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Game-theoretic-based modelling of Krishna waters dispute: equilibrium solutions by Metagame Analysis

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Abstract. Conflicts are inevitable concerning sharing of the resources. Most of the time, due to the opacity of the conflict resolution technique, players involved do not accept the final solution. Therefore, any method adopted for resolving a conflict should involve players to get the equilibrium solution. Besides, the conflict resolution technique needs to be transparent, and the procedure must be the same for all the players involved. Metagame Analysis has the potential to accommodate the above conditions. In this study, we have discussed Metagame Analysis and its application to resolve India's Krishna river basin dispute. Since the environment is an integral part of the river ecosystem, it has also been included as a conflict resolution player. We have also defined and derived Fair and Equitable (F&E) allocation in this regard, considering the factors that form the basis for their right as a rightful owner of the resource. The factors considered for F&E allocation are drainage area, cultivable area, and virgin runoff. The derived F&E allocation is then selected as one of the options for the Metagame Analysis. Metagame Analysis is carried out using two scenarios before and after Andhra Pradesh's reorganization (in 2014). In scenario 1, equilibrium outcomes are 454, 458, and 469. Our results show that excessive demands may harm the water allocation if it violates the total flow. Outcome 469 is the F&E outcome in which all the players are going for cooperated negotiations which maximize their share. Outcomes 454 and 458 are those outcomes in which Karnataka is benefitted as it is getting its first option share. AP's demand cannot be accommodated in any strategy as it exceeds the total flow, while there is a strategy available in which Karnataka's first option can be sustained. The paper shows that the game-theoretic-based techniques can solve real-world disputes and that too as complex as water sharing.

1 Introduction

Conflicts have been part of humankind, since there has been group formation. There are different ideologies involved in any group, and to reach a final consensus, rigorous discussions occur. When these discussions do not reach any final consensus, conflicts arise [27]. Water is one of the most basic and essential needs for all living organisms, and humans are no exceptions. History showed that various civilizations like Mesopotamia, Sumerian, and others collapsed when the water supply ceased. This was believed due to the poor irrigation practices and poor management of this significant source [2]. Since water's importance is enormous, its unavailability has often been a conflict between the nations.

The crucial factors that have been seen to contribute to water problems are fast evolving demographic conditions, rapid urbanization, and industrialization in developing countries, disruptive technological changes, and increasing human expectations [4,5]. The parties involved in sharing river water (as riparian states) often tend to overestimate their share and highlight their contribution to the water management, while they do not recognize the positive contribution of their fellow riparians [8,45].

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The present Krishna river water-sharing dispute dates back to colonial times. The first agreement was done in 1892 between the princely state of Mysore (now Karnataka) and the Madras presidency (which is represented by Andhra Pradesh and Telangana as of today). Many agreements have led to the establishment of the Krishna water dispute tribunal (KWDT—a constitutional body under the Indian constitution). KWDT has made two judgements—one in 1973 and one in 2007. But still, the dissension among the riparian states exists as far as allocation (by KWDT) is concerned. Then, in 2014, Andhra Pradesh reorganized into Andhra Pradesh and Telangana. It gave a new dimension to this water-sharing arrangement. Telangana wants this water-sharing arrangement to be re-negotiated, focusing on this newly formed state's demands.

To obtain the lasting arrangements, the procedure adopted must be Fair and Equitable (F&E) as perceived by all the parties involved. These two concepts Fairness and Equity, instead of complementing each other, tend to oppose each other. More often than not, the results of fairness and need in any allocation problem are different. Fairness is subjective and varies from person to person, and hence, it is challenging to define. While 'Webster' clearly defines 'equity' as 'fairness, impartiality, justice', there is a seemingly endless ongoing debate about the rules used to determine when equity is obtained (Marsh and Schilling 1994). Again, Webster defines need as "something that is required to live or succeed or be happy". It can be seen that how vague this definition is if compared against fairness. Tools like the game theory can help provide the objective basis to fairness, but it cannot be done in case of need as only bounds can be imposed on it, but it can never be discussed under the principle of objectivity. Equitable allocation does not mean equal allocation. Equity here describes deservedness based on contribution. Rasinski [33] has described two components: Fairness and Equity (F&E): Proportionality and Egalitarianism. The former talks about deservedness and the second talks about that equals should be treated equally, and unequal should be treated accordingly. The most appropriate example to describe this is the present case study. The State of Telangana is the recently reorganized state in the Krishna River basin. It does not have as many hydraulic structures as compared to the other states. But being a riparian state, it deserves a fair share in the Krishna water. The entire water allocation process needs to be revisited, including Telangana as a new and deserving party to the table. To give it a level playing field in terms of resources allocation, only virgin runoff flow (the flow without considering any dam or hydraulic structures) should be considered. This will address the second aspect of egalitarianism.

