**ECOHYDROLOGY
ASIA – PACIFIC
REGION**

SUSTAINABLE RIVER'S PERFORMANCE AND ECOSYSTEM'S CARRYING CAPACITY (The Indices Approach for Rivers in South East Asia and Pacific Region)

Proceedings of
Asia-Pacific Workshop
on Ecohydrology,
Indonesia, 2001

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ABSTRACT

The research is a continuing attempt since 1995, to define a sustainable river from its performance level or its ecosystem's carrying capacity. It exercises the data on 25 rivers provided by the UNESCO's CATALOGUE of RIVERS for SOUTH EAST ASIA and THE PACIFIC REGION (1995). 3(Three) decision variables were chosen to define the river's performance, 10(ten) were selected to define the ecosystem's carrying capacity. A set of standards and criteria was statistically derived which further base the weights of the indices.. A confirmation of its sensitivity beside being conducted to the origin 25 rivers was further verified for 3 additional Indonesia's .rivers provided by the same institution in year 1998. Concurrently a further research to optimize land use to result a minimum run off coefficient has also been done to augment the use of the research's output, especially in the necessary circumstances facing the years of water scarcity.

The research's objective is to assist the river's managers to maintain a sustainable river, although at the present stage of its development the qualitative aspects is disregarded due to the unavailability of data on the quality of the rivers' water

Key words: definition of a sustainable river, the decision variables of a river's performance, ecosystem's carrying capacity.

1. BACKGROUND INFORMATION

The objective of the research is to provide river's managers with tools to monitor, evaluate and improve a river's sustainability level. in a more effective manner. It attempts to construct data on the river and its environment into information to base necessary actions in favour of the river's sustainabi-lity as a water resources.

Since data on rivers and their environment usually have diverse dimensions, therefore one of the target of the research is to convert them into non-dimensional-condition- proxy parameters, through setting up standards and criteria for each condition. Thusly a mathematical operation could be conduc-ted, and a holistic and comprehensive evaluation could be done.

The research was started in late 1995, under the auspices of the UNESCO, in the context of People and the Rivers' Environment Conference of the International Hydrological Program. The result was presented in front of the participants of the SE Asia and the Pacific Regional Conference of the UNESCO's of 1996, held in Jogyakarta-Indonesia, and also placed in the journal of the same institution in the corresponding year.

At its first inauguration, the method to ramify the carrying capacity indices was done through a decision tree method.. Later in 1997, with more time to contemplate and more data, the method was proposed to be replaced by the Laplace method. The end results of both method do not vary significantly, but the Laplace method is much simpler, it is therefore more practical.

2. THE CONCEPTUAL FRAMEWORK

The primary conceptual framework was deliberated from the attempt to clearly define a sustainable river, which subsequently the objective of the river management.. It was derived from the meanings of the word sustain according to the Concise Oxford Dictionary ninth edition, of March 1995. Accordingly since water is the essence of living, for a river to be aptly named sustainable water resources, it needs to fulfill the following criteria: 1/ has the endurance capacity to nourish the living beings within its ecosystem and 2/ has a capacity to control hazard or extreme conditions. The decision variables of the river's performance derived therefrom are:

1/ The dependability of the river in catering water to its ecosystem's community (K)
2/ The ratio between the maximum average and the average flow (P_{max})
3/ The ratio between the minimum average and the average flow (P_{min})

Mathematically they are defined as follow:

$$K = \frac{Q_{\text{average}}}{\text{Amount of population}} \tag{1}$$

Since the dependability of a river is its capability to provide water at all times, it will consequ-ently depend on the water requirements. The limits of water requirement is anthropogenically defined, and thus set at the *pareto optimum* level.

$$P_{max} = \frac{Q_{\text{max average}}}{Q_{\text{average}}} \tag{2}$$

$$P_{min} = \frac{Q_{\text{min. average}}}{Q_{\text{average}}} \tag{3}$$

The second conceptual framework is deliberated from an ecologic-hydrological point of views. It was derived from a common understanding of a river. A river is a longish gorge that form the lowest ground surface level of its surrounding area that collects runoffs.and debouch them to sea. Run offs depends on climatic, physiographical and geographical conditions of the drainage basin. The drainage basin of a river is its natural catchment area at the upper reach and its natural and man-made basin at the lower.

