II), (iv) Chatrang Khola, (v) Ladari Khola, (vi) Khageri Khola, (vii) plantation and creating buffer zone between the ring road and the Lothar Rapti Dyke, (viii) preservation and maintenance of the river training works.

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Acknowledgements

Mr. Amon Jonchhe of SDC, Mr. Jagrit Prasad Bhetwal and Mr. Lalmani Chaudhary of Lothar Rapti Dyke Protection Committee (LRDPC), Chitwan are greatly appreciated for having initiated and engineered this study.

Financial Assistance

The study was sponsored by Swiss Agency for Development and Cooperation (SDC) on the request of the community based organization LRDPC. The study was on "Long Term Solution of Flooding in Eastern Chitwan Valley" from January to June 2012 in order to prepare a comprehensive report on watershed management and river training master plan for the flood plain with engineering solution. It was udertaken by SILT Consultant (Pvt) Ltd.

The paper is a synopsis of the detailed study carried out under the sponsorship of SDC.

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Notes

1. The base level is an arbitrary river bed level of the Lothar River before the construction of the Highway Bridge – There was a cause way before the construction.
2. Generally "Khoria" in local term indicate cultivation in the existing forest land by clearing and firing the products for cultivation. The people generally cultivate maize in this forest land for maximum of two to three seasons only, when the nutrition is available, and then it is again abandoned.

CALENDAR OF EVENTS - WATER RESOURCES

Continues from page no. 65

16-20 March, 2013: Transboundary Water Management Across Borders and Interfaces (TWAM) 2013. Location: Aveiro, Portugal. More info: http://ibtwm.web.ua.pt/congress

22 March, 2013: World Water Day 2013. More info: http://www.unwater.org/watercooperation2013.html

8-12 April, 2013: India Water Week 2013. Focusing on the theme, "Efficient Water Management: Challenges and Opportunities". Location: India Exposition Mart, Gautam Budh Nagar, Greater Noida, india. More info: http://www.indiawaterweek.in/html/aboutus.html

23-25 April, 2013: Water Malaysia 2013: International Conference and Exhibition. Location: Kuala Lumpur, Malaysia. More info: http://www.watermalaysia.com/2013/

6-11 May, 2013: Dam Safety Inspection. Location: Trondheim, Norway. More info: http://ich.no/DynamicCourses.asp?ID=90

13-18 May, 2013: World Association of Soil and

Experimental Investigation of Erosion and Performance of Turgo Impulse Turbine

Sourabh Khurana, Varun and Anoop Kumar



Sourabh Khurana Varun Anoop Kumar

Abstract: The present study has been carried out to investigate the effect of silt size, concentration, jet velocity, nozzle angle and operating hour on the erosive wear as well as on the performance of the Turgo impulse turbine in actual flow conditions. Samples of silt were collected from the Beas River (India) near the Pandoh dam. It has been found experimentally that silt parameters, nozzle angle and operating hour of the Turgo turbine increases the erosive wear rate in the turbine components causing efficiency loss in the Turgo impulse turbine and final breakdown of hydro turbines.

Key words: Turgo turbine, nozzle angle, normalized wear, efficiency loss, silt size

Nomenclature

W_d deformation wear at normal impact condition
ε deformation factor
M the total mass of impacting particles
V velocity of particle
h head to the turbine
ρ density of water
g acceleration due to gravity (m/s^2)
P electrical power output (kW)
Q discharge through turbine (m^3/s)
η_g efficiency of generator
η_t efficiency of turbine (%)
C silt concentration (ppm)
S silt particle size (μm)
T operating time (h)
W normalized wear (gram)

Greek Symbols

a angle of attack
θ impact angle (°)

Introduction

The Turgo turbine is a medium head impulse turbine (15 – 300m) that operates in the head range where Pelton and Francis turbines overlap (Koukouvinis, Anagnostopoulos et al 2011). These turbines achieve operational efficiency of more than 84%. Turgo turbines have a flat efficiency curve and provide excellent part load efficiency; so they can be used for large flow rate variations. In Turgo turbines, jet strikes the runner plane at an angle of 25° (Anagnostopoulos and Papantonis 2007).

Silt erosion in hydraulic turbines is a major problem in most of the hydro-electric projects around the world. In India, silt erosion problem occurs mainly in those projects which are situated in the Himalayan and in the north-eastern region (Thapa, Thapa and Dahlhaug 2012). Nepal is also facing silting problem in hydropower plants with sediment yield of about 4,240 tonnes/km²/year. The hydraulic turbine components which are mainly affected by silt are runner blades, nozzle, guide vanes, top and bottom ring liners, labyrinths, inlet valve seals etc (Thapa, Thapa and Dahlhaug 2012; Goyal, Singh et al 2012).

Silt erosion is the gradual removal of material caused by repeated deformation and cutting actions. It depends upon different parameters such as silt size, concentration, hardness, average velocity of particle, shape of particles, angle of impingement and material properties (Padhy and Saini 2008). Erosion of hydro turbine components is a major problem for the efficient operation of hydropower plants. This problem is more intensified if silt contains higher percentage of quartz, which is extremely hard (hardness 7 in Moh's scale) (Tong 1981; Singh 1990).

There are two modes of erosive wear, called the ductile mode of erosive wear and the brittle mode of erosive wear. The maximum erosion rate for ductile materials has been observed between 10° to 30°, whereas lower erosion is found to occur around normal impact. For brittle materials, the erosion rate increases as the angle of impingement increases and is highest at normal impingement (Neupane 2010).

The aim of the present study is to analyze the effect of the nozzle angle and silt parameters on the performance as well as on the erosion of the Turgo impulse turbine.

Literature Review

Koukouvinis, Anagnostopoulos et al (2011) used the SPH method to access the performance of two different Turgo turbine runners and compared it with Computational Fluid Dynamics (CFD) solver Fluent. They found that the SPH method produces similar results in much less time than the fluent software.

Williamson, Stark et al (2012) have developed a two dimensional quasi steady state model for a Turgo turbine and then compared it with test results. They found that the performance of the turbine had been improved by 5% at 3.5m head and at 1.0m head, while 20% improvement in efficiency took place for 20 mm nozzle diameter at a jet inclination of 100 with the jet 6 mm from the top of cup.

Wellinger and Metallk (1949) determined the erosion for ductile (carbon steel) and brittle material (high carbon steel) as a function of impact angle. The hard and brittle steel appeared to be more erosion resistant at low impact angles than the soft steel, while at high impact angles soft and ductile steel appeared to be more erosion resistant.

Pool, Dharan and Finnie (1986) conducted an experimental study of polymer composite materials on an erosion wear tester. The authors concluded that maximum erosion for a ductile material occurred at about 20°, and for brittle materials maximum erosion occurred at 90°.

Lin, Wu and Yeh (2001) conducted an experiment on impingement erosion testing equipment to determine the slurry erosion characteristics of three Ti-Ni shape memory alloys and SUS304 stainless steel by using the liquid/solid impingement. The authors have concluded that more resistant Ti-Ni alloys and less resistant SUS304 stainless steel exhibit ductile behavior, and maximum erosion was observed at 30°, and value of n in the relation $\varepsilon = KV^n$ varied between 2 and 3 for impingement angles between 15° and 90°.

Neilson and Gilchrist (1968) simplified the equation proposed by Bitter, and found that the total wear at normal impact angle can be assumed to be contributed by deformation wear only. For deformation wear, the author has found the following equation:

$$W_C = \frac{1}{2}\frac{M(V\cos\alpha - K)^2}{\varepsilon}$$

Range of Parameters

The effect of the three parameters such as silt size, silt concentration and jet velocity were investigated under the present study. Sample of silt was collected from the Beas river (India) near the Pandoh Dam in which silt concentration during the monsoon season found to be around 34,400 ppm (Awasthi 2001). The range of parameters used for the present study is given in Table 2. The silt was dried under the sun and then a sieve was used to measure the silt size.

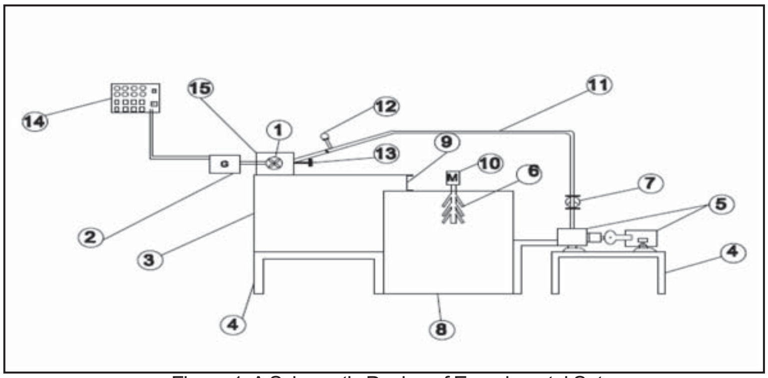
S. No.	Parameters	Range
1.	Silt size	370 µm
2.	Silt concentration	12000 ppm
3.	Jet Velocity	28.81m/s
4.	Operating Time	2 h
5.	Nozzle angle	20°, 25°, 30°

Table 1. Range of Parameters Investigated.

Experimental Setup and Procedure

Figure 1 shows the experimental set up of the Turgo impulse turbine of 1.2 kW capacity which was fabricated and used in the present study. The main characteristics of the turbine are given in Table 2. The blades of the Turgo impulse turbine were made of brass in order to to get a considerable amount of erosion in a short period of time. The weight of each blade was 202 g. A 5 mm thick transparent acrylic casing provided to allow water behaviour to be observed easily over the turbines. Two tanks (680 mm × 530 mm × 810 mm) were fabricated for experimentation work. The first tank was used to store water and to prepare a silt water mixture of concentration 12000 ppm, and the other tank was used to measure the discharge using a rectangular notch. The silt size was measured with the help of sieve of 370 µm. A stirrer was attached to operate continuously during the experiment so as to supply a uniform mixture of silt and water to the turbine. In order to prepare silt water mixture of various concentrations, the required quantity of silt was added to a known volume of water in the tank. The head and flow into the turbine during the experiments were kept constant. A penstock pipe having 71 mm outer diameter and 3 mm thickness was used for supplying water to the turbine. Water was supplied by a 7.5 HP monoblock centrifugal pump having 45 m rated head and discharge capacity of 5.5 l/s. A spear valve was used at the end of the penstock pipe with a nozzle having a diameter of 12.5 mm to regulate the discharge. Water from the turbine outlet was flown through the discharge tank and then discharged to the storage tank. A control valve was used at the delivery side to maintain the required head of water at every time. The head of water was measured by a digital pressure transducer mounted on the penstock pipe at the inlet of turbine.