To determine what constitutes a reasonable and equitable share for each watercourse state, International Law Association, Helsinki, [20], and United Nations Convention on Non-navigational Uses of International Watercourse [47] put together a non-exhaustive list of relevant factors that could provide a basis for estimating individual allocations (Article-VI) of UNCIW [47] that includes the factors like geography, hydrology, and hydrography and also the factors like socio-economic needs, population, etc. Now, since need can be created anytime and it is the main factor causing envy against the very principle of "Fairness and Equity". How can such factors form the basis of fairness? Cooperation is also key in solving the dispute. Alcalde-Unzu et al. [1] highlighted the need for cooperation among the player in any allocation scheme. Unless the players negotiate and are willing to resolve, it is challenging to resolve the conflict. Any resource allocation (especially indispensable and scarce like water) using the above factors (article VI of UNCIW) can never be sustainable in the long run. As can be seen in the water conflicts in India, the decision given by the tribunals has never been able to end the dissension among the states, and they start protesting over it.

The factors for F&E analysis taken in the present study ignore population. The population has been the major factor in resource allocation in various disputes. According to the population, the allocation will violate the principle of F&E. Since the population keeps increasing, water demand also increases, but the runoff contribution within the basin may not increase. Therefore, the need-based allocation will be equally allocated instead of equitable allocation. Here, a particular state can also increase its population by allowing migrants to settle in their state and claim more water. Allocation based on needs can never be a part of Fair and Equitable allocation. The factors chosen for F&E allocation strictly reflect the aspects discussed above.

Perc Matjaž [32] has rightly pointed out that humans/parties behave differently when they work as a group compared to working alone. Perc Matjaž [31] has also emphasized the need for cooperation in the social context and how it can lead to an equilibrium outcome. Suppose the parties involved in a conflict will come together and start negotiations. In that case, there are more chances of solving the parties going for arbitration alone through a mediator who is not part of the conflict.

Water allocation among the riparian states involves ethics, and it should address the internationally accepted principles of stability, fairness, and equity [29]. Hence, the present work's main objective is to develop a Fair and Equitable solution to the Krishna river water-sharing conflict. To address the 'Fairness', we have derived the F&E allocation, and to address the 'Equity', we have used the Metagame Analysis. F&E allocation ensures that the states deserve what they get, and Metagame Analysis ensures the transparency of the procedure used to solve the conflict analysis. Metagame Analysis is chosen as a tool for conflict resolution as all the players involved in the game know about the options presented by each player. It gives equal opportunity to all the players in terms of their representation in the game.

2 Concepts of Metagame Analysis

Metagame Analysis (MA) is a conflict analysis technique [15,18,19]. In the context of Water Resources, Hipel et al. [17] have shown that Metagame Analysis is a potent tool for the decision-makers involved in water resources. Kilgour et al. [22] have established the exact mathematical relationships among important game theory methods and have also endorsed the many inherent theoretical advantages of conflict analysis (CA)-based techniques.

Metagame Analysis [11,12,36], as part of the game theory-based conflict analysis methodology, has been used to incorporate realistically, but almost exclusively, qualitative, political, and social factors in the Krishna conflict model. Specifically, Metagame Analysis has been used to organize information about the political aspects of the Krishna conflict and, following this, to derive feasible equilibrium solutions to the conflict by stability analysis.

Following established nomenclature, the participants in a conflict model are called players and capable of actions, called options, which can impact other players in the conflict. The set of options that a player can take is called a strategy, and the situation where each player selects a strategy is called an outcome of the game. The analysis is complete with the demonstration of the stability of outcomes for every player. For example, if an outcome is stable for a given player, it does not benefit the player to move unilaterally to any other outcome by changing his strategy. Thus, a unilateral improvement (UI) exists for a given player when the player can move to a more preferred outcome by a unilateral change of his strategy. In this unilateral movement, the strategies of other players remain the same.

It is also entirely within the realm of possibility that a player may be deterred from taking a UI from a particular outcome, because, in response to this UI, if at all it is taken by the first player, the other contending players may take corresponding but credible actions that could result in an inferior position and, therefore, a less preferred outcome for the first player (player taking the UI). This deterrence from taking a UI induces the first player to see an element of stability in that particular outcome where a UI was initially considered. This type of stability is termed sequential stability.

Interestingly, a worse outcome may result in one or more players if all players change their strategies simultaneously from an unstable outcome for all players. In these particular situations, the expected movement from the unstable outcome for the desired improvement may become deterred rendering, thereby the earlier outcome as a stable for those players who would otherwise have ended up with worse/less preferred outcomes had they exercised their option of moving away from the current outcome. This form of stability in Conflict Analysis terminology, though not commonly encountered, is termed simultaneous stability or stability by simultaneity and is denoted by a slash (/) superimposed over the letter ‘U’.

