THE ROOT OF THE WATER PARADOX IN BANGLADESH: A CASE STUDY IN GANGES RIVER BASIN

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ABSTRACT

Water resources management aspects have been changed in the different forms and directions since the beginning of the human civilizations. This study clarifies the sharing issue which is critical and nature of dam "Farakka barrage" on Ganges basin areas has led to conflict among co riparian state since 1951. Literature reviews found one of the best institutional framework solutions is bilateral agreement between Bangladesh and India which has been carried out in 1977 agreement, 1982 and 1985 Memorandum of Understanding (MOU), and also historical treaty 1996 (period January 1 to May 31) for 30 years. Our study found a deadlock prevailed between Bangladesh and India on dry seasons. Water sharing treaty 1996 therefore, adopts Article IV of the Helsinki Rules 1966 and granted 35,000 m^3/s water release to Bangladesh. The results suggest that availability of flows is crucial during March 1 to May 31. Moreover, the average flow availability at Farakka was sequentially declining from 1997 to 2007. We found, the average flows availability was worst and were about average 12%, and 25% flows line declining in 2005 and 2006, respectively. Therefore we describe "Stackelberg leader-follower model for optimal water allocation on Ganges river Basin between Bangladesh and India both with and without additional water transfer from Nepal. The results suggest that India will divert less water with flow augmentation than in the case there is no provision to buy water from Nepal. Furthermore considering Indian welfare, water transfer also deter from India and unilaterally reducing the supply of water to Bangladesh. Although Bangladesh gains from water transfer agreement, India may not and could reject any agreement proposing water transfer from Nepal. We strongly recommend to market-based water transfer from Nepal for the Ganges river basin requires the agreement of both Bangladesh and India. This would be a better solution to sustainable water resources management on Ganges river basin.

Keywords: Bilateral, conflict, deadlock, human civilizations, institutional framework, Memorandum of Understanding, Welfare

1. INTRODUCTION

Water resources management aspects are changes in the different forms and directions since the beginning of the human civilizations. Water flows in Bangladesh that is closely linked –quantity, quality and timing [3]. The dynamics of individuals three issues play significantly differ inside Bangladeshi's water bodies. Water contradictions in Bangladesh in terms rotate around one or more of those three issues. The sharing quantity is critical which depends on bilateral agreement among the co riparian state. Therefore the water sharing issues became controversy issues on water resources management [5]. In Bangladesh water sharing issues became also critical because of upstream and downstream features. Here water flow controlling is being a crucial factor to maintenance the amount of water sharing agreement between Bangladesh and India. In Bangladesh, the natural resources are available but the dignity of the level of water becomes a "*Paradox*" by the definition of Professor Gian Maria Zuppi state that "resources are available but can't use, it's a paradox". Water flow on Ganges River adapt consciously or unconsciously by human activities at local and regional level in Bangladesh. Also, the Ganges river water flow is being influencing in Bangladesh mainly from neighbor upstream countries India and Nepal. In the sense, water sharing issue on Ganges River basin upstream and downstream becomes a conflict leads to paradox. The study will be given more priority why and how both from materialistic and from holistic points of view-how water resources become paradox in Bangladesh? This paper aims to analyze favor of Ganges basin water flow augmentation that matching supply and demand in, and also we describe a model Stackelberg leader-follower game model to determine the optimal share of water divert by upstream country with the opportunity of water flows augmentation from Nepal to resolve the water scarcity. In addition, assess the impacts of water transfer from Nepal to Bangladesh and India. Finally the conclusion part will be summarizes the main findings and results of the paper.

2. CASE STUDY: GANGES RIVER BASIN

From 1952-1971, the Pakistani government deliberately neglected to solve the Farakka problem as they were more keen on resolving the dispute over the Indus river [4]. In spite of, there were ten meetings regarding this issue between India and Pakistan and the significant outcome was that India agreed the Ganges as the international river and accepted the principal of sharing its water [4]. Bangladesh emerged as an independent country in 1971 from Pakistan. After that Bangladesh proposed to build storage facilities in the Ganges basin to augment the flow [5]. As this plan would involve Nepal, India rejected that because of not being a bilateral issue [6] On the other hand, India's proposal of diverting water from the Brahmaputra to the Ganges by a link canal was opposed by Bangladesh [5]. Because diversion of the Brahmaputra water during the lean period would cause adverse effects on its downstream and the excavation of a link canal through Bangladesh would cause problem [6]. In 1974, Joint River Commission (JRC) estimated that during dry season the average minimum discharge below the Farakka was 55,000 m^3/s. India claimed 40,000 m^3/s to flush the Hooghly River leaving the rest for Bangladesh whereas Bangladesh demanded the entire

55,000 m^3/s for the dry season. Hence a deadlock prevailed between these two countries [4]. Then Bangladesh's Prime Minister Sheikh Mujibur Rahman intervened to break the deadlock by proposing an "interim agreement" which allowed India to commission the barrage [4]. The agreement was valid for the period between 21 April and 31 May 1975 signed on 18 April 1975 [4]. After the expiry India unilaterally continued the withdrawal of water at Farakka, adversely affecting a vast area of Bangladesh [6].

