THE USE OF AHP (the Analytic Hierarchy Process) METHOD FOR IRRIGATION WATER ALLOCATION IN A SMALL RIVER BASIN (Case Study in Tampo River Basin in West Sumatra, Indonesia)

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Abstract
This paper presents that the water management outcomes in a small river basin are the results of the interaction between the social aspects of water users and the physical aspects of the water resources. The analysis using a cultural ecology perspective to assess the relationship between these two aspects has provided a reasonable rationale to affirm that many social aspects of water users cannot be ignored when deciding or implementing a physical program that may influence the water resources system. Previous experiences have shown that any physical projects in the Tampo basin, West Sumatra, Indonesia have increased the withdraw water at the upstream part and reduce the opportunity for downstream part. As a result, changes in the demand and supply pattern in the basin have created conflict between water users along the river. It is thus clear that an integrated approach in designing and implementing a water resource development and management strategy for the Tampo basin must be used.

In this regard, this study has combined the socio-institutional and physical assessment of water resource management in this basin with the AHP method to obtain the most acceptable alternative of irrigation water allocation for all water users along the river course. Since the purpose of this method is to involve the stakeholders in the decision making process, the AHP method has shown its capability to allow the stakeholders to participate in expressing their preferences to compare alternatives. The process of obtaining their preferences is done after the presentation of and discussion about the impact analysis of their proposed alternatives. Besides having the final conclusion of the acceptable water allocation pattern, this study has also collected such comments and suggestions from the spoke-persons in using the AHP. One important constraint in using the AHP is a time consuming process for ordinary small farmers in the case site. Some tricks and shortcut methods are then used to create the process of discussion and value judgments as effective as possible (*320 words*)

Key words: irrigation, water allocation, AHP, decision making process, river basin.

Introduction

The competition of water use is actually a common problem in water resource management. This commonly occurred in hilly areas where the river basin is an open catchment. The improvement of irrigation facilities including the headwork and canal for the upper system have increased the possibility of upstream farmers to withdraw more water from the river but on another side have also reduced the water for downstream farmers.

Tampo river basin in West Sumatra, Indonesia has a similar case with the above issue. The improvement of irrigation facilities at the upper irrigation system has created conflict of water distribution among irrigation systems along the river. The permanent headworks and lining structure of its canal has increased the capacity to water its own systems but then reduced the portion of water that usually flows down to downstream systems. It mainly occurred because the drainage flow from this system did not flow down to the downstream irrigation system but flows to another catchment (Zein et al., 1986 and Ambler, 1989).

The problem of water distribution becomes worse especially during the low flow period. From June to August in dry season, the average rainfall is lower than the average evaporation. The average flow of 250 l/s at the upper catchment will not be sufficient for more than 1000 ha paddy fields. Moreover, the Coefficient of Variation (CV) of monthly rainfall is relatively high, 0.42 to 0.76 in rainy season and 0.51 to 1.04 in dry season.

Therefore, in order to solve the problem of water management at this river basin, a local university research institution called PSI-Unand has facilitated the establishment of a coordination forum among irrigation systems in 1991 (Tim Peneliti Unand, 1991). This forum is supposed to allocate a place for all irrigators (through their leaders) to discuss the existing problems of water allocation. In this regard, this study haS tried to produce something that is able to encourage the coordination forum to work properly. Since the hydrology information is not adequate, this study had produced a simple methodology as "a decision support tool" that will be able to help all the involved parties to get the best alternative of water management.

This paper will not present all steps of methodology in creating the water allocation model but more on presenting the use of the model with the AHP to get the alternative of water allocation.

The Water System of Tampo River Basin

This study is centered in a sub-catchment area of Tampo river basin, which is located in Kecamatan (sub-district of) Lintau Buo in West Sumatra Province, Indonesia (See Fig. 1.). This sub-district has nine n*agari*[1]; Batu Bulat, Balai Tangah, Tanjung Bonai, Tapi Selo, and Lubuk Jantan in the upper elevation, and; Buo, Pangian, Tigo Jangko and Taluak in the lower elevation. However, by delineating its hydrological boundary, this river basin is mainly in the west side of this sub-district, which covers only six *nagari* in the upper part.

Tampo river basin is a sub-sub-basin of a large river basin of Batang Kuantan. The catchment of this basin is only around 824 ha of forest area. While, as water from this river is also used to water the paddy fields in another sub-basin (Mangus-Sinamar: 18.5 km^2), the whole river basin observed in this study including this sub-basin is about 71.5 km^2. In addition, there are three small streams merging to Tampo River, Batang Sibawak, Batang Kawai, and Batang Lindan.

