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Water deficit sharing: A new approach to conflict resolution among stakeholders in the watershed

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Abstract: Population growth and socio-economic development make the competition for larger share in water allocation more intense among stakeholders in the watershed, which in turn brings up conflicts over the use and allocation of water. Competition for more shares of water between stakeholders, especially in dry areas, leads to over-exploitation of water resources and large deficits in supplying the downstream demands. Equitable allocation of water reduces conflicts among water allocation stakeholders, since it provides equal opportunity for water usage between them. Equitable sharing of deficits among upstream and downstream stakeholders is a promising approach to equitable water allocation. Karkheh watershed is a good example in which operation of very large dam in downstream is influenced largely by hydro-projects to be constructed by upstream stakeholders. Socio-economic development in dam upstream impairs reservoir operation and its capability in supplying water for downstream demands, which in turn brings up conflicts between upstream and downstream stakeholders about future developments in Karkheh watershed. This paper presents a new method for equitable allocation of water resources between different upstream and downstream stakeholders. It is based on mathematical simulation of catchment's hydro-system and evaluation of stakeholders' water usage on deficits upstream and downstream of the watershed. Deficits are distributed among stakeholders based on their share in deficits. Shared deficits are subtracted from each stakeholder target water demand to obtain equitable water allocation to each stakeholder. This approach is applied to Karkheh hydro-system for equitable water allocation in developed state of this watershed, which has developing upstream and developed downstream.

***Keywords*:** *Conflict resolution, equitable water allocation, water deficit sharing, stakeholders, water allocation criteria.*

1. INTRODUCTION

Water resources limitation, development requirements and stakeholders' competition for more profit diversifies and develops the conflict over water allocation in the watershed, temporally and spatially. Besides, water supply becomes much more complicated due to presence of resources limitation and conflicts over resources allocation. Conflict over water allocation can occur at local to international levels, since water becomes more valuable as it becomes scarcer. For resolution of conflict over water allocation, therefore, economic, social, political and environmental considerations must be involved in decision making.

Eleftheriadou and Mylopulous (2008) apply game theory to establishment of least conflict arousing strategy in sharing Nestos/Mesta River water resources between Greek and Bulgaria based on economic returns for both countries. Some recent studies incorporate stakeholders' utility functions in conjunction with game theories in the study of most acceptable water allocations (Ganji et al. 2008; Shirangi et al. 2008). Kampragouet al (2007) used Multi-Criteria Decision Making technique for most equitable water allocation of Nestos/Mesta River among its stakeholders, based on indices like; catchment's area, river runoff, water consumption per capita, population, unemployment ratio, water demand, inefficient use, GDP, and water stress index (WSI). Chermak et al. (2005) used cooperative, non-cooperative and myopic approaches to the optimum groundwater withdrawal planning that maximizes the stakeholders' socio-economic indices. Their analysis shows that cooperative approach leads to best value and Myopic approach leads to least favorable state for the stakeholders. Cai et al (2004) screened hydro-projects development scenarios in Jing-Jin-Tang region, north China, by MODM technique and used MCDM for ranking the reasonable sample of them. MCDM technique is used for equitable allocation of Jordan River water flow between Israel, Jordan, Palestine, Syria, and Lebanon by Mimi and Sawalhi (2003). Indicators such as; catchment's area, contribution to the river flow, current utilization, water demands, economic and social needs, future population, GDP and WSI are commonly used for quantification of stakeholders' benefits from resources utilization that can be used for quantification of equality in resources allocation. Nandala and Simonovic (2003) used system dynamics modeling for solving conflict between two stakeholders in a hypothetical water resources system.

Equitable water allocation is the main theme in most researches on conflict resolution, though not explicitly expressed. Application of Game theory, MCDM, MODM, system dynamics and other techniques is quantification of players' (stakeholders') preferences and their maximization in a manner that leads to maximum consensus. In this paper a new method for conflict resolution based on sharing water deficits between stakeholders is introduced and applied to a real world conflict resolution problem.

