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Game theoretical analysis of China-India interactions in the Brahmaputra River Basin

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ABSTRACT

This paper employs a game model to explain the water politics between China and India in the Brahmaputra River Basin (BRB) for the past two decades. We delve into the strategic dynamics that culminated in the 2002 signing of a data-sharing Memorandum of Understanding (MoU), tracing the evolution of China-India bilateral relations from initial amity to a status quo stance. The study utilised two methods: (i) interviews with experts to analyse the strategic interactions and construct the payoffs and; (ii) a comprehensive literature review focusing on the geopolitical contexts of the BRB. Through our game model, we found that there is an ebb and flow relationship between China and India; with periods of deterioration followed by attempts at improvement. Moreover, the post-2017 border clashes have worsened the trust deficit, between the riparians complicating future water negotiations. We conclude that evolving geopolitics in the subcontinent and emerging hydropolitics have led to a status quo. China and India continue to engage in competitive, unilateral water resource projects, escalating into a "race for dams."

1. Introduction

Transboundary conflict management has garnered significant attention, leading to several approaches to analysing conflicts for prevention and resolution. One notable approach involves game theory, among other methods, such as integrated water resources management (IWRM), hydro-economic modelling, and market mechanisms (Tayia, 2019; Madani, 2010). Traditional river basin management approaches have their strengths, but they tend to treat the entire basin as a unified entity. This perspective often neglects the varying interests and priorities of stakeholders in each country, thereby overlooking the strategic complexities involved in negotiations between nations sharing a river (Madani, 2010). In contrast, game theory offers a more practical approach. It is a mathematical framework designed to analyse situations where multiple players make interdependent decisions, thus providing insights into strategic interactions (Osborne & Rubinstein, 1994). The outcomes for each participant in a game-theoretic model depend not only on their own actions but also on the actions of others. This makes it a valuable tool for analysing conflicts over shared resources such as international rivers (Madani, 2010), where decisions are often interconnected due to competing interests and impact the well-being of all involved. This interconnected decision-making process is termed a strategic interaction or 'game' (Osborne, 2004; Dinar & Wolf, 1994). Thus, game theory has evolved as a valuable analytical framework in transboundary water management, acknowledging the diverse objectives and behaviours of involved parties and providing a more practical and realistic approach to analysing transboundary water interactions (Dinar et al., 2013; Madani, 2010). Numerous scholarly works have applied game theory to study specific river basins worldwide, including the Ganges in South Asia, Nile and Volta in Africa, Nestos/Mesta in Europe, Mekong River Basin in South East Asia etc. (*see* Khachaturyan & Schoengold, 2019; Li et al., 2019; Bhagabati et al., 2014; Liao & Hannam, 2013; Bhaduri & Liebe, 2013; Eleftheriadou & Mylopoulos, 2008).

The Yarlung Zangbo-Brahmaputra-Jamuna River Basin (henceforth the Brahmaputra River Basin) is a critical yet understudied transboundary river system shared by China, India, Bhutan, and Bangladesh (Baruah et al., 2022; Zhang and Li, 2018; Barua et al., 2018; Biba, 2014). The basin is deeply intertwined with the regional geopolitics, particularly the dynamics between China and India, which significantly shape water-related interactions between the two nations. While the broader China-India relationship has been extensively examined by scholars (e.g., Shankar et al., 2018; Panda, 2016), the specific influence of their

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bilateral relations on water negotiations remains largely underexplored. Moreover, game theory, despite its potential, has not yet been applied to study the Brahmaputra River Basin in existing literature, making this approach uniquely innovative.

This paper seeks to fill this gap by applying game theory for the first time to analyse the strategic interactions between China and India over the Brahmaputra River Basin (BRB) during the past two and a half decades. We focus on the year 2000 as the starting point, coinciding with the signing of the Memorandum of Understanding (MoU) between China and India to share hydrological data on the BRB—a key development following the breakdown in relations after the 1962 border conflict (Biba, 2014). We investigate the strategic landscape that led to the signing of the MoU and explore how water interactions have evolved since then in a dynamic geopolitical context using a simple game model. By doing so we aim to make the complex strategic interactions and outcomes between China and India over the BRB more comprehensible and communicable, thus advancing our understanding of the intertwined geo and hydro politics in the BRB.

The paper is structured as follows: Section 2 outlines the methodological framework used. Section 3 analyses the China-India interaction using game theory. Section 4 discusses the findings, and Section 5 provides the concluding remarks.

2. Methods and materials

2.1. Game theory and its application in transboundary waters

Game theory is the mathematical study of strategic decision-making behaviour involving multiple rational actors (Osborne, 2004). Rationality in game theory implies choosing the best for oneself with or without consideration of the opponents, creating situations where the action of one actor impacts the other (Dixit et al., 2010). Game theory can capture such strategic interactions into well-defined models using three elements. These elements are a set of players or actors, strategies or options available to them, and possible outcomes for each combination of such strategies or payoffs. Situations where consideration is made about the opponent's optimal move while optimising their own strategy and when all players do their best against the others are described as the stable or *Nash equilibrium solutions.* It is called a stable solution because each actor forms correct beliefs about the strategies of others, and there is no incentive to deviate as that would yield worse outcomes (Madani, 2010; Dixit et al., 2010).

Since the 1990s, the application of game theory to transboundary waters has grown significantly, reflecting an increasing focus on cooperative management of this vital resource (Dinar, 2004). For instance, Rogers (1969) examined cooperation between India, and Bangladesh in joint water management, emphasising flood protection and irrigation water storage. Dinar and Wolf (1994) integrated physical, economic, and political aspects in analysing coalition formation for trading Nile water and water-saving technologies in the western Middle East (Egypt, Israel, West Bank, and Gaza). Frisvold and Caswell, (2000) utilised bargaining theory to evaluate water management on the Colorado and Rio Grande rivers along the US-Mexico border. Putnam's (1988) two-level games framework has been applied by scholars such as Luzi (2007), Deets (2009), Warner and Zawahri (2012), and Menga (2017) to analyse transboundary river basins like the Nile, Scheldt, and Amu Darya, focusing on how domestic pressures influence foreign interactions and agreements. Vij et al. (2020) further used the two-level game for the Brahmaputra River Basin, examining how national and sub-national levels of government in India and Bangladesh shape transboundary river decision-making and influence outcomes, specifically maintaining the status quo.

Several studies have employed cooperative game theory to assess stable water allocations in river basins like the Euphrates and Tigris (Turkey, Syria, and Iraq) by Kucukmehmetoglu and Guldmann, (2004), in the Nile River basin by Wu & Whittington, (2006), in the Ganges Basin by Bhaduri and Barbier, (2008), Mekong River basin by Liao & Hannam, (2013) and Bhagabati et al., (2014), using concepts such as core, nucleolus, and Shapley value to calculate cooperation gains. Eleftheriadou & Mylopoulos, (2008) have also effectively applied non-cooperative game theory, demonstrating the advantages of interconnected games over isolated ones through issue linkage in Greek and Bulgarian negotiations in the Nestos/Mesta River. In the Volta River basin, Bhaduri & Liebe, (2013) showcased how issue linkages between water and energy sectors fostered cooperation between upstream Burkina Faso and downstream Ghana. In the Kura-Araks basin, Khachaturyan & Schoengold, (2019) illustrated how repeated negotiations using interconnected game theory led to mutually beneficial outcomes between Georgia and Azerbaijan. Using an evolutionary game theory, Yu et al., (2019) demonstrated the transition from non-cooperation to cooperation in hypothetical basins, highlighting the role of incentives, particularly for upstream countries, in achieving cooperative outcomes (Mirzaei-Nodoushan et al., 2021).