Further continuing with the terminologies, an inescapable improvement from an outcome is said to exist for the player, A, if there exists a strategy for A that creates a more preferred outcome for him no matter what options the other players exercise. In contrast to inescapable improvement, an inescapable sanction exists against a possible UI for A if other players move from A’s UI to a preferable position from which no strategy change taken by A results in an outcome preferable to the original outcome by A. Player A is then deterred from taking the UI from its current outcome under consideration due to an inescapable sanction levied by the other players and the outcome is said to be symmetric meta-rational [12].

From the above literature, it is concluded that an outcome that is stable for all the players involved, indeed a stable solution for the Metagame. Such an outcome is called an equilibrium outcome and constitutes a possible resolution to the conflict [28].

Howard [18] defined several situations which determine the membership of an outcome in the set, S_A, of stable outcomes for player A as a basis for MA. Figure 1 explains the Metagame Analysis steps and shows an equilibrium outcome only if the outcome is stable for all the players involved. Each unilateral improvement (UI) should also result in the other players’ stable outcome to obtain the equilibrium outcome.

In MA, if there are four options, then there will be $2^4 = 16$ possible outcomes. But among this, not all the outcome are feasible. Fraser and Hipel [12] suggested the standard outcome removal method to eliminate the infeasible outcome.

Method 1: The method identifies outcomes that select mutually exclusive options for a given player and, therefore, are logically infeasible.

Method 2: The method identifies those preferentially infeasible outcomes for a given player, because this player is not normally expected to select the implied strategy.

Method 3: This method is sequentially the last of the techniques used to effect outcome removal. The method targets outcomes that are logically infeasible between players. Examples include outcomes of the form in which the total demand exceeds the total flow available.

These outcome removal methods considerably reduce the computation and are employed in the Metagame Analysis section.

3 Study area and data

The Krishna Basin consists of four riparian states (after the reorganization of Andhra Pradesh in 2014 into Andhra Pradesh and Telangana), as shown in Fig. 2. The catchment spreads between 73° 17′–81° 9′ East longitudes and 13° 10′–19° 22′ North latitudes. The Krishna basin covers a total area of 2,58,948 km^2. A significant portion (∼75%) of the basin is agricultural land, and ∼4% water bodies cover 4% of the basin. The