Therefore Bangladesh raised the issue to the thirty-first session of the United Nations General Assembly, in September 1976 [6]. But attempt to internationalize the issue was failed and a bilateral solution with India was forced to seek. This attempt reportedly angered the Indian Prime Minister, Indira Gandhi who took a hard line by arguing that Bangladesh was not adversely affected by the Farakka barrage [4]. With the defeat of Indira Ghandi Congress Party in the Indian Parliamentary election in March 1977, the formation of the Janata Party government under Morarji Desai came with a solution to this problem by 1977 treaty for five years [2]. This treaty contained a guarantee clause under which Bangladesh was promised 80 percent of the water available during the lean period [2]. Each side received some satisfaction from the water treaty. Although this was criticised strongly in India by accusing the central Indian government of sacrificing the interests of the state of West Bengal which uses this water to keep Calcutta port navigable [4].

As the expiry date of the 1977 treaty was loomed Bangladesh urgently needed to find another agreement on the sharing of Ganges water. Then two MOU was signed on 7 October 1982 and 18 October 1985 for next two dry seasons and three years respectively according to 1977 agreement [2]. After expiration of second MOU there was no agreement till 12 December 1996 [2]. On 12 December 1996 an accord for thirty years was signed between subsequent Bangladeshi Prime Minister Sheikh Hasina and Indian Prime Minister Deve Gowda known as 1996 treaty [7]

2.1. Ganges Water sharing: institutional framework

Actually the conflict over the Ganges basin between Bangladesh and India dates back to 1951 when India decided to construct the Farakka barrage. When the barrage was opened for operation in 1975; the disputes over the sharing and controlling of the Ganges water flow became the key issue of controversy between these two countries. The chronology of water conflicts and cooperation between Bangladesh and India along the Ganges River basin is presented in Table 1.

Table 1. Chronology of water conflicts and cooperation between Bangladesh and India along the Ganges River Basin

Phases	Outcomes
1951	Pakistan (Bangladesh after 1971) officially objected the plan 29th October 1951 [5]
1961	India officially admitted the unilaterally construction of the barrage on 30th January 1961 [2]
1972	On 24th November 1972, India and Bangladesh signed statuses of the Indo-Bangladesh Joint River Commission (JRC) [3].
1974	Farakka Barrage construction is completed, In a joint declaration on 16th May 1974, Bangladesh and India acknowledged (that there was) a need to augment to lean season flow of Ganges to meet the full requirements of both countries. Indo-Bangladesh JRC study schemes relating to the augmentation of the dry season Ganges flow and makes recommendation to meet the requirements of the both countries [2].
1975	On 18th April 1975 India allowed 310-450 m^3/sec water divert to Bangladesh and test the feeder cannel of the Farakka Barrage through the Ministerial level declaration. Farakka barrage started operations on 21st April 1975 to June 1975. Indo-Bangladesh JRC submitted their report on the 1974 joint declaration. Bangladesh side suggested augmentation of dry season flow through building storage reservoir in Nepal and where as India side stresses augmentation through diversion of water from the Brahmaputra river to Gages rivers [1]
1976	India unilateral diversion of the Ganges flow beyond the stipulated period in 1975, Bangladesh raised the issues to the United Nation (UN) on 26th 1976. UN general assembly adapted to consensus statement which directed both countries to urgently negotiate to fair and expeditious settlement of the Farakka problem to promote the well being of the region [2].
1977	Upon the direction of the United nation, India and Bangladesh signed Ganges water Agreement on 5th November 1977 for the duration of 5 years. [2]
1982	On 7th October 1982, Memorandum of understanding (MOU) was signed between the two countries for sharing dry season flow at Ganges in 1983 and 1984. Provisions similar to 1977 Agreement except it contain a guaranty clause.
1985	There was no agreement for 1985 dry season (January to May); 22nd November 1985 another MOU was signed for three years (1986 to 1988), which expired 31st May 1988.
1988	1988 MOU expired, no agreement, Negotiations continue but without success. Divergence in approach. Relationship between sharing arrangements and augmentation proposal becomes more and more complex issue.
1993	Bangladesh taken the issue to the Commonwealth summit held at Cyprus in October 1993
1995	On 23rd October 1995, Bangladesh again raised the issues to 50th UN general Assembly about the misery of Bangladeshi people due to unilateral water diversion at Farakka Barrage [3]
1996	An historical agreement between Bangladesh and India on sharing water at Farakka barrage was signed 12th December 1996 for duration of 30 years [2].

3. ANALYSIS AND RESULT OF TREATY 1996

Water sharing formula establishing Appendix A was granted 35000 m^3/s water for both countries (Bangladesh and India). Flow availability at Farakka is the crucial fact; therefore treaty 1996 is not well implemented and is different from the agreement of 1977. According to the 1977 Agreement, MOU 1982, MOU 1985 and 1996 Treaty, proportion of water sharing between Bangladesh and India from January 1-May 31, are about 61:39, 60:40, 60:40 and 55:45 respectively shown in Appendix B. Hence Bangladesh's share decreased by about 6 percent under the 1996 Treaty. It is worth mentioning that for the three critical non-monsoon months (March 1-May 31). The share of Bangladesh has decreased from about 61% under the 1977 Agreement to about 55% under the 1996 Treaty, Appendix B.

