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Water Allocation in Transboundary River Basins under Water Scarcity: a Cooperative Bargaining Approach

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Abstract Transboundary river basins are one of the main sources of fresh water which are facing water scarcity. When transboundary water is contested not only the allocation outcomes matter but also the allocation process should possess a certain desirable properties such as flexibility and sustainability. Therefore designing a mechanism that possesses these desirable characteristics and allocates the contested water resource is important as well. This article proposed a water allocation framework by combining the bankruptcy theory with asymmetric Nash bargaining solution concept for solving the water sharing problem in transboundary river basins under scarcity. Furthermore, the allocation framework was applied to the Nile river basin and to a hypothetical water scarce transboundary river basin. The results obtained were then compared with the allocation outcomes from classical bankruptcy allocation rules. The results showed that the proposed method can provide insights which could be useful for obtaining water allocation outcomes which are easier to implement and enforce under water scarce conditions.

Keywords Transboundary river basin · Asymmetric Nash bargaining · Nile river basin · Water scarcity

1 Introduction

Shared natural resources can be major sources of conflict or cooperation among sharing countries. Transboundary river basins are one of these shared natural resources (Wolf et al.

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2006; De Stefano et al. 2012; Mianabadi et al. 2014; Swain 2015). There are around 276 internationally shared river basins in the world (UN-Water 2013). Approximately 40 % of the world's population lives in these rivers basins (UN-Water 2008). Hence equitable and reasonable sharing of these river basin's water among riparian states is very important in order to make these rivers sources of cooperation rather than conflict.

Yet there is no internationally agreed up on water allocation scheme for transboundary river basins (Wolf 1999; Swain 2001; Salman 2007). The main reasons for the lack of internationally accepted and standardized mechanism for allocation of water in border crossing river basins are the socio-economic and environmental disparities among the riparian countries. Hence, finding an allocation mechanism that takes these differences in to account and decide on the allocation of transboundary river basin's water among riparian countries is both crucial and challenging.

Water scarcity is an issue that is having an impact on large portion of the world's population and many countries are already facing the problem (Houba et al. 2014; Mekonnen and Hoekstra 2016; Saz-Salazar et al. 2016). Transboundary river basins are one of the main sources of fresh water which are facing the problem of water scarcity. The rise in water demand and the impacts of climate change are among the main factors that are responsible for water scarcity in most of the border crossing river basins (Rogers et al. 2010; Madani and Hipel 2011; Ansink and Harold 2015). Water scarcity have already materialized in some transboundary river basins. Qezelozan-Sefidrood Basin (Zarezadeh et al. 2012; Madani et al. 2014) and Euphrates-Tigris (Mianabadi et al. 2015b) are instances. It is also predicted to occur in other river basins like the Nile (Brunnee and Stephen 2002; Molden et al. 2010) which are under huge pressure from the rapidly increasing water demand and impacts of climate change. When the river basins being managed are water scarce and transboundary the task of allocating water equitably and reasonably will have huge significance. Mainly because it helps to avoid water conflicts that could endanger the sustainability of the river basins and the socio-economic systems of riparian countries which depend on them. But this task will even be more challenging under water scarcity because the sharing countries will behave as risk averse utility maximizers.

The water sharing problem during water scarcity have similarity with bankruptcy problem. Bankruptcy problem is an economic concept where the amount of divisible resource available for sharing is less than the resource demanded (O'Neill 1982). When the available water in the basin is not enough to satisfy the total water demand the situation can be termed as water bankruptcy scenario. Therefore, designing a water allocation mechanism during water scarcity can be approached as a bankruptcy problem since riparian countries' total water demand is greater than the water available for sharing. After the pioneering work of (O'Neill 1982) where bankruptcy problem was approached from the game theoretic point of view, many resource allocation researchers picked this concept and applied it for allocating various scarce common pool resources including internationally shared water resources (Oftadeh et al. 2016; Degefu and He 2016a; Gallastegui et al. 2002; Sheikhmohammady and Madani 2008; Ansink and Marchiori 2010; Zarezadeh et al. 2012; Ansink and Weikard 2012; Madani et al. 2014; Mianabadi et al. 2015b; Sechi and Zucca 2015). Most of these studies following O'Neill's (1982) approach conceptualized the water bankruptcy problem as a cooperative transferable utility game. Therefore the question that arises is "is it reasonable to treat water sharing problem in transboundary river basins under water scarcity as transferable utility game?"