2. WATER ALLOCATION IN IRAN

Water allocation is very serious in Iran, due to non-integrated development pattern in watersheds. Developed downstream (with government investment) and under-development upstream is a common characteristic of most watersheds in Iran. To keep the balance between upstream and downstream development, due to increasing social problems, like; emigration from upstream, government issued many permits for constructions at the water basin upstream. It brought other social conflicts that can be summarized as:

1. Conflict between upstream and downstream stakeholders
2. Conflict among upstream stakeholders for having more share of limited upstream water resources

Therefore water allocation is becoming more complicated, since downstream water demands rely on upstream withdrawals. At the same time, upstream stakeholders try to get more allocation share from upstream resources. In this situations government wants to know, how benefits of water resources utilization must be shared equitably among the upstream and downstream stakeholders. Another important issue is the compromise between current downstream water rights and future upstream water demands in water allocation planning.

3. KARKHEH WATERSHED

Karkheh watershed contains 3% of Iranian territory surface area and common boundaries with six western provinces from north to south of Iran (Fig. 1). These 6 provinces; Hamedan, Kordestan, Kermanshah, Lorestan, Eilam, and Khozestan, are the stakeholders of Karkheh watershed water resources allocation. The surface area and population of each province in the watershed are presented in table 1. In current study Kordestan provinces due to its small area is not considered in Karkheh watershed modeling. Main river of the basin is Karkheh River, which its head stream is located in Hamedan. It passes through Kermanshah, Lorestan, and Eilam, and at the end flows into Khozestan. The main dam in operation of the basin is Karkheh dam which is located in Khozestan province (downstream of basin).It supplies 2914 Million Cubic Meter (MCM)water for agricultural in Khozestan, 510 MCM water for agriculture in Eilam (one of upstream provinces)and 1283 MCM water environmental demands of dam's downstream. Karkheh dam specifications and location are presented in table 2 and figure 1. Inflow data to Karkheh dam from 1956 to 2005 is shown in figure 2. According to Karkheh dam simulation results, with 5558 MCM long-term mean inflow, reservoir operation targets can be met with 90% volumetric and temporal reliability. Simulation results show that slacks in meeting Karkheh reservoir agricultural targets are within acceptable limits.

Traditional withdrawals in the upstream provinces sums up to 823 MCM based on Iranian Ministry of Energy Database, which its detail by provinces and type of consumption are shown in table 3.

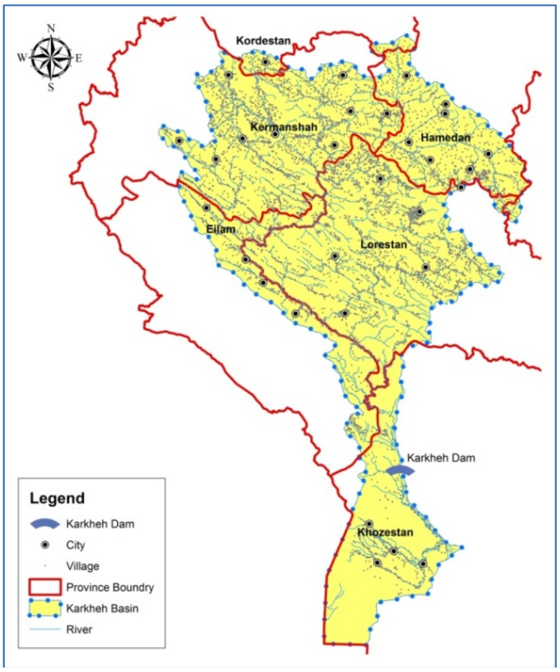

Figure 1. The stakeholders of Karkheh basin

Table 1. The area and population of each province in Karkheh Basin

Province	Area Contained in the Karkheh Waterbasin (Km^2)	Population 2006
Hamedan	6821	624,562
Kordestan	729	68,937
Kermanshah	13433	1,454,079
Lorestan	16713	943,883
Eilam	5363	133,937
Khozestan	9007	211,639
Sum	52065	3,437,037