Along the river, there are 59 small-scale irrigation headworks that water about 1,437 ha paddy field. Based on findings of the previous studies and also the preliminary assessment of this study, the above paddy field area is divided into three regions. The upstream region (584 ha.) is considered as the wettest region because most of irrigators get enough water for cultivating rice continually in a year-around. The midstream region (573 ha.) gets a medium amount of the available water. While the downstream region (280 ha.) is considered as the dry region, as they get only the remaining water from the upstream.

[1] Nagari is a traditional village and later an administration unit below sub-district level.

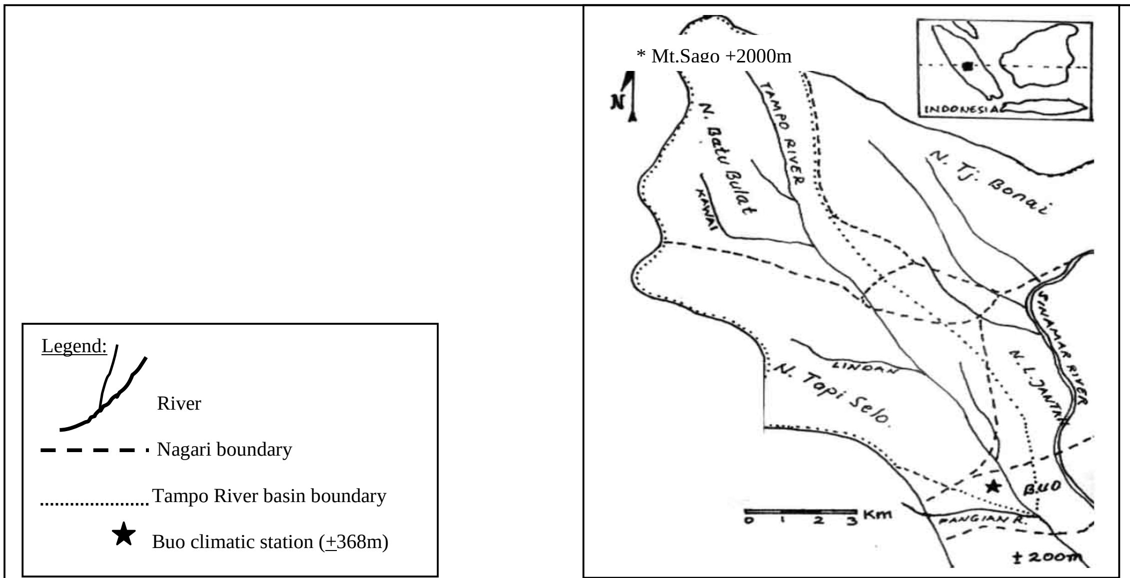

Fig.1. Tampo River Basin in the Sub-district of Lintau Buo, West Sumatra, Indonesia

The Water Balance analysis is used to construct the physical model of water allocation along the river. However, based on the socio-institutional assessment and review of previous studies, the river network was simplified as seen on Fig. 2. The 59 irrigation systems along the river have been combined into 9 offtakes. Each offtake represents several irrigation systems managed by a nagari. In the upstream region, conflict over water use is between N. Batu Bulat (offtake 001 and 004) and N. Tanjung Bonai (offtake 002 and 003).

While, in midstream region, conflict of water is between N. Balai Tangah (offtake 005) and N. Tapi Selo/Lubuk Jantan (offtake 006 and 007). Farmers and Nagari leaders in offtake 008 and 009 (in N. Buo) usually contest their share of water with farmers or nagari leaders in offtake 005 in the midstream area.

Inflow from other rivers, return-flow or outflow from each offtake, and drainage canals are then identified to complete this river network. In order to establish a water balance for the basin, streamflow was recorded at 13 points within the river basin between Nov-1998 and Oct-1999. These data are used to estimate inflow and outflow at each section (See Fig. 2.)

To estimate the irrigation water requirement at each region, the model uses the computer program of IMSOP[2] for each offtake. This program was chose due to its capability to estimate the IWR for multi offtakes, multi set of time planting and multi crops in one simulation step.

[2] IMSOP is an Irrigation Management and System Operation Model. This is a computer program that was developed by International Technology Centre, University of Melbourne, Australia.

