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Cooperative Game Theory to understand the Importance of Real Coordination in Water Allocation: Application to Logone River Basin.

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ABSTRACT

The use of water in the Logone Basin has been a key factor of the conflict between users like farmers, fishers. In this paper, we explore possible ways of understanding the reel importance of coordination through the cooperative game theory. A positive mathematical programming is applied to find the net agricultural benefit of the players involved in the competition about water management. In the second time the Shapley value method is applied to find the suitable equilibrium that satisfies all the users. We applied this method to the real case of the logone river that is one of the river suffering from water shortages in the lac Chad basin. As the contribution of this paper, our results show that collective rationality is suitable to improve agreement among users in the presence of externality.

Keywords: *Logone basin, Shapley value, conflict, game theory, collective rationality*

INTRODUCTION

Climate change, pollution and demography accentuate the water scarcity in the world. This situation leads to conflicts between uses that share the same river and have conflictual interest (Hipel and al.1997; Wang and al. 2003; Fang and al. 1998). It is also estimated that by 2025, 5 billion of people will not get potable water for domestic consumption (Wei and Gnauck, 2007). The logone river basin faces these difficulties characterized by the scarcity of water and the ongoing conflict between the users. The logone river basin has been a field of many confrontations over water allocation problem. In May 1965 Cameroonians fishers and Chadians fishers confronted themselves about water allocation; in 1974, Cameroon and Nigeria settle the irrigation system by embezzling the water of the logone river; that situation unpleased to Chad and accused Cameroon and Nigeria for this initiative. In June 2018, confrontation between farmers made 86 deaths. Since users are rational and take decision, game theory tools are very important to solve these ongoing conflicts in the logone river basin. The objective of this paper is to apply game theory tools to resolve conflicts over the water allocation problem in the logone river basin. Several studies have applied game theory to resolve water conflict. Rogers (1969) applied game theory approach to solve conflicts between Indian and Pakistan in the Ganges-Brahmaputra river basin. Theirs results shows that cooperation is suitable than non-cooperation strategies. Rogers (1991) exposed the cooperative game theory to share the Columbia river basin water between USA and Canada. His results show again that cooperation improve social welfare. Just and Netanyahu (1998) discussed about difficulties relative to the formation of coalitions in the trans boundary river basin. These difficulties concern the asymmetric information between users that have conflictual interest. Madani and Dinar (2011) made a study on the water management conflicts in the Nil basin. At the end of their study, they showed that cooperative game theory tools can resolve conflicts over water allocation. For them, conflict is the result of contradictory interest among Egypt, Sudan, Ethiopia and other countries. In the same logic, Dinar (2004) ran a cooperative game theory analysis over the water resources management. He argues that competition over water leads to conflicts; he urges to cooperation over the water allocation. Houba and al. (2012), agreed that negotiation over the Mekong river basin could lead to optimal water management by implementing cooperation. In the meantime, Shreider and al. (2007) in their works, used game theory approach to model the collective strategies in the Hop-Kins river basin. For them, game theory is widely used as mathematical tools to understand how rational human-being take the decision in the framework of conflicts. Saleth (1996) uses the Nash negotiation solution to cope with conflicts over water allocation. He suggests that the water market right could be rigid. Le Marquand (1977) exposes a general conceptual framework to understand the international cooperation concept by considering hydrologic, economics and politics aspects.

This paper presents the cooperative game theory for resolving conflicts among theusers in the logone river basin. Four players (regions) are involved in the game. The game concerns only farmers that maximize their utility function according to their respective area. In the first time, each player act alone in the framework of non-cooperative game theory; then all players act collectively in the context of cooperation. At the end we compare the gain coming from full cooperation to that of non-cooperation. In section 2, we describe the mathematical methodology; and the case study will be discussed in section 3; the results are presented in section 4; and section 5 concludes the paper.

METHODOLOGY

Shapley Value

the Shapley allocation solution [Shapley, 1953] is another method for fair and efficient sharing of the obtained benefits under cooperation. Under this institution, allocations are determined based on the weighted average of the beneficiaries' contributions to all possible coalitions and sequences [Shapley, 1953], based on

$$\varphi_i(v) = \frac{1}{n!}\sum_{R}\left[v\left(S_i^R \cup \{i\}\right) - v\left(S_i^R\right)\right]$$

The Shapley value is a unique solution that is in the core of convex games. Where R defines the set of all n! permutations of$N$ and $S_i^R \subseteq N$ isthe coalition of players who come beforei in the order R.

$\varphi_i$is the Shapley imputation for player i and$(v)$is the characteristic function.