(Dagan and Volij 1993) stated that coalition formation is not that significant when dividing a fixed amount of resource with the demand on it exceeding its available amount, implying distributing the available resource among the claimants by incorporating a certain desirable properties to the allocation scheme is what matters the most. In addition, due to the socio-economic and environmental disparities among the sharing countries it would be almost impossible to determine the actual value of water and transfer the utility from it in the form of monetary payments and in kind transfers. Furthermore in order to fulfill the amount of water needed to reach their respective satiation point each riparian country will possibly act as risk averse utility maximizer during water scarcity. In which case treating water allocation as cooperative transferrable utility game might not capture the reality which is going on the ground. Besides (Aumann and Maschler 1985; Curiel et al. 1987) proved that it is impossible to drive allocation payoffs out of a pareto efficient, symmetric and strategically equivalent solution concept in transferable utility game. Hence due to these reasons the authors argue that it is more fitting to treat water sharing problem during water bankruptcy as nontransferable utility game rather than a transferable utility game.

Bargaining is one of the cooperative nontransferable utility game that can be applied to resolve resource sharing problems among claimants which have overlapping claims on a resource in a more sustainable manner, given it is designed carefully. Bargaining solutions have the ability to take most of the characterizing features of water sharing problem in transboundary river basin in to account. This makes them sources for water allocation outcomes that can serve as a base for sustainable river water sharing agreements (Carraro et al. 2006). Hence there is an international consensus that transboundary water resource sharing problems should be resolved through negotiation processes (Houba et al. 2014). As the result, cooperative decision making through bargaining is one of the popular trends for transboundary water resource management in recent years (Sgobbi and Carraro 2011). Increasing water scarcity might increase the probability of water allocation agreements being broken if there are or decrease their likelihood of formation if they are yet to exist. But this can be mitigated by designing water allocation mechanisms that yield water allocations by taking all the characterizing features of a water sharing problem in transboundary river basins in to account (Ansink 2009). Combining the bankruptcy solution concept with the bargaining solution process for allocating water in transboundary river basin under water scarcity exactly does that. Inducing the bankruptcy water allocation outcomes through bargaining process could serve as a way to find water allocations which are flexible, self-enforcing and more realistic.

There are various solution concepts to solve bargaining problems. The Nash bargaining theory (Nash 1950, 1953) is one of the most popular bargaining solution concepts that can be used to divide common pool resources among claiming agents. Hence this solution concept can be used to allocate contested water in border crossing river basins through a bargaining process. The Nash bargaining solution satisfies much desired properties such as feasibility, invariance under change of scale of utilities, pareto optimality and unanimity (Nash 1950, 1953).

Conflict resolution materializes if and only if each riparian country finds the solution outcomes to be fair and reasonable (Gray 1989). Therefore general agreement among riparian states concerning the water allocations is required to ensure the realization and sustainability of water allocation outcomes. As a result among the desirable properties of Nash bargaining solution stated above unanimity is the main one particularly when allocating water in border crossing river basins among risk averse utility maximizing sovereign riparian countries. The main reason being the need for self-enforcing allocations due to the absence of independent enforcing institution with the authority to make sure the implementation of water allocation outcomes and agreements in most of these river basins.

In most transboundary river basins the riparian states have different socio-economic and environmental status as the result their bargaining weights are different as well. One of the disadvantages of the classical bankruptcy allocation rules is that they fail to assign weights which reflects these important factors that influence allocation outcomes. (Mianabadi et al. 2015b) adopted weighted bankruptcy allocation rules extended by (Casas-Méndez et al. 2011) to allocate Euphrates-Tigris river basin's water among the contesting riparian countries. But their approach fails to identify and incorporate the variables and desirable properties such as disagreement point and self-enforceability which determines the acceptability of the allocation outcomes. Applying asymmetric Nash bargaining theory (Harsanyi 1982) mitigates this deficiency by assigning bargaining weights to each riparian country according to their relative socio-economic and environmental status while providing a framework that enables decision makers to incorporate these desirable properties.

The need for self-enforcing allocation solution outcomes and its ability to take the disparities among the riparian states in to account makes asymmetric Nash bargaining allocation mechanism an ideal candidate for solving the water sharing problem in transboundary river basins (Houba et al. 2014). More detailed characterization of this bargaining solution concept can be found in (Nash 1950, 1953; Kalai and TelAviv 1975; Herrero 1989; Herings and Predtetchinski 2010; Rachmilevitch 2015).