While the selection of a game model depends on the specific circumstances of the river basin and study objectives, existing literature extensively explores various transboundary scenarios using intricate and sophisticated game models. These models analyse water interactions and outcomes based on the negotiation strategies of involved stakeholders, often relying on quantitative analysis and computation of optimal strategies through utility maximisation or payoff optimisation (Madani, 2010). Transboundary water interactions are inherently political and influenced by evolving socio-economic and political dynamics. Such approaches, while focusing on the outcome of negotiations, may fail to capture the nuanced decision-making processes and the strategic environments where decisions are made. Therefore, it is crucial to understand and analyse the strategic environment that shapes the strategies countries employ to advance their interests during water negotiations. Simple models, without relying on advanced mathematical formulations, can better facilitate understanding of these complex negotiation processes. They can more effectively communicate how the strategic environments and underlying socio-political factors influence water interactions. Further, by focusing on the process rather than just the outcome, such an approach emphasises that altering the factors influencing the negotiation process is essential for achieving different outcomes.

2.2. The Brahmaputra River Basin

The BRB is one of South Asia's largest river basins, with approximately 700 BCM annual discharge and a basin drainage area of 580,000 sq. km (Ray et al., 2015). The BRB is 2,900 km and originates from the Tibet Autonomous Region (TAR). It flows through China (1700 km), where it is called the Yarlung Zangbo, India (918 km) under the names of Brahmaputra and Lohit, and Bangladesh (337 km) as the Jamuna (Rahaman & Varis, 2009). Three main tributaries originate in Bhutan; thus, Bhutan also significantly contributes to the river (Barua et al., 2018). As shown in Fig. 1, 50.5 % of the total basin area lies in China, followed by India (33.6 %), Bangladesh (8.1 %), and Bhutan (7.8 %), and the river empties into the Bay of Bengal.

The BRB ranges among the 10th largest rivers in the world and is the largest braided sand-bed river, known to be one of the world's most unique and majestic river systems. The BRB, known for its biodiversity and substantial potential for irrigation, livelihood opportunities, hydropower generation, and navigation, is crucial in sustaining riparian countries' water-centric lives and livelihoods. Despite the huge potential of the BRB for regional development, disputes, and tensions persist among riparian countries due to diverse national interests and historical disagreements (Barua et al., 2018; Liu, 2015; Biswas, 2011). While no multilateral water treaty governs the BRB, the basin countries have bilateral MoUs to facilitate data and information sharing.

This paper focuses on China and India, two significant riparians of the BRB often referred to as "Asian giants" due to their considerable

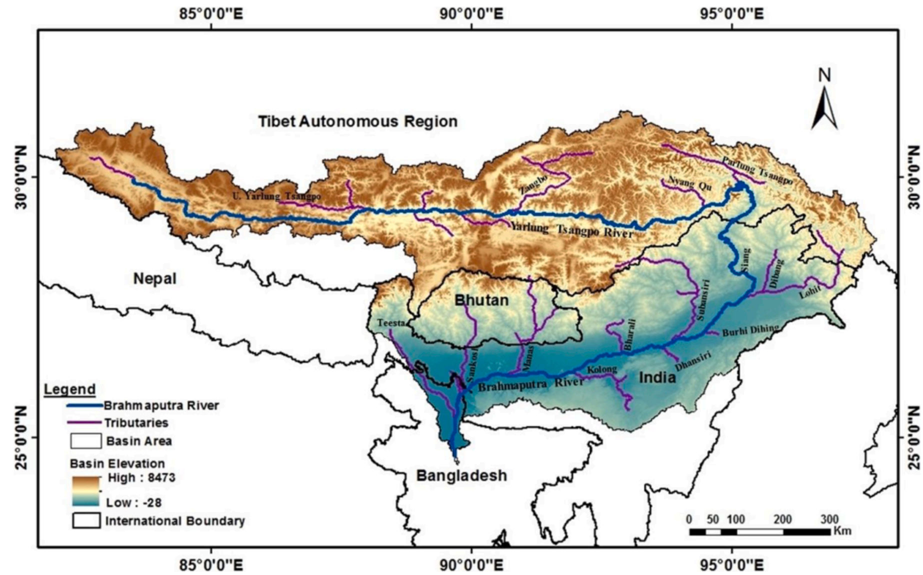

Fig. 1. Brahmaputra River Basin Map Source: Indian Institute of Technology Guwahati, India.

influence on the global economy, demographics, and geopolitics (Paul, 2019). Both countries have experienced remarkable economic growth over the past few decades, lifting millions of people from poverty. Achieving food and energy security remains a high priority for both nations, essential for maintaining economic growth and sustaining the living standards of their vast populations. As the BRB holds significant potential for enhancing energy security and reducing dependence on fossil fuels, China and India have been exploring the river's hydropower potential to meet their growing energy demands (Li et al., 2018; Ray et al., 2015). However, escalating geopolitical tensions and unresolved border disputes hinder collaborative efforts on the BRB (Baruah et al., 2022; Raju, 2020; Zhang & Li, 2018; Boon, 2016; Wouters & Chen, 2013).

2.3. Data collection and data sources

To analyse the strategic interaction and develop the game models, we require background information, and therefore, two key methods were applied to collect data – (i) interview with key experts with an understanding of past and current water issues between China and India, and (ii) detailed literature review was carried out based on the scientific and grey literature (including key reports, podcasts, *Brahmaputra Dialogue* (BD) reports[1], and public lectures). The author(s) conducted a separate media analysis of the BRB using English newspapers from both countries spanning 2010 to 2020 (Deka et al., 2023), and the relevant findings from that study were incorporated into the analysis of this study.

To conduct interviews, the author(s) followed a purposive sampling, at times using a snowball method. Experts interviewed included: academic researcher (possessing hands-on knowledge in transboundary river governance, particularly the Brahmaputra River, river engineering, international relations, and water politics), government officials (current and retired) for non-restraint opinions related to diplomatic affairs, and journalists (specialised in foreign affairs, and environmental journalism). The number of interviews conducted is $I_n = 20$ and $C_n = 5$ for India and China, respectively (see supplementary material *section I for details*). It was challenging to conduct interviews with Chinese respondents due to language barriers and the need for security clearances to openly discuss the BRB. Consequently, the Chinese interviews lacked diversity, as we could only interview academicians and not those actively involved in government policy-making. However, we addressed this gap through a review of secondary literature and the findings from the BD reports, which included participation from several Chinese individuals, including former bureaucrats (see the list of participants and workshop reports in the supplementary material), where author(s) also participated.

The interviews were mostly conducted electronically (via video-calling applications, like WebEx and Zoom), at times due to the travel restrictions due to the COVID-19 pandemic. All interviews were conducted in English between January and November 2022. Interviews were obtained through a semi-structured questionnaire which allowed the respondents to answer flexibly and comprehensively. The interviewer had the scope to ask follow-up questions to dig deeper with clarity. Besides, the questions were customised for every respondent according to country of origin, profession, and area of interest to elicit diverse information on their perceptions. The questionnaire consists of formal introductory questions formed to build a rapport with the respondent, followed by questions relating to the particular riparian's relationship with BRB co-riparians. Next, questions focusing on the bilateral China-India relationship, and lastly examine the scope of incentivising water cooperation. Some of the interviews were via email, along with two physical interviews, and one telephonic interview. Online interviews allowed flexibility in the flow of conversation as the researcher had the freedom to cross-question for deeper investigation. On the other hand, email interviews provided clear-cut answers as the interviewee could abstain from any confusion, deviations, and monotonous replies. Besides, it saved time for transcription.

