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Graph Model Conflict Resolution Approach for Jordan River Basin Dispute

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Authors' contributions

This work was carried out in collaboration between both authors. Both authors read and approved the final manuscript

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ABSTRACT

This paper aims to establish a practical conflict resolution mechanism and applies it to solve the strategic long-term dispute for Jordan River Basin. The paper starts with a brief history of the Jordan River Basin dispute. The paper then presents a game theoretic approach based on the Graph Model technique for conflict resolution, to investigate the Jordan River Basin dispute, considering the complex socio-political aspects involved. The proposed model of defines the courses of actions available to all the involved stakeholders along with their preferences among them. Accordingly, the model applies stability and sensitivity analyses to propose an optimum resolution to the conflict and to examine the sensitivity of such resolution to the uncertainty in stakeholders' preferences. In this study, three scenarios were investigated with different coalition possibilities among different countries, as follow: (i) Syria, Lebanon, Israel, and Jordan; (ii) Lebanon, Jordan, Israel, and Palestine; and (iii) Jordan, Israel, and Palestine. The results suggest that the best resolution for all parties is through combined water and peace treaties. The results also indicate that a peace treaty between Israel and Palestine is the best resolution to the conflicts. The application of the Graph model in this paper shows its practicality and ability to provide each decision maker with a simulation environment to examine the actions and counteractions that take place during the negotiation among the different parties.

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1. INTRODUCTION

Many regions around the world deal with shortages of water. However, some areas deal more with conflicts over poor and insufficient water supplies and disputes over shared water supplies. In regions where countries compete for access to water, the relations between the countries are to be expected unstable. In regions where water supply is limited, fight and combat sometimes appears to be the only way to resolve the problem. It is estimated that there are 1,250 square kilometres of freshwater remaining in the world's semi-arid and arid regions and this supply is not evenly distributed among two or more countries sharing the same water source. Severe water scarcity is strongest in the Middle East, especially in the Jordan and Nile River Basins. The need for water in these regions is essential for food production in farming.

Water systems usually originate and arise in one country and pass through others before reaching the sea or oceans. The rivers and lakes that come off these larger water systems are typically shared by more than one country. The countries where water systems originate try and gain the most control over the water. This is the case along river systems like the Jordan River, where the river originates in Lebanon and passes through Jordan, Syria, and Israel. The river plays a very important role in the agriculture and economic development of these countries. In such a water conflict, the countries are involved as decision makers (DMs) and each can make choices unilaterally. The combined choices of all players (DM) together determine a resolution state or a possible outcome of the conflict. However, instead of unilaterally moving, the DMs may also choose to cooperate or form coalitions. In such environment, Game theory techniques such as the Graph Model for Conflict Resolution, offers a useful and precise language for representing and analysing such disputes.

In the water domain, many researchers have attempted to examine conflicts in a game-theoretic framework [1]. Rogers [2] studied the international conflict over flooding of Ganges and Brahmapurta rivers between India and Pakistan. Dufounaud [3] used Metagame theory for the negotiations over the Columbia and lower Makong river basin. Becker and Easter [4] developed a dominant strategy selection for conflict over water diversions from the Great Lakes between Canada and USA. Obeidie et al. [5] provided a systematic non-cooperative study of a conflict over the proposed export of bulk water from Canada using the graph model. Raquel et al. [6] developed cooperative solution concept for weighing the economic benefits versus negative environmental impact from agriculture production. Fisvold and Caswell [7] implemented cooperative solution concepts for deriving policy lessons useful for US-Mexico water negotiations and institutions. Supalla et al. [8] used second price sequential action method for determining the share and prices of water in the Platte River in the USA (Colorado, Nebraska, and Wyoming). Kucukmehmtoglu and Guldmen [9] developed a cooperative solution concept for developing stable water allocations among the countries riparian to Euphrates and Tigris between Iraq, Syria, and Turkey. Wu and Whittington [10] developed a cooperative solution concept for establishing baseline conditions for incentive-compatible cooperation regimes in the Nile basin among Burundi, Congo, Egypt, Eriteria, Ethipoia, Kenya, Rwanda, Sudan, Tanzania, and Uganda. Madani and Hipel [11] used the Graph Model for Conflict resolution to provide insight into Jordan River Basin conflict between Syria, Lebanon, Jordan, Israel. Sheikhmohammady and Madani [12,13] used fallback bargaining, social choice rules, bankruptcy procedures, and descriptive modeling techniques for providing the most likely outcomes of the Caspian Sea dispute among Azerbajian, Iran, Kazakhstan, Russia, and Turkmenistan. Elimam et al. [14] studied the non-cooperative behaviour of the decision makers involved in the Nile river conflict and determined the most likely outcomes of the conflict using the Graph model.

The objective of this paper is to introduce the graph model for conflict resolution [15] and apply it to analyse the different possible coalitions among the countries involved in the Jordan River Basin. To facilitate the analysis, a decision support system, called "conGres" developed based on the early work of [16], has been used to implement the graph model approach for the Jordan River conflict. The model helps to select the optimum resolution, considering the uncertainty in decision makers' preferences.

2. ANALYZING THE JORDAN RIVER BASIN CONFLICT

The area of the Jordan River Basin, including parts of Lebanon, Syria, Israel, Jordan, and the occupied West Bank (represented by Palestine), is primarily an arid region. The Jordan River basin has an area of 18,300 square kilometres (see Fig. 1). The river originates and begins in Lebanon and has a total average flow of 1,200 million cubic meters per year. This river system consists of the Jordan and Yarmuk River, which flows from Syria. With the low precipitation and arid climate in this region, water has become the most valuable resource. Most countries in the Jordan River Basin are among some of the poorest countries in the region. Groundwater aquifers are the main source for water supplies to the countries that rely on the Jordan River. The use of water varies throughout the region. Israel uses the greatest amount of water and next in line is Jordan. The occupied West bank (Palestine) uses the smallest amount. The daily amount of water per person in the Jordan River Basin is the lowest in the world [17].