A generator was directly coupled with the turbine runner shaft to generate electricity. The output of the turbine was determined by considering the efficiency of the generator. A resistive load was connected to the generator through a control panel. The control panel consisted of a wattmeter, a voltmeter and load in the form of electric bulbs of different ratings. The electric load was measured to determine the output. The weight loss of the blades was measured by using an electronic weight balance having a least count of 0.1 mg. The experimental study was carried out in two steps; at the start a Monoblock was used to draw clean water for different heads from the storage tank and supplied to the turbine to estimate the efficiency of the turbine. As a second step, the



Part Number	Part Name
1.	Turgo Runner
2.	Generator Set
3.	Concrete Tank
4.	Stand
5.	Mono Block
6.	Stirrer
7.	Control Valve
8.	Steel Tank
9.	Rectangular Notch
10.	Motor
11.	Penstock Pipe
12.	Pressure Transducer
13.	Spear Valve
14.	Control Valve
15.	Casing

Figure 1. A Schematic Design of Experimental Setup.

effect of silt parameters on the erosive wear and performance was investigated. The experiments were conducted for fixed values of silt size and concentration values of 370 μm and 12,000 ppm respectively.

The nozzle angles used for the experimental work were 20°, 25° and 30°. Blades were dismantled from the runner after every 2 hours, and cleaned with soft cloth. Then the weight loss of each blade was measured after 2 hours. At the same time, the efficiency of the turbine was also measured. The efficiency of the turbine was also measured for clean water, and by using this value the efficiency losses were estimated.

S. No.	Parameter	Values
1.	Runner Pitch diameter	216 mm
2.	Rotation speed	1108 rpm
3.	Flow rate	$2.96\times10^{-3} m^3/s$
4.	Nozzle Diameter	12.5 mm
5.	Buckets	19
6.	Mechanic Power	1.2 kW
7.	Blade Material	Brass

Table 2. Main Characteristics of the Turgo Impulse Turbine.

Turbine Efficiency

To calculate the efficiency of the Turgo impulse turbine, input in terms of head and discharge was calculated. The power output was measured with the help of a wattmeter. A control panel was connected to the generator to record the power generation from the generator. It consisted of a voltmeter, a wattmeter having a least count of 1 W, and electric bulbs were used as load. The discharge was calculated with the help of a rectangular notch. A pointer gauge was used to measure the height of water over the notch. During the experiments, input to the turbine was maintained constant by keeping the head and flow to the turbine constant. Turbine input was calculated from Equation 1.

$$P_i = \rho\, g\, Q\, H \tag{1}$$

The efficiency of the turbine was calculated from Equation 2.

$$\eta_t = \frac{P_0}{P_i \times \eta_g} \times 100 \tag{2}$$

Results and Discussions

It can be observed from Figure 3 below, that maximum erosion occurs at 20° nozzle angle. This feature is typical for a ductile material. In this case, material is removed by micro cutting as a result of oblique shear force, which increases the erosion rate. The amount of erosion is less at 25° nozzle angle due to increase in the angle of oblique shear force due to which the cutting action gradually converts into impact erosion. Any further increase in the angle will cause pure impact erosion to take place, and the erosion rate increases considerably at an angle of 30°.

Figure 4 shows the effect of nozzle angle on the percentage efficiency loss of the blades for a fixed value of silt size, silt concentration, jet velocity and operating time.

From Figure 4, it can be noticed that at nozzle angle of 20°, the percentage efficiency loss was found to be about 2%, which is higher than at angles of 25° and 30°. This is due to the fact that at 20°, normalized wear is more which increases the friction on the blade surface and, hence, results in loss in efficiency. The rate of percentage efficiency loss was found to be significant in this case. This shows that the rate of percentage efficiency loss is significant for smaller nozzle angles. However, the rate of percentage efficiency loss was found to be about 1.7 % for a nozzle angle of 25° and 1.89 % for a nozzle angle of 30°, due to increase in the wear rate at these angles.

Conclusion

On the basis of experimental investigation, it has been found that silt size, silt concentration, jet velocity, and

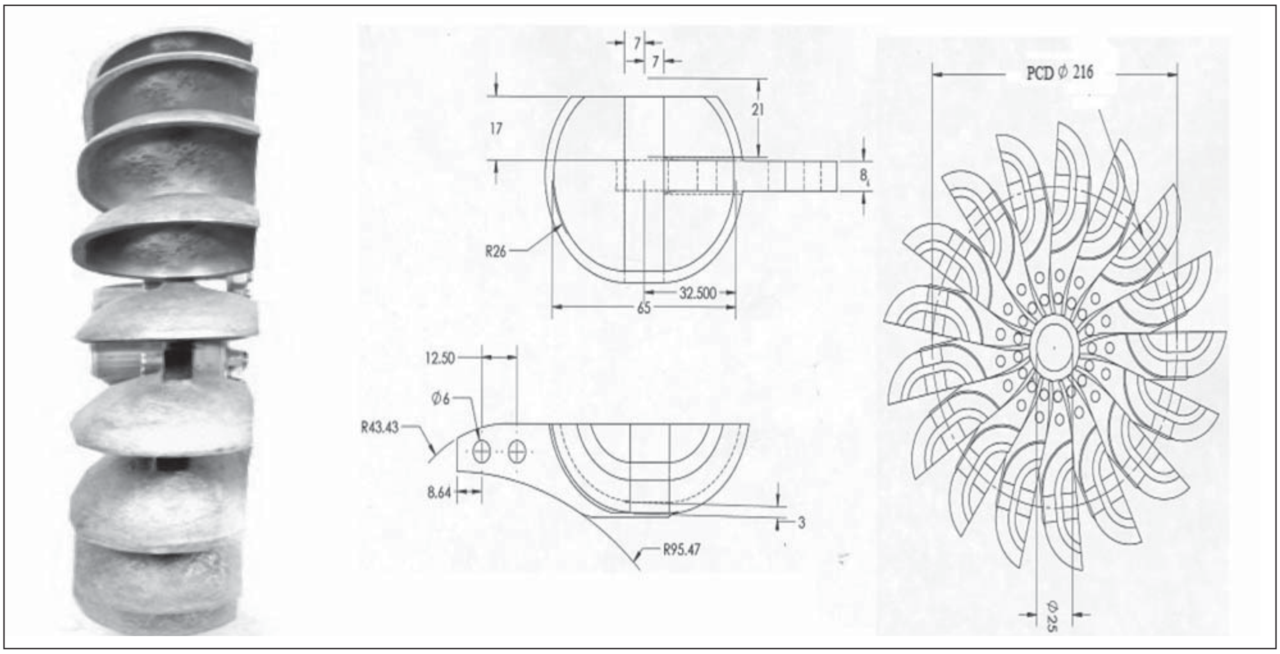


Figure 2. Runner of the Turgo Impulse Turbine.

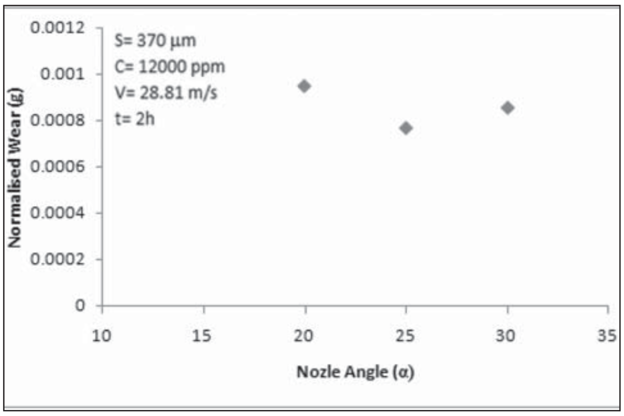


Figure 3. Effect of Nozzle Angle on Normalized Wear for Silt Size 370 µm, Concentration 12000 ppm, Jet Velocity 28.81 m/s, and Operating Time 2h.

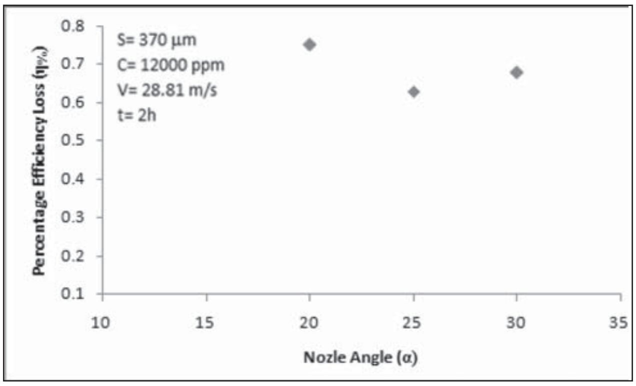


Figure 4. Effect of Nozzle Angle on Percentage Efficiency Loss for 2h , Silt Size 370 µm, Concentration 12000 ppm, Jet Velocity 28.81 m/s.

operating time affects the rate of erosion as well as performance of the Turgo impulse turbine. It can also be concluded from the experiment that maximum erosion occurs at a nozzle angle of 20°, and at angle of 25° less erosion takes place, which is the typical behaviour for ductile materials. However, the rate of percentage efficiency loss was found to be about 2% for a nozzle angle of 20° as compared to 25°.

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Performance Evaluation of Sewage Treatment Plants in Lucknow City

Mansi Tripathi and S. K. Singal


Mansi Tripathi


S. K. Singal

Abstract: The present study was conducted to evaluate the performance of existing sewage treatment plants (STPs) in Lucknow City of India. Currently, two STPs are operating in Lucknow, i.e., UASB reactor and FAB reactor, with total operating capacity of 345MLD and 56MLD, respectively. Since, the wastewater get mix with the domestic effluent while directing towards the STPs, therefore, the concentration of BOD is relatively very low, and hence the amount of biogas production by the UASB reactor is also reduced than its design value. Two approaches, evaluating the treatability performance and Life-Cycle Assessment (LCA) have been used to determine the plants efficiencies. All the results have been interpreted graphically. The results of this study conclude that the UASB reactor is better than the FAB, however in terms of LCA the FAB seems to be more reliable.