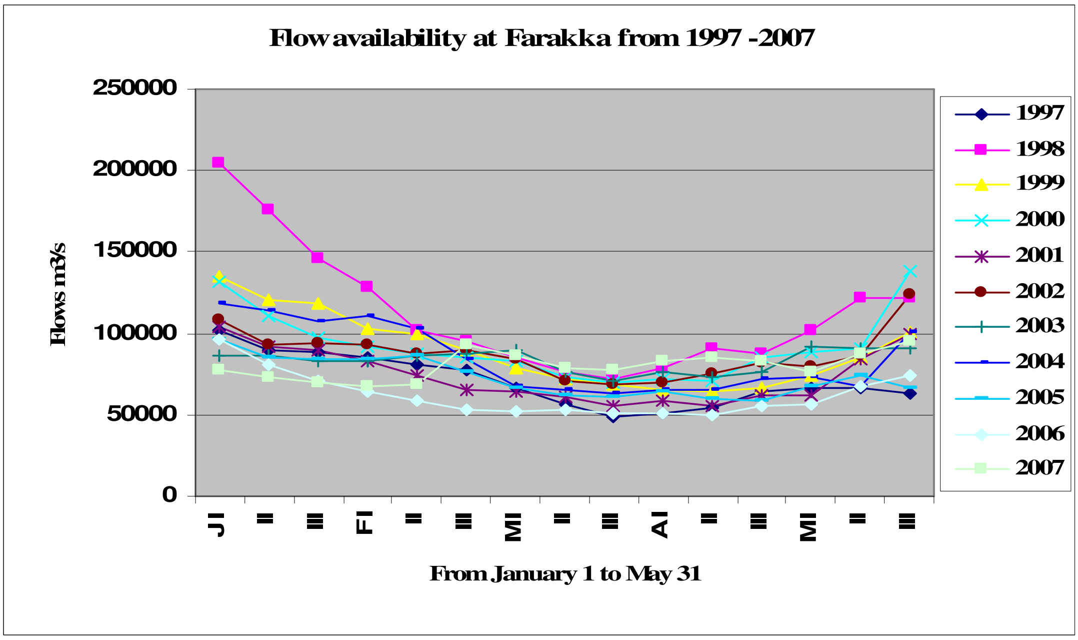

Fig. 1: Flow availability at Farakka 1997-2007(m^3/s)

Figure 2 shows that the average flow availability at Farakka, sequentially declining from 1997 to 2007. The average availability flows line in 1997 and 2001 were about 14% and 10% decline respectively. Sequentially; in 2005 and 2006, the average flows availability was worst and were about average 12%, and 25% respectively flows line declining. However, the 1998 flow availability was increased partially above 36%, see Appendix **C**, but the average seasonal variation Figure 2 shows that critical non-monsoon months from February 20 to May 31 was severe in 1998, the seasonal availability of flow at Farakka mainly the non monsoon season (from March 1 to May 1) were continuously decline from 1997 to 2006, eventually in 2007 seasonal variation become well but average flow availability line remaining below in 2007, see Appendix **D**.

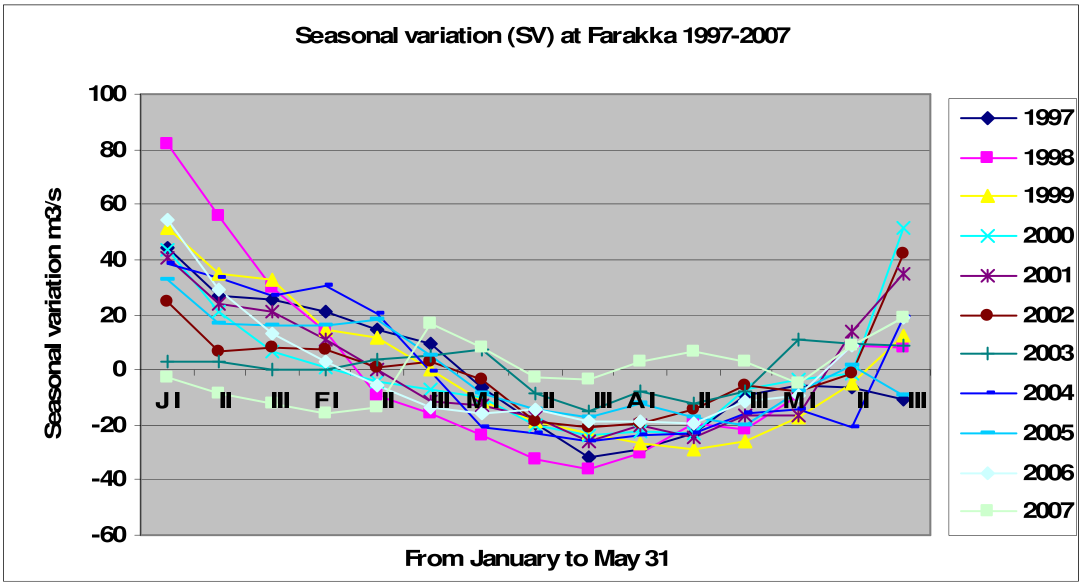

Fig. 2: Average seasonal variation (percentage) at Farakka 1997-2007

We may summarise that indeed, flow availability at Farakka is crucial factor to resolve the water sharing constraints between Bangladesh and India. In order to implement the water sharing formula Appendix A, need to flow augmentation on the Ganges River by third countries water transfer. We were schemes regarding the long-term solution by model study through augmenting dry season flow of the Ganges River. We describe a model Stackelberg leader-follower game model to the optimal allocation of water divert by upstream country with the opportunity of water flows augmentation from a third country to resolve the water scarcity and conflicts.