Demand on water in the region has been increasing faster than the region's water supply. Also previous records show that the options of the DMs have not changed considerably since the foundation of Israel. This conflict has been existed from earlier times and several temporary rulings have been experienced during this relatively long time period.

2.1 Decision Support System

To analyse the Jordan River Conflict, a DSS, called "**con**flict **G**ame for dispute **res**olution, **conGres**", developed based on the early work of [16,18] has been customized for this conflict. As shown on the right side of Fig. 2, the DSS integrates three techniques: (1) the elimination method [19] as a multiple-criteria decision analysis technique used to shortlist decision alternatives; (2) the graph model for conflict resolution [15] to simulate the actions and counteractions that take place during negotiation; and (3) the information gap (info-gap) theory [20] to address the uncertainty associated with the stakeholders' preferences. The following steps demonstrate the implementation of the DSS for Jordan River Basin case study, with the goal of identifying the best resolution. Fig. 3 shows the main interface of the conGres DSS.

2.1.1 Step 1: Define Stakeholder and their options

Five stakeholders (DMs) are involved in this conflict: Lebanon, Syria, Israel, Jordan, and Palestine. The mutually exclusive decision options available to each of the DMs are shown in Table 1. In addition to doing nothing, important options are: unilaterally increases own share of water extraction, holding a peace treaty, holding a water treaty, and doing a counteraction against another country that unilaterally increased its share. Considering a scenario with four key DM countries and their options (3 options Lebanon, 4 options for Jordan, 5 options for Israel, and two options for Palestine), the information was entered into the DSS (see Fig. 4), thus a total of 120 possible decision states were generated (3 × 4 × 5 ×2). These 120 possible solutions or decision states represent all possible combinations of the stakeholders' options.

2.1.2 Step 2: Shortlist feasible solutions

Given 120 decision states, it is important to recognize and eliminate any solution with infeasible combinations of options and then choose and focus on the most promising ones. The advantage of the elimination method provides the ability to eliminate some of the alternatives that do not meet stakeholder threshold values of acceptance. Based on different studies as suggested by [21,11], 113 decision states were eliminated (see Table 3). Only seven (7) feasible solutions were selected, therefore producing a short list of feasible alternatives (Fig. 5).

2.1.3 Step 3: Understanding stakeholders' preferences

Before applying the graph model for conflict resolution considering various coalition scenarios among the DMs, it is important to understand and model the stakeholders' preferences. The Preferences of DMs can be ordinal, where each DM ranks the decision states relative to each other, but is not able to specify their exact payoff values. Alternatively, the preferences can be cardinal, where each DM is able to quantify the payoffs of the different states. For the Jordan River Basin conflict, the payoff values are not available and therefore, ordinal preferences have been used. The preferences of each involved DM are discussed as follows:

Lebanon: Due to water shortage in the area, like other DMs, Lebanon likes to increase its withdrawal of the water if there is no opposition (counteraction) by downstream DMs. Thus, any decision, in which an increase in withdrawal will be countered by downstream parties is least desired by Lebanon. Being the upstream nation and having good access to water resources compared to other DMs, Lebanon is not interested in signing any water or peace treaty with downstream nations which limits their access of water from the Jordan River. It is assumed that Lebanon wants to sign a water treaty only if the other riparian Arab countries choose to sign water treaties with Israel, which may lead to bringing peace to the region.

Syria: Syria mostly prefers to increase its water share if there is no counteraction by downstream DMs. Syria prefers other parties not to increase their withdrawal and it prefers to take counteraction rather than to do nothing in case of a water withdrawal increase by another party. It is also believed that Syria is interested in signing a water treaty only if Jordan and Israel are both involved. Syria prefers a scenario where all parties are willing to sign a water treaty.

Jordan: Jordan is also mainly attracted in increasing its withdrawal from the river if there is no objection and least prefers any counteractions by others. Jordan does not like other parties to increase their withdrawal from River and is only interested in signing a treaty with all other parties. When share is increased by another country, Jordan prefers to react in terms of complaints, rather than military means. Jordan prefers to sign a treaty with Israel. However, it prefers that other countries to sign the water treaty when its right is protected.

Israel: Israel, like other DMs, wants to increase its withdrawal if there is no counteraction by downstream DMs. Israel would like to sign a treaty with other riparian countries and it does not want the other parties to increase their withdrawals from the Jordan River. In case of an increase in withdrawal by another country, Israel prefers to counteract, which has traditionally been in terms of military actions. It is believed that this country would like to have peace treaty with the Palestine.

Palestine: It is assumed that the Palestine prefers to have peace and therefore more access to water. Therefore, Palestine prefers to have peace treaty with Israel.

2.1.4 Step 4: Accounting for uncertain information

In this step, the uncertainties associated with ambiguity in stakeholder preferences are considered and its impact measured on the final resolution of the conflict. The DSS uses the info-gap theory [20] to furnish the user with the ability to consider such uncertainties. The info-gap method runs a systematic procedure for investigating the robustness of a decision under the uncertainty of the stakeholder preferences [22]. Info-gap modelling could be interpreted as a comprehensive approach to sensitivity analysis.

3. CONFLICT RESOLUTION UNDER COALITION SCENARIOS

In this study, the graph model [15] has been applied to the conflict. This comprehensive decision technology has been applied to a range of different conflicts, including local and international trade disputes. In a recent research [18], the graph model was used to resolve a construction conflict between a contractor and an owner.