This article provides novel contribution by combining the bankruptcy theory with asymmetric Nash bargaining solution concept for solving water sharing problem in transboundary river basins under water scarcity as a non-transferrable utility game. In addition, to demonstrate its applicability the water allocation framework was applied to the Nile river basin and to the water scarce hypothetical transboundary river basin proposed in this article. Furthermore the results obtained were then compared with the results gained by applying the classical bankruptcy allocation rules.

The rest of this research article is organized as follows. Section two describes the methodology used. In section three the proposed allocation framework will be applied to the Nile and to the hypothetical border crossing river proposed in this article. In this section the results will also be presented and discussed. Section four summarizes and concludes the paper.

2 Method

Asymmetric Nash bargaining theory combined with water bankruptcy concept was applied to allocate water in transboundary river basin under water scarcity by taking in to account the riparian's relative utility function $f_i(x_i)$, bargaining weights $w_i = w_1, w_2, w_3 \ldots w_n$ and the minimum water allocation they are willing to accept i.e. disagreement allocation point (m_i)in a convex, closed and bounded feasibility space. The water allocation problem during water bankruptcy situations can be written as $(N, E, c, f(x))$, where N is the number of riparian states, E is the water resource available for division and c is the water claims of riparian countries.

Nash (1950, 1953) proved that such optimization problem with utility functions space that is convex, closed and bounded have a unique solution that satisfies a certain set of desirable properties. The solution tend to maximize the area between the pareto optimal frontier x_i and the disagreement (m_i) allocation points. The authors assumed that the minimum water allocation to riparian (m_i) is equal to the minimal water right of each riparian country i, i.e. the amount of water which is not claimed by the other riparian countries. This is the minimum water allocation the riparian is willing to accept. The minimal water right of each riparian is defined as the following (Curiel et al. 1987);

$$m_i = \left(E - c\left(N/i\right)\right) = Max\left\{\left(E - c\left(N/i\right), 0\right\}\right. \tag{1}$$

Given that:

$$m(N) = \sum_{i \in N} m_i \le E \tag{2}$$

For a bankruptcy resource sharing problem $(N, E, c_i, f_i(x_i))$,when the condition $E \le c(N/i)$ is satisfied for every $i \in N$ the resource sharing problem is called zero normalized bankruptcy problem since the minimal rights of all the claimants are zero (Curiel et al. 1987). When this condition is met by riparian states of a river sharing problem it is called zero normalized water bankruptcy problem. The disagreement point for such water bankruptcy problem is zero for all riparian states. In addition, water claims are considered unreasonable and irrational if they outstrip the available water supply. Therefore after assigning the minimal water right each riparian's water demand should not be more than the available water resource in the basin.

$$c_i \le E - \sum_{i \in N} m_i \tag{3}$$

The maximum possible water allocation to the riparian states are their respective water claims (c_i).The utility function for transboundary river basin's riparian countries can be defined as linear interval function (Wu and Xu 1996 as cited in Wang et al. 2013). Hence it can be formulated as follows using the water claims, disagreement water allocations and optimized water allocations of riparian states.

$$f_i(x_i) = \frac{x_i - m_i}{c_i - m_i} \tag{4}$$

The disagreement utility value can be obtained from the following equation;

$$d_i = f_i(m_i) \tag{5}$$

Where:

d_i is the disagreement utility point of each riparian country i.

When the bargaining weights of the riparian countries are taken in to account the allocation optimization problem for water allocation under water bankruptcy scenario can be written as the following (Harsanyi 1982).

$$\text{Maximize } N^{w_i} = (f_1(x_1) - d_1)^{w_1}(f_2(x_2) - d_2)^{w_2}(f_3(x_3) - d_3)^{w_3}(f_n(x_n) - d_n)^{w_n} \tag{6}$$

The model is constrained by individual rationality, efficiency while the disagreement points and claims serve as the lower and upper bounds respectively. For the Nile river basin case study presented in section three the water allocation optimization problem can be written as:

$$\text{Maximize } N^{w_i} = (f_{Eth}(x_{Eth}) - d_{Eth})^{w_{Eth}}(f_{Sud}(x_{Sud}) - d_{Sud})^{w_{Sud}}\left(f_{Egy}(x_{Egy}) - d_{Egy}\right)^{w_{Egy}}\left(f_{Up}(x_{Up}) - d_{Up}\right)^{w_{Up}} \tag{7}$$

Given: $\sum_{i=1}^{n} w_i = 1$.

Where:

$f_{Eth}(x_{Eth})$ relative utility function of Ethiopia.

d_{Eth} disagreement utility point for Ethiopia.

