A Case Study on Teesta Water Conflict: A Game Theory Approach

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Abstract

Conflict arises over shared resources when resource owners have individual strategy rather than collaboration. Teesta river basin shared by India and Bangladesh is known for its lack of an agreement between these two countries over sharing its waters. Such situation is creating distress and misunderstandings between these two countries. In this paper we have used a system analysis technique including linear programming and game theory by considering a rational plan which includes water storage, power production, irrigation and salinity control. Moreover using game theory we have investigated a range of strategies which will result in significant benefits for each country.

Keywords
Game theory, Linear programming, Teesta basin.

1. Introduction

Undoubtedly, water is one of the most vital elements of nature for the existence of any living creature including human, plant and other species. However, developing countries are struggling with scarceness of pure water supply. It is estimated that by 2050, 6 billion people of the world will face hurdles for fresh water (Boretti and Rosa 2019). Consequently, stakeholders are conflicting with each other for water resources and creating disputes worldwide (Dinar and Hogarth 2015). For instance, disputes between Shaanxi and Hubei for Hanjiang River Basin (Wei and Gnauck 2007a), Kyrgyzstan and Uzbekistan for Syrdarya Basin over water allocation (Melnikovová 2017), Namibia and Botswana for protecting the Okavango Delta (Wolf et al. 2005) and so on. The clashes among the stakeholders create hostile movements for their contradictory goals and tactics (Petersen-Perlman et al. 2017). On the other hand, interests and benefits of stakeholders cannot be denied (Mei 2015). For the purpose of mitigating these issues, the prevailing regulations do not work effectively (Dinar and Hogarth 2015). For utilizing the concepts of the interests and benefits of the stakeholders, studies should be come to light to resolve these conflicts and game theory plays a significant role in this regards.

At the very first time, game theory was used to apply in water resource projects for equally cost allocation in water management (Dinar and Howitt 1997; Heany and Dickinson 1982; Young et al. 1982). Therefore, Nash Bargaining Solution, Shapley value, Least Core etc. has been established from this model for distributing cost (Lejano and Davos 1995). After that, many researchers have concentrated in resolving water conflicts by using game theory (Wei and Gnauck 2007b).

In this paper, we will show a linear programming model how an international river Basin conflict may be viewed in the light of simple game theory. The region comprises northern part of west Bengal, Sikkim, Northern part of Bangladesh. The agriculture of the region is dominated by the monsoon. From June to October the rainfall is heavy, much of the plain is subject to flooding, and rice is almost the sole crop harvested. During the dry season from November to May only precarious winter crops of cereals, pulses, and oil seed can be grown without irrigation. Hence, rice dominates the agricultural economy and the diet. But people of this region is not getting enough water in the dry season especially people of Bangladesh. The river flows are highly seasonal and as a result are inadequate for full irrigation during the dry seasons unless over season storage is provided. Clearly, the dominant fact upon which the future development of the river basin depends upon the political relationship between India and Bangladesh. On these rivers India lies everywhere upstream of Bangladesh, and hence any Indian developments could have adverse effects upon Bangladeshi projects downstream unless the river basin is developed as a comprehensive system. There will of course be a large amount of complementarity between the effects of the Indian actions and the Bangladeshi goals.

2. Literature Review

Game theory is about to analyze tactical collaboration among rational judgments taken by different decision-makers approaching with mathematical strategies (Myerson 1991). Initially, game theory used to be referred by zero sum games where each member's benefits or damages are precisely well-adjusted via another members. John Yon Neumann & Oskar Morgenstern wrote a book named 'Theory of Games and Economic Behavior' in 1944 where they presented a standard method in game theory and mathematical economics explaining cooperative games of multiple performers indicating modern game theory (Neumann and Morgenstern 1944). There is no field in computer, logic and system science including social science where it cannot be applied. It is also a widely used tool in every other sector including biology, projects management, political science, normative analysis, description and modeling. There are many game types such as simultaneous and sequential, cooperative and non-cooperative, zero-sum and non-zero-sum, perfect information and imperfect information, discrete and continuous games, meta games, pooling games, evolutionary game theory, differential games and so forth.

In 1913, Zermelo implanted the growth of today's game theory and in 1942, Ransmeier addressed the use of game theory in water resource management issues to the Tennessee Valley Authority investment venture and after that it has been amplified to use game theory for solving water conflicts (Dinar and Hogarth 2015). For example, Kyrgyzstan and Uzbekistan have water conflicts towards Syrdarya Basin over water allocation. Lea studied on this issue by implementing a model of cooperative game which gave a Nash bargaining solution (Melnikovová 2017). In 1969, Rogers provide a study highlighting India and Pakistan conflicts for the Lower Ganges using game theory in which he investigated various strategies focusing on benefits of each (Rogers 1969). Wang et al. (2003) offered a proposal for solving water distribution glitches through a cooperative game theoretic method.