We collected scientific literature using bibliographic databases like Scopus and Web of Science enabling a comprehensive coverage of peer-reviewed journals. Preliminary data search through keywords "China-India" AND "Brahmaputra" revealed that the China-India Brahmaputra interaction is inseparable from politics, specifically border issues. This led to the screening process of secondary data beyond transboundary river issues and seeking knowledge on: how is China-India bilateral relations and how is it influencing decision-making on the Brahmaputra River? Apart from peer-reviewed literature, as mentioned above the

[1] The BD project was initiated by the South Asia Consortium for Interdisciplinary Water Studies (SaciWATERs) in 2013 for improved water governance in the Brahmaputra. Key participants of the dialogue included multiple stakeholders from academia, government departments, development organisations, civil society, and media. The dialogues provided a platform for riparian interaction to discuss the challenges and possibilities for cooperation, enabling joint socio-economic and policy research.

study incorporates grey literature to include information for the strategic environment and synthesise all available evidence.

2.4. Data analysis

Using an interpretive approach, data analysis of the semi-structured interviews involved an iterative process (Denzin & Lincoln, 1994) of repeatedly reading the recorded transcripts to get a sense of the country-wise perceptions regarding Brahmaputra cooperation. We used an inductive and deductive coding process for data analysis; where respondents were coded (ensuring confidentiality) based on country-wise interviews (supplementary material*: Section II,* Table A1). As all the experts from China are academicians, we refer to them as C_{AC}. In the case of India, we refer to academicians as I_{AC}, government officials as I_{GO}, ex-bureaucrats as $I_{EB,}$ and journalists as I_{MP}. All recorded interviews were transcribed for thorough analysis in Otter.ai, an AI-based software.

We observed an interesting distinction between Chinese respondents based on their location: those residing in China expressed different perspectives on China-India relations and the possibility of cooperation compared to Chinese respondents living and working overseas. Notably, those overseas tended to be more optimistic in describing the relationship.

A thorough assessment of the power dynamics between China and India involved evaluating factors such as military capabilities, economic prowess, geopolitical influence, and diplomatic relations. Historical analyses of their relationship shed light on past interactions, conflicts, cooperation, and agreements, significantly influencing present perceptions, trust levels, and decision-making strategies. Geopolitical considerations, including territorial disputes, border tensions, regional alliances, and global power shifts, were examined for their impact on the strategic environment between the two countries and their implications for transboundary water management approaches. Evaluating institutional frameworks and mechanisms for transboundary water cooperation, such as existing agreements, treaties, joint committees, and dispute-resolution mechanisms, provided insights into shaping the strategic environment.

2.5. Elements of the game

2.5.1. Key players of the game

China *(Player 1):* China is one of the world's largest economies, with consistent GDP growth averaging around 10 % per year, now second only to the United States. China's military has modernised significantly, reflecting its broader geopolitical ambitions (Raghavan, 2019). China is also home to major transboundary rivers like the Mekong, Brahmaputra, and Indus amongst others, and has undertaken extensive hydropower projects on some of these rivers, affecting downstream countries (Zhang & Li, 2018). As Brahmaputra's upstream riparian, China's plans for hydropower development and water diversion projects on the BRB, known as the Yarlung Tsangpo in Tibet, have sparked concerns in India and Bangladesh about potential downstream impacts on water availability, flood risk, and ecological integrity. China has already developed several hydropower projects on its stretch of the river, intending to contribute to China's energy security by providing clean and renewable energy to its rapidly growing economy (Lyu et al., 2023). While China has stated that its hydropower projects on the Brahmaputra are for domestic energy, downstream countries remain wary of the potential consequences. Despite concerns, China has yet to ratify the UN Watercourses Convention (UNWC). China's preference for bilateral approaches underscores its prioritisation of national interests and diplomatic flexibility, resulting in limited cooperation on river management and a lack of binding agreements on water sharing.

India *(Player 2):* India has experienced notable economic growth over the past few decades. While India has emerged as one of the world's largest economies, it still lags behind China in GDP and overall economic output (ADB, 2023). India has a sizeable military force and is one of the largest defence spenders globally. India shares several transboundary rivers with its neighbouring countries, including the Indus, Ganges, Brahmaputra, and Mahakali Rivers. Like China, India also engages in bilateral approaches to managing transboundary rivers and has not ratified the UNWC. To meet growing energy demand, the Indian government has also planned several hydropower projects in its tributaries of the BRB, raising concerns in downstream Bangladesh and even within India regarding water security, environmental impacts, and transboundary river management (Baruah et al., 2022). However, for India, the benefits extend beyond mere economic and energy gains. The river offers a unique opportunity to integrate the isolated Northeast region through localised development facilitated by water infrastructure projects (Barua, 2018). Such initiatives would mitigate floods and erosion while harnessing the river's hydropower potential.

2.5.2. Strategic environment of the game

Following India's independence in 1947, China and India established diplomatic relations marked by cooperation and mutual respect (Bajpai et al., 2015). India's early recognition of the People's Republic of China in 1949 laid the groundwork for formal ties, culminating in the signing of the Panchsheel Treaty in 1954, emphasising peaceful coexistence (Bajpai et al., 2020; Bajpai et al., 2015). However, tensions arose over border disputes, especially regarding the undefined boundary between Tibet (under Chinese control) and India. China-India territorial disagreements date back to British rule, stemming from an ill-defined and disputed border in the western and eastern sectors (Baruah et al., 2022; Bhasin, 2021; Xuecheng, 2011; Guruswamy & Singh, 2009). In the western sector, the Aksai Chin region is a sparsely populated high-altitude desert area administered by China but claimed by India as part of the Union Territory of Ladakh. In the eastern sector, the Indian state of Arunachal Pradesh, south of the McMahon Line, which China claims in its entirety as part of South Tibet (Raju, 2020; Topgyal, 2011). The McMahon Line, defining the Indo-Tibetan border, was the outcome of the 1914 Simla Convention between British India and independent Tibet, and hence, China disowned the agreement as it was not a signatory (Xuecheng, 2011; Soni & Marwah, 2011). The disputes escalated into the Sino-Indian War of 1962, which significantly strained diplomatic relations between the two countries (Raju, 2020; Zhang & Li, 2013). Despite subsequent agreements like the 1993 Agreement on Peace and Tranquility, border conflicts persisted, notably the Depsang in 2013 and Doklam standoffs in 2017. These tensions worsened in 2020 with clashes in the Galwan Valley, followed by another military face-off in the Tawang sector in Arunachal Pradesh on 9 December 2022 (Bhalla & Negi, 2022). Such disputes have soured bilateral relations, fostering mutual suspicion and distrust, with little optimism for immediate resolution (Baruah et al., 2022; Ahlawat & Hughes, 2018). As pointed out by one of the respondents, *"Given the border issues, water cooperation is considered low politics by both riparians and as such officially will not see this as a problem till the time their economic interests are hurt"* (I_{AC}).