$f_{Sud}(x_{Sud})$ relative utility function of Sudan.

d_{Sud} disagreement utility point for Sudan.

$f_{Egy}(x_{Egy})$ relative utility function of Egypt.

d_{Egy} disagreement utility point for Egypt.

$f_{Up}(x_{Up})$ relative utility function of the hypothetical coalition of upstream riparian countries on the White Nile.

d_{UP} disagreement utility point for the hypothetical coalition of upstream riparian countries on the White Nile.

The model is subjected to the following constraints;

1, The utility derived from water allocated to each riparian state should be greater than or equal to its disagreement utility point.

$$f_i(x_i) \geq d_i, i = 1, 2, ..., n \tag{8}$$

$$m_i \leq x_i \leq c_i$$

2, The lower and upper water consumption bounds for each riparian state are it's minimal water right and water demand respectively.

$$m_i \leq x_i \leq c_i \tag{9}$$

Where:

$$m_i = \left(E - c\left(N/i\right)\right) \tag{10}$$

3, The total allocated water in the basin should be less than or equal to the amount of water available for division.

$$\sum_{i=1}^{n} x_i \leq E \tag{11}$$

In this article two cases were analyzed. The first case is when the bargaining weights of riparian countries are assumed to be equal. This is the special case of asymmetric Nash bargaining solution. Every asymmetric Nash solution is induced by symmetric Nash solution or by limits of such solutions. Therefore asymmetric Nash solutions induce symmetric Nash solutions and the converse is also true (Kalai and TelAviv 1975). It is important that bargaining weights are determined carefully using the appropriate method that considers all the issues that can be a source of asymmetry among the riparian states. Hence the authors chose not to assign random bargaining weights without further study and applied equal bargaining weights to the riparian countries of the Nile basin.

In the second case in order to show the influence of incorporating unequal bargaining weights on water allocation outcomes the allocation scheme was applied to a hypothetical transboundary river basin under water scarcity. Exogenous bargaining weights and weights derived from water claims were considered.

For the Nile river basin case the predicted water demands of the riparian countries were used as input for the model. The upstream riparian countries on the White Nile were pooled in to an assumed cooperative coalition. Hence the upstream riparian states on the White Nile where considered as one agent and their water demands were summed up as well. Treating the upstream riparian states on the White Nile as one stakeholder is idealistic but in addition to its analytical advantages there are four important reasons which makes the assumed coalition justifiable (Wu and Whittington 2006). First, with the exception of Uganda, the issue of the Nile's water is much less in these riparian states than in Egypt, Sudan, and Ethiopia. This is largely because these riparian states receive more precipitation than other riparian countries, and also do not rely solely on the Nile as their major source of fresh water. Second, the major tributaries of the Nile are found in Ethiopia, the other most upstream country on the Blue Nile. The riparian states on the White Nile only control a small portion of the total river flow hence their bargaining power is much less. Third, with the exception of water conservatory infrastructures in Uganda, there are few planned large scale water use infrastructures in the sovereign territories of the riparian countries on the White Nile. Therefore the possibility of the river's water being a source of conflict in the future is much less. Fourth, because of the high transaction costs of participating in international negotiations, it might be more convenient for the riparian states of the White Nile to pool their resources and coordinate their actions.

2.1 Solution Framework

The utopia and disagreement points as well as the amount of water available for consumption is determined first. Then the optimization result for the decision variable is obtained using the asymmetric Nash bargaining model. The maximization solution procedure for water allocation problem under water bankruptcy using a bargaining approach is described below in Fig. 1.

When the demand and the available water in the river basin changes with time the optimization process is repeated again by updating the treat and utopia allocation points as well as the bargaining weights of the sharing countries accordingly.

3 Results and Discussion

3.1 Case Study

Studies indicated that fresh water is becoming increasingly scarce in transboundary river basins (Houba et al. 2014). Such a scenario could be a source of conflict and cooperation (Homer and Thomas 1994; Gunasekara et al. 2014). The problem appears to be growing mainly in river basins located in arid and semi-arid geographical regions where precipitations levels are low (Gleick 2000; Raskin et al. 1998). Moreover in these river basins lack of proper water management due to inadequate institutional capacity further intensifies water scarcity and the possibility of water conflict (Mianabadi et al. 2015a).