The graph model mathematically describes how stakeholders (DMs) interact with one another in terms of negotiation moves and countermoves, based on their preferences. After specifying the stakeholders' preferences, the process examines the stability of the shortlisted solutions with respect to four main stability concepts: Nash (R); General Metarationality (GMR); Symmetric Metarationality (SMR); and Sequential Stability (SEQ), as described in Table 2. For mathematical definitions of the stability concepts, all information can be found in [15,23]. Each of the four stability concepts tests a solution from a different perspective. For instance, a decision state is considered Nash stable for one DM if the DM cannot find a more preferred state to move to. When a decision state is found to be stable for all the stakeholders, it represents an equilibrium situation, i.e. a decision state that has high potential of satisfying all parties.

In this study, the conflict resolution process has been applied under three scenarios with different coalition possibilities among the DMs: (1)

coalition among Lebanon, Jordan, Israel, and Palestine; (2) coalition among Jordan, Israel, and Palestine; and (3) coalition among Syria, Israel, Jordan, and Lebanon. The graph model process was applied to these scenarios separately aiming to obtain the robust and stable solution according to stakeholders' preferences.

3.1 Scenario One: Coalition between Lebanon, Jordan, Israel and Palestine

In this scenario, coalitions among four stakeholders are considered, Lebanon, Jordan, Israel, and Palestine. The first stakeholder (Lebanon) has four mutually exclusive decisions: Increase share, counteraction, water treaty, and do nothing. The second stakeholder (Jordan) has the same mutually exclusive decisions. The third stakeholder (Israel) has five mutually exclusive decisions: Increase share, counteraction, water treaty, peace treaty, and do nothing. The fourth stakeholder (Palestine) has two mutually exclusive decisions: peace treaty and do thing. All of these mutually exclusive decisions are explained in details in Table 1.

Specifying the stakeholders of four countries (Lebanon, Jordan, Israel, and Palestine) and their options results in a total of 120 possible "decision states" (3 × 2 × 4 × 5). The 120 possible solutions or decision states represent all possible combinations of the stakeholder options.

Based on different studies which are suggested by [21,11], 113 decision states were eliminated. Only seven (7) feasible solutions were selected, therefore producing a short list of feasible alternatives (Fig. 4). The shortlisted solution will be further examined. In this study, various stakeholder preferences on scale (0-100%) were considered, as shown in Table 4.

The shortlisted solutions obtained by the elimination method were further examined. The stakeholder preferences, based on [21], among the various decision states are as follow (decision preference set 1): Lebanon has 50% preference in a Water Treaty; Jordan has 50% preference in a Water Treaty; Israel has 30% preference in a Water treaty; and Palestine has a 100% preference in a Peace Treaty (see Fig. 5).

The results indicated that among the seven feasible solutions for the first stakeholder preferences, solution one (1) is the best solution with 18300 payoffs (see Table 3 and Fig. 6). The model finds all stability concepts (R, SEQ, GMR, and SMR) are in equilibrium status for the best solution. This implies that the peace treaty between Israel and Palestine and a Water treaty between Israel, Jordan, and Lebanon is a robust and stable solution.

Alternatively, the stakeholder preferences were changed among the various decision states are as follow (decision preference 2): Lebanon has 50% preference in a Water Treaty; Jordan has 100% preference in a Water Treaty; Israel has 100% preference in a Water treaty; and Palestine has a 100% preference in a Peace Treaty (see Fig. 7). Results indicated that solution (1) still the robust solution with payoff of 19500 (see Fig. 8).

Furthermore, when reducing the 120 solution to 20 solutions instead of seven (7) solutions and considering more solutions which includes increasing shares and counteraction, result still suggests the first options (water treaty, peace treaty) as the best solution (Fig. 9). The results suggest that the status quo scenario (Do nothing) has received the lowest payoff score and is not Nash (R) stable. However, the solution still less risky than increasing withdrawal by the upstream parties (Fig. 10).

The results are not stable (Equilibrium) when the parties increased share. All results are stable when decision makers choose the water and peace treaties. The option of do nothing is the least preferred with the lowest payoff among other options. However, the results suggest that the do nothing option is less risky than one nation may decide to increase its share. Therefore, it is more desirable that parties could find the best and stable solution and to have several attempts to reach the preferred equilibrium option.

Since stakeholders are not certain about their goals and preferences, because Jordan may not trust the Syria and Israel for this problem. Therefore, uncertainty analysis associated with stakeholder preferences was performed. Table 3 lists the percentages of the assumed uncertainty for each stockholder's preference values. The stakeholders are assigned a high value of +10% uncertainties to their preferences. Once the uncertainty level is specified, the DSS then performs a number of experiments (with 100 experiments). It then presents the results in the form of a histogram (see Fig. 6).

3.2 Scenario Two: Coalition between Jordan, Israel and Palestine

Specifying the stakeholders of four countries (Lebanon, Jordan, Israel, and Palestine) and their options results in a total of 40 possible "decision states" (2 × 4 × 5). The 40 possible solutions or decision states represent all possible combinations of the stakeholder options. They were shortlisted to seven (7) options as described in Figure but excluding Lebanon. Alternatively, the solutions were also reduced to 20 options to consider increasing share for different stakeholders. Interestingly, in both cases, the results suggest that solution one (1) is the best solution after considering the two different stakeholder preferences (0-100%). The best solution is stable with all stability concepts R, GMR, SMR, and SEQ. The results also shows that the do nothing or status quo solution received the lowest payoff values, but is more preferred than increasing withdrawal of water from one party.