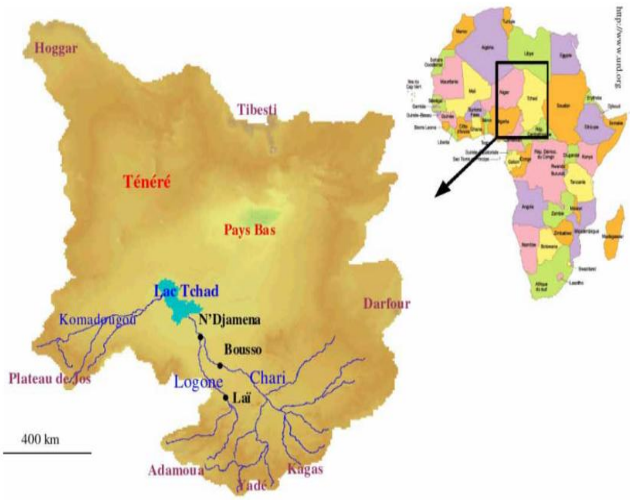

Figure1. *location of the logone river basin*

CASE STUDY

The logone riveroriginates in the Adamaoua mountains and flows toward the Chari river in N'djamena after it travelled Doba, Moundou, Lai and bongor towns. The logone is formed by two rivers coming from Adamaoua in Cameroon: the Vina and the Mbere. It is 960 km long. The Maga dam was built on the river in 1974 to enhance the local economic activities. It provides water to many towns in Chad and Cameroon for irrigated agriculture, domestic and industrial consumption. The gross agricultural area of the basin is 2893 ha for Kousseri, 6306 ha for Yagoua, 5347 ha for Maga, 2104 ha for Sategui-Daressia and 943 ha for Bongor. These agricultural areas are very crucial for the live of the population in the region. In addition to agricultural consumption, the logone river supplies water to other sectorial economic. Because of the limited water supply, there is an on ongoing conflict among the water users. The mains agricultural activities are the culture of maize, onion, rice, tomatoes and vegetables. In this paper we consider four intensive agricultural municipalities that are Mayo danay, Kousseri, Bongor and Sateguidaressia. Our data is collected with the cooperation of CBLT, SDEA, SEMRY and the MINEE.

Calculating the Payoff of Players Using Characteristic Function

The net agricultural benefit is defined as in Howitt (2006) by:

$$Max\pi = \sum_i \sum_j \left[p_{zi} \left(\mu_{zi} \left[\sum_j \beta_{zij}\, x_{zij}^{\gamma_i} \right]^{\vartheta_i/\gamma} \right) - \left(\left(\alpha_{zi} + 0{,}5\theta_{zi} x^2{}_{zi,land} \right) + \sum_{j \neq land} \omega_{zij}\, a_{zij} \right) \right] x_{zi,land} \quad 3$$

Subject to

$$\sum_i a_{zij}\, x_{zi,land} \le b_{zj} : \forall z, \quad j = \{\text{land, water, labour}\} \quad 4$$

$$\sum_t x_{z,water\ ,t} \le \xi b_{z,water} \quad \forall z \quad 5$$

$$\sum_t x_{z,labour} \le \xi b_{z,labour}\ \forall z \quad 6$$

Subscripts z, i, and j denote respectively the zone, farmer and crop.

p_{zi} is the unitary selling price of crop i in the zone z

The decision variable x_{zi} represents the amount of land to crop i in the zone z.

ω_a gives the cost variable mean per acre of land.

Parameter b is the maximum quantity of resource j.

v_i is the parameter associated with the return to scale.

γ is given by $\sigma - 1/_{\sigma}$ where σ is the elasticity of input substitution.

We assume here that farmers operate under constant returns to scale and that the elasticity of input substitution is 0,25.

And the characteristic function for full cooperation is defined by:

$$v(N) = Maxf^N = \sum_i \sum_j \left[p_{zi} \left(\mu_{zi} \left[\sum_j \beta_{zij}\, x_{zij}^{\gamma_i} \right]^{\vartheta_i/\gamma} \right) - \left(\left(\alpha_{zi} + 0{,}5\theta_{zi} x^2{}_{zi,land} \right) + \sum_{j \neq land} \omega_{zij}\, a_{zij} \right) \right] x_{zi,land} \quad 7$$

S.t

$$\sum_i a_{zij}\, x_{zi,land} \le b_{zj} : \forall z, j = \{\text{land, water, labour}\} \quad 8$$

$$\sum_t x_{z,water\ ,t} \le \xi b_{z,water} \quad \forall z \quad 9$$

$$\sum_t x_{z,labour} \le \xi b_{z,labour} \quad \forall z \quad 10$$

The parameters and variables are defined above.