The Nile river basin is among these most important river basins in Africa facing the challenges mentioned above. It is the longest river basin in the world stretching 6695 km, draining an area of 3.1million square kilometers and covering roughly 10 % of the African continent (Nile Basin Initiative 2012). The basin is characterized by rapidly increasing water demand and asymmetrically distributed water resources through time and space (Mark 2011; Nile Basin Initiative 2012).

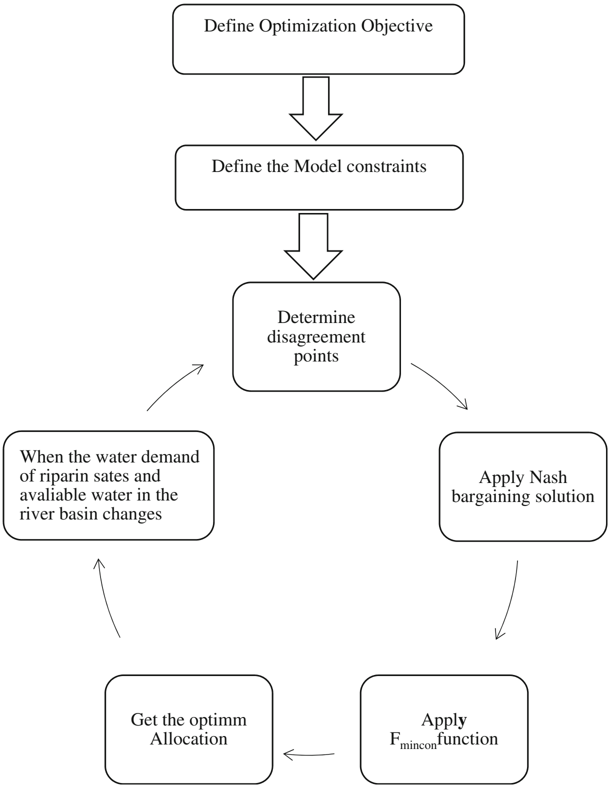

Fig. 1 Bargaining solution procedure for water sharing problem under water bankruptcy

Because of the continuing water dispute among the riparian countries the river basin has become a center of attention. The major water consumers in the river basin, Egypt and Sudan are claiming the majority of the river basin's water based on the principle of prior utilization and the bilateral agreement they signed in 1959, that completely excluded the other upstream countries on the blue and white Nile. On the other hand the upstream riparian states which are the sources of the major tributaries of the river argue that they have the sovereign right to use the river's water within their borders. Such conflicting and extreme positions taken by the riparian countries are the reasons for the existing water dispute among them and could result in inefficient and unsustainable management of the river basin (Degefu and He 2016b). Until now equitable and reasonable water allocation agreement for the river basin is yet to exist. The absence of an enforcing institution with the authority to implement equitable and reasonable sharing and management in the river basin (Ansink 2009; De Bruyne and Fischhendler 2013) being one of the reasons aside from the differences among the riparian countries in terms of their socio-economic and environmental status.

Some studies predicted that the river's water might not be enough to satisfy the water demands of riparian countries in the future. Among them a study done by (Awulachew et al. 2012) taking in to account the current unilateral water utilization and planning trends in the basin predicted that the Nile river will be short of water in the near future. The study projected that the total water demand for the medium term and long term scenario would be 94.5 $km^3$and 127 km^3, respectively higher than the 84.1 km^3 short term and the 88.2 km^3 long term predicted average water that is expected to be available in the basin. (Brunnee and Stephen

2002; Molden et al. 2010; Keith et al. 2013) also stated that in the future the available water in the basin might not be enough to satisfy the total water demand (Fig. 2).

Large portion of the Nile river basin lies in arid and hyper arid geographical regions which are characterized by high climatic uncertainty and variability (Nile Basin Initiative 2012). Hence in addition to increasing water demand climate change is expected to have its impact on

