River Performance Assessment Model

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River performance assessment model

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1. Introduction

According to the United Nations Educational, Scientific and Cultural Organization (UNESCO) the Earth's freshwaters represent only 2.7% of the total water availability. Most part of that small value (77.2%) is found in

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polar caps, glaciers and icebergs, and the rest is distributed as: 22.4% stored in aquifers and groundwater; 0.36% in rivers, lakes and swamps, and 0.04% in the atmosphere [1]. Water on the river becomes crucial during wet and dry season. The problem during dry season consists of the quantity and quality of water. Both of them have strong relation to river ecosystem health [2]. In contrast during rainy season it always excesses of water.

River is a natural water flow or a place to storage the form of water drainage network along with water in it, from upstream to the estuary, with restricted right and left by a line of separation. River is the combination of river stream and water flow [3], while the definition of rivers infrastructure is the physical infrastructure constructed for river management including supporting facilities [4], such as: 1) Intake and water withdrawals structure, 2) Flood control structure, 3) Sediment control structure, 4) Protecting and strengthening riverbanks structure, 5) Regulating the flow direction structure, and 6) data monitoring structure.

Surface water such as water on the lake and swam is transported mainly flows on the river. Rivers play an important role on transporting of water [5]. They transport water by gravity, from headwaters to ocean. Topography of land surface becomes important part of transporting water on the river. The performance of the river system should be known exactly during the operation of the river and river infrastructure [6]. If the performance is well the river and river infrastructure will be operated normally and only need routine maintenance, but in contrast special maintenance or rehabilitation need to be done in worse river performance. The question is what the specific method to count the river and river infrastructure performance.

The assessment of river and rivers infrastructure performance in this study is specifically as a function of drainage purpose. River functions as a provider of water and as a water storage as well as purification of water quality is not reviewed in this research [4]. Rivers infrastructure performance assessment conducted to measure the ability of streams and rivers infrastructures/facilities to serve its function. Assessment of river physical condition as mentioned above is a powerful tool to evaluate the initial condition before river restoration takes place [7].

The objective of this research is to prepare an assessment model to evaluate the river and river infrastructure performance. This study is intended to make the method for assessing the performance of the river and river infrastructure. The benefits of the performance assessment can be used to determine the priorities of river and river infrastructure maintenance order and the benchmarking of restoration existing condition. At this time no standardized criteria in Indonesia and is therefore the purpose of this research is to develop river performance assessment framework that can be used for the assessment of existing condition of the river and river infrastructure.

The research method in this study is the experimental method started with the preparation of the river performance assessment model. This study is an investigation in the field of getting a technique of assessing the performance of the river and river infrastructure. This field survey method begins by making the design criteria and making the assessment river streams method. River performance assessment is done by assessing the score.

Assessing river performance based on river condition and function is not developed formally in Indonesia. Some assessment methods develop based on the environment and ecological approach. Biological-based river performance assessment basically is developed on watershed and biological river area. Approach assessment condition mainly assesses the water quality and river levels of pollutants.

The methodology to assess river performance in Indonesia become important especially intended to make decision on maintenance priority scale on river and river infrastructure physical condition. In this moment a river and river maintenance priority scale is done by partial decision on a specific damage not systematic approach. This river performance assessment model later used to measure the performance of physical and functions condition of river. The application of this model will state the percentage of the performance by mean the function and condition of the river. In short by using an assessment results can be used to determine sequence of priority of rehabilitation or maintenance in case of limitation of funds condition.

2. Material and Method

The study area is located in Central Java, Indonesia. It consists of four rivers which is a tributary of Bengawan Solo River. The selected river to be studied is a small river in the upstream of Bengawan Rolo River System. It's composed of: (1) Rivers Pepe, a river which flows across Surakarta City, (2) Rivers Samin, a river which flows near settlement and industrial area at Karanganyar District, (3) River Jlantah, a river which is located on mostly agriculture suburb area at Sukoharjo District, (4) River Dengkeng, a rather big river in Klaten District.