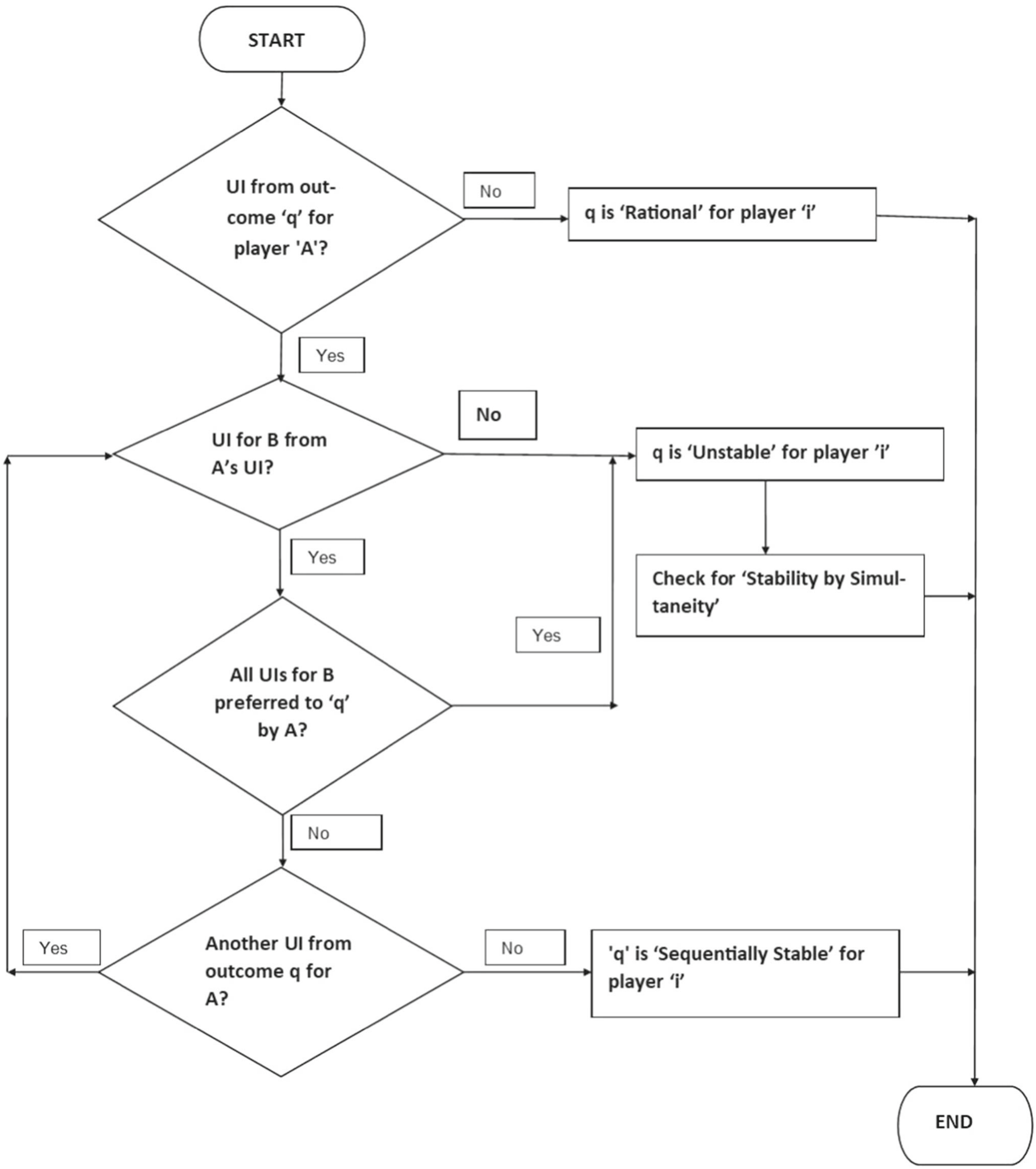

Fig. 1 A flowchart explaining the stability analysis between players A and B

Fig. 2 Krishna Basin consisting of four riparian states involved in the Metagame Analysis

catchment area of the Krishna river basin along with all the riparian states and the newly formed Telangana (after its division from the erstwhile Andhra Pradesh) is also shown Fig. 2. Maharashtra and Karnataka states are the upper riparian states, whereas Telangana and Andhra Pradesh are the lower riparian states. Maharashtra being the upper riparian state, can control the downstream flow towards the lower riparian states. There is delta formation when the river deposits all its sediments in Andhra Pradesh before joining the Bay of Bengal.

Aforementioned, factors considered for F&E distribution in the present study are drainage area of each state in the basin (F1), cultivable area (F2), and virgin runoff contribution of each state is shown in Table 1. The data are taken from India WRIS from the period 1973 to 2015 and KWDT (1973).

4 Results

Section 4.1 shows the derivation of Fair and Equitable (F&E) allocation based on the factors chosen in Table 1. The F&E allocation addresses the Fairness aspect. The F&E allocation is based on the fact that the total allocation cannot exceed 100%, and players will have to compromise with their highest ranked factor if the resource's total allocation exceeds 100%. Section 4.2 deals with the metagame formulation and the Metagame Analysis (MA), considering two different scenarios (before and after reorganizing the erstwhile Andhra Pradesh). The players have chosen options for the Metagame Analysis (options are chosen to maximize the share). F&E allocation is chosen as one of the options in the MA. Finally, the stability analysis has been carried out to obtain the final solution.

4.1 Derivation of Fair and Equitable (F&E) allocations

Preference vectors of the factors [23,30] are presented in Table 2 based on the factors chosen (Table 1) for F&E allocation. Bhattacharjee [6] has highlighted the concept of voting weights while negotiating over an issue. While deriving the F&E allocation in the present work, equal weights are assigned to each factor. Since 'fairness' is of prime importance and each state has a different preference of these factors, unequal weights will render the allocation unfair. In addition, unequal weights assignment will give undue power to one of the players, which is not suitable for the resolution. Each state will now rank the factor in which its contribution is maximum. The ranking of the states is given in Table 2.

Table 1 Contribution of each player for the calculation of F&E allocation

State	Drainage area (F1) (%)	Cultivable area (F2) (%)	Virgin runoff (F3) (%)
Maharashtra	26.79	21	33
Karnataka	43.85	48	39
Andhra Pradesh	20.11	12	11
Telangana	9.25	19	17

Table 2 Preference vector of each player based on their level of contribution

State	Rank 1 Factor/percentage	Rank 2 Factor/percentage	Rank 3 Factor/percentage
Maharashtra	F3/33	F1/26.79	F2/21
Karnataka	F2/48	F1/43.85	F3/39
Andhra Pradesh	F1/20.11	F2/12	F3/11
Telangana	F2/19	F3/17	F1/9.25

Table 3 Cooperative negotiation allocation based on the assumption that the resource's cumulative allocation cannot exceed 100%

Rank 1 sum	$(33 + 48 + 20.11 + 19) = 120.11$	>100%	Infeasible
1st Compromise (Rank1; Rank2)	$(26.895 + 45.925 + 16.055 + 18) = 106.875$	>100%	Infeasible
2nd Compromise (Rank1; Rank2; Rank3)	$(26.93 + 43.61 + 14.371 + 15.08) = 100$	= 100%	Feasible solution

Following the procedure outlined by Ravikumar and Khosa [35], if all the states insisted on allocations in proportion to the respective highest ranked factor, a total water requirement equal to (33+48+20.11+20)= 120.11% is implied. This, of course, is not possible, and the need for a compromise is recognized as such by each of the contending states. Thus, they will then consider their second-ranked factor. This will continue when the allocated resource is within 100%. This procedure is outlined in Table 3. Here, the process seeking fair share allocation in respect of Maharashtra, Karnataka, Telangana, and Andhra Pradesh converges to the point of agreement with allocations of total availability, respectively.