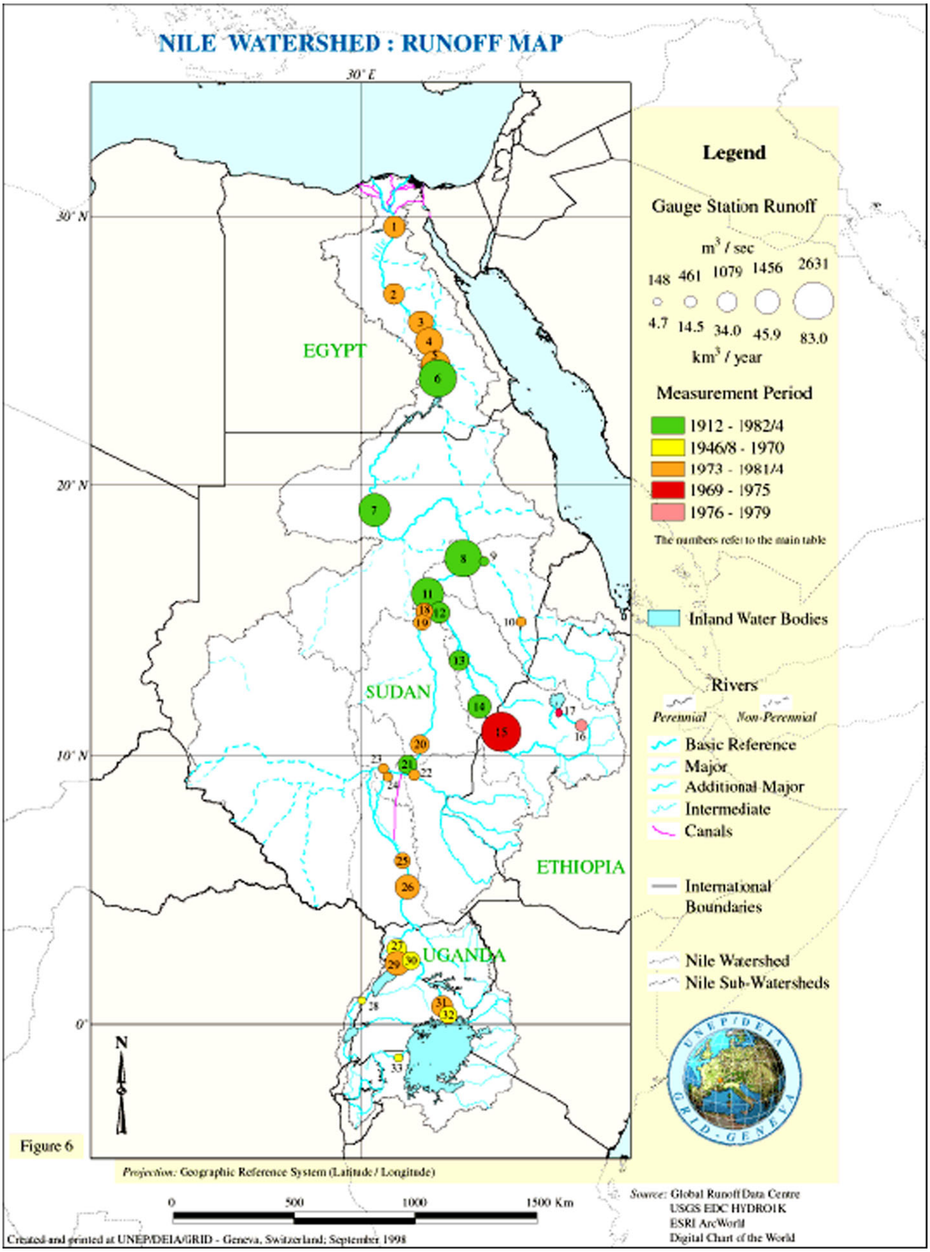

Fig. 2 The Nile River Basin runoff map (UNEP/DEWA/GRID-Geneva 1998)

the river basin too (Eckstein 2009). Even though it is not known with a great deal of accuracy weather the runoff volumes of the Nile will increase or decrease as the result of climate change, it is predicted that its adverse effects most probably outweigh its uncertain benefits (Nile Basin Initiative 2012). For this reason, before this uncertainty is realized it is wise to prepare management schemes which can deal with all sorts possible scenarios that could materialize in the future. Designing self-enforcing water allocation mechanism for possible water scarce scenario is one of the precautionary approaches that should be taken in order to avoid water disputes not only in the Nile basin but also in other border crossing river basins as well.

Tables 1 and 2 below shows the results obtained after applying the proposed allocation framework and constrained equal award rule(*CEA*) to the Nile river basin. *CEA* rule ensures the sustainability of smaller water claims (Herrero and Villar 2001). The allocation outcomes from *CEA* rule for the case study demonstrates this by allocating their full claim to the upstream countries on the Blue and White Nile. For both medium term and along term scenarios the proposed water allocation framework also rewarded these countries with 100 % of their water claim. Since their water demands are lower than equal division the fact that the allocation process recognizes this and gives priority to fulfilling their water claims seems reasonable.