Key words: Sewage treatment, life cycle analysis, pollution, UASB, FAB, land cost, influent, effluent, Lucknow City, India

Introduction

The overall water management objectives of sewage treatment are associated with the removal of pollutants and to protect and preserve our natural water resources. Protection of human health from the pathogenic organisms present in sewage prior to the treated effluent being discharged to the receiving water bodies are of specific concern. The purpose of sewage treatment is to remove the organic and inorganic solids where the organic solids are decomposed by microorganisms and inorganic solids due to sedimentation. As the rivers are the major sources of drinking water needs, the treatment of sewage becomes necessary before discharging into the rivers.

Lucknow city is the capital of Uttar Pradesh state in India. It is situated on the banks of the river Gomti, and has a current population of about 2.803 million. This study is concentrated in the area of Lucknow city with latitude-longitude extent of 26.85°N and 80.92°E. According to IS: 1171-1971 an average domestic consumption of water under normal conditions is 135 lit/cap/day in India (Chavan 2007). Hence for a population of 2.803 million, by considering losses in the treatment plant and distribution system as 15% and 5% for non domestic supply, wastewater treatment plants with a total capacity of 454.086 MLD are required. However, as per the predicted population in the year 2010, Lucknow should have faced a wastewater generation of just 344 MLD. In the current sewerage scheme of the city, there are four separate Sewerage Districts each with its own commissioned or proposed treatment plant as shown in Table 1.

S. No.	Areas covered	Name of STP	Capacity of STP (MLD)	Proposed / Running
1	Chowk, Hardoi Road, Cambell Road, Dubagga	Daulatganj	56	Running
2	Amausi and Sarojini Nagar	Khwajapur	108	Proposed for 2040
3	Total Trans Gomti side	Bharwara	345	Running
4	Remaining C is Gomti side	Mastemau	270	Proposed for 2040

Table 1. Sewerage Districts in Lucknow City.

Technologies Used For Sewage Treatment

Upflow Anaerobic Sludge Blanket (UASB) and Fluidized Aerobic Bioreactor (FAB) are the two technologies currently being used to treat the sewage being generated in the city Lucknow, India. The UASB based STP in Lucknow has a total capacity of 345 MLD and is located in Bharwara, Lucknow and was commissioned under the Gomti Action Plan Phase II. The second STP is FAB based and has a total capacity of 56 MLD. Located in Daulatganj, Lucknow; originally it was commissioned under the Gomti Action Plan Phase I and its capacity was later extended under the Jawaharlal Nehru Urban Renewal Mission. The entire Sewerage network of Lucknow city comprises of 26 major drains which used to directly drain the raw sewage into the Gomti before these STPs came up. Four drains out of these have now been directed to the Daulatganj STP, and the remaining 22 have been proposed to be directed to the Bharwara STP. The Sewerage interconnection work is not yet complete in the city. Figure 1 shows the proposed diversion of the drains to the STPs via several small pumping stations, two intermediate pumping stations and one main pumping station.

In a UASB reactor with three distinct zones- sludge bed, sludge blanket and settling zone, solids get suspended in the blanket and slowly decompose. At the top, solids get separated from the gas and liquid, and biomass rises from sludge bed. Particles in the settling zone settle into the sludge bed after moving through the sludge blanket zone (Hwang and Hansen 1991; Heertjes and Van Der Meer 1978; Lettinga et al 1979; Lettinga et al 1980; Godwin et al 1982). Under favorable physical and chemical conditions, small sludge granules begin to form whose surface area is covered in aggregations of bacteria. Eventually the aggregates form dense compact structures and settle down. On the other hand, the FAB technology is essentially the same as activated sludge except that the media suspended in the reactor offers additional

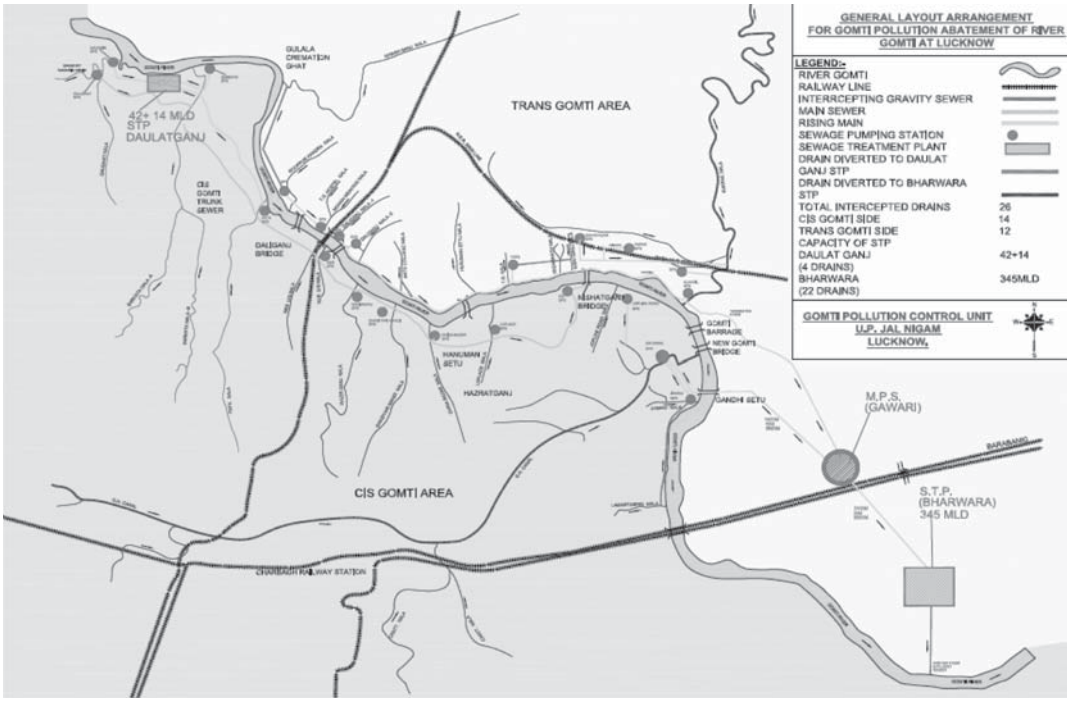

Figure 1. General Layout of Arrangement for Gomti Pollution Abatement at Lucknow. (Courtsey: Gomti Pollution Control Unit, U. P. Jal Nigam, Lucknow)

based plant at Bharwara, Lucknow and 56 MLD FAB based treatment at Daulatganj, Lucknow. Observations of the trends of their Life Cycle Costs with varying land cost and treatment capacity have also been reported in this study.

Methodology for Performance Evaluation

Parameters Taken

First of all, water quality parameters namely BOD5 (testing for BOD after taking incubation period

surfaces for the microbes to grow and this in turn maximizes the growth of microbes in a given volume of aeration tank compared to the conventional aeration without the media. In FAB technology, the media is kept stationary and is fluidized in the aeration tank. The STP at Daulatganj was initially started as a 42 MLD project in 2002 and later extended to 56 MLD in 2010. The results have been reported for a combined capacity of 56 MLD. The sludge generated in both the cases was dried in sludge drying beds and later dumped as waste or given away to local farmers for free. The treated water in both the cases is discharged into the Gomti River.

While designing a plant, it is tough to decide whether it is efficient to design a single plant that treats a large volume or several plants that treat individual small flows. Thus it is necessary to judge the environmental implications of a sewage treatment plant, considering its capacity. The Life Cycle Analysis (LCA) is a tool used for the evaluation of sewage treatment systems. The LCA weighs the environmental and other potential impacts through the lifetime of a product or service, from the use of raw materials, creating the product, its use and providing it to the customers (Margareta et al 2000; Gallego et al 2008; Hospido et al 2007; Patricia 2011).

The main objective of this study is to review and techno-economically compare the performance of the 345 MLD UASB

S. No.	Date	Inffluent			S. No.	Effluent		
		TSS (mg/ l)	BOD (mg/l)	COD (mg/l)		TSS (mg/ l)	BOD (mg/l)	COD (mg/l)
1.	1/04/2012	210	104	217	2.	20	23	50
3.	2/04/2012	250	108	207	4.	20	23	57
5.	3/04/2012	230	116	209	6.	30	26	56
7.	4/04/2012	260	110	212	8.	30	21	50
9.	5/04/2012	210	100	215	10.	20	24	58
11.	6/04/2012	230	118	217	12.	20	27	48
13.	7/04/2012	270	102	215	14.	30	22	52
15.	8/04/2012	210	110	211	16.	20	24	54
17.	9/04/2012	250	116	211	18.	20	22	54
19.	10/04/2012	270	108	213	20.	30	21	51
21.	11/04/2012	240	118	205	22.	20	28	52
23.	12/04/2012	210	100	209	24.	20	22	53
25.	13/04/2012	260	126	215	26.	30	29	56
27.	14/04/2012	180	104	211	28.	20	28	51
29.	15/04/2012	230	114	210	30.	20	26	52
31.	16/04/2012	250	124	217	32.	30	28	53
33.	17/04/2012	190	100	208	34.	20	21	48
35.	18/04/2012	220	110	206	36.	20	24	49
37.	19/04/2012	270	118	218	38.	20	26	59
39.	10/04/2012	230	102	221	40.	20	23	46
41.	21/04/2012	210	102	216	42.	30	20	45
43.	22/04/2012	250	118	222	44.	30	25	55
45.	23/04/2012	270	124	209	46.	30	28	48
47.	24/04/2012	250	114	217	48.	20	24	58
49.	25/04/2012	230	111	220	50.	20	24	52
51.	26/04/2012	300	115	213	52.	30	25	46
53.	27/04/2012	240	100	204	54.	20	23	56
55.	28/04/2012	190	124	214	56.	20	20	47
57.	29/04/2012	270	113	219	58.	30	23	55
59.	30/04/2012	235	107	209	60.	24	24	49
	Mean	**237**	**111**	**213**		**24**	**24**	**52**

Table 2: Results of wastewater quality parameters for the 60 samples collected at Daulatganj STP