Selection the river location is based on the variation of the river characteristic mainly on the river morphology, hydraulic and hydrology and the land use of river basin. The samples were also taken into consideration of river against chemical and biological context to consider the relation of river and watershed and also river disturbance. The river watershed and rural farmland will be very different from the river in urban areas and industrial sites. Expected populations studied represent the diversity of a natural river. Sample selected is on a segment of the river that does not have a reservoir to regulate the flow of water. All the rivers have the natural flow conditions without setting the flow rate from the reservoir.

This research is preparing an assessment model of river and river infrastructure performance. The research method is done with investigations on the field. River performance was good if all component of the river and river infrastructure functioning well and good physical condition. Otherwise bad river performance is all components of the river and river infrastructure is not functioning well and his physical condition was broken. In a simple stage of making the assessment model are as follows:

- Identifying of variables that affect the river and river infrastructures performance on the fieds and literatures.
- Analyzing the relation of those variables in point 1 and grouped in different major component.
- Determining the variables (as indicator of performance) that are sensitive to changes in the performance of the river and river infrastructures.
- Conducting field research on the performance of a river reach is observed.
- Finding the magnitude of the effect of changes in the variables of the river and river infrastructures against performance index of rivers and river infrastructures.
- Developing an assessment of river and river infrastructures.
- Verifying developed method at point 6 to selected rivers.
- Refining and concluding the method and the results of the verification of the assessment method.

The assessment of the performance of the river and river infrastructure is limited by specifying the criteria and indicators of functions and physical condition of the river and river infrastructures. The rate of river management such as the personnel, finance, facilities and method of river operation and maintenance do not assess.

The model is to determine the components of the river and river infrastructure. Each component has a performance indicator and criterion of rivers and river infrastructure that may perform well. Each component and sub component as the indicator then determined the specific criterion.

Assessment criteria of river physical condition are the assessing the structural condition based on the level of damage. If the damage is extensive or more 60% of new condition then the criterion is bad. If there is no damage or incidental damage about less than 20 % of new condition put in a good criterion, while the damage is lightweight or between 20-40 % of new condition is fair condition [8]

The criteria of river and river infrastructure according to function performed by examining the function of the river and river infrastructure based its functions as a drainage. If the river and river infrastructure functioning is reduced until less than 60 % of planned functioning is bad criterion, while if the function more than 80 % of planned function is good criterion. The criterion in fair if the river and river infrastructure functioning in between 80 – 60 % of planned function (4).

The performance of river and river infrastructure is as a result of combination between condition and functioning of the river or river infrastructure. In many cases of river or river infrastructure have bad physical condition but still good serve, in contrast a good physical condition of river or river infrastructure do not have good function. The combination of river and river infrastructure then are divided into nine criteria. River and river infrastructures combination indicator on physical condition and functioning of infrastructures as presented in Table 1.

Table 1. Combination score physical and functional condition.

No	Score	Criteria		Description of Physical and functioning condition
		Physical	Function	
1	1	Bad	Bad	degree of damage > 60 %, function of infrastructure < 60 %
2	2	Fair	Bad	degree of damage 20 – 40 %, function of infrastructure < 60 %
3	3	Good	Bad	degree of damage < 20 %, function of infrastructure < 60 %
4	4	Bad	Fair	degree of damage > 60 %, function of infrastructure 80 – 60 %
5	5	Fair	Fair	degree of damage 20 – 40 %, function of infrastructure 80 – 60 %
6	6	Good	Fair	degree of damage < 20 %, function of infrastructure 80 – 60 %
7	7	Bad	Good	degree of damage > 60 %, function of infrastructure > 80 %
8	8	Fair	Good	degree of damage 20 – 40 %, function of infrastructure > 80 %
9	9	Good	Good	degree of damage < 20 %, function of infrastructure > 80 %

The score is based on function, its intended that higher score on functioning than physical condition. For example a river structure which has bad physical condition but still has a good function, has higher score than the good physical condition but fair function condition.