3.3 Scenario Three: Coalition between Syria, Lebanon, Jordan, Israel

Specifying the stakeholders of four countries (Syria, Lebanon, Jordan, and Israel) and their options results in a total of 240 possible "decision states" (5 × 4 × 4 × 3). The 240 possible solutions or decision states represent all possible combinations of the stakeholder options. They were shortlisted to 7 solutions and allow consider increasing share and counteractions among stakeholders. The results still suggest that signing water treaty among parties is the best and stable solution. The best solution has achieved equilibrium four stability concepts of R, GMR, SMR, and SEQ. It is also concluded that do nothing solution is not a Nash stable solution, but still better than increase withdrawal and counteraction.

Table 1. Decision makers and their options [11]

Decision makers (DMs)	Options
Syria	▪ Increasing withdrawal from Jordan River System (Share Increasing) ▪ Counteraction against a country that increased its withdrawal ▪ Signing Water Treaty with other countries (Water Treaty) ▪ Nothing
Lebanon	▪ Increasing withdrawal from Jordan River System (Share Increasing) ▪ Signing Water Treaty with other countries (Water Treaty) ▪ Nothing
Jordan	▪ Increasing withdrawal from Jordan River System (Share Increasing) ▪ Counteraction against a country that increased its withdrawal ▪ Signing Water Treaty with other countries (Water Treaty) ▪ Nothing
Israel	▪ Increasing withdrawal from Jordan River System (Share Increasing) ▪ Counteraction against a country that increased its withdrawal ▪ Signing Water Treaty with other countries (Water Treaty) ▪ Signing a water treaty with the Palestinian Authority (Peace Treaty) ▪ Nothing
Palestine	▪ Signing a water treaty with the Palestinian Authority (Peace Treaty) ▪ Nothing

Table 2. Solution concept for conflict resolution

Solution concept	Description
Nash stability (R)	No other decisions bring a better payoff.
General metarationality (GMR)	If a better option is decided, opponent's counter-actions are safe.
Symmetric metarationality (SMR)	If a better option is decided, opponent's counter-actions are safe and not harmful to opponent.
Sequential stability (SEQ)	If a better option is decided, opponent's beneficial counter-actions are safe.

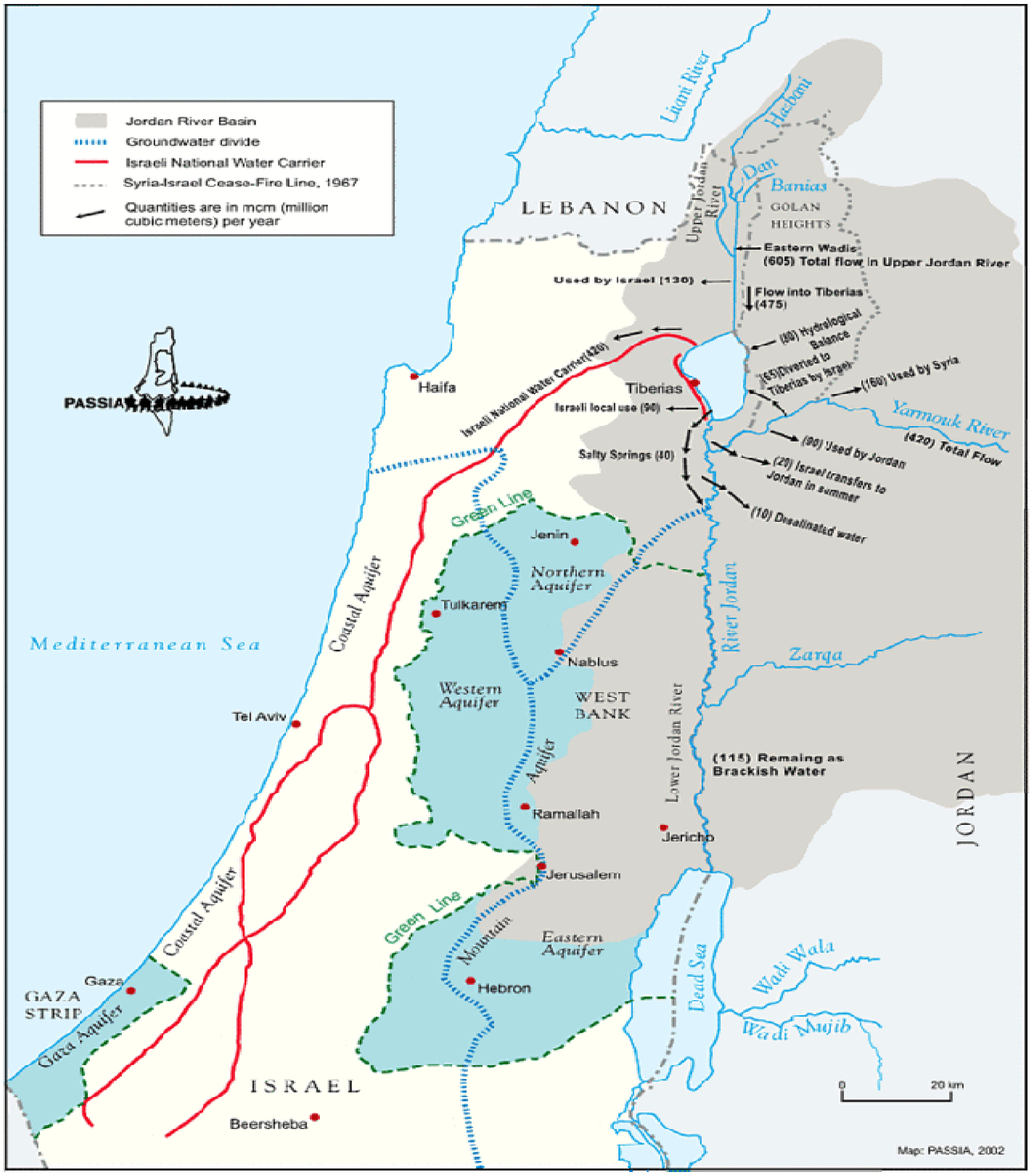


Fig. 1. Jordan River Basin (Adopted from [24])