S. No.	Date	Influent TSS (mg/ l)	Influent BOD (mg/l)	Influent COD (mg/l)	S. No.	Effluent TSS (mg/ l)	Effluent BOD (mg/l)	Effluent COD (mg/l)
61.	1/04/2012	233	115	209	62.	24	25	42
63.	2/04/2012	206	91	213	64.	21	21	46
65.	3/04/2012	223	98	203	66.	23	22	51
67.	4/04/2012	221	93	205	68.	23	22	57
69.	5/04/2012	192	80	199	70.	22	24	48
71.	6/04/2012	213	89	207	72.	24	20	51
73.	7/04/2012	234	100	209	74.	22	23	52
75.	8/04/2012	221	91	203	76.	24	19	42
77.	9/04/2012	332	92	208	78.	25	26	49
79.	10/04/2012	256	94	207	80.	23	22	43
81.	11/04/2012	209	88	202	82.	21	21	47
83.	12/04/2012	174	92	211	84.	17	23	48
85.	13/04/2012	239	108	200	86.	26	22	56
87.	14/04/2012	188	83	210	88.	23	23	49
89.	15/04/2012	207	93	204	90.	17	22	43
91.	16/04/2012	217	88	200	92.	24	24	52
93.	17/04/2012	219	92	205	94.	22	21	50
95.	18/04/2012	178	85	212	96.	23	20	44
97.	19/04/2012	190	90	213	98.	25	22	56
99.	10/04/2012	232	102	208	100.	23	25	55
101.	21/04/2012	225	82	200	102.	21	23	47
103.	22/04/2012	216	96	212	104.	24	22	41
105.	23/04/2012	213	87	206	106.	23	20	49
107.	24/04/2012	192	90	199	108.	26	21	45
109.	25/04/2012	173	80	201	110.	20	18	46
111.	26/04/2012	205	89	201	112.	22	19	54
113.	27/04/2012	185	93	212	114.	33	22	44
115.	28/04/2012	228	90	204	116.	30	20	50
117.	29/04/2012	190	106	206	118.	21	24	55
119.	30/04/2012	176	91	211	120.	25	18	53
	Mean	**213**	**92**	**200**		**23**	**22**	**49**

Table 3. Results of wastewater quality parameters for the 60 samples collected at Bharwara STP.

of sample for five days), COD and TSS of the influent and effluent of the two STPs were analyzed under controlled conditions of temperature and pH. Then, the most cost-effective and sustainable STP for the city of Lucknow is chosen from the analysis of Life Cycle Cost of STPs in a particular locality based on the above technologies and having the same capacity of treatment but at different land costs. Other results were interpreted in a similar condition but with constant land costs and different capacities. Water quality parameters as considered, BOD5, COD and TSS of the influent and effluent of the two STPs have been tabulated and analyzed in terms of percentage removal. The analytical procedures used have been adopted from Guide Manual: Water and Wastewater Analysis-Central Pollution Control Board, India (Guide Manual 2011).

Data Collection and Sources of Data

Data of the influent and effluent of each plant were collected and tested for analysis. These tests were conducted in Water Testing Laboratories at the sites of the Sewage Treatment Plants. Overall a number of 120 samples were tested during the pre-monsoon month of April, 2012 in order to minimize chances of dilution of sewage due to rain water which may otherwise affect the actual results. The operating temperature and pH were controlled between 28-32^{o}C and 7±0.5 respectively. The primary data were obtained by analysis of samples collected whereas the secondary data was collected from U.P. Jal Nigam, Gomti Pollution Control Unit, Lucknow. Sampling was done in a composite manner and collected samples were refrigerated during the time between collection and analysis. Analysis of the samples was done on the day of collection.

Analysis of Water Quality Parameters

Three wastewater quality parameters namely; BOD5, COD and TSS of the 120 samples as collected during April, 2012 have been evaluated and given in Table 2 and 3. Percentage removal for all these parameters has been calculated, and shown in Figure 2 and Table 4. Figure 2 shows the comparison in percentage removal efficiency of these two STPs for the considered water quality parameters. From the Table 4 and Figure 2, it can be concluded that:

1. BOD removal efficiency of Daulatganj STP is better than Bharwara STP.
2. COD removal efficiency of Bharwara STP is better than Daulatganj STP.
3. TSS removal efficiency of Daulatganj STP is better than Bharwara STP.

From the above Figure 2 and Table 4, it is clear that in the above condition, to select the best technology with a significant margin on the basis of performance comparison is difficult because BOD and TSS values of Daulatganj STP show greater removal efficiencies while Bharwara STP give greater removal efficiency for COD. However, the difference in removal efficiencies of both the reactors is ±2%, thus these results are not of much use to draw a final conclusion. Hence, the Life Cycle Cost

S. No.	Water Quality Parameter	Daulatganj STP In flow	Daulatganj STP Out flow	Daulatganj STP % Removal	Bharwara STP In flow	Bharwara STP Out flow	Bharwara STP % Removal
1	BOD_5 (mg/l)	111	24	78	92	22	76
2	TSS (mg/l)	237	24	90	213	23	89
3	COD (mg/l)	213	52	76	200	49	76

Table 4. Treatment Characteristics of Treatment Plants considered under Study.

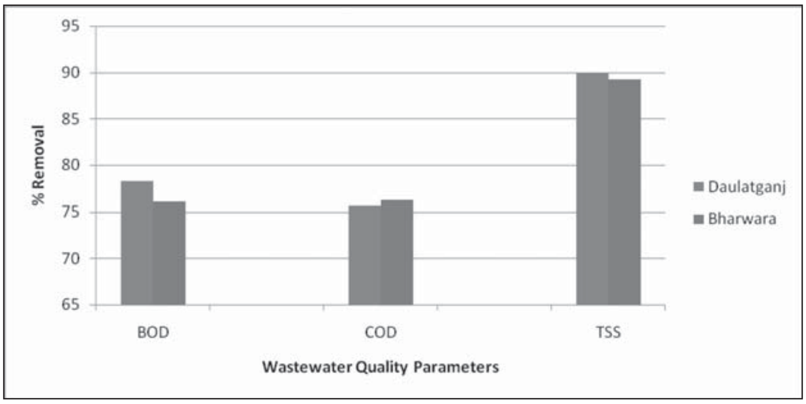

Figure 2. Removal Efficiencies of STPs.

of different technologies used in these STPs has been carried out for selecting the best technology.

Life Cycle Analysis

Details of Sewage Treatment Plants

The data collected for both the STPs has been summarized in the following Tables 5 and 6.

S. No.	Description	Daulatganj STP	Bharwara STP
		Amount (in million Rs.)	
1	Staff	1.37	7.34
2	O/M Works	31.48	25.40
3	O/M of Chemicals	0.36	6.72
4	Electricity Charges	36.13	15.33
5	Diesel Charges	-	6.94
	TOTAL	**69.34**	**61.73**
6	Revenue from sale of sludge	0.72	1.80
	NET O/M COST	**68.62**	**59.93**

Table 5. Per Annum Cost of Net Operation and Maintenance.

S. No.	Description	Unit	Daulatganj STP	Bhar-wara STP
1	Technology	-	FAB	UASB
2	Capacity	MLD	56	345
3	Construction cost (exc. land)	Rs. (million)	223.92	1697.10
4	Annual Power Cost	Rs. (million)	36.13	22.27
5	Net annual O/M Cost	Rs. (million)	68.62	59.92
6	Land required	Ha	2.02343	48.56
7	Sludge produced	TPD	16	40
8	Biogas generation	m^3/h	NIL	Insuf-ficient

Table 6. Details of STPs.

Life Cycle Cost

For calculating, comparing and analyzing the Life Cycle Cost for each of the above mentioned STPs, it is considered that 10 MLD capacity plants based on each of the above mentioned technologies i.e. FAB and UASB are to be constructed, operated and maintained at Lucknow in the same locality to serve the same community. The life of these STPs is assumed to be 20 years (n) and interest rate (i) to be 10% as prevailing. Life Cycle Costs have been calculated by keeping the capacity of the plant fixed and varying the rate of land. Then Life Cycle Costs have been calculated by varying the size of the plant but keeping the cost of the land constant.

Per MLD annual cost of O&M is calculated by adding the annual per MLD cost of power and maintenance cost. The total annual O&M cost is calculated for 10 MLD. Then, the capitalized cost of O&M for 20 years is calculated by using the following formulas:

- Capitalized O&M cost for 20 years =(Total annual O&M cost) x[{1-1/(1+i)^n}/i]
- Life Cycle Cost for 20 years= Capital cost including land cost + Capitalized O&M cost for 20 years.

The potential cost recovery from the sale of sludge has been deducted to calculate the net operation and maintenance cost as shown in Table 5. These cost recovery amounts from sale of sludge generated are approximately Rs. 0.72 million for Daulatganj STP and Rs. 1.8 million for Bharwara STP. Though the recovery amounts are comparatively low still they can be used to compensate a portion of electricity and other bills. It is necessary to deduct the potential cost recovery from the by-products. From the data available at the plants, the following has been deduced:

- Treated effluent is not sold and is discharged into the Gomti river.
- Sludge cakes are taken away by the local farmers for free or are dumped by the Nagar Nigam.
- FAB plant does not produce biogas as it is aerobic.
- UASB plant produces very insignificant amount of biogas as it receives very low organic load.

In Table 7, the Life Cycle costs of the Bharwara and

S. No.	Description	Unit	Land rate = 1 million Rs./ha		Land rate = 5 million Rs./ha	
			Daulatganj	Bharwara	Daulatganj	Bharwara
1	Design flow	MLD	10	10	10	10
2	Unit cost of construction	million Rs./MLD	4.0	4.92	4.0	4.92
3	Cost of construction (except land)	million Rs.	40.0	49.20	40.0	49.20
4	Unit area required	ha/MLD	0.04	0.14	0.04	0.14
5	Area required	ha	0.40	1.40	0.40	1.40
6	Cost of land	million Rs.	0.40	1.40	2.00	7.00
7	Total cost of construction	million Rs.	40.40	50.60	42.00	56.20
8	Unit annual net O&M cost	million Rs. /MLD	1.23	0.17	1.23	0.17
9	Annual cost of net O& M	million Rs.	12.30	1.70	12.30	1.70
10	Capitalized cost of net O&M	million Rs.	104.67	14.48	104.67	14.48
11	Cost of STP for 20 years	million Rs.	145.07	65.08	146.67	70.68
12	Life Cycle Cost of STP	million Rs.	**145.00**	**65.00**	**147.00**	**71.00**

Table 7. Life Cycle Cost Analysis for 10 MLD for Lucknow.

Daulatganj STPs has been calculated considering a constant STP capacity of 10 MLD for land costs of Rs. 1 million/ha and Rs. 5 million /ha.

In Table 8, the Life Cycle costs of the Bharwara and Daulatganj STPs has been calculated considering a constant STP capacity of 10 MLD for land costs of Rs. 9 million/ha and Rs. 13 million/ha.