4. MODEL STUDY

Stackelberg leader-follower model study considers two actors like upstream country as a leader who can make a choice how much or what quantity of water to divert for its own purpose, and downstream country as a follower who only consumptive usage of water is dependent on the flow of water divert. We develop a model of two-country river basin water allocation, with the opportunity of water augmentation from a third country; applying a leader-follower game to determine the optimal share of water divert by upstream country. Therefore the agreement of water flow augmentation between two countries – India and Bangladesh with Nepal, is better idea to resolving the water sharing conflict on Ganges Rivers.

4.1: Step one. Water sharing proportion

We assume that,

i. Two countries have proportional right for water allocation
ii. Two countries are authorized to buy water from third country Nepal

iii. India diverts water at a single location on the Ganges River at Farakka Barrage

Therefore, we may claim that the proportion of water allocated to India at this point of diversion is α, and the proportion of water allocated to Bangladesh is 1-α, with 0< α<1.

4.2: Step two: Flow augmentation

We assume that water flows on the Ganges River can be augmenting by additional water transfers or releases from Nepal. So the storage water as S in Nepal, could release the amount of water to downstream country for flow augmentation on the Ganges Rivers. India is downstream country compare with Nepal, and Bangladesh is also more downstream country. The sharing parameter (β) is determinate by agreement or treaty. So the sharing proportion β flow to Indian downstream then the proportion (1-β) flow to Bangladesh even further Downstream with 0<β<1.

Above the two step argument model key point is the choice variable α, as India can make own decision to buy water from Nepal and option of unilaterally diverting additional water rather than paying a price to buy water from Nepal. The constraint is that, one option for Bangladesh to augment of water flows is to buy more water from Nepal. However, Nepal will release additional water from their reservoirs only if both downstream countries, Bangladesh and India, pay for their increased share of this released water. In this case; Bangladesh is buying (1-β)*S amount of water from Nepal, Then India needs to buy the remaining β*(S) amount of water. Otherwise, Nepal will not be fully compensate for the water it releases from their storage and thus will not agree to the water transfer. Indeed, Bangladesh need to make an agreement with India for water transfer from Nepal and also may forces to India to buying more water from Nepal to diverting more water (i.e. increasing α) at Farakka barrage on the Ganges River. Even Bangladesh may impose its own credible threat of buying more water from Nepal (i.e. increasing S). In this situation, the key issues are arising: initially how does additional water transfers from Nepal to India and Bangladesh? Secondly additional water transfers from Nepal to India and then Bangladesh. With welfare effects in mind, would India ever agree to an additional water treaty between the three countries to allow such water transfers to take place? And thirdly why India reject latter proposal to augment the flow of Ganges Rivers?

In the circumstance, our model study at first examining the case of the situation with water transfer treaties exist between Bangladesh, India and Nepal to compare the situation without it, and then we examine what happens if India's share of water transfers, β, is increased. We assume that Bangladesh could increase water diversion from India is to request more water release by Nepal and imposing higher transfer costs on India as well.

4.3. Model application

We can represent a function by

$$\omega i = f_i(\alpha, S),\ \text{With the subject to constraint}\ f' > 0, f'' < 0 \quad i = 1,2...... \qquad (1)$$

Where

$$f(\alpha,S)=\alpha^a S^b, 0<a,b<1 \qquad \text{for India, and}$$
$$f(\alpha,S)=\alpha^{-c} S^d, 0<c,d>1 \qquad \text{for Bangladesh} \qquad (2)$$

We assume that:

α = the consumptive usage of water for India and Bangladesh is a function of the share of water diverted in India
S = amount of water transferred from Nepal to both countries
ω_i = he contribution of α and S to the consumptive usage of water.

So the country utilizes own water to produce some economic output (e.g. Agricultural production, industrial production etc), $P_i = p_i(\omega i, v_i)$ for i=1, 2, where v is the vector of inputs used in the production. The production for India (P_1) and Bangladesh (P_2) respectively represent by the equation (3)

$$P_1 = p_1(\omega_1, v_1) = Av_1\alpha^a S^b,\ \text{and}\ P_2 = p_2(\omega_2, v_2) = Bv_2\alpha^{-c} S^d \qquad (3)$$

In addition, Nepal will charge the price for supplying water to both countries Bangladesh and India. Where the function of r is the total amount of water demanded by both India and Bangladesh from Nepal S and represented by equation (4)

$$r = r(S) = kS^{\gamma} \qquad -1 < \gamma < 0, k > 0 \qquad (4)$$

The price of water will be charge by Nepal, therefore rate of charge γ tells us, demand r will decrease at an increasing rate (γ). This assumption has bearing as it increases the reliability of the threat to India from Bangladesh's actions. If India does not provide enough water to Bangladesh then Bangladesh can buy more water from Nepal at a lower price.