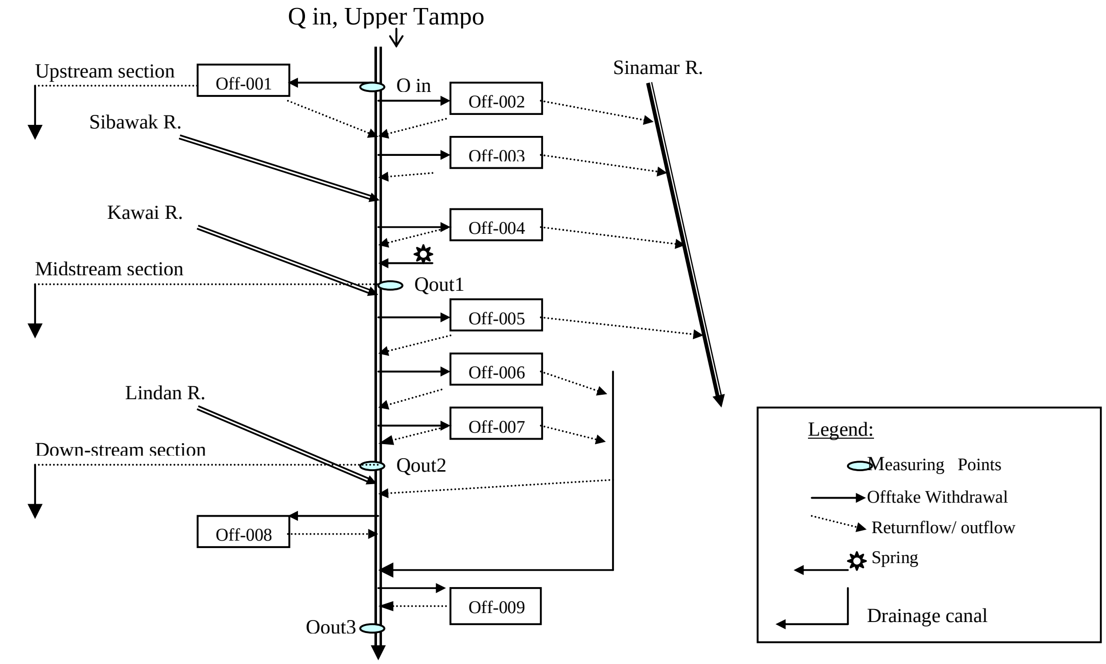

Fig. 2. The Simplified River Network

The Analytic Hierarchical model

This study combined the Analytic Hierarchical Process (AHP) and the fuzzy set theory in order to get the best alternative of water management in the case site. The AHP, developed by Saaty (1988), is based on a pair-wise comparison of the indicators. By applying the AHP, several identified indicators could be ranked based on the preferences made by several involved parties. While the fuzzy set theory used for this study is based on the fuzzy dominance method developed by Klir and Folger (1988). Both methods are outlined in Appendix A.

1. The Impact Analysis of Current Allocation Pattern

The impact of this current water management is seen from two sides, i.e. economic and water condition. Both are analyzed in terms of their real value and the equity value. The equity value of average income and water condition at all offtakes is calculated by using Gini coefficient as described by Feinerman (1988). The condition of water availability at each offtake is identified by a K factor[3]. If a value of K factor of an offtake is less than 50%, its paddy field will be in a stress condition. The number of period of this condition is then converted into a ratio of water condition every season.

[3] Pasandaran et al. (1989) defined the ratio between available flow and irrigation demand is a K factor on the Pasten Distribution Method. The water condition is still adequate if K factor over 75%, and it is a problem if K is less than 50%.

Income at each offtake is calculated according to this water condition. From the field interview at each region within the river basin, the minimum and maximum level of rice productivity is summarized. The minimum level of rice production is assumed to have been occurred mainly when the available water is very low or at 50%. The maximum level of production is assumed at 100% of water condition.

As seen in Table 1, the current water management produces a high inequality of water condition and income among offtakes. The tail offtakes at each zone get much lesser water than the head offtakes, so they get relatively lower income. Almost all farmers interviewed in this study realize this situation. In this regard, basically they have mentioned three alternatives; regulating the sharing system in water withdrawal system, lengthening the difference of time planting at each offtake and practicing the rotation of diversified crops.