S. No.	Description	Unit	Land rate = 9 million Rs./ha		Land rate =13 million Rs./ha	
			Daulat ganj	Bhar wara	Daulat ganj	Bhar wara
1	Design flow	MLD	10	10	10	10
2	Unit cost of construction	million Rs. / MLD	4.00	4.92	4.00	4.92
3	Cost of construction (except land)	million Rs.	40.00	49.20	40.00	49.20
4	Unit area required	ha/MLD	0.40	0.14	0.04	0.14
5	Area required	ha	0.40	1.40	0.40	1.40
6	Cost of land	million Rs.	3.60	12.60	5.20	18.20
7	Total cost of construction	million Rs.	43.60	61.80	45.20	67.40
8	Unit annual net O&M cost	million Rs. / MLD	1.23	0.17	1.23	0.17
9	Annual cost of net O& M	million Rs.	12.30	1.70	12.30	1.70
10	Capitalized cost of net O&M	million Rs.	104.67	14.47	104.67	14.47
11	Cost of STP for 20 years	million Rs.	148.27	76.27	149.87	81.87
12	**Life Cycle Cost of STP**	**million Rs.**	**148.00**	**76.00**	**150.00**	**82.00**

Table 8. Life Cycle Cost Analysis for 10 MLD for Lucknow.

S. No.	Description	Unit	10 MLD		20 MLD	
			Daulat ganj	Bhar wara	Daulat ganj	Bhar wara
1	Design flow	MLD	10	10	20	20
2	Unit cost of construction	million Rs./ MLD	4.00	4.92	4.00	4.92
3	Cost of construction (except land)	million Rs.	40.00	49.20	80.00	98.40
4	Unit area required	ha/MLD	0.04	0.14	0.04	0.14
5	Area required	ha	0.40	1.40	0.40	1.40
6	Cost of land	million Rs.	0.40	1.40	0.80	2.80
7	Total cost of construction	million Rs.	40.40	50.60	80.80	101.20
8	Unit annual net O&M cost	million Rs./ MLD	1.23	0.17	1.23	0.17
9	Annual cost of net O& M	million Rs.	12.30	1.70	24.60	3.40
10	Capitalized cost of net O&M	million Rs.	104.67	14.47	209.35	28.93
11	Cost of STP for 20 years	million Rs.	145.07	65.07	290.15	130.13
12	**Life Cycle Cost of STP**	**million Rs.**	**145.00**	**65.00**	**290.00**	**130.00**

Table 9. Life Cycle Cost Analysis for land cost of 1 million Rs./ ha for Lucknow.

In Table 9, the Life Cycle costs of the Bharwara and Daulatganj STPs has been calculated considering a constant land cost of 1 million Rs./ha and varying STP capacities of 10 MLD and 20 MLD-

In Table 10, the Life Cycle costs of the Bharwara and Daulatganj STPs has been calculated considering a constant land cost of 1 million Rs./ha and varying STP capacities of 30 MLD and 40 MLD.

PS: 1 Indian Rupee = 0.02 US$

Results and Discussions

The LCC of the selected STPs at Lucknow; namely UASB based STP at Bharwara and FAB based STP at Daulatganj has been shown in Tables 7-10. Tables 11-12 and Figure 3-4 show the analysis of the LCC values obtained under two conditions i.e. constant land cost (with varying capacity) and constant capacity (with varying land cost).

S. No.	Description	Unit	30 MLD		40 MLD	
			Daulat ganj	Bhar wara	Daulat ganj	Bhar wara
1	Design flow	MLD	30	30	40	40
2	Unit cost of construction	million Rs./ MLD	4.00	4.92	4.00	4.92
3	Cost of construction (except land)	million Rs.	120.00	147.60	160.00	196.80
4	Unit area required	ha/MLD	0.04	0.14	0.04	0.14
5	Area required	ha	1.20	4.20	1.60	5.60
6	Cost of land	million Rs.	1.20	4.20	1.60	5.60
7	Total cost of construction	million Rs.	121.20	151.80	161.60	202.40
8	Unit annual net O&M cost	million Rs./ MLD	1.23	0.17	1.23	0.17
9	Annual cost of net O& M	million Rs.	36.90	5.10	49.20	6.80
10	Capitalized cost of net O&M	million Rs.	314.02	43.40	418.69	57.87
11	Cost of STP for 20 years	million Rs.	435.22	195.20	580.29	260.27
12	**Life Cycle Cost of STP**	**million Rs.**	**435.00**	**195.00**	**580.00**	**260.00**

Table 10. Life Cycle Cost Analysis for Land Cost of 1 million Rs./ ha for Lucknow.

Case 1: Life Cycle Cost Analysis of STPs with varying land cost but fixed capacity

The results of Tables 7-8 are summarized as Table 11 and Figure 3, which show the LCC of STPs when both have treatment capacity of 10 MLD but their cost of land is increasing. In this case, the LCC increases for both FAB and UASB technologies as the land cost increases but the LCC remains lower for Bharwara STP with UASB technology.

Varying Land cost (million Rs. / ha)					
S. No.	STP Name	1	5	9	13
1	**Daulatganj**	145.00	147.00	148.00	150.00
2	**Bharwara**	65.00	71.00	76.00	82.00

Table 11. Life Cycle Costs (million Rs.) of STPs with varying Land Cost at Fixed Capacity.

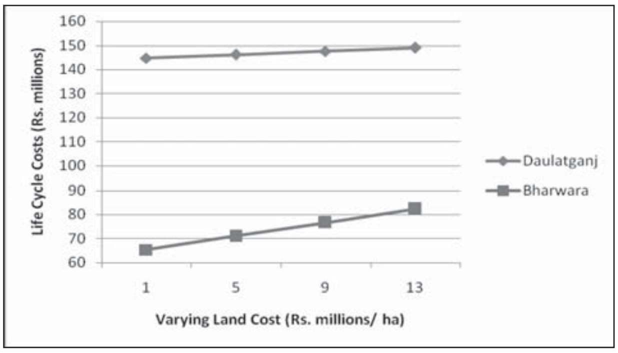

Figure 3. Life Cycle Costs (million Rs.) of STPs with varying Land Cost at Fixed Capacity.

Case 2: Life Cycle Cost Analysis of STPs with varying capacity but fixed land cost

The results of Tables 9-10 can be summarized as Table 12 and Figure 4, which show the LCC of the two STPs when the cost of land is fixed at 1 million/ha and they are operating at different capacities. Figure 4 shows that the LCC for both STPs increases with the increase in treatment capacity but the LCC of UASB based STP at Bharwara is lower.

Varying capacity (MLD)					
S. No.	STP Name	10	20	30	40
1	**Daulatganj**	145.00	290.00	435.00	580.00
2	**Bharwara**	65.00	130.00	195.00	260.00

Table 12. Life Cycle Costs (million Rs.) of STPs with varying Capacity at Fixed Land Cost.

The results of the techno-economical analysis of the two STPs in Lucknow have been summarized in Tables 11-12 and Figures 3-4.

Figure 3 and Figure 4 show that the LCC of Bharwara STP is lower than that of Daulatganj STP in both the cases considered. Other observation from Figure 3 and Figure 4 is that in both the cases the line representing the growth of the LCC for Daulatganj and the line representing the growth of the LCC of Bharwara STP will intersect at a critical point. This critical point represents the critical value of land cost (per hectare) beyond which if the land cost increases, then the Bharwara STP will have a greater LCC than the Daulatganj STP. Similarly, in the second case this critical point represents the critical value of the capacity of STP (MLD) beyond the Bharwara STP will have a greater LCC than the Daulatganj STP.

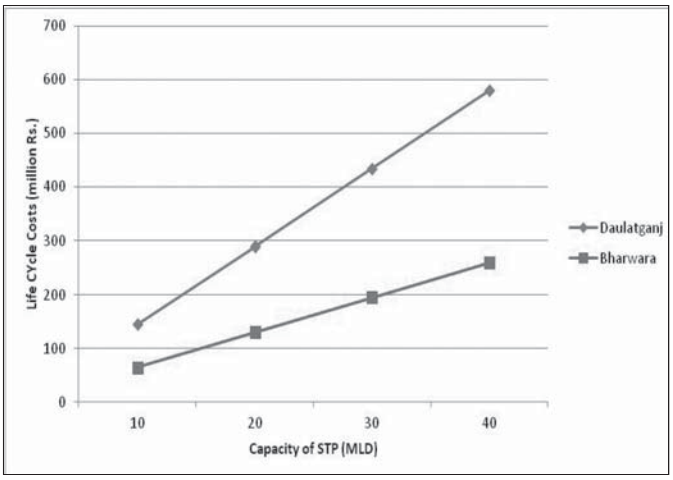

Figure 4. Life Cycle Costs (million Rs.) of STPs with varying Capacity at Fixed Land Cost.

From the above observations, it is clear that in both the cases i.e when the capacity remains constant and when the land cost remains constant, the **UASB based STP at Bharwara shows a lower LCC than the FAB based STP at Daulatganj. It is also seen that in both the cases, the rate of increase of the LCC is greater for the Bharwara plant.**

Conclusions

Lucknow city was selected for the study of the performance of two STPs in running condition i.e. the 345 MLD based STP at Bharwara and 56 MLD based STP at Daulatganj. Life Cycle Cost analysis was done for a period of 20 years for the two STPs and the conclusions drawn from the study are as follows:

1. Both of the existing sewage treatment plants are working properly and the results of treated water are observed as per the central pollution control board norms. It has been observed that 100 % of the waste water generated is not treated; thus more plants are required.
2. More foam was observed at site during the visit in the final polishing ponds of the UASB reactor. Antifoaming agents are available in the market to remove the foam, and should be used.
3. Due to the inefficient sewerage network, highly diluted sewage is received at the Bharwara plant due to which there is insignificant biogas generation which could otherwise be used for power generation; hence, cost recovery.
4. All treated water is disposed into the Gomti River. The treated water may be used for industrial and irrigation purposes.
5. Several important Water Quality Parameters like Faecal Coliform, Sulphate, Oil and Grease are not measured on a regular basis.
6. For a particular location i.e. fixed land cost, the LCC of the FAB and UASB reactors increases with the capacity of the STP but the LCC is lower for the UASB reactor up to a particular value of the STP's capacity; however, the rate of increase is greater for

the UASB reactor.

7. If land the cost increases and the capacity of the STP remains constant, the LCC of both FAB and UASB reactors increases but the LCC is lower for the UASB reactor up to a particular value of the land cost.
8. Due to the low LCC of the UASB based Bharwara STP, it is better for a city like Lucknow.

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Interview with Dr. Keshab Man Shakya, Hon'ble Minister for Science, Technology and Environment

Dr. Keshab Man Shakya, granted an interview to Mr. Jeewan P. Thanju, Editor-in-Chief, Hydro Nepal Journal. Excerpts from the Interview.