Table 2. The characteristics of Karkheh Dam

Name	Karkheh Dam
Targets	Agriculture, Environment, Hydropower
Name of River	Karkheh
Annual Inflow	5558
Active Reservoir Capacity (MCM)	3840
Regulated water volume (MCM)	4707
Agriculture (MCM)	3424
Environment (MCM)	1283
Total Hydropower Installed Capacity (Mega Watt)	400
Number of Turbines	3
State	Under Operation

Table 3. Traditional water withdrawals from Karkheh River in upstream provinces

Province	Traditional Agriculture Water Withdrawal (MCM)
Hamedan	251
Kermanshah	287
Lorestan	0
Eilam	285
Sum	823

According to Iran Ministry of Energy Database, total water demands of upstream provinces in future sums up to 3576 MCM that 1333 MCM of it is currently used (traditional agriculture water withdrawal: 823 MCM, Eilam agricultural demand from Karkheh dam: 510 MCM) and it is planned to regulate remaining 2243 MCM by construction of new dams, which its detail by provinces and type of consumption are shown in table 4.

If all planned dams be constructed in Karkheh upstream, inflow to Karkheh dam and its capability in supplying the current downstream demands will decrease significantly. How water resources of Karkheh watershed should be allocated between upstream and downstream stakeholders to provide equitable opportunity for hydro-developments and prevent shortage in supplying different demands in downstream, is a challenge in Karkheh hydro-system planning.

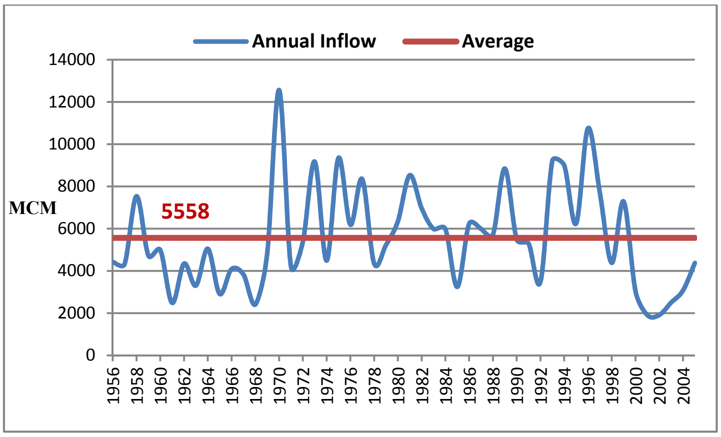

Figure2. Annual inflow of Karkheh Dam from 1956 to 2005

Table 4. New water demands for upstream stakeholders (MCM)

Province	Domestic	Industry	Agriculture	Environment	Sum
Hamedan	24	7	90	39	159
Kermanshah	10	18	391	16	435
Lorestan	73	22	807	6	908
Eilam	25	7	690	18	740
Sum	132	54	1978	78	2243

4. PROPOSED METHOD

Equity is defined as the same marginal costs (profits) for all stakeholders per additional allocated water [Dinar et al. 2005]. Equity normally within governmental attitude towards services to stakeholders is defined as equitable sharing of opportunities for utilization of resources, such as; water. It is not an economic oriented approach to resources allocation. It is very important to notice the equity as a social acceptability essence for decisions and rules rather than an economically efficient way for decision making. Social acceptability of decisions is proven to be a guarantee for application of economically efficient decisions or rules. In the context of Iranian socio-economic conditions, equitable water allocation balances upstream social costs with downstream economic benefits. Water allocation at upstream must be determined in a manner that has the least impacts on downstream water supply. In this research, equity is quantified as share of each stakeholder from deficits, which is decided up on by consensus between stakeholders. The practical method to obtain this consensus is holding session with them and collecting their views about the share ratios. Water allocation in this approach is implemented as:

1. Initial analysis of the hydro-system for determination of deficits at downstream

2. Determination of deficit sharing ratios between upstream and downstream stakeholders. The ratio is determined by processing the session results held with upstream and downstream stakeholders.
3. Modification of water allocations based on results of initial analysis and deficit sharing ratios.
4. Determination of upstream stakeholders' water allocation share ratios based on consensus of upstream stakeholders on the water allocation ratios.
5. Upstream water allocation based on consensual ratios

According to the outlined water allocation method opportunities for upstream development is provided with the least costs for downstream water supply. Details of this approach to water allocation are explained as follows:

- Gathering the information: Information of all suggested projects in upstream and downstream must be gathered and each project simulation model should be prepared.
- Watershed system modeling: Based on hydro-system network and prepared simulation model for each project, hydro-system complete model must be developed including water withdrawal by stakeholders. By analysis of the hydro-system complete model, impacts of upstream projects operation on flow reduction at downstream projects and traditional water withdrawal points are estimated. This analysis shows whether initial goals of projects are met or not after construction of upstream projects. Besides, it shows water rights of traditional water users are met or not. At this step, conflicts are diagnosed and guidelines for resolving them can be thought out.In the watershed hydro-system model, this policy is followed that water must be allocated to municipal, industrial, environmental and agricultural demands respectively.
- Conflict resolution between upstream and downstream stakeholders: based on sessions with upstream and downstream provinces (stakeholders), consensus on the share of upstream and downstream must be called for as an equitable water allocation measurement. Watershed hydro-system model analysis shows the amount of deficits on downstream demands due to upstream withdrawals. This deficit in downstream is then divided between upstream and downstream based on consensual shares. In this study consensual shares are each stakeholder's demand ratio to total demand as shown in equation 1 and 2.

$$UDS = DIN \times \frac{TDU}{TDB} \quad (1)$$

$$DDS = DIN \times \frac{TDD}{TDB} \quad (2)$$

Wherein,

UDS: upstream deficit share (MCM)

DIN: deficit in downstream (MCM)

TDU: total demands of upstream (MCM)

TDB: total demands of basin (MCM)

DDS: downstream deficit share (MCM)

TDD: total demands of downstream (MCM)

After calculation of upstream and downstream stakeholders' share from deficits, water allocations are updated by subtracting the share of stakeholders' deficit from their total demands as shown in equations 3 and 4.

$$WAU = TWDU - UDS \quad (3)$$

$$WAD = TWDD - DDS \quad (4)$$

Wherein,

WAU: water allocation of upstream (MCM)

TWDU: total water demands of upstream (MCM)

WAD: water allocation of downstream (MCM)

TWDD: total water demands of downstream (MCM)

- At this stage, total water allocation to upstream is calculated and share of each stakeholder must be determined.
- Conflict resolution between upstream stakeholders: This part of water allocation method mainly deals with conflict resolution between upstream stakeholders after upstream modified total water allocation is determined. Himi and Sawalhi (2003) listed 9 water allocation indicators that can be used for equitable water allocation. In this method holding sessions with stakeholders, proposing different indicators to them, receiving their feedbacks and selecting the most favorable indicator (combination of indicators) is set forth as the conflicting resolution approach in water allocation. Therefore, based on many sessions and meetings with decision makers in each province (stakeholders), ratio of each province produced runoff to the total upstream runoff, was selected as water allocation indicator at upstream in this research. Therefore, water allocation to each stakeholder is calculated as shown in equation 5.

$$WAP = WAU \times \frac{RPP}{TRPU} \quad (5)$$

Wherein,

WAP: water allocated to each province (MCM)

RPP: runoff produced in province (MCM)

TRPU: total runoff produced in upstream (MCM)

In this study, VENSIM software is used for preparing project and basin simulation models. VENSIM is simulation software capable of simulating the dynamic behavior of systems with complexities, such as; feedbacks, based on causality loops.