Table 1. The impact of current water management during rainy season (from Sep'98 to Feb'99)

Water Condition and Equality	**Upper Zone**				**Middle Zone**			**Down zone**	
	Of-1	Of-2	Of-3	Of-4	Of-5	Of-6	Of-7	Of-8	Of-9
Water availability Rainy season (%)	100	89	78	61	100	61	50	94	61
Dry season (%)	100	72	61	33	100	39	33	67	39
Equality in water distribution	0.1786								
Equality in income distribution	0.4678								

2. Alternative Analysis

The AHP model is used to assess the social acceptance of each objective criterion. Actually, more participants giving their assessment the better preferences we had from that model. However, at this moment, this study was only able to collect the preferences from 10 farmers within the study area. As a result, the weighting factors for each criteria obtained by this method are: water condition = 0.23, average income = 0.15, equality in water condition = 0.35, equality in income = 0.27. The Fuzzy dominance method is then done to select the best alternatives to solve the conflict of water management in the case site.

Based on these findings, the study then construct the hierarchy for further analysis on AHP method. The hierarchy was set up as follow:

There are three hierarchy levels designed and named as goals (level 1), objectives (level 2) and alternatives (level 3). Below is a description of these three levels.

Level 1: Goal

The central problem in this river basin is conflict over resource sharing among nine offtakes that are managed by six nagari. Farmers in the lower nagari are subject to an inequitable water supply because excessive water is diverted by farmers in the upstream nagari. To solve this problem, farmers and other key stakeholders in the river basin have suggested several water management options. Therefore, the goal for this hierarchy is represented by the most acceptable management option to eliminate the water allocation conflict among nagari.

Level 2: Objective criteria

As this study uses an adaptive and integrated approach, the objective criteria in this hierarchy are also based on the needs of all interest groups. In fact, when alternative solutions to solve the conflict are being discussed, they would mainly need to know the impact of those alternatives on water availability at their site and on the equality of water distribution. Therefore, in order to judge the preferred outcome, the objective criteria in this hierarchy are first set in terms of the average amount of water available for users and of the equity of water distribution among them. In addition to having information about the impact on water availability, it is also important to inform them of the impact of alternatives on their income, either in terms of average nominal income or in terms of equality of income distribution.

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In sum, there are six objective criteria set for the AHP method. They are:

1. The average water availability (%)
2. The average regional income (Rp.000,-/ha)
3. The equality of water distribution (Gini Coefficient)
4. The equality of regional income distribution (Gini Coefficient)
5. Sensitivity of the average water availability to changes in water supply (%)
6. Sensitivity of the average regional income to changes in water supply (%)

Level 3: Alternatives

Not all alternatives identified by all relevant key stakeholders are feasible to be analyzed. As there is only a little room to increase the available water in the basin, the most feasible alternative is changing the demand pattern of water use. In this regard, this study has identified four plausible demand-management alternatives to be analyzed:

a. continuing the current pattern of water demand,
b. practicing a water-sharing allocation system for all offtakes, especially during the low flow period,
c. changing the planting schedule by increasing the staggered time between block/offtakes and,
d. practicing a crop diversification system at each offtake, where some percentage of paddy field area is used for second crops (known as *palawija*). These crops should be rotated among farmers/block every season.

For the purpose of analyzing the impact of these alternatives, at least two alternatives are combined resulting in two additional alternatives. To focus the analysis on the practice of a new water allocation system (alternative b), the last two alternatives (c and d) are combined with alternative b. In this case, changing the planting schedule and practicing crop diversification are combined with the new water allocation system. These combinations result in six alternatives as described in

Table 2. Six alternatives in the hierarchy of AHP method

Alternatives	Alternative combination		
	Crops	Stagger time	Water share
1 Continuing current practices	similar	similar	similar
2 Practicing new water sharing	similar	similar	new
3 Changing the planting schedule	similar	new	similar
4 New schedule and water sharing	similar	new	new
5 Practicing crop diversification	diversified	similar	similar
6 Crop diversification and water share	diversified	similar	new

Those alternatives are then simulated using the presented Water Balance model in order to get the impact of each alternative in term of the above-mentioned criterion (Table 3.).