Both nations are major emerging economies competing for regional influence and global market share. Both seek to expand their influence in South Asia and the Indian Ocean region (Indurthy, 2016). China's close ties with Pakistan and its projects in Pakistan-occupied Kashmir (PoK) are a major source of tension for India (Ranjan, 2015). India's refusal to join China's Belt and Road Initiative (BRI) due to sovereignty concerns further exemplifies their strained relations (Kumar, 2019). China's opposition to India's membership in the Nuclear Suppliers Group (NSG) and the United Nations Security Council (UNSC) also adds to the diplomatic friction (Mohan, 2021). This evolving tension has hindered diplomatic ties and border negotiations, often leading to retaliatory actions, thus making transboundary water interaction challenging.

2.6. Analysis of China-India water interaction using game model

This section analyses the intricate dynamics of the China-India

Brahmaputra river interaction using a game model, considering the strategic environment elucidated earlier. We aim to explore the nuanced preferences of each country regarding the BRB and assess the resulting outcomes or payoffs of transboundary water interactions within the broader context of the bilateral relationship between China and India. Over the decades, the relationship between China and India has experienced fluctuations, shaped by power dynamics and geopolitical considerations. Despite the complexities of this relationship, particularly concerning the BRB, a notable achievement stands out: the signing of the MoU in 2002, between China and India. While this MoU represents a pivotal moment in matters directly related to the BRB, it is essential to acknowledge the evolution of preferences and payoffs surrounding the BRB since the signing of the MoU in 2002. These changes have been significantly influenced by regional geopolitics and border conflicts, which have considerably impacted the dynamics of cooperation and interaction between the two nations regarding the BRB. Hence, the analysis will focus on delineating how these preferences and payoffs have played out over time due to the evolving strategic environment, shedding light on the intricate interplay between regional geopolitics, bilateral relations, and water management strategies within the BRB.

2.6.1. *Signing of MoU in 2002*

In 2000, severe flash floods caused by the bursting of upstream artificial lakes were reported in the Sutlej and Siang rivers that flow from Tibet through the Indian states of Himachal Pradesh and Arunachal Pradesh (Zulfiqur Rahman, 2017). The issue brought up by Indian officials was the alleged culpability of the Chinese army in breaching temporary lakes created by landslides without adequate warning to the Indian side, causing loss of life and damage to infrastructure such as roads, bridges, and hydroelectric plants. The Chinese officials denied the charges, although the Indian Space Research Organisation (ISRO), through the help of satellite imagery, claimed to have identified the lakes that were breached (Zulfiqur Rahman 2017; Gautam, 2008). India asserted that early warning and access to Chinese data could have helped prevent such extensive damage caused by flash floods in June 2000. This led to the 'confrontation of the issue' (Mirumachi & Allan, 2007), as the issue of flash floods was acknowledged by the Chinese too. The confrontation of the issue led to the MoU being signed between the Ministries of Water Resources of China and India in 2002, which related to the provision of hydrological data and information on the Brahmaputra during flood season by China to India for a period of five years (2002–2007). The implementation plan was also signed between the two countries, which fixed the hydrological data sharing (water level, discharge, and rainfall) concerning three hydrological stations, namely Nugesha, Yangcun, and Nuxia, all located on the Chinese side, from 1 June to 15 October every year, which will then be used by the Central Water Commission of India for flood forecasting purposes and early warning uses (Ministry of Jal Shakti, n.d.).

The above milestone in water interaction between China and India is represented as an extensive form of the game, often referred to as a game tree (Fig. 2). Extensive games capture the dynamic nature of strategic interactions, allowing players to make purposeful moves in turns and making them well-suited for analysing transboundary interaction. In a game tree, branches depict player strategies, and the resulting payoffs are indicated at the terminal nodes. The first value in the payoff vector corresponds to *Player 1*, while the second pertains to *Player 2*. Traditionally, *Player 1* is depicted at the root node, signifying the initial stage of the game. *Player 1* has two strategies: 'cooperate' and 'defect'. At the same time, *Player 2* follows with four possible actions: 'cooperate' and 'defect' in response to *Player 1's* cooperation, and 'cooperate' and 'defect' in response to *Player 1's* defection. As the upper riparian, China has the advantage of making the first move by deciding whether to share data. Accordingly, four distinct scenarios can be developed, as depicted in Fig. 2.

In the game presented in Fig. 2, U_I and U_C represent the unilateral benefits derived from the river by China and India before any interaction concerning the BRB. But $U_I < U_C$, as China, the upper riparian, being economically and militarily stronger, gains larger benefits by unilaterally utilising the river than India, the lower riparian. As a lower riparian country, and without any water-sharing agreement, India is particularly vulnerable to upstream activities. Before the interaction for the MoU, India's payoff was $(U_I - Q)$, where Q represents the downstream vulnerability, for any upstream activities such as dam construction, water diversion for irrigation, and industrial use, can affect the quantity and quality of water flowing downstream, leading to water shortages.

2.6.2. *Case of Player 1 (P_1)*

China, as *Player 1*, had two options: to accept India's request for data sharing or to reject it. The signing of the MoU indicates that China chose to embrace India's request and proceeded with the agreement. In this scenario, China preferred to reestablish diplomatic ties with India, recognising the importance of mutual trust-building and diplomatic stability between the two countries. This move was particularly significant considering the strained bilateral relations following the 1962 Indo-China War (Raghavan, 2019). In terms of *payoff* (see Fig. 2), *Player 1* achieved a higher payoff $(U_C + P_1)$ by cooperating with India as it

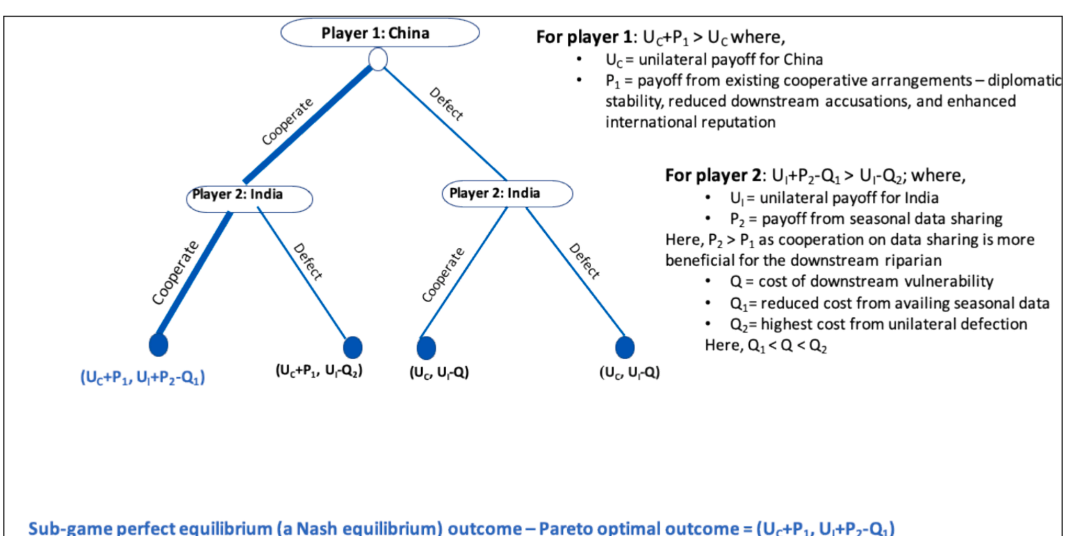

Fig. 2. China –India Extensive Game: Analysis of signing of MoU in 2002. Source: Author's creation.

includes benefits such as diplomatic stability, trust-building, reduced downstream accusations, and enhanced international reputation. The payoff associated with cooperation $(U_C + P_1)$ outweighs defection (U_C).