The water resource allocation of Teesta river has always been an apple of discord between Bangladesh and India. Giving a solution to this issue based on a mathematical modeling approach, is the prime objective of this research paper. Previously many researchers from both sides tried to provide a result to this issue based on different mathematical modeling tools. Economic valuation of river water of Teesta, has been used previously used to optimize water need of both sides (Mullick 2010). In this approach the researchers tried to define total and marginal profit function based on economic values of agricultural and other products dependent on river water and optimizing the functions to determine the water need of both sides. Linear modeling and Zero sum game approach also have used been previously to solve the dispute (Arfanuzzaman 2018). The results of the previous researches show co-operation from both sides can be fruitful for both countries. This paper tries to find out which approach from each side can be fruitful.

The rest of the paper is organized as follows. **Section 2** reviews the related literature of game theory and Teesta water dispute, and **Section 3** presents the methodology through the case study. **Section 4** presents the results and discussions. Finally**, Section 5** concludes with scopes of improvement.

3. Methodology

According to concepts of game theory, each player attempts to maximize his payoff and at the end for lack of collaboration water becomes adulterated. Prisoners' dilemma is that kind of game. The motto of this technique is to crack the game of the prisoners' dilemma is to adjust the game rule with each other by developing their alliance. A game can be remarked by, G and the function of a game can be presented as, $G = \{R, S, P, D, O, E\}$ where, R – Respondents/Players, S - Strategies, P - Payoff, D - data, O - Outcome and E – Equilibrium. RSPD are the regulators of a game and OE are results of a game.

We used a linear programming model. While developing the model, political influences and issues have not been taken into account and environmental money effect of the system has been ignored in some extent due to lack of data and study. The task of linear programming model is to maximize the net benefits the power produced at the surface storage sites and of the irrigation water made available in the dry seasons of the year. The linear programing model that we have set up here is a deterministic stationary model. In other words we assume that the hydrology of the basin is completely determined and is invariant from year to year. The model then represents one year's operation of the system .In the linear program outlined below, the Objective function to be maximized deals only with power benefits, irrigation benefits, cost of surface and ground-water storage, all reduced to annual payments. Salinity controls, and flood control, for which we have no benefit functions, are handled implicitly by setting them as constraints upon the system.

3.1 Terminology and Parameters

$J = wet\ month\ index\ (MAY \ldots\ldots\ldots\ldots. OCTOBER)$
$I = dry\ month\ index\ (NOVEMBER \ldots\ldots.. APRIL)$
$T = total\ inflow\ in\ the\ dry\ season\ in\ west\ bengal$
$Dj = water\ flow\ causing\ flood$
$S = salinity\ constant(flow\ needed\ to\ maintain\ the\ natural\ behavior\ of\ the\ river)$
$Gi = maximum\ capacity\ of\ ground\ water\ development(G1 = BD; G2 = IND)$
$Vi = capacity\ of\ storage\ water(V1 = bd; V2 = Ind)$
$K = capacity\ to\ produce\ electricity\ in\ gojoldoba\ project$
$M1 = per\ unit\ oputput\ from\ flow\ (\ crop\ production\ in\ Bd)$
$M2 = per\ unit\ output\ flow\ (from\ crop\ production\ in\ INDIA(west\ Bengal))$
$M3 = per\ unit\ utility\ of\ electricity\ production$
$M4 = losses\ due\ to\ iron\ sailnation\ in\ westbengal\ due\ to\ lack\ of\ water\ flow$
$M5 = utility\ ground\ water\ development(in\ BD);$
$M6 = utility\ ground\ water\ development(INDIA)$
$M7 = cost\ of\ storage\ water\ development(in\ BD);$
$M8 = cost\ of\ storage\ water\ development\ (in\ INDIA)$
$C1 = losses\ due\ to\ flood\ in\ unit\ flow$
$X = water\ flow\ BD\ getting(30\%or\ 50\%)$
$A1 = water\ flow\ used\ to\ produce\ crop\ in\ BD$
$A2 = water\ flow\ used\ to\ produce\ crop\ in\ INDIA$
$A3 = access\ flow\ of\ water\ causing\ flood$
$A4 = water\ flow\ used\ to\ produce\ electricity$
$A5 = ground\ water\ flow\ in\ BD; A6 = ground\ water\ flow\ in\ India$
$A7 = water\ stored\ in\ BD$
$A8 = water\ stored\ in\ INDIA$

Maximize:

$$Net\ benefits, Z = M1 * A1 + M2 * A2 - C1 * A3 + M3 * A4 + M5 * A5 + M6 * A6 - M7 * A7 - M8 * A8 - M4 * (T - X);$$

Subject To:

$$A1 <= X - S;$$
$$A2 <= T - X;$$
$$A3 > D;$$
$$A4 <= K;$$
$$A5 <= G1;$$
$$A6 <= G2;$$
$$A7 <= V1;$$
$$A8 <= v2;$$

For solving this maximizing function with linear programming, limits and units of parameters and variables are presented in Table 1.