The assessment method is done by giving score every component which is available on the field. Every component will contribute to the river performance based on the weight of the river and river infrastructure function mainly as a drainage system. Weights performance is calculated by the method of Analytical Hierarchy Process (AHP) [9]. The weight factor is calculated by comparing the size of the relative importance of components compared with the other components. Standard weighting based on a scale ranging from 1 (mean the two things are equally important) to 9 (indicate the activity is very much more important than the others) to be used in the pairwise comparison matrix. An evaluation sample consisting of n elements, with the pairwise comparison matrix is written as follows:

$$\begin{bmatrix} w_1/w_1 & w_1/w_2 & \cdots & w_1/w_n \\ w_2/w_1 & w_2/w_2 & \cdots & w_2/w_n \\ \cdots & \cdots & \cdots & \cdots \\ w_n/w_1 & w_n/w_2 & \cdots & w_n/w_n \end{bmatrix} \tag{1}$$

Establishing priorities in the selection of AHP is done by calculating the eigenvector and eigenvalue through matrix operations. Eigenvector determines the ranking of the alternatives selected, while the eigenvalue provides a easure of the consistency of the comparison process. Calculation column vector (Vj) is performed by the following equation :

$$Vj = Kij \times Wi \tag{2}$$

Where Kij is a matrix of the form :

$$\begin{bmatrix} w_{11} & w_{12} & \cdots & w_{1p} \\ w_{21} & w_{22} & \cdots & w_{2p} \\ \cdots & \cdots & \cdots & \cdots \\ w_{n1} & w_{n2} & \cdots & w_{np} \end{bmatrix} \tag{3}$$

with the purpose/objective i = (1,2,3 ... , p) , and w is an alternative weighting 1 for the purpose 1, p represents a number of alternatives, and n is the number of destinations. Column vector, V_j, stating the final ranking of the alternatives tested in the analysis

The performance assessment of river and river infrastructure is based on the function and physical condition. The assessment of the river is conducted by the four component groups. Each group components consists of several sub-components with the weight of each factor. The calculation of the performance assessment of the river is done by calculating the performance of each sub-component. Each sub-component is given a score and multiplied by the weight factor. An example calculations on the performance of the sub-components River Side Slope (RSS) is as follows:

$$RSS = \frac{\Sigma(\frac{SRSS_i}{MSRSS} * LRSS_i)}{TLRSS} * WRSS \quad (4)$$

Where:

RSS = Performance of River Side Slope (%)
$SRSS_i$ = Score of River Side Slope location i
MSRSS = Maximum Score of River Side Slope location i
$LRSS_i$ = Distance of River Side Slope Location I (m)
TLRSS = Total Distance of River Side Slope (m)
WRSS = Weight factor of River Side Slope (%)

The river performance assessment on one component carried by summing the performance of each sub-component, then the result is multiplied by the weight factor. If one sub-component is not exist in river systems assessed, the standardization of weights applied to make adjustments of weighting factor to get balance the weighting factor for its component. The equation of river performance calculations is as follows:

$$RSF = \frac{(RSS+RBS+RCD+RDt)}{(WRSS+WRBS+WRCD+WRDt)} * WRSF \quad (5)$$

Where:

RSF = Performance of River Shortcut Floodway (%)
RSS = Performance of River Side Slope (%)
RBS = Performance of River Bad Slope (%)
RCd = Performance of Riparian Quality (%)
RDt = Performance of River Index Disturbance (%)
WRSS = Weight Factor of River Side Slope (%)
WRBS = Weight Factor of River Bad Slope (%)
WRCd = Weight Factor of Riparian Quality (%)
WRDt = Weight Factor of River Index Disturbance (%)
WRSF = Weight factor of River (%)

The assessment component of the river conducted by adding up all the components performance assessed. In another word performance calculations river infrastructure components should be performed for all sub-components. If the assessment component or sub-component is not completed then the performance value only takes into sub components by revised the weight factor. The overall assessment of the function and condition of the river is done by calculating the performance river/Shortcut/Floodway, river conservation infrastructures, utilization infrastructure and flood control infrastructure. The calculation is as shown in the following formula:

$$RIP = RSF + CsI + UtI + FCI \quad (6)$$

where :

RIP = River and River Infrastructure Performance (%),
RSF = Performance of River/Stream/Shortcut/Floodway (%),
XsL = Performance of Conservation infrastructures (%),
UtI = Performance of Utilization infrastructures (%).
FCI = Performance of Flood Control structures (%).