This gives the F&E allocation as listed below in Fig. 3. The total water available is 2275 TMC [23,24,30], and Fig. 3 shows the F&E allocation both in absolute and relative terms. Maharashtra gets the highest allocation, and Andhra Pradesh gets the lowest allocation as per the computations in Table 3. The derived F&E allocation is used in the Metagame Analysis as one of the possible solutions.

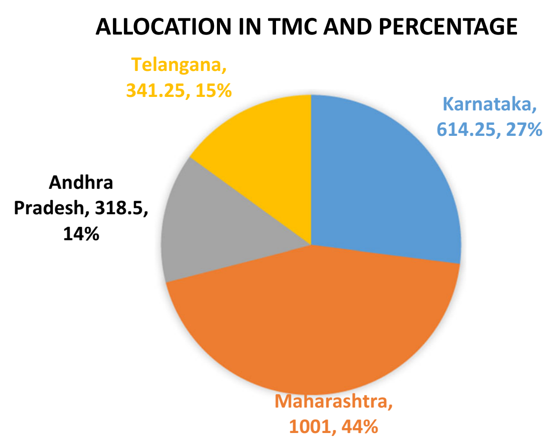

Fig. 3 F&E allocation based on each player's highest factor (both in TMC and percentage)

4.2 Metagame Analysis of Krishna river dispute

In the present framework, two scenarios are considered. First deals with the state of a dispute before the reorganization of Andhra Pradesh in 2014, including the environment as a player and without considering any hydraulic infrastructure projects. This is done to remove any inequality based on economics and technology. Branas-garza et al. [7] have highlighted that economic inequality has a detrimental effect on allocation. The second scenario deals with all the players, including various hydraulic projects, as well. The need for this scenario is there to address the 'Equity' again. The reorganization of erstwhile Andhra Pradesh into Andhra Pradesh and Telangana should not compromise the newly formed state's right as a rightful player in the Metagame Analysis.

Options have been formulated for all the players [23,24,30]. The ranking of option and proper choices is crucial, and it affects the solution drastically. Therefore, the state must formulate judiciously. For example, if all the states will go for excessive demands, there may not be any solution as the demands exceeding the

Table 4 Four players, namely Karnataka, Maharashtra, Andhra Pradesh, and environment, and correspondingly, nine options are proposed

Players	Options under scenario I	Options under scenario II
Karnataka	1. Fair and Equitable allocation (1001 TMC) 2. Allocation of 1430 TMC of water annually to meet the irrigation requirements	1. Fair and Equitable allocation (1001 TMC) 2. Store water up to the level of 524.256 m in the Almatti Dam instead of 519.0 m 3. Allocation of 1430 TMC of water annually to meet the irrigation requirements
Maharashtra	1. Fair and Equitable allocation (614.25 TMC) 2. Allocation of 828.8 TMC of water annually to meet the irrigation requirements	1. Fair and Equitable allocation (614.25 TMC) 2. Maharashtra to divert about 97 TMC for Koyna Hydel Project (out of the Basin Transfer) 3. Allocation of 828.8 TMC of water annually to meet the irrigation requirements
Andhra Pradesh	1. Fair and Equitable allocation (659.75 TMC) 2. Allocation of 1594 TMC of water annually to meet the irrigation requirements 3. Protection of annual utilization of 214 TMC based on Prior appropriation doctrine for the Krishna Delta system	1. Fair and Equitable allocation (318.5 TMC) 2. Protection of annual utilization of 214 TMC based on Prior appropriation doctrine for the Krishna Delta system 3. Allocation of 1594 TMC of water annually to meet the irrigation requirements
Environment	1. F&E allocations for all the states when the required E-flow is released 2. River water quality constraints for the protection of downstream flora and fauna	1. F&E allocations for all the states when the required E-flow is released 2. River water quality constraints for the protection of downstream flora and fauna
Telangana	–	1. Fair and Equitable allocation (341.5 TMC) 2. Allocation of 318.5 TMC of water annually to meet the irrigation requirements 3. Surplus flows from the upstream areas (excess flows than normal average)

total flows is infeasible. Therefore, there should be some optimum value of demands, such that it should fit the total flow criterion. These allocations do not include return flow additions available to downstream areas upon irrigation and other utilizations (in the form of the water usage from the hydraulic structures) in the basin's upstream regions. The options in the MA are based on what these players demand. These demands are taken from the KWDT-1, and KWDT-2 report and the states themselves have made these demands depending upon their requirements. One of the options is F&E distributions, which have been derived for all the parties involved.