2.6.3. Case of Player 2 (P_2)

The MoU held particular significance for *Player 2* (India), due to the frequent floods experienced in the Northeast region, notably Assam and Arunachal Pradesh, caused by the Brahmaputra River. Before the MoU, *Player 2* relied solely on domestically generated data, but given the transboundary nature of the river, access to upstream data from *Player 1* could significantly mitigate flood disasters (Correspondent, 2002). Therefore, regarding *Player 2's* preference, cooperation was the best strategy, with the payoff $(U_I + P_2\text{-}Q_1)$, where P_2 includes the benefits from the data sharing MoU and renewed diplomatic ties with *Player 1* (see Fig. 2). Q_1 represents the reduced downstream vulnerability $(Q > Q_1)$ that would exist without data sharing. As a lower riparian, India inherently faces downstream vulnerabilities without a basin-level treaty, and data sharing reduces this vulnerability to Q_1. The cooperative payoff for *Player 2* is greater than that for *Player 1* ($P_2 > P_1$), as cooperation on hydrological data sharing is more beneficial for the downstream player than for the upstream player. Further, downstream defection is not a viable option for India in this context, as India approached China for the data and the signing of the MoU was beneficial for India. Rejecting *Player 1's* offer of seasonal data sharing would leave *Player 2* with no data and no platform for interaction, resulting in a lower payoff of $(U_I\text{-}Q_2)$, where $Q_2 > Q_1 > Q$. Here, Q_2 represents the highest cost for *Player 2*, as defecting from *Player 1's* cooperative move could make future negotiations difficult and result in a loss of international support to persuade *Player 1* for future cooperation. Further, *Player 2* would miss out on the 'P_2'' component and be in a worse-off position. The resulting outcome of $(U_I\text{-}Q_2)$ is less desirable than $(U_I + P_2\text{-}Q_1)$.

Thus, cooperation was both *players' best strategy and preferred option*. The players reached the subgame perfect Nash equilibrium (SPNE) with payoffs of $(U_C + P_1)$ for China and $(U_I + P_2\text{-}Q_1)$ for India, which is also one of the Nash equilibria of this interaction, as shown in Fig. 2. This SPNE is a refinement of the Nash equilibrium concept, specifically applied to dynamic games. The interaction between China and India in 2002 was influenced by a strategic environment that favoured cooperation for both parties. However, bilateral relationships between sovereign nations are dynamic, and so are their water interactions. Consequently, decisions to cooperate or defect are made at various stages, representing "subgames" within the larger game. These subgames start at specific decision points, such as the signing of the MoU, and include all subsequent actions and payoffs from that point forward. Furthermore, the outcome $(U_C + P_1,\ U_I + P_2\text{-}Q_1)$ is Pareto optimal, providing both players with the highest possible benefits from that particular interaction in 2002.

2.6.4. Setting up of an Expert Level Mechanism in 2006

The preference for cooperation established in 2002 was further reinforced by the creation of an Expert Level Mechanism (ELM) in 2006 between China and India aiming to facilitate dialogue and cooperation regarding the management and utilisation of the Brahmaputra River's resources (Ministry of Jal Shakti, n.d.). This step advanced the goal of sharing data towards a shared objective, though without joint action. The establishment of the ELM presented an opportunity for both nations to convene and engage in discussions regarding pertinent issues concerning BRB. Similar to data sharing, this initiative embodies a form of technical cooperation, albeit it changed the payoff structure from signing of MoU in 2002 $(U_C + P_1,\ U_I + P_2\text{-}Q_1)$ to $(U_C + P'_1,\ U_I + P'_2\text{-}Q'_1)$ with the setting up of ELM. The signing of the Expert-Level Mechanism (ELM) resulted in a higher payoff for both China and India by establishing a formal platform for dialogue and cooperation. This mechanism enhanced communication between the two countries, particularly on shared water concerns, leading to greater mutual benefits. As a result, China's new payoff (P'_1) is higher than its previous payoff in 2002 (P_1), and the same improvement is true for India. The ELM, therefore, represents a positive shift in their interactions, fostering a more structured approach to managing their shared resources. Here, $P'_1 > P_1$ and $P'_2 > P_2$ with a reduced downstream vulnerability for India $Q_1 > Q'_1$ due to a formal platform for India to discuss and identify opportunities for cooperation with China. However, ELM has not yet resulted in joint strategies for water management, such as coordinated water allocation plans, joint monitoring programs, or collaborative disaster management. Such cooperative actions in river utilisation would have helped *Player 2* eliminate the cost *'Q'* as decisions would be made jointly. Nonetheless, these developments in bilateral relations have fostered a positive relationship between China and India, setting the stage for further cooperation in the future.

2.6.5. Renewal of 2002 MoU in 2008, 2013 and 2018

The 2002 MoU was renewed in 2008 for more years, but a new clause was introduced to the MoU. Under this clause, India was required to make payments for the data it received, which assists in flood preparedness, enhancing flood forecasting and timely warnings for mitigation measures (Zulfiqur Rahman, 2017). The other terms of the MoU remained unchanged; the same data had been provided to India free of charge since 2002, and China required payment for the information starting with the renewal in 2008 and the subsequent years. The Indian side accepted this clause, understanding that China requested a token amount to support staff and equipment maintenance at the monitoring stations in challenging terrains. Given the critical nature of the data for India, it was willing to make the payment. It also indicates India's vulnerable position as a lower riparian in the BRB, as India now needs to pay to obtain the data. The payoff shifts from $(U_C + P'_1,\ U_I + P'_2\text{-}Q'_1)$ to $(U_C + P'_1 + M_C,\ U_I + P'_2\text{-}Q''_1)$, where '$M_C$' represents the increase in China's payoff due to the payment from India for data access, and Q''_1 indicates India's downstream vulnerability, as India had to agree to pay China $(Q''_1 > Q'_1)$. While India's downstream vulnerability (Q''_1) is approximately similar to the 2002 level (Q_1) in terms of magnitude, but the circumstances are different. Unlike in 2002, India now incurs a cost by paying China for the hydrological data, which was not the case previously. The 'M_C' component illustrates how China leveraged its position as an upstream nation to make India pay for critical hydrological data essential for flood forecasting. This dependency was exploited by China to gain benefits and reaffirms its control over the data as the upstream country.

While the MoU between China and India was renewed in 2013, it occurred amidst several significant events (MEA, n.d.). One of the significant narratives that started to take centre stage was the credibility of the data shared by China with India. This apprehension came up due to the understanding that all three stations from where India receives that data are located in the rain shadow region of Tibet (Ranjan, 2023). Hence, data exchange for early flood warnings is not very effective. According to this narrative, despite the positive intentions of friendly cooperation, equality, and mutual benefit enshrined in the agreement, the primary purpose of designing an effective early-warning system seems to have been lost. This also raised concerns about the payments India makes to access the data, as the same data is provided free to Bangladesh. Amidst these discussions on data sharing, the bilateral relationship between China and India deteriorated due to the 2013 Depsang standoff. This significant military confrontation occurred in Eastern Ladakh near the Line of Actual Control (LAC), the de facto border between the two countries. Although both sides agreed to withdraw their troops after three weeks of negotiations, the incident eroded trust and prompted a reassessment of military strategies and preparedness along the LAC. However, despite these tensions, the MoU on hydrological data sharing was renewed in 2013 for another five years, underscoring the importance of water relations between the two countries. In fact, in 2014, China agreed to extend the hydrological data-sharing period by two weeks, changing it from June 1 to October 15, to

May 15 to October 15. This was a significant step forward since the monsoon in Northeast India begins in May, aiding better flood forecasting. However, the monitoring stations remained the same, and India continued to pay for the data. While the extension was appreciated, it was not widely applauded. Respondents from India emphasised, "*Given India's payments, China should have readily provided this extension*" (I_{AC}, I_{MP}). Despite the shortcomings in the MoU, the extended data provision has reduced downstream vulnerability for India, resulting in Q'''_1, which is approximately of the same magnitude as Q'_1 from 2006, but not identical considering the evolving circumstances between the two countries. Meanwhile, there was no change in China's payoff. The new payoff and the Nash equilibrium in 2013 moved from $(U_C + P'_1 + M_C, U_I + P'_2\text{-}Q''_1)$ to $(U_C + P'_1 + M_C, U_I + P'_2\text{-}Q'''_1)$.