In lieu of the available data the selected decision variables representing the climatic factor is the average annual rainfall in mm; the ones representing the geographic condition are the population density and the land use. The physiographical conditions are denoted by the basin characteristics, and the channel characteristics.: The decision variables of the basin characteristics are: the basin area, slope, drainage density, geological condition, and the presence of lakes/swamps in percent of runoffs being hindered. Whereas the ones for channel characteristics, the length and slope. These variables are then discerened into the variables of the river's natural environment, and the variables of its development. Thus:*the Natural Environment Variables,consist of six decision variables, they are: the slope (S); the drainage density (D); the average annual rainfal (R); the geological condition (G); the catchment area (A); the length of the river (L) While the Development Variables consists of four decision variabales, they are: the population density; land use (C); percent of controlled runoffs (La); percent of forest area (F).*

The representativeness of the variables is tested using the existing accepted formulas. For the ones where no corelational formulas exists, a fuzzy logic is implemented. This method is rechecked by the outcome of the significancy coeffients of the existing accepted formulas.

Within those conceptual frameworks a river's performance should be able to be forecasted by its ecosystem's carrying capacity. And this forms the research's hypothesis.

3. THE DATA

The twenty five rivers being scrutinized consists of: the Burdekin and the Pioneer of Asutralia; the Prek Thnot of Cambodia; the Bei-jiang, the Jinjiang and the Jiyun of China; the Citarum, the Bengawan Solo and the Brantas of Indonesia; the Yoshino, the Arakawa and the Mogami gawa of Japan; the Pyung Chang Gang, the Geumho and the Miho chun of South Korea; the Batang of Malaysia, the Buller of New Zealand; the Ilog Magat and the Pampanga of the Phillipine; the Ping and the Mae Klong of Thailand; the Ky Chung, the Thu Bon , the Ba and the Srepok of Vietnam. Later Asahan, Citanduy and Serayu of Indonesia was added.

The range of observations of the climatic data being used are between 6 –108 years for 1-6 stations; while for the rivers arre between 3-73 years. For 3-6 stations. Both the Phillipines' rivers unfortunately had to be dropped due to insufficient data. The range of data being studied varied as presented in Table 1.

4. THE CONSTRUCTED STANDARDS AND CRITERIA

The conditions are discerned into four category, they are: bad; critical; very good and excellent. These conditions are weighted and consequently the weight becomes the related variable's parameter.

Table 1. The range of variations of the studied Data

The category of data	The range of variation
1. Catchment area (A)	1,781-130,000 km^2
2. Population	9,220- 13,500,000.
3. Population density	0.18 – 3,015 cap/km^2
4.Q_{avg}/cap	0.021 – 2.482 l/sec
5. $Q_{max\ avg}/Q_{avg}$	3,39 – 87.06
6. $Q_{min\ avg}/Q_{avg}$	0.003 – 0.264
7. The length of the river(L)	89 – 800 km
8. Average annual rainfall (R)	594 – 2,763 mm
9.Geologic condition (G)	1 – 4 (scale of hardness)
10 Channel /Area Slope (S)	0.13 –1.47%
11.Run off Coeffficient (C)	0.14 –0.46
12. Drainage density (Dd)	0.01 – 0.209
13. % of controlled runoffs (La)	0.00 – 1,58 %
14. Forest cover	0 – 87.7%

Table 2. The weight allocated to each condition

The Condition	The Weight
Bad	1
Critical	2
Very good	3
Excellent	4

Table 3. The Standards and Criteria of the Performance Variables

No	Decision Variables	Indicator	Condition			
			Bad	Critical	Very Good	Excellent
1	Water dependability (l/sec)	Q_{avg}/cap	<0. 0207*/	0.0207-0.39	0.4 - 0.8	>0.8
2	Maximum flow control	$Q_{max\ avg}/Q_{avg}$	>40	30 – 40	20 – 29	<20
3	Minimum flow control	$Q_{min\ avg}/Q_{avg}$	<0.1	0.1 - 0.2	0.21 - 0.3	>0.3

Note: */ was derived from statistically determined pareto optimum condition in this research, using under developed, developing, medium developed, and highly develped countries' water requirement per capita data provided by the World Bank's Reports of 1982-1990

Table 4. The Standards and Criteria of The Decision Variable of the Ecosystem's Carrying Capacity