The profit functions represent the payoff function to Bangladesh and India is given by their respective profit functions

$$\Pi_1(\alpha, S) = (p-c)p_1(\omega_1, v_1) - r\beta(S) \qquad \text{For India} \qquad (5)$$

and

$$\Pi_2(\alpha, S) = (p-c)p_2(\omega_2, v_2) - r(1-\beta)S \qquad \text{For Bangladesh} \qquad (6)$$

We first compute Bangladesh's reaction to an arbitrary share of water diverted in upstream by India. So R_2 (α) solves the following equation.

$$\underset{S>0}{Max}\prod_2(\alpha,S)=\underset{S>0}{Max}\left[(p-c)Bv_2\alpha^{-c}S^d-k(1-\beta)S^{\gamma+1}\right]$$

First order condition with respect to S yields the following

$$(p-c)Bv_2\alpha^{-c}dS^{d-1}-k(1-\beta)(\gamma+1)S^{\gamma}=0 \qquad (7)$$

The expression of equation (7) propose that Bangladesh will maximize their profit function; if the net marginal benefit $\left[(p-c)Bv_2\alpha^{-c}dS^{(d-1)}\right]$ of buying additional water from Nepal equals the marginal cost of the water $\left[k(1-\beta)(\gamma+1)S^{\gamma}\right]$.

The reaction functions for Bangladesh for an arbitrary value of α.

$$S=R_2(\alpha)=X\alpha^{-\delta},$$

Where $\delta=\dfrac{c}{\gamma-d+1}$ and $X=\left[\dfrac{(p-c)Bv_2d}{k(1-\beta)(\gamma+1)}\right]^{\frac{1}{\gamma-d+1}}$ (8)

In the equation (8); R_2 (α) is Bangladesh's best responses function to India's share of water diversion α;

The slope of reaction function is:

$$\frac{\partial S}{\partial\alpha}\begin{matrix}>\\<\end{matrix}=0 \quad if\ \gamma=d-1\Rightarrow\frac{\partial\ln(MC)_2}{\partial\ln(S)}\begin{matrix}<\\=\\>\end{matrix}\frac{\partial\ln(NMB)_2}{\partial\ln(S)} \qquad (9)$$

Equation (9); the slope of the reaction curve will be positive, if water diversion increased by India, the proportional change in the net marginal benefit $(NMB)_2$ to Bangladesh of purchasing water from Nepal exceeds the proportional change in the marginal cost $(MC)_2$. Therefore Bangladesh will be gainer. So India decreases the share of water diverted to Bangladesh, then Bangladesh will buy water from Nepal provided the proportional change in net marginal benefits exceeds the proportional change in the cost. Since India can resolve Bangladesh's problem as well, India should anticipate that the amount of water bought from Nepal will be met with the reaction $R_2(\alpha)$. Thus India's could maximize their profit functions is:

$$\underset{\alpha>0}{Max}\prod_1(\alpha,S)=\underset{\alpha>0}{Max}\left[(p-c)Av_1\alpha^aS^b-k\beta S^{\gamma+1}\right] \text{ Subject to constraints } S=R_2(\alpha)=X\alpha^{-\delta},$$

India maximization problems and first order conditions, with respect to the choice variable α yield results in the following objectives functions for India,

$$(p-c)Av_1X^b(a-\delta b)\alpha^{a-\delta b-1} - k\beta X^{\gamma+1}[-\delta(\gamma+1)]\alpha^{-\delta(\gamma+1)-1} = 0 \quad (10)$$

The equation (10) suggest that India will choose a level of water diversion α, up to net marginal benefit $\left[(p-c)Av_1X^b(a-\delta b)\alpha^{(a-\delta b-1)}\right]$ of increasing α equals the marginal cost $\left[k(\beta)X^{(\gamma+1)}[-\delta(\gamma+1)]\alpha^{-\delta(\gamma+1)-1}\right]$. The net marginal benefit is the marginal value to India of a unite increasing in the share of water in upstream. Therefore, equation (10) will yield India's optimal value of α*

$$\alpha^* = Y^{\frac{1}{\theta}}, \text{ and}$$
$$\theta = \delta(b-\gamma)-(a+\delta) > 0 \Rightarrow \delta > \frac{a}{(b-\gamma-1)} \Rightarrow \frac{\partial \ln(MC)_1}{\partial \ln\alpha} > \frac{\partial \ln(NMB)_1}{\partial \ln\alpha} \quad (11)$$

At the optimum level, positive values of θ, that means the proportional change in the marginal cost $(MC)_1$ to India due to increased water diversion will exceed the proportional change in net marginal benefits $(NMB)_2$. Equation (11) indicates that optimal level of water diversion by India's, α*, will be affected not only by the marginal costs but also its affect the share of water transfers from Nepal, β. As we demonstrate in the appendix E, if there is an increase in the share of water divert from Nepal to India, then the optimal level of water divert by India will decrease i.e. $\frac{\partial \alpha^*}{\partial \beta} < 0$. This result implies that, if India's shares of water from Nepal as observe by a water augmentation treaty is in fact raise higher, then the optimal amount water diversion α will decrease because Bangladesh will impose more cost on India by buying water from Nepal. Therefore India will actually divert less water to Bangladesh.