In 2014, China completed the construction of the Zangmu Dam on the Yarlung Zangbo for hydropower and irrigation purposes without formally informing India. This unilateral action raised significant concerns over transparency and exacerbated tensions between the two countries. Although China did not publicly declare its plans, various sources revealed that China intended to construct five multipurpose dams on the upper Yarlung Zangbo, leading to heightened mistrust and further straining the relationship between the two nations. However, one of the Chinese respondents disagreed with the blame and stated, "*China publishes a lot of information, including numerous records and yearbooks, written in Chinese and the use of the local language is not China's problem and, therefore, should not be considered a lack of transparency*" (C_{AC}).

Bilateral relationships were further disturbed by the Doklam standoff in 2017, a significant military standoff between China and India in the disputed tri-junction area involving China, India, and Bhutan. During the 73-day military standoff at the Doklam trijunction, China suspended the sharing of hydrological data with India for the BRB, citing that the interruption was due to technical upgrades at water stations in the upstream region (Feng et al., 2019). During the same time, the annual meeting of the ELM was also cancelled. However, in the same period, Bangladesh received data on the Brahmaputra's water levels from China (Ranjan, 2023). Although the standoff ended in late August 2017, when both sides agreed to withdraw their troops from the face-off site, it marked the first time that border disputes had repercussions on water relations. In fact, a respondent from China mentioned, "*This temporary suspension of data sharing was resumed later for the sake of India by fixing the hydrological stations despite China having the option not to share to restore diplomatic ties*" (C_{AC}).

The suspension of data sharing increased the downstream vulnerability for *Player 2* as the data suspension occurred during the critical monsoon season, a period when such data is vital for flood forecasting and management in downstream regions of India (Deka, 2021). This reduced payoff to $(U_I\text{-}Q)$ for *Player 2*, the same as the pre-2002 period before any MoU was signed. For *Player 1*, the payoff also fell back to U_C, similar to pre-MoU times. However, it is important to note that although these payoffs resemble those of the pre-2002 period, the bilateral relationship deteriorated due to border crises. This highlights how broader geopolitical tensions can easily disrupt agreements like MoUs, undermining their reliability and effectiveness.

Despite the deteriorating bilateral relationship between China and India following the Doklam crisis and the suspension of the MoU in 2017, the MoU was renewed in June 2018, reinstating the previous payoffs. This lower payoff was thus temporary, and while the downstream vulnerability for India has remained similar to 2013, it is not identical due to the changing geopolitical circumstances. As a result, the Nash equilibrium in 2018 is represented as (UC + P'_1 + MC, $U_I + P'_2 - Q''''_1$), where Q''''_1 reflects India's downstream vulnerability under these new conditions.

The downstream vulnerability, denoted by Q, has changed from the pre-2002 period to 2018 as $Q > Q_1 > Q_1' < Q_1'' < Q_1''' < Q_1''''$. While the geopolitical landscape and bilateral relations have fluctuated, the magnitude of Q remains relatively consistent. Notably, Q_1', representing the year 2006 when the Expert Level Mechanism (ELM) was established, reflects the most favorable situation for India, both geopolitically and as a downstream riparian. No better outcome has been achieved since, and due to a lack of trust and the fear of worse outcomes, both China and India have maintained the status quo, refraining from further cooperation beyond the early 2000 s agreements on hydrological data sharing and the ELM setup.

3. Discussion

The payoffs from the water interaction on the BRB show an ebb and flow pattern (Fig. 3), with periods of deterioration followed by attempts of improvement, yet, the threshold remains the 2002 MoU and 2006 ELM. Thus, the intertwining of hydropolitical challenges with geopolitics enabled China and India to purposefully maintain a status quo in the BRB that serves their respective development agendas (Baruah et al., 2022, Vij et al., 2020). Status quo in transboundary interactions implies using power interplay to deliberately avoid concrete decision-making on issues such as water sharing, water resources development, joint research, and other issues (Vij et al., 2024). While there is no active conflict or violence over the BRB, genuine cooperation or positive relations are also absent. Underlying issues and disagreements remain unresolved due to a lack of trust and collaboration. Both countries aim to avoid direct conflict on water sharing in the BRB, but recent border clashes have deepened the trust deficit, highlighting the volatility of the border situation and complicating future negotiations related to the BRB. There is little hope that both nations can rebuild the eroded trust. An Indian respondent even blamed China stating, "*Trust-building can only be meaningful if both parties are willing to reconcile and find a way to resolve their disputes. If one party believes that disputes are a source of leverage against the other country, then sincere trust-building is impossible*" (I_{AC}).

While writing this paper, the authors observed that the MoU between China and India, renewed in 2018, expired on June 5, 2023, and is currently pending renewal. Since 2018, the geopolitical and hydropolitical landscape in the region has evolved significantly (Raju, 2020). In this section, we analyse the strategic environment that led to the initial signing of the MoU in 2002 and trace the evolution of the China-India bilateral relationship from a budding friendship to a status quo situation.

4. Signs of cooperation in China-India Relation

In the aftermath of the 1962 war, diplomatic relations between China and India fluctuated, marked by periods of tension and reconciliation. For India, China's agreement to sign the MoU was crucial in reestablishing its relationship with China after the war, significantly influencing subsequent bilateral relations. The war, described as a traumatic shock for India (Cohen, 1971), dealt a severe blow to the pacifist views of the Sino-Indian relationship in the post-colonial period, with India suffering defeat at the hands of the Chinese military (Maxwell, 1970). The conflict largely stemmed from the colonial legacy of unresolved borders between India and China, particularly in the eastern sector of the Sino-Indian boundary dispute in Arunachal Pradesh (Raghavan, 2019). The Yarlung Tsangpo-Brahmaputra river flows from Tibet through Arunachal Pradesh in India, a region central to the 1962 war and claimed by China as South Tibet. Thus, China's agreement to the MoU was a welcome gesture for India, as it aimed to restore diplomatic ties and provide India with access to upstream data and information. This access would help better flood forecasting, improve environmental, economic, and social outcomes, and maintain diplomatic stability with China. Various factors including high-level visits, agreements on peace and tranquillity, and establishing economic cooperation mechanisms, provided a conducive environment for China to consider reestablishing diplomatic ties with India.