Metagame formulation
As discussed in Sect. 4.1, a total of 9 (14) options are proposed (Table 4) for four (five) players, namely Karnataka, Maharashtra, Andhra Pradesh, and Environment (Telangana) under the scenario I (II). These include two options each for Karnataka, Maharashtra, Environment, and three options for Andhra Pradesh's states. Following Hipel and Fraser [14], Fraser and Hipel [11] and Bergstrom and Godfrey-Smith [3], an outcome—selected strategies of all players considered together—may be expressed in terms of a binary code where "1" indicates a chosen option for a player, while a "0" denotes a rejected option.

Outcomes and infeasible outcome removal
The total number of outcomes possible under scenarios I and II are $2^9 = 512$ ($2^{14} = 16384$). However, all the outcomes are not feasible due to the present situation and because some are logically infeasible. For, e.g., outcomes like (- - , - -, - - -, 0 0) are not feasible. Hence, we have employed standard outcome removal methods [12], as discussed in Sect. 2.

Metagame Analysis for scenario I
After removing the infeasible outcome, a preference vector is formed by each player who ranks the options that suit each player's best interest. The players have

arranged options according to their preferences, i.e., the order in which their share is maximized (Table 5). The last column in Table 5 reports the decimalized value of the preference vector.

Decimalized value is a succinct representation of the vector. Vector (1, 0, 1, 0, 1, 0, 1, 1, 1) can be decimalized as: $1*2^0+0*2^1+1*2^2+0*2^3*1*2^4+0*2^5+1*2^6+1*2^7+1*2^8 = 469$. This combination helps in increasing the computational efficiency and saves data requirements. All the options ranked in the preference vector to maximize the share. All the states have made gross crop requirement as their first options as it maximizes their share. The environment has placed F&E as its choice as it entails the release of the required E-Flows. The set of options (strategy) decimalized for the sake of convenience (and a reduction in storage in case of computer algorithm-based analysis). The stability analysis performed in the same manner as is shown in the Chicken Conflict example, Bergstrom and Godfrey-Smith [3]. The complete table of stability analysis is presented in Table 6.

Final solution is an outcome no. 454, 458, and 469.

Metagame Analysis for scenario II

This scenario considers the newly divided state, i.e., Telangana as the new player in the MA. Each player forms the preference vector (after the removal of the infeasible outcome, as discussed in Sect. 2) as per the ranking, which maximizes each player's share. Table 7 shows the preference vector as prepared for scenario II.

The stability analysis for scenario II has been worked in the same manner as in scenario I, and the equilibrium solution comes out to be 15067 (which once again includes F&E). For brevity purposes, stability analysis for the second scenario has been included in the supplementary section (Table S1). This completes the Metagame Analysis, and all the scenarios have at least one solution as F&E allocation.

5 Discussion

The present work is divided into two sections. The first section (Sect. 4.1) includes the calculation of F&E allocation for each state. The second part deals with the Metagame Analysis before and after the reorganization of Andhra Pradesh. The erstwhile Andhra Pradesh reorganized into new Andhra Pradesh and Telangana in June 2014. This has led to the emergence of a new player in this conflict. Earlier, some hydraulic structures projects were the parts of undivided Andhra Pradesh, and now, they lie entirely in one of the states (almost all in Andhra Pradesh). This has raised further contentions in this matter as the claim and allegations of Telangana are that Andhra Pradesh intentionally devoid Telangana of various projects meant for irrigation in their area. Indeed, these projects need to be appropriated as well between these two states.

Table 5 Preference vector and its decimalized value for scenario I (players before the reorganization of Andhra Pradesh)

S. No.	Karnataka		Maharashtra		Andhra Pradesh			Environment		Decimalised value
1	1	0	1	0	1	0	1	1	1	469
2	1	0	1	0	1	0	0	1	1	405
3	1	0	0	1	1	0	0	1	1	409
4	1	0	0	1	0	0	1	1	1	457
5	0	1	1	0	0	0	1	1	1	454
6	0	1	0	1	0	0	1	1	1	458
7	1	0	1	0	0	0	1	1	1	453

Table 6 Stability analysis for scenario I

Column number		1	2	3	4	5	6	7
Player	Overall stability	**E**	**E**	**E**	**X**	**X**	**X**	**X**
Karnataka	Stability	R	R	**R**	U	U	U	R
	Preference vector	454	458	469	405	453	409	457
	UIs					454		458
Maharashtra	Stability	R	R	R	R	R	U	U
	Preference vector	457	409	458	469	405	453	454
	UIs						457	
Andhra Pradesh	Stability	R	U	R	U	U	R	R
	Preference vector	469	405	409	453	457	454	458
	UIs		469		405 469	453		
Environment	Stability	R	R	R	R	R	R	R
	Preference vector	469	405	453	409	457	454	458
	UIs							