Table 3. The impact of each alternative

Alt.	Impact in Real Condition		Impact in Equality	
	Average Water Availability	Average income (Rp.000/ha)	Water condition	Income
1	68	2108	0.1786	0.4678
2	88	3717	0.0828	0.1547
3	76	2745	0.1215	0.2681
4	92	4049	0.0569	0.1057
5	71	2574	0.1559	0.2783
6	90	3912	0.0716	0.1142

Nagari; Buo, Lubuk Jantan (LBJ), Batu Bulat (BB), Tanjung Bonai (TB), Tapi Selo (TS) dan Balai Tangah (BT) in the basin, the most acceptable alternative for solving the problem of conflict over water in the case site is alternative 3 (see Table 4.). Therefore, they need to enforce and mediate the changes in planting schedule. They could also promote the expansion of second crops (alternative 6) if they were implemented only with a water sharing system.

Table 4. Alternative rangking using AHP method

Alt. No.	AHP score at each Nagari						Final Score		
	BUO	LBJ	BB	TB	TS	BT	W	**S**	R
1	0.036	0.168	0.265	0.160	0.049	0.060	0.14	0.107	5
2	0.149	0.059	0.048	0.037	**0.299**	**0.306**	0.28	0.154	4
3	**0.333**	0.114	**0.277**	**0.431**	0.115	0.081	0.14	**0.240**	1
4	0.181	0.073	0.190	0.243	0.212	0.233	0.14	0.186	3
5	0.150	0.162	0.114	0.071	0.042	0.061	0.28	0.103	6
6	0.150	**0.422**	0.106	0.059	0.284	0.026	0.03	0.210	2

Note: W: Weighting, S: Score, R: Ranking
The shaded figures are the highest rank of alternative for each Nagari

Conclusion

The absence of a detailed hydrology database is a common problem in many water resource studies. There are, however, many useful results have been also obtained by using simulation-modeling techniques. In this study itself, a combination of simple models has significantly provided an effective tool in the assessment of a complex system of an ungauged river basin.

In its application, the integrated model has been used as a means of determining the economic impacts of alternative water management strategies. The AHP and Fuzzy dominance method were also applied as a decision tool to select the best alternative. Nevertheless, a caution is required. The simulation model should be continually verified by providing better and complete required data.

For further agenda there is a need to develop a pattern for institutional adjustment in river basin manegement. Farmers (through their association) should be involved in collecting the required data especially the related data of their field and irrigation systems. While, the local irrigation officers should not only focus on the water management of one-single irrigation system but should be in charge to manage and control the water use along the river.

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Appendix A.

1. The Analytic Hierarchy Process (AHP)

Application of the AHP model requires definition of a hierarchy of criteria and sub-criteria by which alternatives will be evaluated. The evaluation is based on a pair-wise comparison of two indicators as follow:

INSERT	IF
1	A and B are equally important
3	A is weakly more important than B
5	A is strongly more important that B
7	A is demonstrably or very strongly more important than B
9	A is absolutely more important than B
2,4,6,8	Intermediate values

Subsequently, a matrix **C** is constructed in which the entries are the result of pair-wise comparisons between indicators is as follow:

1. if $c_{ij} = \alpha$, the $c_{ji} = 1/\alpha$
2. if i = j then $c_{ij} = c_{ji} = 1$

Saati (1988) has shown that the eigenvector corresponding to the dominant eigenvalue of matrix **C** represents the preference weighting factors. The eigenvalue-eigenvector problem to be solved is :
$\mathbf{C}.\mathbf{W} = \lambda_{max} .\mathbf{W}$, where λ_{max} = the maximum eigen value and **W** = eigenvector corresponding to λ_{max} .

2. Ranking Method using The Fuzzy Dominance

The first step in this method is to establish the data matrix **X**. This matrix is made up of a set *m* alternatives (rows) and the set of the *n* performance variables (columns).

	I_1	I_2	…	I_j	…	I_n
A_1				.		
A_2				.		
:				.		
A_j	.	.	.	x_{ij}		
:						
A_m						

The second step is normalizing the matrix **X**. Matrix **Y** is generated by normalizing matrix **X** using the following function:

$$y_{ij} = \frac{x_{ij} - x_{worst}}{x_{best} - x_{worst}}; \qquad i = 1, 2, \ldots, m; j = 1, 2, \ldots, n.$$

where

x_{ij} = original data entry in matrix **X**;
x_{worst} = worst data entry in column j;
x_{best} = best data in column j.

Note: if x best > x worst then y ij = 1 when x ij = the largest entry in column j, conversely
If x best < x worst then y ij = 1 when x ij = the smallest entry in column j.

The last step is selecting the best alternative by multiplying matrix **Y** with the weighting factors of the preferences, **W** in AHP method. The highest score indicates the best alternative.