5. STRATEGY IMPLEMENTATION

Fit a strategy on water transfer from Nepal to India then water divert from India to Bangladesh. Initially we will significantly consider India's welfare without water augmentation. We will presume the additional amount of water transfer by Nepal will affects by India welfare, will compare to the situation without water flow augmentation.

We assume that India's water scarcity is not binding. Therefore, we may claim that India's profit function is concave in diverting α. We also justified by diminishing marginal productivity nature of water utilization and negative second order profit condition in Figure 3. We see Figure 3, the producer in India could maximize their profit up to the net marginal benefit of increasing sharing divert in upstream equals to marginal cost see in Figure 3. Secondly we assume that there is no provision of additional water supply from Nepal and there no longer exists a credible threat from Bangladesh in response to India increasing to divert α. Then India has a unilateral option for making decision to divert water, and the efficient rate water utilization corresponds to the optimal level of water divert α. We define the function, $\omega_1 = f(\alpha)$ is ensure that net benefit or payoff will be optimal level at $\overline{\pi_1}$ in Figure 3, and payoff relationship through choice of α is $\pi_1 = (p-c)p_1(\omega_1, v_1)$, therefore the first order condition maximizing the payoff relationship is $(p-c)\frac{\partial(p_1)}{\partial(\omega_1)}\frac{\partial(\omega_1)}{\partial(\alpha)} = 0$ which shows that the payoff India will be maximize when the marginal benefit of water diversion equal to zero. Since the function $\omega_1 = f(\alpha)$ is convex, that means the slope of profit function with respect to the share of water diversion is positive $\alpha < \overline{\alpha}$ and conversely is negative $\alpha > \overline{\alpha}$ in Figure 3.

In that case we assume that usage of water is a fixed proportion of the availability of water and is a function of α, a lower rate of water utilization would require a lower value of α. Thus lower value of α under-utilization condition of water brings lower profit for producer. Similarly over-utilization of water will ensure a lower profit $\pi < \overline{\pi}$ in Figure 3, because of diminishing marginal productivity of water and the negative second-order profit condition. We claim that there is no credible threat from Bangladesh; India could maximize their up to profit $\overline{\pi}$ by diverting $\overline{\alpha}$, share of water in the upstream and allocating the rest to flow downstream to Bangladesh. In Figure 3, we can compare the results and immediately say that water transfer from Nepal will reduce the payoff to India, as we see the equation (10) and equation (11), for India welfare condition, when water transfer from Nepal take place forces to India to face a additional cost to increasing diverting α. Eventually Bangladesh use credible threats to India by buying water from Nepal for diverting less water to Bangladesh then India optimal level of share of water divert in upstream α* will be less than the optimal level of the share of water divert by India in the unconstrained case, α see in Figure 3. In that case, India would be better off without a water augmentation treaty, as it would have a higher level of payoff to India for water transfer from Nepal. This perhaps better explains why India has strongly resisted efforts in the past by Bangladesh to couple any agreement on water sharing with proposals for augmenting the Ganges dry season flow with water transfers from Nepal [8].

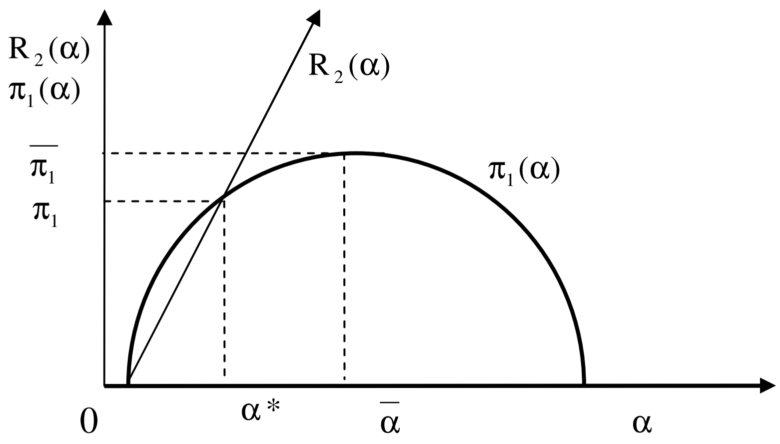

Fig. 3: Optimal level water diversion by India

6. CONCLUSIONS

We may says water sharing issue between Bangladesh and India regarding the Ganges River basin is being a unique example for developing countries because of its wide varieties impacts, though solution approach must not be the same with others International river basin. The term “Farakka barrage” is a matter of controversy between Bangladesh and India. It has induced a lot of negative socio-economic and environmental impacts on Bangladesh. The Ganges water-sharing treaty of 1996 between Bangladesh and India is great leap forward that might has lead in a new era of positive sign of good political commitment on the way to solve long-standing disputes. But the vital thing is the insufficient water flows from March to May at Farakka barrage on the Ganges river basin which seems to be a questionable to meet the future demands of both Bangladesh and India.