The result of the assessment models can be one of these options: (a) if river and river infrastructure performance is very low (below 60 %) the river need to rehabilitated, (b) if the rivers and river infrastructure has moderate performance (60-80%) the river need special maintenance to restore the function and (c) if the river and river infrastructure performance can perform well (above 80%) its indicate only need routine maintenance.

3. Result and Discussion

There are many varieties of river infrastructures in the field. Assessment should take into account the possibility of all the infrastructures or groups of infrastructures. Indonesian Government Regulation No. 38 (2011) classifies into 3 groups of rivers infrastructures: (1) conservation, (2) utility and (3) flood control. Assessing the component of river and river infrastructures in this research is grouped as follows:

1. River/shortcut/Floodway
2. River Infrastructures
   a. Conservation infrastructures
   b. Utilization infrastructures
   c. Flood Control Infrastructures

These models are made using four components river performance: (1) River/shortcut/Floodway (RSF), (2) Conservation Infrastructures (CsI), (3) Utilization Infrastructures (UtI), (4) Flood Control Infrastructure (FCI). All components above are an indicator of the performance assessment of the river and rivers infrastructures. Assessed component of river/shortcut/ floodway need sub component for detail of assessing. The purpose of making the sub-component are to describe the performance in more accurate. For example the sub component of the river/ shortcut/floodway consist of: (1) River side slope (RSS), (2) River bad slope (RBS), (3) Riparian Quality (RQt), River Index Disturbance (RDt). Component and sub-component which is rated the performance using a standard criterion as guidance. The explanation of the model components and sub-components as indicators and criteria in judging the performance of the river presented at Table 2. Indicator, Weight Performance and Criteria.

As mentioned on the methodology that the assessment of river and river infrastructure is done by giving a weight each component of river and river infrastructure. River and river infrastructure performance is the combination of the percentage of the weight of the function and the condition of both river and river infrastructure. The purpose of giving the weighting factor is to provide the level of interest in accordance with the judging measurement function of the river and river infrastructures. Weight of the river and river infrastructures can be different that depend on the degree of interest function of the river and river infrastructures. The method of calculating the weight using hierarchy analytical process provides the possibility to distinguish the level of importance of the indicator compared to other indicators.

Total weight for the entire assessment of performance as a function of the drainage river is 100 %. The result of the calculations of weights for each component is: (1) River/shortcut and floodway 39%, (2) Conservation Infrastructures 6%, (3) Utilization Infrastructures 11%, (4). Flood Control Infrastructure 44%.

The calculation results of weighted indicator in the model stated that the two indicators are dominant in the measurement of the river infrastructure performance as the drainage system. It indicates that the river/shortcut/ floodway and flood control infrastructure components is more important. Both of two components have high effect in the river as a function of the drainage system. Instead of two components that are not sensitive is the Conservation Infrastructures 6%, while Utilization Infrastructures is only 11%.

Calculation of weights for each component then detailed for sub components. A weighting factor in the component river streams/Shortcut/Floodway is grouped into 4 sub-indicators with the results weighted as follows: River Side Slope (7%), River bad Slope (9%), Riparian Quality (11%) and River Index Disturbance (12%). The weighting calculation in the model is described the Quality and River Riparian Disturbance Index states that more influence to the river functions. Weights calculation result for all components and sub-components in the model of the river assessment is presented in Table 2 column (3) and (5).