Table 7 Preference vector for scenario II

S. No.	Karnataka			Maharashtra			Andhra Pradesh			Telangana			Environment	
1	1	0	0	1	1	0	1	1	0	1	0	1	1	1
2	1	0	0	1	1	0	1	1	0	1	0	0	1	1
3	1	0	0	1	1	0	1	1	0	0	1	1	1	1
4	1	0	0	1	1	0	1	0	0	1	0	1	1	1
5	1	0	0	1	1	0	1	0	0	1	0	0	1	1
6	1	0	0	1	1	0	1	0	0	0	1	1	1	1
7	1	0	0	1	0	0	1	1	0	1	0	1	1	1
8	1	0	0	1	0	0	1	1	0	1	0	0	1	1
9	1	0	0	1	0	0	1	1	0	0	1	1	1	1
10	1	0	0	1	0	0	1	0	0	1	0	1	1	1
11	1	0	0	1	0	0	1	0	0	1	0	0	1	1
12	1	0	0	1	0	0	1	0	0	0	1	1	1	1
13	1	1	0	1	1	0	1	1	0	1	0	1	1	1
14	1	1	0	1	1	0	1	1	0	1	0	0	1	1
15	1	1	0	1	1	0	1	1	0	0	1	1	1	1
16	1	1	0	1	1	0	1	0	0	1	0	1	1	1
17	1	1	0	1	1	0	1	0	0	1	0	0	1	1
18	1	1	0	1	1	0	1	0	0	0	1	1	1	1
19	1	1	0	1	0	0	1	1	0	1	0	1	1	1
20	1	1	0	1	0	0	1	1	0	1	0	0	1	1
21	1	1	0	1	0	0	1	1	0	0	1	1	1	1
22	1	1	0	1	0	0	1	0	0	1	0	1	1	1
23	1	1	0	1	0	0	1	0	0	1	0	0	1	1
24	1	1	0	1	0	0	1	0	0	0	1	1	1	1

Nevertheless, unlike any automobile plant, these projects are various dams, canals, and barrages, which cannot be transferred. The possible solution is the compensation in monetary terms (or perhaps in a fixed amount of agricultural yield as an agricultural resource is limited in Telangana). This will benefit both the states as Andhra Pradesh have a productive delta area with high yield and high revenues. Therefore, Andhra Pradesh can give compensation in kind.

In Sect. 4.1, we derived F&E allocation based on each player's actual contributions to the resource. In these factors, the population is not considered a valid contribution factor as it does not contribute to the resource. Similarly, surface runoff is chosen, as there lies uncertainty concerning groundwater estimation. Only virgin flow is taken to remove the bias because of technical backwardness avoiding hydraulic structure like the dam. Inclusion of these would have led to Telangana discrimination, as it is a new state with poor infrastructure. The highest use of the resource is allocated to agriculture [37]; hence, the gross cropped area is used as the third factor. Finally, F& E contribution is worked by giving all these factors equal weightage and imposing the condition that the total allocated resource is 100%. If all the states chose their rank 1 factor, then the total resource requirement goes beyond 100%, which is infeasible. Thus, they will then consider their second-ranked factor as well as a level of compromise. The average of Rank1 and Rank2 factors is taken, and the sum is obtained. Even this is greater than 100%. This share also cannot be allocated as the maximum limit of the resource is 100%. Hence, as another level of compromise, Rank3 factors are also taken and Rank1 and Rank 2 factors. The compromised sum comes out to be exactly 100%. Hence, this is taken as the final compromised F&E allocation. This combination considers the maximum contribution of each player, but at the same time restricts the total allocation to 100%. Thus, F&E share allocates to each state is Andhra Pradesh (14%), Telangana (15%), Maharashtra (27%), and Karnataka (44%). The concept's beauty is that it is rational, and the states are working it out themselves.

After deriving the F&E allocations, a Metagame Analysis for the two scenarios was conducted in Sect. 4.2 using F&E allocations. As seen above, F&E allocations are at least one of the solution in all the scenarios. In scenario I, the four players included are erstwhile Andhra Pradesh, Maharashtra, Karnataka, and environment. scenario I also excludes any anthropogenic influence (dams and various projects), because obviously, the developed states can easily invest in these projects, whereas, for poor states, these investments are difficult. This will ensure procedural justice.

Reorganization of erstwhile Andhra Pradesh into Telangana and Andhra Pradesh took place in 2014. Since the present framework incorporates equitable treatment, the second scenario considered with all the possible players. Scenario II in itself includes the MA between Andhra Pradesh, and Telangana as a two-player game. It has not been included separately, even though the state's reorganization is an issue between Andhra Pradesh and Telangana. For the fairness and equitable treatment of the game, it is essential that all the player must come together and table their options in front of each other. This will require the game to include all the player instead of only two players, i.e., Andhra Pradesh and Telangana. This maintains the transparency in the Metagame Analysis. This is also very essential for conflict resolution.