Therefore we work how to augment water flows at Farakka barrage on the Ganges River basin. Our model studies suggest that water transfer from Nepal would augment the flow of water at Farakka during the dry season, and period of droughts. Therefore we may believe that the market-based water transfers from Nepal which might be great relevance to resolving the water sharing conflict between Bangladesh and India. If the price of water charge by Nepal is demand determined, then water can be use efficiently in the two countries and thus it can help in mitigating the water scarcity problem. Although water supply from Nepal is non-separable between India and Bangladesh that means any water augmentation treaties will most likely requires that if Bangladesh buy excess water from Nepal then India will also have to pay for an additional proportion of water from Nepal. If a water augmentation treaty is exist, then Bangladesh can also use this opportunities to impose a credible threat to India to stop the latter from diverting more water at Farakka. In the contrasts, when there is no treaty and thus no credible threat from Bangladesh to India. Moreover India can gain from deciding unilaterally on how much water to divert. Equation 10 and 11, suggest that India is likely to be better off than if a water treaty is exist. Our analysis also suggest that India has a incentive to reject any proposal of water storing and transfer facility in Nepal as it is done consistently in the past.

Regarding such situation our analysis appears several policies. First of all we may assume that, Bangladesh and India water sharing conflicts is now resolved by existing treaty at Farakka barrage on Ganges River basin. Our analysis strongly suggest that India would be strongly motivate to ignore the provisions of the treaty and to decide how much water to divert, as indicated in Figure 3, India can maximize its benefits by choosing unilaterally how much water to divert. However, water augmentation treaty between Bangladesh, India and Nepal not only provides additional water to both downstream countries in times of chronic scarcity but also gives Bangladesh a mechanism for deterring India from violating the Ganges River treaty and deciding unilaterally to divert more water at Farakka barrage. In this regard, a water augmentation treaty is likely to reinforce the existing Ganges River Treaty.

According to equation 10 and 11, our analysis suggests that India would not be happy to build up any water augmentation treaty with Bangladesh and Nepal. Without India's cooperation, such a market-based water transfer's treaty would not be negotiate and implemented. Eventually, Nepal and Bangladesh will both benefit by water transfers. If a treaty is establish, our analysis suggests that it may be in the interest of all parties to ensure that share of any water transfers is relatively large.

Indeed, international river basin problems are more complex than the complexity of the national river basins [5]. Therefore, the international river basin conflicts can be dealt with at international forum or at the bilateral forum depending on the type of basin [2]. It is wise not to impose solution but to resolve among the nations involved. Furthermore, actual implementation of this treaty depends on India which has the control over others co-riparian countries of the Ganges basin in respect of economical, political, and geographical situations. For sustainable solution of the Ganges water sharing, integrated water resources management with technological advancement among the riparians is vital and further research study is needed.

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Appendix A: Water share of Ganges between Bangladesh and India, units are m^3/s.

Availability at Farakka	Share of India	Share of Bangladesh
70,000 m^3/s or less	50%	50%
70,000 - 75,000 m^3/s	Balance of flow	35,000 m^3/s
75,000 m^3/s or more	40,000 cusecs	Balance of flow

Appendix B: Different phases water sharing treaty and agreement at Farakka Barrage on Ganges River basin between Bangladesh and India

Period		Agreement 1977	MOU ' 82	MOU ' 85	Treaty ' 96
	1949-1973	1978-82	1983-84	1986-88	1997-07
Month	Average BD	BD:IND	BD:IND	BD:IND	BD:IND
J I	109830	62:38	62:38	66:34	65:35
II	101285	60:40	60:40	61:39	61:39
III	94092	59:41	58:42	58:42	59:41
F I	90618	61:39	58:42	58:42	57:43
II	87407	61:39	58:42	58:42	55:45
III	83025	60:40	56:46	57:43	53:47
M I	78414	61:39	59:41	59:41	**52:48**
II	73706	61:39	60:40	60:40	**53:47**
III	69256	61:39	59:41	59:41	**45:55**
A I	66276	61:39	60:40	59:41	54:46
II	63191	63:37	63:37	63:37	**47:53**
III	61611	63:37	63:37	63:37	54:46
M I	63730	62:38	62:38	62:38:	**52:48**
II	69475	61:39	59:41	59:41	54:46
III	77372	64:36	61:39	60:40	61:39
		61:39	60:40	60:40	55:45