4. RESULTS

Karkheh hydro-system analysis results shows that average inflow to Karkheh dam falls to 3523 MCM if all upstream hydro-projects are constructed. Figure3shows yearly simulated inflow to Karkheh dam after all new demands is present in the watershed. Simulation results for Karkheh dam with new inflows, shows that agricultural demand will not satisfied fully and it has considerable deficit of 1628 MCM in future (Table 5).

Karkheh dam downstream agricultural demand supply deficit is 1628 MCM. Upstream and downstream water demands are 3576 MCM and 2914 MCM respectively. Therefore, upstream and downstream stakeholders' shares in agricultural deficit are calculated as 897 MCM and 731 MCM respectively. By these share values, allocated water to upstream and downstream stakeholders become 2679 MCM and 2183 MCM respectively. These total water allocation values for upstream and downstream regions, based on runoff produced in each province (Table 6), are allocated between provinces as shown in table 6.

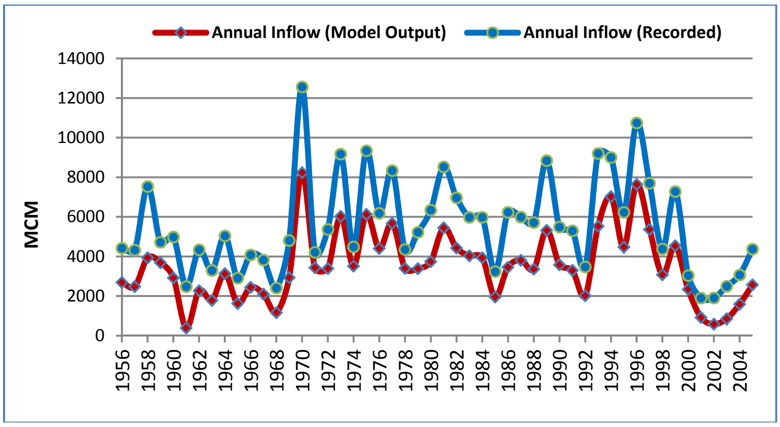

Figure 3. Inflow to Karkheh Dam from 1956 to 2005before and after considering all new demands

Table 5. Simulation results for Karkheh dam considering new water demands in upstream (MCM)

Demand	Initial Target	Reliable Supply	Volumetric Reliability (%)	Temporal Reliability (%)	Deficit
Environment	1283	1283	100	100	0
Agriculture (Eilam)	510	510	90	90	0
Agriculture (Khozestan)	2914	1286	90	90	1628
Sum	4707	3079	-	-	1628

Table 6. Runoff produced in upstream provinces and allocated water for them (unit: MCM)

Province	Runoff Produced (MCM)	Allocated Water (MCM)
Hamedan	546	267
Kermanshah	1644	805
Lorestan	2260	1107
Eilam	1019	499
Sum	5469	2679

5. CONCLUSION

In this research conflicts about water allocation in the watershed were studied and equitable water allocation was used for resolving these conflicts between upstream and downstream stakeholders. Equitable water allocation seems a suitable choice for governments, since they must distribute development and well-being opportunities equitably amongst all stakeholders. Water deficit sharing, which is based on equitable water allocation concept, was introduced as an approach to conflict resolution about water allocation. In this approach, deficits are shared between stakeholders based on their influence on water deficit all over the water basin. Stakeholders with more impact on water supply deficits, due to increase in stakeholder water demand, have more share of deficit in their water demands.

Water deficit sharing approach is applied to Karkheh hydro-system for water allocation in developing upstream regions, while not impairing downstream water rights and opportunities for development. Water deficit sharing approach, which is a simple and fast method, application to Karkheh watershed shows that 2679 MCM and 2183 MCM allocations are equitable for upstream and downstream, respectively, in developed state of Karkheh watershed. Besides, runoff production ratio to total runoff of each province (as stakeholders in water allocation), which is used as indicator for equitable water allocation between stakeholders suggests 41% of 2679 MCM (1107 MCM) to be allocated to Lorestan province, since has the largest share in runoff production.

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