While the allocations payoffs obtained for Sudan and Egypt are different from the allocation payoffs that were obtained by applying *CEA* rule because their minimal water rights are different and non-zero and the allocation scheme took that in to account. For the medium term scenario water allocations equaling 86 % and 89 % of their water claims were obtained for Sudan and Egypt respectively. Whereas the allocation solution allocated 61 % and 63 % of their water demand to Sudan and Egypt for the long term scenario. This is unlike *CEA* rule which allocates the remaining water resource by equally dividing it among the downstream countries when the available water resource is not enough to honor each riparian with the water demand of the riparian with the smallest water claim.

In order to show the impact of incorporating bargaining weights the proposed allocation procedure and the popular classical bankruptcy allocation rules were applied to a hypothetical border crossing river basin under water scarcity. Table 3 shows the allocation results obtained from the proposed allocation methodology and some of the popular classical bankruptcy rules when applied to the hypothetical transboundary river basin under water scarcity. (Dagan and

Table 1 The optimized water allocation for riparian countries (Million.m^3) for medium term water scarcity scenario

Available water(E)	84,100						$CEA\ x_i$
Total claim(C)	94,541						
Riparian countries(n)	The water demand (Awulachew et al. 2012) c_i	Maximum value c_i	Minimum value / disagreement point m_i	Relative bargaining weights w_i	Optimization results x_i	Allocation percentage p%	
Upstream countries	2170	2170	0	0.25	2170	100 %	2170
Ethiopia	4190	4190	0	0.25	4190	100 %	4190
Sudan	39,239	39,239	28,798	0.25	34,019	86 %	38,870
Egypt	48,942	48,942	38,501	0.25	43,721	89 %	38,870

Table 2 The optimized water allocation for riparian countries (Million.m^3) for long term water scarcity scenario

Available water(E)	88,200						CEA x_i
Total claim(C)	127,661						
Riparian countries (n)	The water demand (Awulachew et al. 2012) c_i	Maximum value c_i	Minimum value/ disagreement point m_i	Relative bargaining weights w_i	Optimization results x_i	Allocation percentage p%	
Upstream countries	6823	6823	0	0.25	6823	100 %	6823
Ethiopia	15,178	15,178	0	0.25	15,178	100 %	15,178
Sudan	50,992	50,992	11,531	0.25	31,262	61.3 %	33,099.50
Egypt	54,668	54,668	15,207	0.25	34,937	63.9 %	33,099.50

Volij 1993) stated that asymmetric Nash bargaining model results in allocation outcomes for bankruptcy allocation problem that corresponds to the proportional (*PRO*) allocation rule when the disagreement allocation points are zero and the bargaining weights assigned to the resource claiming agents are derived from their claims. The results obtained agrees with this proposition when the bargaining weights are claim based and disagreement point is zero for all the riparian states. Therefore when the bargaining weights are claim based and minimal rights are taken as disagreement allocation points, applying the asymmetric Nash bargaining solution to the water sharing problem $(N, E, c_i, f_i(x_i))$ where every riparian $i \in N$ satisfies $E \leq c(N/i)$ yields allocation payoffs equal to the ones that can be obtained by applying *PRO* rule.

As it can be seen from Table 3 when unequal exogenous bargaining weights are taken the proposed mechanism allocates the available water in the hypothetical water scarce river basin proportionally but the results are different from the *PRO* bankruptcy allocation rule. This is because these assumed bargaining weights are derived from factors other than water claims of the riparian countries.

The allocation results obtained when equal bargaining weights are taken are similar with allocation outcomes from *CEA* rule. (Dagan and Volij 1993) proved that Nash bargaining solution corresponds to *CEA* rule when zero is taken as a treat point. Therefore when the bargaining weights are equal for all riparian countries and the minimal rights are taken as disagreement allocation point, applying the asymmetric Nash bargaining solution to the water sharing problem $(N, E, c_i, f_i(x_i))$ where every riparian $i \in N$ satisfies $E \leq c(N/i)$ yields allocation payoffs equal to the ones that can be obtained by applying the *CEA* bankruptcy rule.

Principle of self-enforceability is important property that implies allocation outcomes from an allocation rule maximizes the benefit of each riparian country (Barrett 1994). The water allocation outcomes obtained for each basin riparian country in the Nile and hypothetical river basin are self-enforceable because they maximizes the disagreement water allocation amount. Since water conflict is triggered by the increasing water demand and decrease in river flow, this water allocation methodology is also flexible with the changing demand and available water. This property helps basin riparian countries to adjust the variables and repeat the process there by creating the chance to negotiate and avoid the possible water conflict. This is also important because it avoids basin countries' concern that any decision reached now could endanger the possible claim they might have on the river basin's water in the future.