Appendix C: Flow Available at Farakka 1997 – 2007 on the Ganges river basin

Month	m^3/s											Average
	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	1997-2007
January I	102180	204814	135181	131608	104511	108722	85844	118194	96582	95840	77966	114677
II	89635	175566	120633	110876	91952	92854	85968	113867	85112	80471	73141	101825
III	88672	145866	118742	97686	89740	93951	83409	107844	84257	70562	70037	95524
February I	85604	128186	102433	92253	82454	93470	83099	111099	84455	64118	67454	90420
II	81015	101841	99878	87517	73971	87921	86566	102534	86341	58701	69072	85032
III	77399	94738	89343	84905	65703	89561	87672	84392	76854	53566	93280	81583
March I	66170	85323	78920	82439	64517	84251	89132	67625	66715	52340	86441	74898
II	56769	75967	72413	72966	61085	71160	76328	65626	62459	53040	78063	67807
III	48487	71570	69108	69849	54898	68694	70486	63344	60309	50727	77321	64072
April I	50481	78588	65244	71449	59123	69960	76474	64784	64120	50674	82445	66667
II	54526	90955	63826	70570	55813	74856	72992	65416	60037	50118	85068	67652
III	63933	87901	65910	85124	62078	82152	76789	71754	58371	54889	82496	71945
May I	66728	102203	73928	88719	62039	80155	92199	72746	67015	56534	75862	76193
II	66055	122062	85128	90767	84218	86215	91018	67490	74175	67490	87100	83793
III	63309	121210	100644	138675	99808	124218	90601	101060	65902	73926	94937	97663
Average flow in years	70731	112453	89422	91694	74127	87209	83238	85185	72847	62200	80046	82650
Flow variation in Year (%)	-14	36	8	11	-10	6	1	3	-12	-25	-3	

Appendix D: Seasonal variation (%) Flow Available at Farakka 1997 – 2007 on the Ganges river basin

	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
J I	44	82	51	44	41	25	3	39	33	54	-3
II	27	56	35	21	24	6	3	34	17	29	-9
III	25	30	33	7	21	8	0	27	16	13	-13
F I	21	14	15	1	11	7	0	30	16	3	-16
II	15	-9	12	-5	0	1	4	20	19	-6	-14
III	9	-16	0	-7	-11	3	5	-1	6	-14	17
M I	-6	-24	-12	-10	-13	-3	7	-21	-8	-16	8
II	-20	-32	-19	-20	-18	-18	-8	-23	-14	-15	-2
III	-31	-36	-23	-24	-26	-21	-15	-26	-17	-18	-3
A I	-29	-30	-27	-22	-20	-20	-8	-24	-12	-19	3
II	-23	-19	-29	-23	-25	-14	-12	-23	-18	-19	6
III	-10	-22	-26	-7	-16	-6	-8	-16	-20	-12	3
M I	-6	-9	-17	-3	-16	-8	11	-15	-8	-9	-5
II	-7	9	-5	-1	14	-1	9	-21	2	9	9
III	-10	8	13	51	35	42	9	19	-10	19	19

Appendix E: Comparative static

$$\frac{\partial\alpha^*}{\partial\beta}=\frac{\partial\alpha^*}{\partial Y}\cdot\frac{\partial Y}{\partial X}+\frac{\partial\alpha^*}{\partial Y}\cdot\frac{\partial Y}{\partial X}\cdot\frac{\partial Y}{\partial\beta} \tag{A1}$$

$$\frac{\partial\alpha^*}{\partial Y}=\frac{1}{\theta}Y^{\frac{1}{\theta}-1}>0, \text{ as } \theta>0 \text{ and } Y=\left[\frac{(p-c)Av_1X^b(a-\delta(b))}{-\delta(\gamma+1)k\beta(X^{\gamma+1})}\right]>0 \tag{A2}$$

Y can be expressed as $Y=Z_1\beta^{-1}$,

$$\text{where } Z_1=\left[\frac{(p-c)Av_1X^b(\alpha-\delta(b))}{-\delta(\gamma+1)k(X^{\gamma+1})}\right]>0 \qquad \frac{\partial Y}{\partial\beta}=-Z_1\beta^{-2}<0 \tag{A3}$$

Y can expressed as $Y=Z_2X^{b-\gamma-1}>0$

$$\text{where } Z_2=\left[\frac{(p-c)Av_1(\alpha-\delta(b))}{-\delta(\gamma+1)k}\right]>0 \qquad \frac{\partial Y}{\partial X}=(b-\gamma-1)Z_2X^{b-\gamma-2}>0$$

as $\frac{\partial\ln((NTB)_1}{\partial\ln S}>\frac{\partial\ln(TC)_1}{\partial\ln S}$.

where $(NTB)_1$ is the net total benefit of India and $(TC)_1$ is the total cost of India for buying water from Nepal.

X can be written from (10) as $X=Z_3(1-\beta)^{-\frac{\delta}{c}}$ where $Z_3=\left[\frac{(p-c)Bv_2d}{k(\gamma+1)}\right]^{\frac{\delta}{c}}>0$

$$\frac{\partial X}{\partial\beta}=\frac{\delta}{c}(1-\beta)^{-\frac{\delta}{c}-1}Z_3<0, \qquad \delta<0, c>0 \tag{A4}$$

Taking into account of the signs of the derivations in (2), (3) and (4) and substituting in (A1), we get,

$$\frac{\partial\alpha^*}{\partial\beta}=-\frac{1}{\theta}Y^{\frac{1}{\theta}-1}.Z_1\beta^{-2}+\frac{1}{\theta}Y^{\frac{1}{\theta}-1}.Z_2X^{b-\gamma-1}.\frac{\delta}{c}(1-\beta)^{-\frac{\delta}{c}}Z_3<0 \tag{A5}$$