The ordering of the options, i.e., preference vectors, is an essential factor in deciding the equilibrium analysis. In Metagame, all the players know the preference vectors of all the other players. In a real-world game situation, this is not generally true, but for a dispute like this, where the dissension has become the part of the argument, any covert motives will only increase the problems. Therefore, Metagame Analysis is better suited to the problem like these. Here, all the players know every possible demand of the other players, and hence, they can table their demands in the like manner. Hence, if any game considering all these demands (factors) is analyzed and it results in any final solution, it will indeed be an equilibrium solution, and all the players will surely accept it, because it is the players themselves who have arrived at this solution by tabling their respective options.

From Table 6, it is seen that some of these outcomes, expressed in terms of their decimal equivalents in the preference vector, have an accompanying unilateral improvement (UI). As the label suggests, a UI is a more preferred outcome to which a particular player can move by a unilateral change of strategy. In contrast, other players' strategies remain the same. Such a unilateral movement can occur at each stage of the game for a given player if that improvement is possible. For some options, there is no UI, and hence, it is automatically stable for that player. Finally, the outcome that is stable for all the players becomes the solution to the Metagame Analysis. For example, consider outcome 453 for the state of Karnataka; it has a single UI from 453 to 454. As can be seen from the table that all the other players do not have any UI from Karnataka's UI. Therefore, 454 is rationally stable for all the other players. Naturally, then Karnataka will not opt for outcome 453 as a more favorable outcome is available to it.

Similarly, the entire stability analysis can be completed. Now, as it can be seen from the table that equilibrium outcomes are 454, 458, and 469. The results show that excessive demands may harm the cause if it violates the total flow availability (as can be seen in Andhra Pradesh). Outcomes 469 is the F&E outcome in which all the state are going for cooperated negotiations on the basic options which maximize their share. Outcomes 454 and 458 are those outcomes in which Karnataka is benefitted as it is getting its first option share. Andhra Pradesh's demand cannot be accommodated in any strategy as it exceeds the total flow, while there is a strategy available in which Karnataka's first option can be sustained.

Similarly, the second scenario has been worked out. The equilibrium solution comes out 15067, which once again includes F&E. This reiterates that a solution obtained on a cooperated basis works better and has a better chance of success. Through the Metagame Analysis, in both scenarios, at least one solution as F&E is obtained.

Making excessive demands (more than the available resource) will only work against a player. As seen with Andhra Pradesh's case, its excessive crop water demands have made any strategy including this option infeasible (as it violates the total flow availability in average flow conditions). The demand to F&E ratio for Telangana is more than 3 (KWDT-1,2), whereas there are scenarios in which crop demand for Maharashtra and Karnataka has been included as these strategies are feasible. Therefore, this clearly shows how the ranking of options can affect the outcome. The environment has also been considered as a player in the analysis, since both of its option can be met simultaneously, so for simplicity, its preference vector has been taken as $[1, 1]^{\mathrm{T}}$. Since the environment was not the player in the F&E allocation, it agrees to F&E if the states release the required environmental flow. Since ample return flow is available from the agriculture and states also understands the need for instream requirements, so it has been assumed that this condition will always be met. Stability analysis further supports the F&E allocation principle and proves its efficacy.

6 Conclusion and scope of future work

This study explores the potential of game-theoretic techniques to solve the real-world dispute (as contentious as a water-sharing treaty). The work has derived the F&E allocation to address the Fairness part and then used Metagame Analysis to address the transparency of the procedure, which is very important as far as conflict resolution is concerned. Metagame Analysis has been worked out under two different scenarios: one before Andhra Pradesh's reorganization and the second one after Andhra Pradesh's reorganization in 2014. F&E results show that Karnataka gets the maximum share (44%), and Andhra Pradesh gets the least share. In the first scenario, equilibrium outcomes are 454, 458, and 469, and in scenario two, the equilibrium outcome is 15067. Metagame Analysis shows that F&E allocation is part of the equilibrium outcome in scenario one, and F&E allocation is the only solution in the case of the second scenario. This validates the use of F&E allocation as the offered solution. Though exciting results were obtained, but there is scope for further improvement. For instance

(i) The study has ignored the possibility of a coalition between two or more players in the game. Coalition Analysis, as a conflict analysis methodology, may be a recommended future addition that studies how a game would develop these coalition partners plan and execute joint strategies.

(ii) The operating reservoir policy for each reservoir can be made, so that the time and the quantity of water to be released can be found.

(iii) Hypergame Analysis in which the various parties involved are unaware of the option chosen by them can be employed to test the efficacy of the F&E allocation further.

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Declarations

Conflict of interest The authors declare that they have no conflict of interest.

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