The 2002 MoU was a significant opportunity for China to reestablish diplomatic ties with India, recognising the importance of mutual trust-

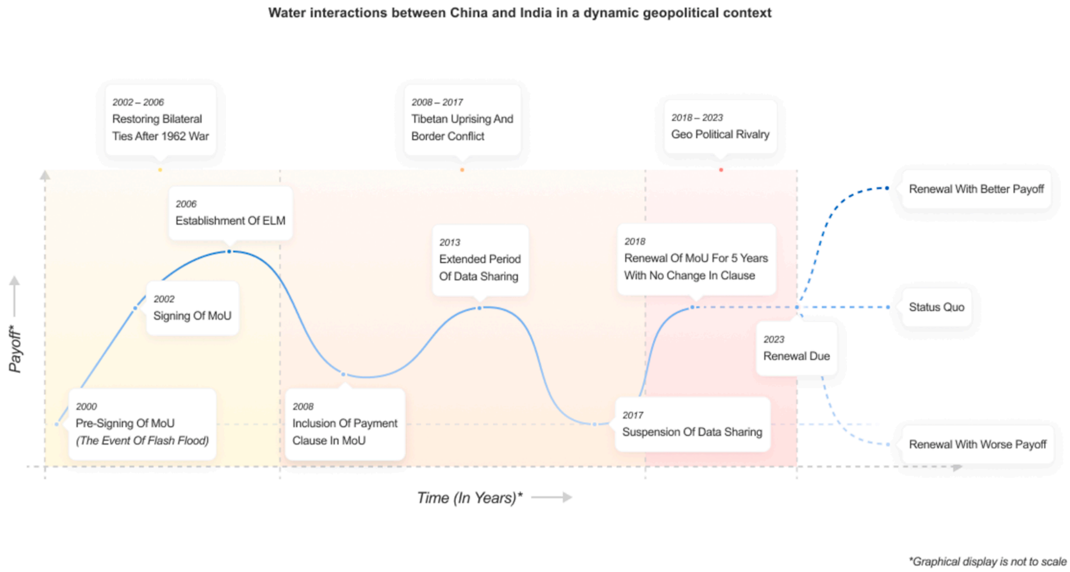

Fig. 3. Ebb and flow water interaction between China and India in a dynamic geopolitical context. Source: Author's creation.

building and diplomatic stability between the two countries following the border war. However, potential barriers and concerns, such as national security, historical border disputes, and the autonomy of being an upstream country, could have influenced China to 'defect' or deny India's request for data sharing. Ultimately, China's preference for the MoU was driven by the strategic environment and the opportunity it presented for technical cooperation. The signing of the MoU provided a chance to address a pressing issue (flash floods) and improve the situation through emergency actions (Mirumachi & Allan, 2007). Despite potential divergences in policies and actions, China recognised the value of technical cooperation in addressing shared water-related problems, leading to the decision to sign the MoU in 2002.

Establishing the ELM in 2006 was also a significant step towards fostering bilateral relations and improving water management in the region. Several key developments led to this initiative, such as additional measures added in 2005 to the 1996 agreement on Confidence-Building Measures in the military field along the LAC in the China-India border areas, indicating a mutual willingness to strengthen it further. In 2003, both sides decided to appoint Special Representatives to explore a boundary settlement framework from a political perspective, resulting in the signing of an agreement on Political Parameters and Guiding Principles for the Settlement of the China-India Boundary Question. This evolving positive bilateral relationship was also reflected in the commencement of 22 direct weekly flights between China and India in 2002 and the declaration of 2006 as the "Year of India-China Friendship" (Lu, 2014). These developments in bilateral relations have fostered a positive relationship between China and India, setting the stage for further cooperation in the future. As data and information sharing are crucial first steps towards building trust and confidence, mitigating conflicts, and affirming long-term cooperation (Xie & Jia, 2017), the payoffs associated with signing the MoU and establishing ELM are higher than in pre-2002, as shown in Fig. 3.

4.1. Prisoner's dilemma between China and India's water interaction

China's signing of the MoU in 2002 was well-received in India, with several newspapers applauding the achievement till the next renewal in 2013. The newspapers primarily highlighted China's recognition of lower riparian rights, a unique gesture since China has refused to formalise this with any other neighbouring country (Subramanian, 2013; SANDRP, 2013). Although the MoU was renewed three times (2008, 2013, and 2018), however, India paying China for hydrological data came under heavy criticism. The critics argued that India became financially dependent on China for critical hydrological information, potentially compromising its sovereignty. Instead, they contended that hydrological data sharing in a transboundary river basin like the BRB should be a cooperative and reciprocal process rather than a transactional one. The larger narrative suggests that China, as an upstream country, is using this data to assert dominance, negotiate favourable terms, and create strategic dependencies, thereby shaping the river basin's political, economic, and environmental landscape. "*There is also a growing call within India to develop its own capabilities to monitor the river independently*" (I_{AC}, I_{MP}, I_{EB}, I_{GO}). Critics argue that with advances in satellite technology and remote sensing, India should invest in its own infrastructure to gather hydrological data. This would enhance self-sufficiency and reduce dependency on China for critical information.

The data issue became particularly pertinent in 2017 after the Doklam standoff when China withheld hydrological data from India. This incident highlighted the vulnerability and potential risks associated with dependency on China for crucial water-related information. As a Chinese respondent rightly pointed out, "*The MoU on hydrological data sharing was considered an indicator of improved relations, but it was violated during the period of deteriorated bilateral relations in 2017, showing that MoUs cannot define bilateral ties*" (C_{AC}). The Doklam conflict significantly strained diplomatic relations and eroded the fragile trust between China and India, leading to a war of words through official statements and media outlets (Raju, 2020). By withholding hydrological data, China demonstrated its ability to use water as a strategic weapon even without direct conflict. The suspension of data sharing can be seen as geopolitical leverage, signalling to India the potential costs of challenging Chinese strategic interests (Baruah et al., 2022). This incident highlights the interconnectedness of regional security issues and transboundary water management. An Indian respondent argued, "*Even if territorial issues between China and India are resolved, there is no guarantee that China will participate in basin cooperation with India over the Brahmaputra due to sovereignty concerns related to Tibet*" (I_{AC}).

Another pivotal concern complicating the China-India relationship regarding shared water resources is China's unilateral construction of hydropower dams. While India announced its intentions to develop several hydroelectric projects on the Brahmaputra River as early as 2008 for energy generation, these plans encountered delays due to environmental concerns and opposition from local communities. Meanwhile, China completed the Zangmu Dam in 2014 and has plans for several more hydropower dams in the BRB, but this information was not officially shared publicly. It was only in China's 14th Five-Year Plan (2021–25) that hydropower development in the BRB was explicitly mentioned. This lack of transparency from China regarding its planned dams has exacerbated mistrust and significantly complicated efforts to cooperatively manage transboundary water resources.

Such a situation, where a strategy to maximise individual gain results in a sub-optimal outcome for the entire system, is called a prisoner's dilemma (Madani, 2010). The prisoner's dilemma is a classic example from game theory that illustrates why two rational individuals might not cooperate, even if it appears that it is in their best interest to do so. India could have leveraged the existing institutional mechanism (ELM) to bridge the crucial data gap by amending the MoU to modify the choice of gauging stations, particularly since India is paying for the data it receives from China. This would enhance the payoff for both China and India and improve their bilateral hydropolitical relations concerning the Brahmaputra. However, due to a lack of trust and effective communication, there is a fear that any move from the existing arrangement of data sharing might lead to greater loss and betrayal, thus creating a prisoner's dilemma. This illustrates that China and India are faced with a situation where cooperative behaviour would yield the best overall outcome, but the fear of unilateral defection leads to non-cooperative actions, resulting in worse outcomes for both. Hence, between 2008 and 2018, as shown in Fig. 3, the payoffs from the MoU have remained more or less stagnant, giving rise to a status quo situation. The MoU continues to represent shallow, reluctant, and piecemeal cooperation that serves to avoid conflict but does not assist development efforts or provide long-term sustainability of the agreements (Barua, 2018).