Representatives of	Decision Variables	Criteria of Each Condition			
		Bad	Critical	Very Good	Excellent
Natural Environment	1.Catchment area(Km^2)	<5000	5000-15000	15000-30000	>30000
	2.Length of the river (Km)	<100	100-250	251-500	>500
	3.Slope (%)	>1.00	0.75-1.00	0.5-0.75	<0.5
	4. Geological Condition	4	3-2.9	2-2.9	1-1.9
	5.Average annual rainfall (mm)	<1500	1500-2000	2000-2500	>2500
	6.Drainage density	<0.025	0.025-0.075	0.075-0.125	>0.125
Development	7.Population density (org/km^2)	>1000	501-1000	100-500	<100
	8.Runoffs coefficient	>0.4	0.3-0.4	0.2-0.29	<0.2
	9.%run offs volume under control	<0.01	0.01-0.25	0.25-0.75	>0.75
	10.% forest cover	<30	30-50	50-70	>70

5. THE METHOD OF INDICING

Laplace (in H.Thaha, 1992) stated that in a complex situation where the contribution of each production factor is unknown, it should be assumed that each factor has equal contribution toward the goal achievement.
Therefore to predict the performance level of the river and the carrying capacity of its ecosystem, the following Laplace operation is proposed.

For the river's performance:

a. Its cumulative performance level:

$$Z_a = \sum p_i\, V_i \quad \text{.................................... } 4/$$

where p is the parameter of the related variable

b. Its average performance level:

$$Z_b = {}^1/_n \sum p_i\, V_i \quad \text{.................................... } 5/$$

where n is the number of the related decision variable

For the ecosystem's carrying capacity

a.Its natural ecosystem cumulative carrying capacity level:

$Z_c = \sum q_j V_j$ 6/

where q is the parameter of the related variable

b. Its ecosystems' development cumulative support level:

$Z_d = \sum r_k V_k$ 7/

where r is the parameter of the related variable

where j and k are the numbers of the related decision variable of Zc and Zd

c. Its ecosystem's cumulative overall conditionsupport

$Z_e = Z_c + Z_d$ 8/

For its overall ecosystem's average carrying capacity:

$Z_f = {}_{min} Z_e - {}_{max} Z_d$ 9/

Using these concepts and the standards and criteria as stated in Tables 1, 2, 3 and 4 the following sustainability level is statistically derived:

Tabel 5. The Performance Level Cumulative and Average Indices denoting the Category of River's Sustainability

Performance Indices		Category of Sustainability
Cumulative	Average	
<5	<1.6	Bad
5 – 6	1.6 – 2.2	Critical
7 - 8	2.3 – 2.8	Very Good
> 8	> 2.8	Excellent

Tabel 6. The Ecosystem's Cumulative and Average Carrying Capacity Indices denoting its level of support to the River's Sustainability

Natural Ecosystem's Carrying Capacity Indices		Ecosystem's Development's Carrying Capacity Indices		The Ecosystem's Carrying Capacity		Category of Support for River's Sustainability
Cumulative (1)	Average (2)= (1)/6	Cumulative (3)	Average (5)= (3)/4	Cumulative (1)+(3)	Average Mini-max{(1)+(3)}	
<12	<2.0	< 7.0	< 1.75	<19	< 1.75	Bad
12 – 14	2.0 – 2.4	7.0 – 10.0	1.75 – 2..5	19 – 24	1.75 – 2.4	Critical
15 – 17	2.5 – 2.8	10.0– 13.0	2.51-3.25	25 – 30	2.5 – 3.250	Very good
>17	> 2.8	> 13.0	>3.25	> 30	>3.250	Excellent

6. The Sensitivity Analysis Result

The sensitivity of the standards, and the resulting river's performance level derived from that standards and the sensitivity of the ecosystem's carrying capacity in forecasting the river's performance level were tested with the detail qualitative information on related rivers. The following is the result:

Tabel 7. Sensitivity Result

No.	The Rivers	The River's Performance Index		The Performance Indices according to the Ecosystem's Carrying capacity		The Qualitative information on the rivers	The Conclusion
		Index	Category	Index	Catagory		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1	**Burdekin**	2.3	Very good	2.5	Very good	Frequent floods occur on its deltaic zone. Varieties of fish species exist and conserved.	OK
2	**Pioneer**	1.7	Critical	2.3	Critical	Very wet climate in upper catchment. Primary issue is lac.k of water. The upper region is inhabited by 23 fish species, 25 species of birds and 48 species of mammals	OK
3	**Prek. Thnot**	2.7	Very good	2.8	Very good	The most severe flood happened in 1922. Very high rainfall, 3000 mm. And flood occurs at the lower most zone, due to the flat condition of the reach.	OK
4	**Bei jiang**	2.3	Very good	2.8	Very good	Dykes to prevent floodings have been erected	OK
5	**Jinjiang**	2.0	Critical	2.2	Critical	The population density is very high.	OK
6	**Jiyun**	2.0	Critical	2.0	Critical	The population density is very high	OK
7	**Citarum**	2.3	*Very good*	2.2	*Critical*	Lack of water during dry season, and floods during wet season	The ecosystem's carrying capacity's indices depicts the river's condition better
8	**Bengawan Solo**	2.3	*Very good*	2.4	*Critical*	-	
9	**Brantas**	2.7	*Very good*	2.1	*Critical*	-	
10	**Yoshino**	2.3	Very good	2.8	Very good	-	
11	**Ara**	1.3	*Bad*	2.3	*Critical*	Has 3 floods wave each year. 22km dykes of 50 m breadth have been constructed to prevent floods. The ground surface is sinking	-do-
12	**Mogami**	2.7	Very good	2.7	Very good	Belongs to one with the highest snowfall of the world	OK
13	**Pyung Cha**	2.3	Very good	2.5	Very good	-	OK
14	**Geumho**	1.1	*Bad*	2.4	*Critical*	-	The ecosystem's carrying capacity's indices depicts the river's condition better

Table 7. Cont.

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
15	Miho	2.0	Critical	2.0	Critical	-	OK
16	Buller	3.1	*Excellent*	2.8	*Very good*	Has the highest flashflood; rainfalls range between 2000-6000mm. Main issue is balancing between developing and keeping its natural environment. Floods and channel erosion are limited	OK
17	MN Ping	3.3	Excellent	2.8	Excellent	-	OK
18	MN Klong	2.7	Very good	3.1	Very good	-	OK
19	Kychung	2.3	Very good	2.6	Very good	The main issues are meeting various water demand and flood control.	OK
20	Thu Bon	2.3	Very good	2.5	Very good	The main issues along with meeting various water demand is long draughts, salt water intrusion and pollution.	OK
21	Ba	2.0	*Critical*	2.5	*Very good*	The forest cover in most sub catchment is 20% except for Khe An. Severe dry seasons, and only 3 months wet season, lavishing 1650 mm rain.	OK
22	Srepok	2.7	Very good	2.7	Very good	Annual rainfall between 2500-28000mm	OK
23	Asahan	3.3	*Excellent*	2.7	*Very good*	High population density	The ecosystem's carrying capacity's indices depicts the river's condition better
24	Citanduy	2.3	Critical	2.0	Critical	Harmful land use and high populat-ion density	OK
25	Progo	2.3	Critical	2.4	Critical	Harmful land use and high populat-ion density	OK

Note: the three rivers of the Phillipine's were dropped out of insufficient data.

32% of the rivers' sustainability level forecasted from the ecosystem's carrying capacity disagree one level with the determined performance level's. Deeper scrutiny on the rivers' information prompt a conclusion that the exact conditions of the disagreeing rivers are in between the forecasted and the determined level. Out of the disagreeing ones, 67,5% are forecasted one level lower and they befit the qualitative information better. Or less than 9% of the total sample are incorrectly forecasted by their ecosystems' carrying capacity.

Thus it is concluded that a river's sustainability forecasted from its ecosystem's carrying capacity, using the constructed standards and criteria could well depict its real sustainability level. While the one derived from its performance level could sufficiently be made as an indicator.

7. CONCLUSION

The performance variables may be used as indicators of the river's sustainability level. Whereas the river's ecosystem's carrying capacity could be used to forecast the sustainability level of the river. The category level of each decision variable could be used to determine the needs of improvement to increase the river's sustainability level.

The lack of water quality data made the inclusion of pollution level impossible in the model. Whereas a really sustainable condition should encompass them. A more complete deterministic model for river's sustainability level improvement could be augmented should the concurring water quality- water quantity data are provided.

An optimum water based land use tables, under limited forest cover have been prepared to help chose an economically most viable land use.

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