There have been serious objections from the developers for the long time (about 2 years) taken to approve an EIA report. Why this cannot be done in a few months time?

Generally EIA report comes to the Ministry without proper and required documents to process it. If the developers submit EIA report to the Ministry with all the required documents it will not take more than three to four months to approve the EIA report. After I came to the Ministry, I have directed concerned officials in the Ministry to make EIA timely and transparent and to speed up the approval process.

There is very high pollution in Kathmandu from vehicles and other sources. Why there is no enforcing of the Emission standards in the field; and your Ministry's role is not heard? When will there be an effective monitoring?

In order to deal with the air pollution problems, the Government has taken preventive and corrective measures like import of only unleaded gasoline and less than 0.25% sulfur content diesel; ban on the import of two stroke engine vehicles, second hand and reconditioned vehicles; introduction of vehicle emission standards for existing vehicles plying in the streets; introduction of Nepal Vehicle Mass Emission Standard 1999 (EURO-I) now upgraded to EURO-III for new vehicles to be imported; and phasing out of highly polluting diesel operated three wheelers from Kathmandu Valley and highest priority has been given for the promotion of electric vehicles through incentive mechanism. Beside, our Ministry has introduced vehicle emission testing and green stickers system in five major cities other than Kathmandu Valley.

Major steps have been taken in the area of vehicular emission, provision of environmental inspectors for the management and monitoring of pollution by industries, development of air quality monitoring stations for urban areas specially for Kathmandu have been under taken. Beside introduction of various environmental standards and regulatory measures for controlling pollution there is little success mainly because of the weak institution, lack of proper infrastructure and trained manpower and government's low priority on the sector of environment. The task of controlling pollution is not merely the responsibility of the government but it is equally the role of industries, private sectors, civil society and citizen as a whole. Recently government has made a decision to establish the Department of Environment with a major goal of environmental management and control of pollution. I hope with the establishment of the Department of Environment, it will speed up the enforcement and environmental governance in the country.

Climate change in Nepal is real. The snows in Great Himalayas will be no more in a few decades. How your Ministry plans to tackle this?

Climate change becoming a growing challenge in our pursuit to sustainable development especially for least developed country like Nepal. A study done by CSIRO, 2006 has estimated that in general, the Asia Pacific region will experience increase in temperature by the order of 0.5–2°C by 2030 and 1–7°C by 2070. A similar study conducted by India and the UK also indicate that the Himalayan region will be some of the worst hit due to climate change impacts.

As climate change impacts is a global phenomena triggered by the industrial activities of the developed world, it needs a global cooperation to mitigate and reverse the trends of climate change. As you are aware that Nepal is the least emitter of green house gas. Nepal has maintained 39% of the forest cover and 23.23% of the Nepal's land area is covered by protected and a conservation area which is a significant step in carbon sequestration to halt the impact of climate change. Moreover, MoSTE has initiated various projects to deal with the impact of climate change like Pilot Project for Climate Resilience (PPCR), Nepal Climate Change Support Programme (NCCSP), Scaling up of Renewable Energy Programme (SREP). To deal systematically with the climate change, the Government of Nepal has already prepared National Adaptation Plan of Action to Climate Change, 2010; Climate Change Policy, 2011 and Local Adaptation Plan of Action (LAPA), 2012. I believe that such initiative will certainly help to mainstream climate change issues in our development planning and help to address the impact of climate change in Nepal.

There has been big talk about wind energy in Nepal; but, no concrete steps taken so far for commercial exploitation of wind energy. In our opinion about 200 kW plant each in 2 promising locations could be established as a pilot project; and if the results are encouraging then large scale commercial exploitation can be initiated. What is your view point?

As per AEPC study 3000 MW of electricity can be generated from wind energy which is far greater than electricity demand of Nepal. However, beside this great potential, there is certain thing that needs to be addressed. For example, there is a need to conduct comprehensive study and mesoscale modeling for estimating exact energy that can be harnessed from wind power. To generate sufficient data on wind power exploitation, we have to expand wind power measurement stations network throughout the country. For demonstration purpose we can install few wind power electricity generating stations in certain part of the country.

What is the output of NAST in regards to investment in it? Are you satisfied with its output?

Nepal Academy of Science and Technology (NAST) is an autonomous body affiliated to the Ministry of Science, Technology and Environment with the main objective of advancement of science and technology for all-round development of the nation, modernization of indigenous technologies and promotion of research in science and technology. Investment in science and technology is for the future as output of the investment in this field cannot be materialized in short span of time. Development of technology and findings of any research has to go through rigorous process following scientific protocols and methodology. In fact investment in science and technology sector is not satisfactory as our resources and energy still dedicated to fulfill the basic necessities of the people. But at the same time I want to emphasize that scientific community should be responsible to the people and nation as investment in this field should come with innovative technology that can be applied in real field that serve the advancement of economy and living standard of its people.

The Ministry of Forest and Soil Conservation has announced that there will a 5% Environment Service Fee on the annual profits of a hydropower project. The developers claim that they are already paying various taxes and royalists to the Govt. What is your opinion on it?

One thing we need to consider is that any investment in development sector and large scale infrastructure development has negative implication on the environment and ecosystem. In order to mitigate the negative impact of development it is wise to allocate certain percentage of the project cost or the revenue generated from such project to repair the damage caused by the development endeavors. In my opinion holistic development can be achieved only by balancing three pillars of sustainable development that is economic, social and environmental.

Would you like to give any message to the related stakeholders?

Environment is a common entity for all of us in which we live and depend for our survival and well-being. It is our responsibility to protect and manage our environment wisely taking into consideration of the limitation posed by our natural system. The natural system and natural resources that are present in our surrounding is not only for us as it is our responsibility to protect it for future generation also. We should be very careful in the use of natural resources as one person's over use cuts the needs of other individual. It is always good to apply the principle of equity and fair distribution of natural resources that promote peace and harmony in the society. We are facing with unprecedented challenges of climate change and pollution at our door step. In such a circumstances, let us work together to protect our environment and make Nepal a hospitable and prosperous place to live in. Finally, I would like to urge all to work together with the Ministry of Science, Technology and Environment for our common goal of maintaining a clean, green and pollution free environment. Thank you.

CALENDAR OF EVENTS - WATER RESOURCES

Continues from page no. 65

Water Conservation Conference. Location: Bangkok, Thailand. More info: http://www.ldd.go.th/web_waswac2/index.htm

15-17 May, 2013: The 16th German Dam Symposium. Location: Magdeburg, Germany. The theme for the conference is "Dams ensure the future". Contact Email: jana.radoi@conventus.de. More info: www.talsperrensymposium.de

19 - 23 May, 2013: Fourth Session of the Global Platform for Disaster Risk Reduction. Location: Geneva, Switzerland. Contact Email: CDsymposium@unesco-ihe.org. More info: http://www.preventionweb.net/globalplatform/2013/

29-31 May, 2013: 5th Delft Symposium on Water Capacity Development. Location: Delft, Netherlands. More info: http://www.unesco-ihe.org/CD-Symposium

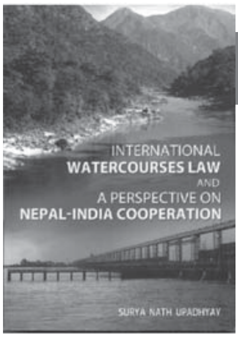
12-16 August, 2013: The 2013 ICOLD Annual Meeting. Location: Seattle, Washington, USA. Contact Person: Larry Stephens, United States Society on Dams. Contact Email: stephens@ussdams.org. More info: www.icold2013.org

2-5 September, 2013: 12th International Symposium on River Sedimentation. Location: Kyoto, Japan. More info: http://www.dpri.kyoto-u.ac.jp/~ISRS2013/default.html

8-13 September, 2013: The 35th IAHR World Congress> Location: Chengdu, China. The central theme of the Congress will be 'The wise find pleasure in water'. Contact: China Institute of Water Resources and Hydropower Research (IWHR). Contact Email: iahr2013@vip.163.com. More info: www.iahr2013.org

22-25 October 2013: 7th IWA Specialist Conference on Efficient Use & Management of Water. Location: Paris, France. More info: http://www.iwaefficient.com/2013/

27-29 November, 2013: International Conference on Climate Change, Water Resources and Disasters in Mountainous Regions: Building Resilience to Changing Climate. Location: Kathmandu, Nepal.



BOOK REVIEW Reviewed by **Jeewan P. Thanju**

International Watercourse Law and A Perspective on Nepal-India Relation

By Surya Nath Upadhaya
Kathmandu, Nepal: Ekta Books, 435pp, Rs.650/- (US$ 35)

This book is written by a prominent person with more than three decades of experiences and expertise in the sector of water resources. Nepal's water resources have a very high potential to benefit the people of this region; which is not happening in practice. The people of this region have a right to know, why the water resources of Nepal have not been fully exploited - asserts the author. The book tries to answer this query. The book reviews the water relationship between Nepal and India in the perspectives of International Law. The author has analyzed in detail the various aspects of the Kosi, Gandak agreements and the Mahakali River Treaty between Nepal and India. In the considered opinion of the author, Nepal has failed miserably to benefit from Nepal-India bilateral agreements.

The book has two parts: a) International law, and b) Nepal-India Cooperation on water resources. The Appendices include Rules and Laws on International Rivers/water courses, agreements on the Kosi, Gandak rivers and the Treaty on the Integrated Development of the Mahakali River.

Chapter 1: Introduction:- In the first part there are two Chapters, Chapters 2 and 3.

Chapter 2: International Water Law:- It deals with the various laws on the international rivers/water courses. It explains the Helsinki Rules on the uses of Water of International Rivers, and Convention of the Non-navigational Uses of International Water Courses. India has not signed this convention. Further, it is not yet adopted by the UN due to lack of sufficient number of signatories. Though, India has not signed the Convention, it has a moral obligation to follow the laws. The basic feature of the International Law on Watercourses is **Equitable utilization within border**, and **No significant harm to other countries**. The Author has described the Regional Convention regarding the international watercourse in Africa, Americas, and Europe. Treaties dealing with the agreements between the USA and Canada, Bulgaria and Turkey, Lesotho and South Africa, Mekong River Commission, Nile Water, Columbia River, The Indus Basin, Bangladesh and India are discussed in detail. In addition it gives the decisions of International or national Courts or Tribunals on 15 cases of Disputes. It has given description of International Legal agencies in the sector. The Indian Arbitral Awards are cited as good examples for resolving disputes.