3.2 The Strategies and Pay-Off

Table 1: Price, Parameters and Limits

Parameters and variables	Limits	Unit
T	1920	cusec
D_J	10000	cusec
S	.2(T-A1)	cusec
G1	100	acres*10^6
G2	150	acres *10^6
V1	10	acres -feet*10^6
V2	15	acres -feet *10^6
K	20	M^3*10^6
M1	1.250	Dollar/cusec
M2	1.1	Dollar/cusec
M3	30	Dollar/cusec
M4	50	Dollar/cusec
M5	48	Dollar/cusec
M6	45	Dollar/cusec
M7	1.2	Dollar/cusec
M8	1.6	Dollar/cusec

So far we have found out three strategies that west Bengal may like to follow. They are;

1. They do nothing i.e. they stop their dams and help the natural course of the river.
2. They use 70% of the dry season water flow and share 30% with Bangladesh during dry season.
3. They share 50% with Bangladesh during the dry season.

However, Bangladesh can also follow two strategies;

1. They do nothing and bear the losses.
2. They go with their Dalia project with the available water during the dry season.

4. Results and Analysis

Following the methodology, the data were given into proposed model. The outputs are shown in Table 2.

Table 2: Two Person Nonzero-Sum Game: Payoff Matrix

	Indian Strategies			
Bangladesh Strategies	**Strategies**	*Do nothing*	*Share 30%*	*Share 50%*
	Do nothing	-15000000, -15000000	-15000000, 1292000	-15000000, 1300000
	Go with their Dalia project	1291800, -15000000	6418000, 1292000	1291800, 1300000

Player 1 (Bangladesh)

There are two strategies. Strategy 2 has larger payoffs than strategy1.

Strategy 1 payoffs of BD		Strategy 2 payoffs of BD
-15000000	<	1291800
-15000000	<	6418000
-15000000	<	1291800

Here, strategy 1 is dominated by strategy 2 and so strategy 1 can be eliminated.

Player 2 (India)

There are three strategies. Comparing between strategy1 and strategy 2:

Strategy 1 payoffs of India		Strategy 2 payoffs of India
-15000000	<	1292000
-15000000	<	1292000

Here, strategy 1 is dominated by strategy 2and so strategy 1 can be eliminated. Comparing between strategy2 and strategy 3:

Strategy 2 payoffs of India		Strategy 3 payoffs of India
1292000	<	1300000
1292000	<	1300000

Here, strategy 2 is dominated by strategy 3and so strategy 2 can be eliminated.

4.2 Nash Equilibrium

In this study, Nash equilibrium is Bangladesh goes with their Dalia project and India share 50% of water with Bangladesh during the dry season. As strategy 2 of player 1 and strategy 3 of player 2 intersect at (1291800, 1300000) point in payoff table. Through this, Bangladesh and India could make profit of 1291800 units and 1300000 units respectively.

Observing the payoff table we can see that Bangladesh must go for strategy 2 as in strategy 1 there is no chance for Bangladesh to make profit. India plays any of their strategies; Bangladesh is making profit by applying strategy 2. India will apply strategy 2 or 3 as strategy1 bears loss for India. So we can divide in six cases.

4.3 Investigation of Strategies

Case 1 (Bangladesh and India both do nothing): This is not an interesting case as both countries face with huge losses.

Case 2 (Bangladesh does nothing and India share 30%): By this India could get profit but Bangladesh still faces with big loss. So it might not an acceptable case for Bangladesh.

Case 3 (Bangladesh does nothing and India share 50%): By this India could get profit more than case 2 profit but Bangladesh still faces with big loss. So it also might not an acceptable case for Bangladesh. And it seems that India is getting more profit by sharing more water up to 50%.

Case 4 (Bangladesh goes with their Dalia project and India do nothing): Though Bangladesh is making profit in this case but India will not be interested to go for this case as they are bearing loss in this case.

Case 5 (Bangladesh goes with their Dalia project and India shares 30%): In this case though both countries are making profit so it can be a solution of this problem. But Bangladesh is getting larger profit than India which may a reason for India not to choose this case as by sharing more 20% of water India can make more profit than this.

Case 6 (Bangladesh goes with their Dalia project and India shares 50%): Through this case both countries could make profit. India is getting a large portion of profit than Bangladesh. Though Bangladesh is making less profit here than case 5, case 6 is the most stable case and indicating Nash equilibrium of this game as there is a question in case 5 that 'do India will accept less profit than Bangladesh or not'. So case 5 is not a pure dominating case.

5. Conclusion

Water resource management could become a complex job, as the stake-holders may hold sometimes conflicting and contradictory views and interest. The water resource distribution between Bangladesh and India is one such case. This issue is one of the burning thorns in these two countries relations for last few decades. The game theory could be an efficient tool for solving this issue. In this case study, linear programming and game theory have been used as the modeling approach to mitigate the hurdles and to look for the better solution to this burning issue. From the game model and Nash equilibrium we can see the 6^{th} case where Bangladesh goes with their Dalia Project and India shares 50% of Teesta rivers water is most beneficial for both sides. In this scenario, both Bangladesh and India profits and they make up a profit of total 2.59 Million units. So it is the most stable solution. However, while developing the model due to lack of study there environmental economic effects have been neglected. This can be the future scope of study. In conclusion, game theory is quite a powerful tool in resolving water resource conflicts, as this approach not provides a clear comparison between the different water users, but is also beneficial to water decision makers.

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