Table 3. Preferences and best solution for coalition scenario 1, with decision preference set 1

Option	Lebanon payoff	Jordan payoff	Israel payoff	Palestine payoff	Scores	Best solution	Equilibria
1	W.treaty (50)	W. treaty (50)	W. treaty (30)	P. treaty (100)	18300	1st (best)	R, GMR, SMR, SEQ
4	W.treaty (0)	W. treaty (50)	W. treaty (30)	P. treaty (100)	17800	2nd	R, GMR, SMR, SEQ
5	W.treaty (50)	W. treaty (50)	W. treaty (30)	P. treaty (0)	17300	3rd	R, GMR, SMR, SEQ
2	W.treaty (0)	W. treaty (50)	W. treaty (30)	P. treaty (100)	16800	4th	GMR, SMR, SEQ
3	W.treaty (0)	W. treaty (50)	W. treaty (30)	P. treaty (0)	15800	5th	GMR, SMR, SEQ

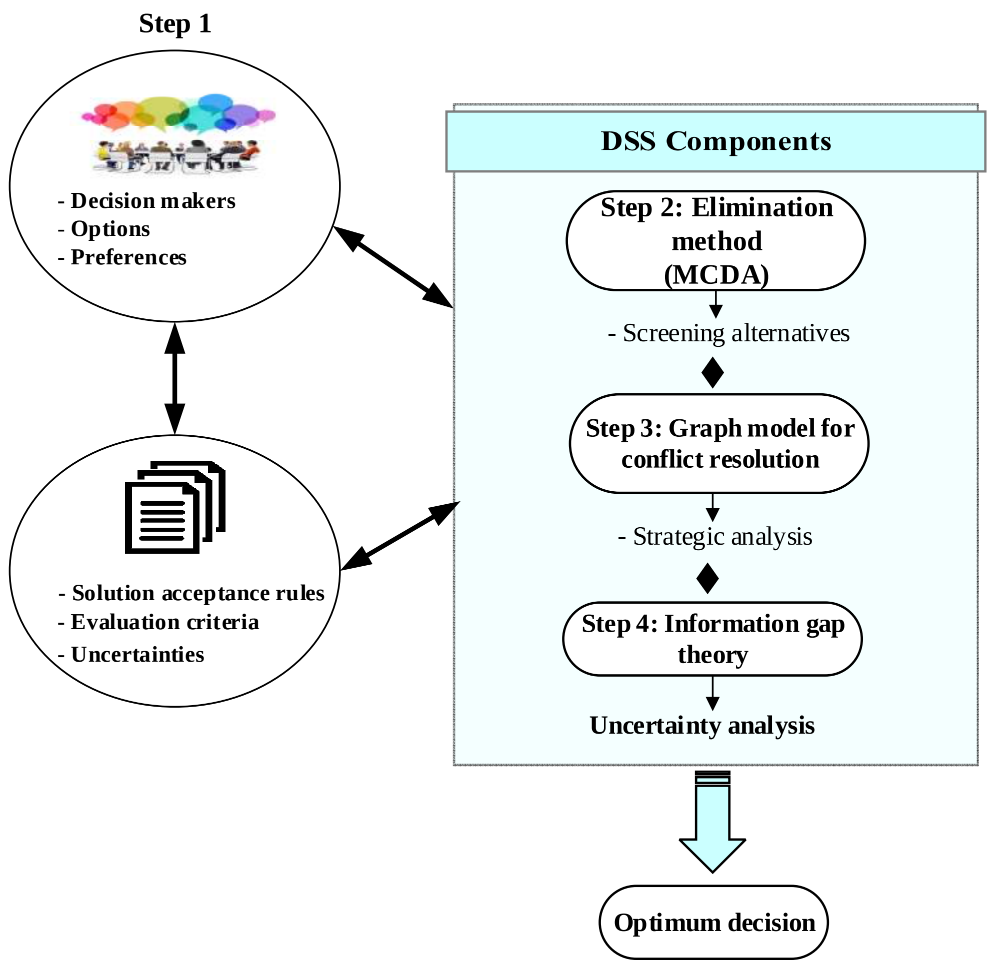


Fig. 2. Components of the decision support system (DDS) for water dispute problem