4.2. Water interaction moving towards a chicken game

Despite numerous talks, no progress on border delimitation has been achieved (Pant & Bommakanti, 2019). The situation worsened in 2020 with multiple standoffs in Ladakh, culminating in a deadly clash on 15 June 2020, in the Galwan Valley, resulting in the deaths of 20 Indian soldiers and an undisclosed number of Chinese troops. This violent skirmish, triggered by competing border infrastructure constructions, marked a significant shift in India's stance towards China from a hedging strategy to a more hawkish approach (Jacob, 2022; Boon, 2016). For example, post-Galwan, India sanctioned several border infrastructure projects to facilitate troop deployment.

Tensions further escalated with the latest military face-off in the Tawang sector of Arunachal Pradesh on 9 December 2022, involving physical confrontations and resulting in injuries on both sides. After this clash, India geared up its internal balance strategies to cope with China. For example, in response to China's model villages program aimed at enhancing rural development in strategic areas, India launched the Vibrant Villages Programme (VVP) in February 2023, developing border villages and mini hydropower projects in Arunachal Pradesh to boost the local economy and prevent youth out-migration, asserting dominance over China.

Another layer of geopolitical competition exists between China and India concerning their influence in South Asia. Historically, India has dominated the economic and political landscapes of Bhutan and Bangladesh, both riparian countries of the BRB (Hossain & Islam, 2021; Paul, 2019). However, China's growing trade and infrastructure investments in the region, particularly in Bangladesh, have challenged India's strategic interests. Consequently, India has refrained from participating in China's BRI due to concerns over national sovereignty and potential 'debt trap' risks (Baruah et al., 2022).

China and India are also economic competitors, vying for market access, investment opportunities, and strategic resources (Ahmed & Sheikh, 2021). India's growing trade deficit with China further complicates their economic rivalry (Freeman, 2018). Additionally, both nations compete for influence in multilateral forums and maintain strategic partnerships with major powers like the United States and Russia. India's involvement in the Quadrilateral Security Dialogue (Quad) with the US, Japan, and Australia aims to counter China's influence in the Indo-Pacific region. The Quad helps India diversify its trade and investment partnerships, reducing dependence on China, particularly in strategic sectors like technology and supply chains. China views the Quad as a containment strategy by the US, despite seeking bilateral engagements with Quad members on economic and trade issues (Tarapore, 2023). In fact, a Chinese respondent emphasised, "*In the future, it is very hard to see the relationship between India and China improving given India-US relations which have been framed largely alongside Quad*" (C_{AC}).

Notably, China announced a 60GW hydropower dam in the Great Bend of the Brahmaputra, crucial for its carbon neutrality goals by 2060. In response, India declared a 10GW hydropower dam in Assam for flood control, asserting its user rights as a lower riparian. Both nations are now engaged in competitive prior appropriation rights, each asserting their claims over the shared basin. For example, India's push for dam construction in Arunachal Pradesh serves as part of its broader strategy to enhance its energy infrastructure and as a countermeasure to assert its rights over transboundary waters in response to China's upstream activities. China and India have engaged in a competition for hydropower projects on the BRB, leading to a 'race for dams'. This rivalry, intensified by the 2020 Galwan crisis, has escalated into unilateral water interventions. The BRB, already suffering from border conflicts, is now entangled in the hydropolitics between China and India. The race for dam construction between the two nations signifies emerging hydropolitics intertwined with the region's geopolitics (Baruah et al., 2022). As the Indian respondent reiterated, "*India should also enter into the "dam race" to harness its water wealth and avail power marketing opportunities and fulfill the power demands of India, Myanmar, and Bangladesh*" (I_{GO}).

Given the shift in *Player 2*'s attitude towards *Player 1* since the 2020 Galwan crisis and aggressive China-India bilateral behaviour, *Player 2* might break the current status quo and engage in competitive unilateral water interventions like Player *1*. However, when both players resort to unilateralism, the resulting outcome $(U'_C, U'_I\text{-}Q'_2)$ where $U'_C < U_C$ and $U'_I < U_I$ will be the worst because it will lead to the 'tragedy of commons' with both nations building dams in the seismic Himalayan zone, potentially destroying the Brahmaputra ecosystem. A contested control in the form of a dam race in the seismic Himalayan zone will destroy the relatively pristine Brahmaputra ecosystem and cause irreversible consequences. It will be especially bad for *Player 2*, imposing cost Q'_2 where $Q'_2 > Q_2 > Q'_1$. This situation is much worse than the defection from the signing of the MoU in 2002 (Q_2), as there was no competition over shared water between China and India at that time. Additionally, as the lower riparian, India faces increased vulnerability due to climate change uncertainties and the lack of basin-wide impact assessments for the dams, which translates into a significant risk of socio-ecological loss. The bilateral interaction is evolving from *a 'prisoner's dilemma'* into a *'chicken game'*, where neither side wants to 'swerve' first. Game theory suggests that to avoid the worst outcomes, one player must take the initiative to cooperate. However, it remains to be seen who will 'swerve' as the MoU renewal approaches.

5. Conclusion

By applying game theory, this paper examines the water interactions between China and India, highlighting how the strategic environment shapes their negotiation strategies, potential for cooperation, and conflict. We chose a simple game model in our paper, not because we believe advanced game models are incorrect or unnecessary, but because we found a simpler approach more suitable for this study. Given that the Brahmaputra River Basin is relatively underexplored, we wanted to use the model to set the foundation and effectively communicate our findings to a broader audience. The used model and approach in this paper also paves the way for future research using more advanced and complex game models that could capture the evolving dynamics between the basin's riparians.

The strategic environment is integral to understanding water interactions in a transboundary context. It frames the negotiation process, influences each country's strategies, and ultimately determines the dynamic and evolving payoffs. By focusing on the strategic environment, the paper underscores the complexity and interconnectedness of geopolitical and hydropolitical factors in shaping transboundary water negotiation outcomes between China and India. It emphasises that negotiation outcomes or payoffs are not static but change as the strategic environment evolves. For instance, improved bilateral relations can lead to cooperative water management initiatives, whereas deteriorating relations can result in unilateral actions and increased tensions, as evidenced by ongoing border conflicts.

The 2002 MoU was intended as a first step toward further cooperation in the joint management of this crucial river basin, which has enormous potential for regional development. However, evolving geopolitics and emerging hydropolitics have complicated water interactions, leading to a status quo in the BRB. Both nations avoid direct conflict over the Brahmaputra River but engage in competitive and unilateral water resource projects without effective communication or joint agreements, potentially exacerbating long-term regional stability and sustainability issues. What remains to be seen is how the renewal of the MoU will unfold and whether India can successfully negotiate for data from gauging stations that are more relevant to its needs, given that India is paying for this data from China. Achieving this would increase the payoff for both nations and could break the current status quo.

CRediT authorship contribution statement

Anamika Barua: Writing – original draft, Supervision, Methodology, Formal analysis, Data curation, Conceptualization. **Tanushree Baruah:** Writing – review & editing, Methodology, Data curation, Conceptualization. **Sumit Vij:** Conceptualization, Formal analysis, Methodology, Validation, Writing – review & editing.

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Open Research.

No data repository is used for this research. All secondary information have been properly cited in the text and referenced. All information regarding the primary data used has been provided in the Annexure.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jhydrol.2024.132602.

Data availability

No data was used for the research described in the article.

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