RESULTS

Functions Characteristics Results

The results of all the characteristic function are resumed in the table below:

Table1. *characteristicfunctionsresults*

orders	Coalitions	Characteristicfunctions (10^6FCFA)
1	$\{M\}$	$v(M)$=5,333333
2	$\{S\}$	$v(S)$=4,25
3	$\{K\}$	$v(K)$=3,333333
4	$\{B\}$	$v(B)$=3,5
5	$\{M,B\}$	$v(M,B)$=9,375
6	$\{M,S\}$	$v(M,S)$=10,3125

7	$\{M, K\}$	$v(M,K)$=8,125
8	$\{S, B\}$	$v(S,B)$=8,4345
9	$\{K, B\}$	$v(K,B)$=7,5
10	$\{S, K\}$	$v(S,K)$=8,4375
11	$\{M, B, S\}$	$v(M,B,S)$=13.055
12	$\{M, B, K\}$	$v(M,B,K)$=11,111
13	$\{K, B, S\}$	$v(K,B,S)$=11,3888
14	$\{M, K, S\}$	$v(M,K,S)$=11,944
15	$\{M, B, S, K\}$	$v(M,B,S,K)$=17,8125

Table2. *coalitional benefits*

Coalitions	benefitsprovided by coopération (%)
$\{M\}$	0
$\{S\}$	0
$\{K\}$	0
$\{B\}$	0
$\{M, B\}$	0,542
$\{M, S\}$	0,729
$\{M, K\}$	0,541
$\{S, B\}$	0,684
$\{K, B\}$	0,667
$\{S, K\}$	0,854
$\{M, B, S\}$	0,028
$\{M, B, K\}$	1,972
$\{K, B, S\}$	0,305
$\{M, K, S\}$	0,972
$\{\boldsymbol{M}, \boldsymbol{B}, \boldsymbol{S}, \boldsymbol{K}\}$	1,394

Bymeans of GAMS, we have gotten the possible results of different characteristic functions. They show us results weither players decide to form coalition among them. $v(M)$, $v(S)$, $v(K)$, $v(B)$ show the benefit of players under non-cooperation institution.

The other results show us that players formcoalitions. By acting alone, over production, each player chooses the strategy of non-cooperation. For example we can see that, if M and B coordinate their characteristic function increase than when they act alone. Obviously, we get that $(vM) + v(B) = 8{,}83333$and $v(M, B) = 9{,}375$. This show that cooperation is better than non-cooperation institution. Cooperation has increased the collectif utility by 6,13%. The single coalitions M, S, K, B did not get additional benefit because they act under non-cooperation institution. Our results are on line with that of (Rogers, 1969; Dinar et al.2004; Wei, 2010).

Results of Shapley Values

If players M,B,K,S coordinate over production, we can notice that M get the great part of the total utility. That is because the marginal contribution of player M is more than those of other players (Shapley,1976).

Table4. *Shapley values*

players	Shapley values
M	4,97
B	4,23
S	4,877
K	3,635

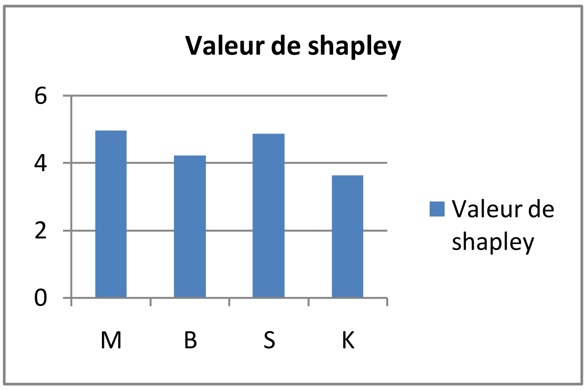

Figure1. *distribution of Shapley values*

We can then estabilish the order classification in respect to their marginal contribution. We get:

$\Omega_M > \Omega_S > \Omega_B > \Omega_K$

$\Omega_M, \Omega_S, \Omega_B, \Omega_K$are respectively the imputations of M, S, B et K.

Our results are on line with that of previous works (Rogers, 1969; Dinar et al.2004; Dinar et

Howitt, 1997) that show that cooperative game theory lead to optimal water allocation and cope with conflicts among users. raphically we can get the Shapley values for each player according to his contribution.

Conclusions

This paper used the cooperative game theory model to analyse a water conflict in thelogone river basin among farmers. The mathematical tool used is the Shapley value. This approach attempts to resolve the problem of optimal water allocation. We analysed the process when the farmers act alone and when they act try to form coalitions. Comparing these two institutions, cooperation gives the best results than that of non-cooperation. The importance of the Shapley value in this study is that it allocates resources in the fair manner. At the end, our study demonstrated that cooperative game theory can be applied to resolve water conflicts and the authority can then implement institutions that urge to coordination.

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