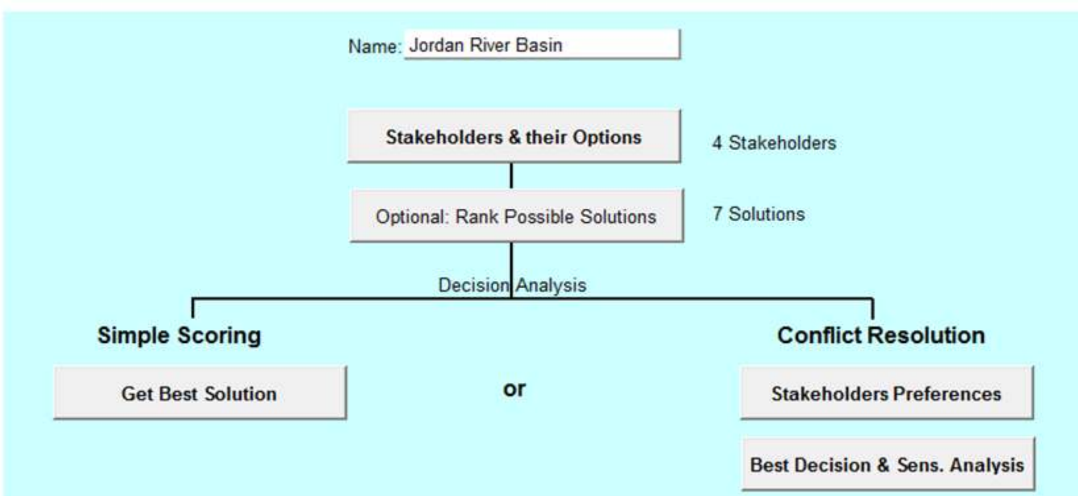
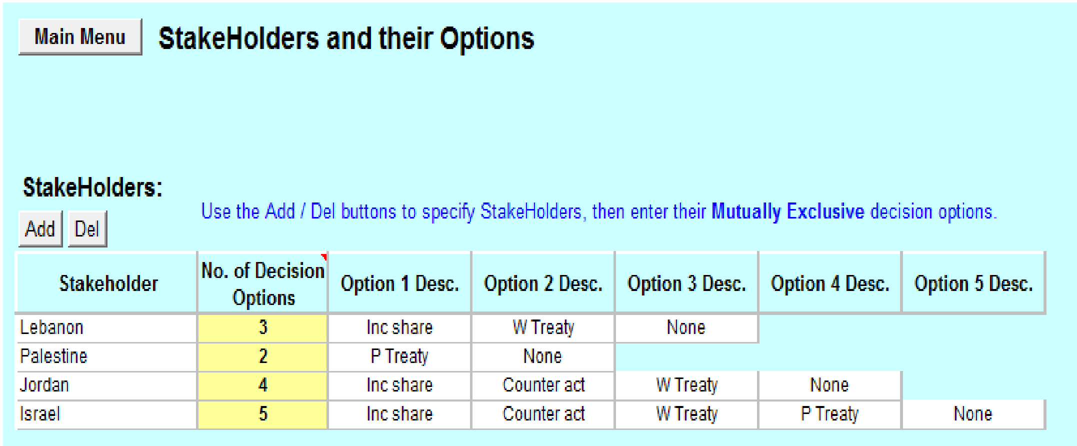
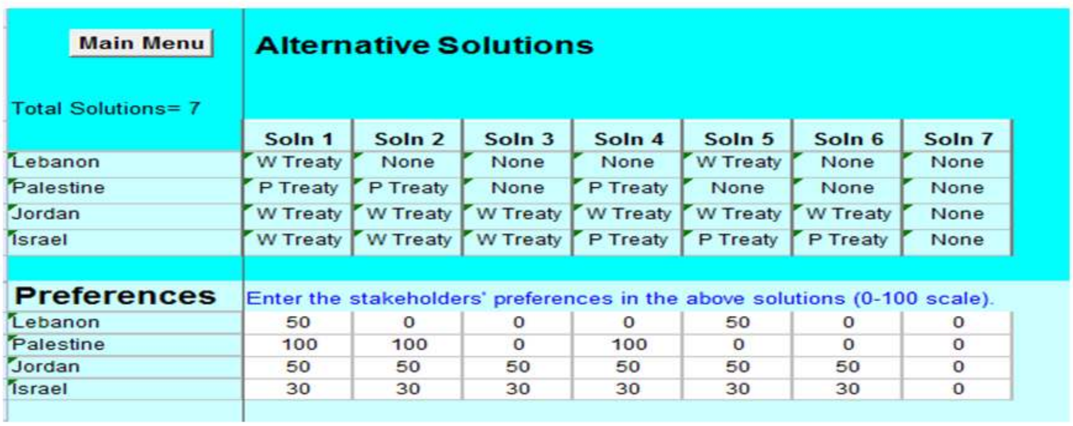


Fig. 3. Main interface for the "conGres" decision support system



Stakeholder	No. of Decision Options	Option 1 Desc.	Option 2 Desc.	Option 3 Desc.	Option 4 Desc.	Option 5 Desc.
Lebanon	3	Inc share	W Treaty	None		
Palestine	2	P Treaty	None			
Jordan	4	Inc share	Counter act	W Treaty	None	
Israel	5	Inc share	Counter act	W Treaty	P Treaty	None