The author's point of view is that adherence to the International Laws by India and Nepal will benefit both the countries, and as such there will not be any sense of cheating between them.

Chapter 3: Laws on Procedures of Cooperation in International Water Courses:- The following points are covered in this Chapter:

1. Obligation to Notify about Planned Measures;
2. Obligation to Exchange Information;
3. Obligation to Consult and Negotiate in Good Faith;
4. Issues Connected to Obligations to Exchange Information's in Good Faith;
5. Issues connected to Obligations to Exchange Information, notify Planned Measures and Negotiate in Good Faith;
6. Silence to Notifications and Reservation to Future use;
7. The World Bank Policy on the Use of International Water courses; and
8. Benefit Sharing among the Watercourse States.

Chapter 4: Nepal's Water Resources:- The author cites that the 138.5 Billion m^3 of water storage behind high dams in Nepal will be vital to India for irrigating its land in the light of increased population, climate uncertainty, and transfer of water in deficit states. Climate change will decrease the water flows considerably. Further, the acute shortage of electricity in India's Northern Grid can be alleviated to a great extent from the high value peaking hydropower from the storage projects in Nepal.

Nepal's interest should be to have rightful access to the sea through water transports via the Ganges through the water resources development of Nepal.

Chapter 5: Agreement on the Kosi Project:- It sheds light on how the lease period of 99 years was changed to 199 years that was bargained politically in the highest level. The benefits accrued to Nepal are negligible compared to the benefits to India. Due to poor monitoring by Nepal, it has not been able to get the concessions that were agreed in the agreement. For example, compensation has not been paid to the land owners of 10,000 Bigha (6250 ha) even after 58 years have elapsed, the land tax has not been fully paid to the Government of Nepal for a long time, royalty for the hydropower sold in India (generated from the project) has been neither asked by Nepal nor paid by

India. The breach of the Left Kosi Embankment in 2008 created havoc and misery to millions of people in Nepal and India. It was the responsibility of the Government of India for the maintenance and safe operation of the Kosi Barrage complex including the embankments. And it was India's responsibility to rehabilitate the infrastructures and the people after the catastrophic flood. However, the Government of Nepal had to repair the road and conduct other rehabilitation works; and compensation was not demanded from India for the loss and suffering of the Nepalese people.

The book discusses about the proposed Kosi High Dam Project (KHDP) for which investigation is ongoing. The author is concerned that the Nepalese counterparts in the Study Team are paid salary by India; and, hence, they will not be effectively working for the interest of Nepal and they may be the mere witness of the Study. No office has been established for the study of navigation and irrigation benefits in the Indian Territory.

The author's view point on the KHDP is that India desperately needs it to be executed in earnest. For this Nepal should be adequately compensated and the benefits generated by the regulated water downstream should be evaluated and shared because about 100 sq miles of Nepal land will be submerged, and hundreds of thousands of people will be displaced and need to be rehabilitated in Nepal. The author suggests striving to get the benefits as royalty similar to Lesotho getting benefits from South Africa or Canada getting downstream benefits of the Columbia River project between the USA and Canada. Further, it will be in Nepal's interest to make provisions for ensuring a rightful way to gain access to the sea through water transport.

The author has not mentioned that the intention of the KHDP is to construct two very long canals; one of them to link Mechi River in the east (Kosi - Mechi Link canal). Its DPR is already prepared by the state of Bihar and approved by the Central Govt. of India. Another is the link to enter India near Birgunj of Nepal that will gobble up very large farmland of Nepal's Terai which is the bread basket of the country.

Chapter 6: The Gandak Project Agreement :- The author perceives that the agreement was conceived, designed and implemented for fulfilling the requirement of India. Even small benefits allowed in the agreement are never honestly implemented, i.e. the agreed 850 cusecs of water for the Nepal Eastern Canal and agreed quantity of water for Nepal Western Canal were never supplied in full capacity. In the Eastern Canal, the water release was only 56% (World Bank's average figure) of the 850 cusecs in the 1980s. Further, there is a provision of water transport for Nepal in the agreement for access to the Ganges. However, nothing has happened so far in this regard.

Chapter 7: Treaty on the Integrated Development of the Mahakali River:- The Author was also a member of the Negotiating Team with India on this Treaty; and hence, the author had first hand information on the subject. The author has analyzed in detail all aspects of the Treaty. It is a combined Treaty of the Sharada barrage, Tanakpur barrage, and the Pancheshwar Multipurpose project (6480 MW). In Nepal, this treaty attracted many street protests, political maneuvers, and was ultimately ratified by the parliament with a two third vote.

Like in other agreements, the agreed benefits are not extended to Nepal such as release of 10 cumecs of water for Dodhara Chadani (Nepal's territory) by India; India says that this provision is applicable only after completion of the Pancheshwar project, lowering the higher sill level provided for release of water to Nepal in the Tanakpur barrage has been put on limbo. The water of the Mahakali River at the Pancheshwar dam site was apportioned to half to Nepal and half to India *without prejudice to their respective existing consumptive use of the waters of the Mahakali River*. It is not clear about the meaning of this phrase. Is it the 50:50 for both countries so that it should not be less than the existing consumptive use of each country; or the total existing consumptive use is deducted and the remaining water is 50:50 for the two countries. Further, there is also a provision in the Exchange of Letters that *no party will claim the unutilized portion of the Mahakali water*. Many scholars interpret the meaning of these two points as harmful to Nepal. However, the author seems confident of Nepal getting a fair share. Further, there is a provision of the *avoided cost principle* for determining the price of the exported electricity to India. Experts believe that the export price needs to be based on the peaking value of the generated electricity from the storage project.

Sixteen years have passed, and the much anticipated Detailed Project Report (DPR) said to be completed within six months in the Treaty is far from completion. There is never ending negotiation between the two countries on this project. This project and also the Koshi High Dam project may receive much lip-service during up-coming general election in India.

Chapter 8: Understanding India's Approach to the Development of Water Resources in the Region:- This is the most important chapter of this book. The basic Indian approach has been first to construct without consultation, and later negotiate if necessary. The author has listed eight points on India's approach. These are: no regionalization, deal only bilaterally; engage in all projects but advance only those projects which primarily serve India's interests; delink hydropower from water resources; try to gain maximum control over the resources directly or indirectly; avoid generalization of policy so as to not to make it a precedent; continue engagement in project wise basis; proactively create favorable internal situations in the neighboring countries that is favorable for deal making on the part of India[1]; and to continue to exert leverages on the deals on water resources. The author rightly questions Indian approach and opines that such an approach is harmful to India as well. In the author's view, India needs to be open and have a liberal attitude to accommodate the interests of all the countries in the region.

Chapter 9: Conclusion and Recommendations:-
This chapter deals with the strategy Nepal should follow, course of policy and action for future. This chapter has dealt with the subject of electricity export, and Nepal's desire of India extending facilities for easy access to Bangladesh. In addition, he advises to get even the small benefits to Nepal as agreed in the Kosi, Gandak and Mahakali agreements before negotiating further with India.

The author recommends taking up projects without hesitation that are in the interest of Nepal. And he argues that a better served Nepal can only be relied upon and be competent enough to negotiate an enduring treaty with India.

It is a good book and a *must read* for decision and policy makers of Nepal or anyone interested in the field of water resources development of Nepal. It will also be equally useful for the officials in the regional countries, and for the US and Chinese officials to critically understand the Indian water attitude.

Another Reviewer of the Book Dr. Yuba Raj Sangraula has greatly praised the book and suggests that *"This Book needs to be immediately incorporated by universities as a "reference book" in their syllabus*." He rightly thinks that this Book is a milestone to correct India-Nepal Bilateral relations and make it a pragmatic and mutually beneficial one.

The author deserves a grateful thank you for his hard and sincere work in his extensive research and writing this brilliant book.

In conclusion, it is worth to quote Dr. Upendra Gautam, a founding member of JVS and president of CMS, the institutional partner of GWP Nepal, who summarizes the book thus, "The greatest merit of the book lies in providing a wider regional or Himalayan perspective to Nepal-India cooperation in the framework of international water law. Conclusion of such a perspective is that the optimum beneficial conservation and harnessing of water lie in greater regional cooperation."

Notes

1. Most people believe that abolition of Ministry of Water Resources in Nepal was such an internal move duly promoted by the Indian design.

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Call for Nomination for the Excellence Award 2013

Many people and institutions have rendered their services in the field of water, energy and/ or environment. HYDRO Nepal Excellence Award is established to recognize their efforts and honor them. **HYDRO Nepal** journal solicits nominations from among the experts, professionals or other individuals, institutions involved in the pursuit of excellence in the field of water, energy or/ and environment sector in Nepal for the annual HDRO Nepal Excellence Award for the year 2013.

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News

Diesel Plant: A Wrong Decision

Under intense pressure from the Prime Minister (PM) Mr. Babu Ram Bhattarai, the Nepal Electricity Authority (NEA) Board has reversed its earlier decision to cancel the bidding process to install 36 MW of diesel plant in the country. The new Chairman of the Nepal Electricity Authority (NEA) Board, the Chief Secretary, had taken bold decision earlier to revoke the bidding process. Eventhough, media has published news of procuring Diesel plant, the Chairman of the Board has declined that no such decision has been taken and insists that he has instructed only for study on the requirement of the Diesel plant.

An underdeveloped country like Nepal can neither afford the expensive imports of fuel and the operating cost of the Diesel Plant, nor is it a sustainable solution to the recurrent problems of the energy crisis. Further, it cannot be justified that Nepal should become dependent on petroleum products for energy while the invaluable water from the rivers of Nepal flows down without its judicious utilization.

The electricity generated by the Diesel plant costs about Rs.35 per unit; whereas the average selling price of the NEA is about Rs.7 per unit. The estimated cost for an 80 MW diesel plant is Rs. 10 billion, and the fund required for a 36 MW diesel plant is said to be Rs. 3 billion. The costing figures released by the NEA are not consistent. The said cost for an 80 MW Diesel plant is nearly equal to a low cost hydropower plant. Normally, the total cost for diesel plant installation comes to be about 50% for a small plant and about 40% for large plants (in hundreds of MW) of the total cost of hydropower.

The disturbing news is that the procured units will be second hand. It is argued that new plants will be designed and manufactured in the factory only after the contract award and take about one and one half years for manufacturing and installing the plant at site. Even the procurement of a second hand plant will not be any use for this dry season; and further, it will take about 8 more months for delivery and installation.