Table 3 Water allocations for riparian states in the water scarce hypothetical transboundary river basin

Available water E	10							$PRO\ x_i$	$CEA\ x_i$
Total claim C	17								
Riparian n	Water demand c_i	Disagreement point m_i	Claim based bargaining weights w_i	Assumed exogenous bargaining weights w_i	Optimization results x_i				
					Exogenous weights $m_i = 0$ $w_1 \neq w_2 \neq w_3$	Claim based weights $m_i = 0$ $w_1 \neq w_2 \neq w_3$	$m_i = 0$ $w_1 = w_2 = w_3$		
1	4	0	0.24	0.5	5.0	2.4	3.33	2.4	3.33
2	7	0	0.41	0.3	3.0	4.1	3.33	4.1	3.33
3	6	0	0.35	0.2	2.0	3.5	3.33	3.5	3.33
Total	17	0	1	1	10	10	10	10	10

Even though the proposed allocation mechanism provides a framework for considering important variables that are needed to be incorporated such as minimum acceptable water allocation and bargaining weights as well as desirable properties like self-enforceability and flexibility, it does not provide allocation solutions which solves the water disputes in an international river basins like the Nile fully. The proposed water allocation methodology can be seen as first step in multi-agent, multi-criteria strategic modeling of water allocation problem in transboundary river basins under water scarcity.

Therefore the suggested method even though it provides strategic insights in to the allocation of water in transboundary river basins it should be supported by further research to find a way to take in to account all the crucial factors in deciding water allocations. Three most important factors that needs to be addressed through further research are mentioned here. First, the role the political and military power of each riparian country plays in terms of increasing the potential water conflict among the riparian countries should be taken in to account. Second, in this article the designed water allocation framework did not take the multi-objective nature of the transboundary river basin's water in to account. The authors only took the consumptive water demands of the river sharing countries in to account. Therefore the method should be further developed to take in to account the non-consumptive uses of transboundary river basin's water. Third, this study assumed that the water demands of riparian countries are justified and the bargaining weights of riparian states are equal for the Nile river case. But in reality this is not the case. Hence the water demands and bargaining weights of the riparian countries should be determined taking in to account the important factors stated for equitable and reasonable utilization of an international watercourse in the United Nations Watercourses Convention (1997) and other additional factors that are specific to each transboundary river basin.

4 Conclusion

In this research the asymmetric Nash bargaining theory combined with bankruptcy concept was applied to allocate water in transboundary river basin under water scarcity. The main feature of this approach is that the water allocation payoffs of the classical bankruptcy allocation rules were induced through a bargaining framework. This solution framework was applied to the Nile river basin and to the hypothetical water scarce transboundary river basin proposed in this article. Then results were compared with the water allocation outcomes from the classical bankruptcy allocation rules. In order not discriminate among the riparian countries without further research equal bargaining weights were considered for the Nile river basin countries. Applying the asymmetric Nash bargaining solution to the water sharing problem under water scarcity yielded allocation payoffs equal to the ones that can be obtained by application of the *CEA* bankruptcy rule for Ethiopia and for the hypothetical coalition of riparian countries on the White Nile. While the allocations payoffs obtained for Sudan and Egypt are different from the allocation payoffs that are obtained by applying *CEA* rule. This is because the allocation scheme took in to account the fact that the minimal water rights of these riparian countries are non-zero and different. In addition the allocation scheme was also applied to a hypothetical transboundary river basin under water scarcity in order to demonstrate the influence of taking exogenous and claim based bargaining weights on water allocation outcomes. When exogenous weights are taken the proposed mechanism allocated the available water in the hypothetical water scarce river basin proportionally but the results obtained are different from those of *PRO* bankruptcy allocation rule. This is because the bargaining weights are different and derived from factors other than the water claims of riparian states. But when bargaining weights are derived from the water claims the result obtained concurs with the *PRO* rule when every riparian $i \in N$ satisfies $E \leq c(N/i)$.In addition when the equal bargaining weights are taken the allocation outcomes obtained from the allocation framework agrees with the allocation outcomes obtained from *CEA* rule given every riparian $i \in N$ satisfies $E \leq c(N/i)$.Generally, the water allocation framework presented in this article can assist policy makers in their effort to avoid water disputes, which could undermine the benefits the riparian countries can gain from the utilizing a transboundary river basin's water.

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