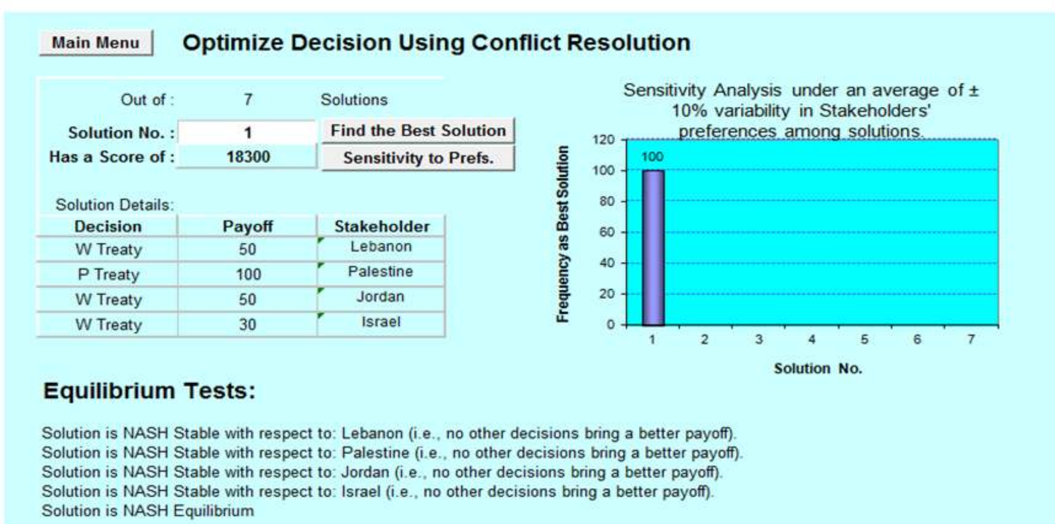
Fig. 4. Stakeholders and their options



	Soln 1	Soln 2	Soln 3	Soln 4	Soln 5	Soln 6	Soln 7
Lebanon	W Treaty	None	None	None	W Treaty	None	None
Palestine	P Treaty	P Treaty	None	P Treaty	None	None	None
Jordan	W Treaty	W Treaty	W Treaty	W Treaty	W Treaty	W Treaty	None
Israel	W Treaty	W Treaty	W Treaty	P Treaty	P Treaty	P Treaty	None

Lebanon	50	0	0	0	50	0	0
Palestine	100	100	0	100	0	0	0
Jordan	50	50	50	50	50	50	0
Israel	30	30	30	30	30	30	0

Fig. 5. Shortlisted solutions after elimination for coalition scenario 1, with stakeholders' preferences set 1



Decision	Payoff	Stakeholder
W Treaty	50	Lebanon
P Treaty	100	Palestine
W Treaty	50	Jordan
W Treaty	30	Israel

Fig. 6. Decision optimisation using conflict resolution

Main Menu

Alternative Solutions

Total Solutions= 7

Stakeholder	Soln 1	Soln 2	Soln 3	Soln 4	Soln 5	Soln 6	Soln 7
Lebanon	W Treaty	None	None	None	W Treaty	None	None
Palestine	P Treaty	P Treaty	None	P Treaty	None	None	None
Jordan	W Treaty	W Treaty	W Treaty	W Treaty	W Treaty	W Treaty	None
Israel	W Treaty	W Treaty	W Treaty	P Treaty	P Treaty	P Treaty	None

Preferences Enter the stakeholders' preferences in the above solutions (0-100 scale).

Preferences	Soln 1	Soln 2	Soln 3	Soln 4	Soln 5	Soln 6	Soln 7
Lebanon	50	0	0	0	50	0	0
Palestine	100	100	0	100	0	0	0
Jordan	100	100	100	0	100	100	0
Israel	100	100	100	100	100	100	0

Fig. 7. Shortlisted solutions after elimination for coalition scenario 1, with stakeholders' preferences set 2

Main Menu

Optimize Decision Using Conflict Resolution

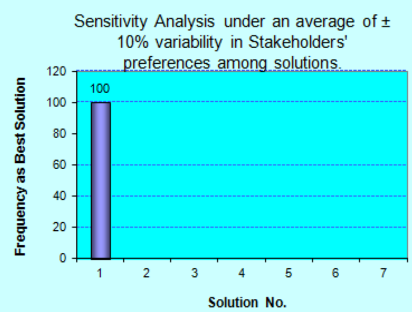
Out of : 7 Solutions

Solution No. : 1 — Find the Best Solution

Has a Score of : 19500 — Sensitivity to Prefs.

Solution Details:

Decision	Payoff	Stakeholder
W Treaty	50	Lebanon
P Treaty	100	Palestine
W Treaty	100	Jordan
W Treaty	100	Israel



Equilibrium Tests:

Solution is NASH Stable with respect to: Lebanon (i.e., no other decisions bring a better payoff).
Solution is NASH Stable with respect to: Palestine (i.e., no other decisions bring a better payoff).
Solution is NASH Stable with respect to: Jordan (i.e., no other decisions bring a better payoff).
Solution is NASH Stable with respect to: Israel (i.e., no other decisions bring a better payoff).
Solution is NASH Equilibrium

Fig. 8. Decision optimisation using conflict resolution with stakeholder preferences of 100% stakeholders preferences are assigned for Israel, Jordan, and Palestine

Main Menu

Alternative Solutions

Total Solutions= 20

	Soln 1	Soln 2	Soln 3	Soln 4	Soln 5	Soln 6	Soln 7	Soln 8	Soln 9	Soln 10
Lebanon	W Treaty	None	None	W Treaty	None	None	W Treaty	None	W Treaty	None
Palestine	P Treaty	P Treaty	None	P Treaty	P Treaty	P Treaty	None	None	P Treaty	P Treaty
Jordan	W Treaty	W Treaty	W Treaty	None	None	W Treaty	W Treaty	W Treaty	None	None
Israel	W Treaty	W Treaty	W Treaty	W Treaty	W Treaty	P Treaty	P Treaty	P Treaty	P Treaty	P Treaty

	Soln 11	Soln 12	Soln 13	Soln 14	Soln 15	Soln 16	Soln 17	Soln 18	Soln 19	Soln 20
Lebanon	W Treaty	None	W Treaty	None	W Treaty	None	W Treaty	None	W Treaty	None
Palestine	None	None	P Treaty	P Treaty	None	None	P Treaty	P Treaty	None	None
Jordan	None	None	W Treaty	W Treaty	W Treaty	W Treaty	None	None	None	None
Israel	P Treaty	P Treaty	None	None	None	None	None	None	None	None

Preferences Enter the stakeholders' preferences in the above solutions (0-100 scale).