The fuel requirement for a daily six hours peaking operation for one year for a 36 MW plant will be 21.6 million liters of diesel considering one liter of diesel will generate 3.65 units of electricity. All the export items from Nepal are not sufficient to import one item i.e. petroleum products, and the proposed diesel plant will further aggravate the situation. The Multi fuel plant in Duhabi and Diesel Plant in Hetauda are frequently closed for lack of fuel. While the Nepal Oil Corporation (NOC) has limitation in supplying fuel to the existing thermal plants of NEA; one can visualize the situation that will occur when new diesel plants are operated.

It has been more than 4.5 years, since the energy crisis started and Energy Emergency declared in the country, and it was announced that the existing multi fuel plant in Duhabi (39 MW) and 14.4 MW diesel plant in Hetaunda will be repaired soon and put into operation. But, it took more than a year to repair (Completed only recently) the plants even with the financial credit assistance of the World Bank; and the Finnish Ambassador to Nepal was requested to urge the supplier company Wartshilla for repairing the plant.

The evaluation done by the Govt. of Finland found that the Duhabi Multifuel plant has manufacturing defects and the installation was not at par with acceptable standards.

Some proponents of Diesel plant advocate that the diesel plant is already in use in large numbers in shops, hospitals, banks, hotels etc. to the tune of more than 300 MW, and installing a large diesel plant by NEA is necessary and beneficial compared to the small units in use by the public. For a peak demand of about 1050 MW there is shortfall of 700 MW, in the dry season. Hence, according to them, there is no alternative to the diesel plant for immediate relief.

However, for a country with abundant water resources and huge hydropower potential, installing diesel plants cannot be justified. Nepal requires a sustainable solution for the energy crisis rather than benefitting a few people from the crisis.

Capacity Increase of Upper Trishuli-3A: Death of a Hen that Lays Golden Eggs

The Govt.'s decision to increase the capacity of the Upper Trishuli-3A to 90 MW from 60 MW as per the demand of the Chinese contractor has caused a barrage of protests by the public and also by five influential ex-ministers namely, Dr. Ram Sharan Mahat, Mr. Gokarna Bista, Mr. Surendra Pandey, Dr. Prakash Chandra Lohani and Dr. Prakash Sharan Mahat.

The main point is that while the Chinese contractor in the Bid Documents had quoted US $22 million extra for increase to 90 MW, now the Nepal Govt. has approved more than double Rs. 4 Billion, and an additional time of three years. It is a clear case of foul play and under the table dealing. Many suspect that when an effective Commissioner joins the CIAA, those responsible for the Trishuli-3A case may go to jail under corruption charges.

All the various Employees' unions in the NEA have opposed the capacity increase. There is a likelihood that the Contractor will have reasons to make claims on delays and ultimately run away from the site.

The Upper Trishuli-3A HEP is under implementation under an Engineering Procurement and Construction (EPC) contract. It is similar to a turn key job where cost variation and time extension are not allowed. Till date about 29% of the works has been competed against the remaining time of only about 16 months. Critics claim that instead of commissioning the plant in the next 16 months, and alleviating the energy crisis, the three years' time extension will bring the plant under operation when there will be a glut of electricity after completion of various large scale hydropower projects.

Due to various oppositions and the petition in the Supreme Court, the longer the time taken for Judgement, the Chinese contractor is likely to run away from the site if the capacity increase and 3 year time extension is not granted. This will create confusion and loss of valuable time and possibility of claims/counter claims.

Data released by the Ministry of Energy indicates that the Upper Trishuli-3A has an IRR of more than 24% for a 60 MW plant. This is a very good return on investment and one can say it is a **"Hen that lays Golden eggs"**. People with bad intention have put this Hen in death bed for their own interest.

India Plans to Develop a Forecasting Model for Energy Demand and Supply

Rajeev Jayaswal, ET Bureau Jan 15, 2013

New Delhi: India plans to develop a forecasting model for energy demand and supply that will help in policy decisions. The model, on the lines of UK's Energy Calculator 2050, will be available to industry and researchers.

"The proposal has in-principle approval of the Prime Minister and the task to set up a model is entrusted to Planning Commission," a senior government official said.

Apart from India, China is also in talks with UK's Department of Energy and Climate Change (DECC) to set up a similar model. "This will be the government's own energy model, which will provide energy pathways for four decades. This will provide effective tool for taking energy related policy decisions in an integrated manner," Planning Commission Adviser-Energy Anil K Jain said. The model will be handy to predict demand, supply and pricing more objectively and in a manner, which will help to optimize natural resources, he added.

Planning Commission is creating this energy model because the country has separate ministries and departments for different types of energy such as coal, power, petroleum, nuclear and renewable. It will also guide Indian negotiators in taking stand at international forums, especially on the climate change, he said.

Bangalore-based Center for Study of Science, Technology and Policy (CSTEP) is assisting Planning Commission in setting up the model. CSTEP's Chairman VS Arunachalam says that since GDP growth is dependent on energy supply, it is important to know how much energy India would need and how to meet the demand.

Currently, the Planning Commission's recommendations on energy are based on studies carried out with expert groups, but these often do not capture the changes in global energy scenarios and technological advances. Jain said almost all developed nations have their own energy models that help them in taking crucial policy decisions regarding demand, supply, pricing and utilization. US Energy Information Administration is one such model that keeps global energy data and has been a resource center for various countries including India.

Working Procedure Approved for Power Development Agreement

Ministry of Energy (MoE), Nepal has approved a Working Procedure for Power Development Agreement (PDA) for under 500MW projects. A Task Force under Coordinator ship of Joint Secretary Mr. Sunil Bahadur Malla was established about four months ago to prepare this working procedure.

Projects awarded without competition will be charged US$1500 per MW as a processing fee. Any Developer of electricity development for in country consumption need to apply for PDA with documents consisting of cost estimate, financial analysis, designs document, updated Feasibility Study, final report submitted for EIA approval, and copy of Power Purchase Agreement (PPA) with NEA.

Lower Solu (82 MW) and Upper Trishuli -1 has demanded PDA saying that their foreign partners will not vbe coming without a PDA.

'Super Six' Projects in Limbo

Six hydro projects called 'Super Six' totaling 210 MW were awarded licenses in Asad 2067 (July 2010) through competitive bidding in which the developers paid Rs. 450 million and deposited Rs. 110 million as Bank Guarantee. Nepal Government had made written commitment that the NEA/ Nepal Govt. will construct transmission lines; and also pay penalty to the developers if the lines do not become ready in time.

The Developers have invested more than Rs. 2 billion for survey, investigation, design work and procuring land. If NEA had done PPA timely, four projects would have been completed by 2014 and other two in 2015. In Asad 2069, MOE (July 2012) instructed NEA to get PPA done within 21 days, but 9 months have elapsed PPA has not been done. Ten NEA Board meetings have taken place after submitting PPA proposal in the Board. However, the Board has not approved the PPA.

MOE and NEA are giving lame exuse of lack of funds for the transmission lines despite the commitment of the Exim Bank of India during the India visit of PM Babu Ram Bhattarai to provide US$ 20 million at concessional loan for the transmission line. Developers point of view is that NEA and MOE are irresponsible for not approving PPA and implementing required transmission lines despite such a huge energy crisis in the country.

It is very strange of NEA & MoE that they are determined to bring Diesel plant and discouraging the local hydro developers.

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Water and Energy Commission Secretariat: A Lamed Agency

Jeewan P. Thanju

Water and Energy Commission Secretariat (WECS) is the premier institution of Government of Nepal having mandate to guide the overall development of water and energy resources in a sustainable manner. However, due to lack of an adequate legal provision, it has not been effective. Its importance is much more evident in the light of the present energy crisis in Nepal.

WECS is the think tank on the water and energy issues. Its main job is to advise the related Govt agencies on the matters of Water and Energy. However, no agency has asked for advice and most of the ministries give little weightage to WECS. WCS is used, contrary to its main objective, as a dumping site for civil servants.

Mr. Dipak Gyawali ex-water resource Minister of Nepal wrote in a paper that one of his friend became member of WEC. His two terms elapsed without him being called for a single meeting. Such was the condition of WEC. WECS Chief is secretary level and WECS is placed under the then Water Resource Ministry and now Energy ministry headed by an equal ranked Officer.

Very large resources had been used to create this agency. Canadian support was there for more than 20 years. Hence, it needs to be strengthened and be made a professional institution. The comparable institution in India is Central Water Commission (CWC). All the important large projects need to get Techno-economical clearance from CWC before getting approval for implementation. Similar mandatory mandate needs to be given to WECS. The members of the CWC are full time.

WECS had formulated Water Resources Strategy and prepared Water Plan. Long time ago it prepared Nepal's Master Plan for Irrigation. Similarly, WECS has produced several guidelines on the related subject of water and Energy in Nepal. A technique developed for Hydrological analysis in the ungauged Rivers of Nepal is a grand tribute of WECS which is very widely used. WECS has prepared National Energy Strategy after several years of work. However, it is not yet approved by the Nepal Government. One of the ongoing activities is formulation of a long term vision on Water Resources of Nepal. Other ongoing works are opening of Basin Office for Hydrology data collection, preparation of Water Resources Database etc. Most of the activities are dictated by the Donors rather than the immediate need of the country. WECS need to concentrate in the down to earth problems on plans for solving drinking water scarcity, electricity crisis etc.

WECS is the right institution to provide its independent/professional advice on controversial issues such as Procurement of Diesel Plant, capacity up-gradation of Upper Trishuli - 3A HEP, preparing a framework for the dealing/ negotiation of the with India in bilateral or various joint committees on water resources, preparing master plan for electricity development, basin wise planning etc.

Mr. Vishwa Prakash Pandit, Executive Secretary of WECS opines that without a a binding legal provision, WECS will not be able to function effectively; and adds that WECS should be headed by a water resources professional.

Prof. Suresh Raj Chalise, Ex-officer of ICIMOD says that he had envisaged WECS as a fusion point of University and Civil servants. However, it is run by Civil servants only. In fact it should have been University, Civil servant and experts from private sector.

Mr. Som Nath Paudel, Ex-executive Secretary of WECS opines that without provision in an Act, there is no future for WECS. He had drafted an Act; and with recommendation of the then Water Resources Ministry forwarded to the Ministry of Law where it was positively moved ahead by its Joint secretaries. However, the then Secretary of Law Mr. Shakya refused to recommend it.

The draft Act needs to be provoked and the process restarted for its approval.