Preferences	Soln 1	Soln 2	Soln 3	Soln 4	Soln 5	Soln 6	Soln 7	Soln 8	Soln 9	Soln 10
Lebanon	50	0	0	50	0	0	50	0	50	0
Palestine	100	100	0	100	100	100	0	0	100	100
Jordan	50	50	50	0	0	50	50	50	0	0
Israel	30	30	30	30	30	30	30	30	30	30

Preferences	Soln 11	Soln 12	Soln 13	Soln 14	Soln 15	Soln 16	Soln 17	Soln 18	Soln 19	Soln 20
Lebanon	50	0	50	0	50	0	50	0	50	0
Palestine	0	0	100	100	0	0	100	100	0	0
Jordan	0	0	50	50	50	50	0	0	0	0
Israel	30	30	0	0	0	0	0	0	0	0

Fig. 9. Twenty shortlisted solution after elimination of the non-feasible ones, with different stakeholder preferences

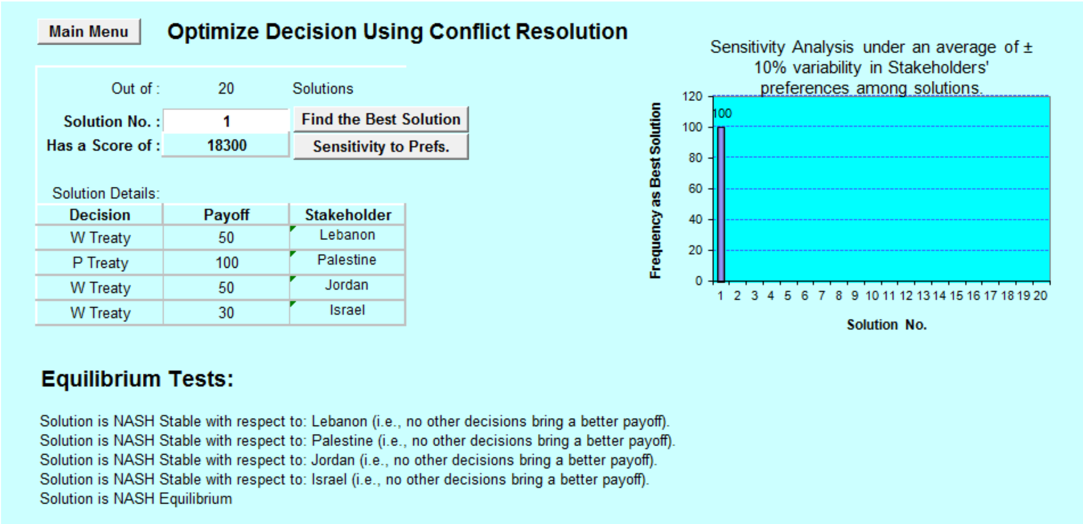


Fig. 10. Decision optimisation using conflict resolution for the twenty shortlisted solution when different stakeholders preferences are assigned

Table 4. Preferences and best solution for coalition scenario 1, with decision preference set 2

Option	Lebanon payoff	Jordan payoff	Israel payoff	Palestine payoff	Scores	Best solution	Equilibria
1	W.treaty (50)	W. treaty (100)	W. treaty (100)	P. treaty (100)	19500	1st (best)	R, GMR, SMR, SEQ
5	W.treaty (50)	W. treaty (100)	W. treaty 100)	P. treaty (0)	18500	2nd	R, GMR, SMR, SEQ
4	W.treaty (0)	W. treaty (0)	W. treaty (100)	P. treaty (100)	18000	3rd	R, GMR, SMR, SEQ
3	W.treaty (0)	W. treaty (100)	W. treaty (100)	P. treaty (0)	17000	4th	GMR, SMR, SEQ
6	W.treaty (0)	W. treaty (100)	W. treaty (100)	P. treaty (0)	16000	5th	GMR, SMR, SEQ

Table 5. Uncertainty and stakeholder preferences with 100 experiments

Stakeholder preferences	Variability range (0-100%)
Lebanon	±10
Jordan	±10
Israel	±10
Palestine	±10

4. SUMMARY AND CONCLUSION

This study introduces the graph model for the water dispute in Jordan River Basin problem. This study clearly proves that the Graph Model for conflict resolution can be used to solve socio-political conflict appropriately. Further, the model can be flexible and simplify all process and consider stability and sensitivity analysis. That is, it eventually finds the optimum solution based on stakeholders preferences. Using graph model make it possible to shortlist various decision makers and infeasible solutions. In Jordan River Basin problem, the 120 and 240 solutions were reduced to only seven (7) feasible solutions. In addition, using conflict resolution with info-gap theory led to solution one (1) as the best solution. After testing three different scenarios with different coalition and preferences among parties, results found water treaty between Syria, Lebanon, Jordan, Israel produce the robust and stable solutions. It is also established that the current situation is the least desirable solution but is more preferred and stable than increasing the abstraction of water from the upstream parties.

The Jordan River Conflict is a good example for interstate water conflict where upstream and downstream parties cannot agree on the amount to be withdrawn from a common pool aquifer or a river. The results of this study established that the upstream parties would not increase their share of water from the Jordan River, to avoid any possible counter act from the downstream parties. After agreement among parties for cooperation, parties can sign water treaties agreements that each part receives a certain amount of water. Such water treaty agreements will be more favourable than counter acting and colluding among parties, and will secure parties right and reduce their concerns.

This study examines the Jordan River basin generic conflict on water from the socio-political aspect. It ignores other issues such as religious, regional, and environmental factors that may indirectly affect this conflict. Further, this paper did not focus on the source of water whether it is a groundwater as a common pool or surface water of the Jordan River. It is only examined the used of the graph model for resolving water in general for this river basin.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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