Table 2 Indicator, Weihgt Performance (WP) and Criteria

Referenc e Number	Indicator	WP (%)	Sub-Indicator	WP (%)	Criteria (physical and function condition)
1	2	3	4	5	6
1.	River/shortcut/flood way (RSF)	39			Draining properly and good physical condition
1.a.			River side slope (RSS)	7	Land slide stability of river and side slope in draining water
1.b.			River bad slope (RBS)	9	River bad stability and sediment transport
1.c.			Riparian Quality (RQt)	11	Riparian changes quality of natural condition
1.d.			River Index Disturbance (RDt)	12	Disturbance level by human and animal
2.	Conservation Infrastructures (CsI)	6			Flow conservation / erosion and sedimentation control at the river bad
2.a.			Sediment control structure (SCS)	2	Total volume erosion and aggradation
2.b.			River bad stabilization structures (RBS)	4	The stability of the slope of the river bad
3.	Utilization Infrastructures (Utl)	11			Retrieval and Utilization of river water
3.a.			Free Intake (Fin)	1	Service water discharge
3.b.			Weir (Wi)	3	Setting the water level and water discharge
3.c.			Supply Reservoir (SRv)	4	the amount of water supply
3.d.			Pumping installation (Pum)	3	Pumping of Water
4.	Flood Control Infrastructure (FCI)	44			Control of water damage
4.a.			Levee (Lev)	11	Protection of flood
4.b.			Revetment/Lining (Rev)	4	Strengthening Slope stability
4.c.			River banks Protection. (Masonry/ Concrete)	5	Protection of landslides and slide erosion
4.d.			Krib	4	Guiding the flow and protecting the slide
4.e.			Groins/Jetty (Gro)	4	The ability to guide the flow
4.f.			Side Spillway (SSw)	4	Dividing water
4.g.			Flow Regulation structure (FRS)	5	Regulating water
4.h.			Flood Control Reservoir/Detention/ Retention area (FCR)	6	Regulating peak discharge
4.i.			Hydraulic Monitor Equipment (HME)	3	Recording discharge
Total(%)		100		100	

The research result on four rivers shows that that the river performance of Pepe is 73.87 % while the rivers Dengkeng, Jlantah, Samin are 60.53%, 77.31%, and 87.78%. The result shows that the river performances do not have all similar components and sub components. River Pepe calculate score based on 4 components as a result of 9 sub components. The river dengkeng is assessed based on measured 4 components but not exactly similar in 9 sub-components. While Samin river only measured from 3 components of 8 sub-components, and the last is Jlantah rivers measured 3 components of 10 sub-components.

No one of 4 rivers that assessed using all standards sub components in the model developed. Jlantah and Samin rivers are only using 3 components. Jlantah and Samin used different sub components assessment indicator. With the difference in components and sub-components of the standard weighting in the model it is necessary to adjust the weight becomes relative weights. That particular weight is only valid in the rivers reach were assessed. The assessment was used the specific weight.

If one the component is not complete and needs correction of weights, the standard of weight should be distributed into the other component groups concerned. If the rivers assessed do not have the score of a component, the weight of these components is distributed proportionally to each sub-component. In accordance with the method of performance assessment, the final result of the 4 river as a river's are presented in Table 3.

Table 3. The River Assessment of Pepe, Dengkeng, Jlantah and Samin Rivers

No	Component	Sub Component	Stand. Weight (%)	Pepe River			Dengkeng River			Jlantah River			Samin River		
				Avg Score	Relative Weight (%)	Performance (%)	Avg Score	Relative Weight (%)	Performance (%)	Avg Score	Relative Weight (%)	Performance (%)	Avg Score	Relative Weight (%)	Performance (%)
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	**River (PDR)**		**38.9**		**38.9**	**25.4**		**38.9**	**27.6**		**41.2**	**33.1**		**43.8**	**37.5**
1.1		Riverside Slope (RSS)	7.1	2.0	7.1	1.6	3.6	7.1	2.8	6.7	7.5	5.6	7.4	8	6.5
1.2		River bad Slope (RBS)	8.8	6.2	8.8	6	7.2	8.8	7.1	7.2	9.4	7.5	7.7	9.9	8.5
1.3		Riparian Quality (RQt)	10.6	6.7	10.6	7.8	6.7	10.6	7.8	7.7	11.2	9.5	7.5	11.9	10
1.4		River Index Disturbance (RID)	12.4	7.2	12.4	9.9	7.2	12.4	9.9	7.2	13.1	10.5	8.1	13.9	12.5
2	**Conservation Infrastructure (Poc)**		**5.6**		**5.6**	**3.9**		**5.6**	**2.8**		**0**	**0**		**6.3**	**5.5**
2.1		Sedimen Control Structure (SCS)	1.4												
2.2		River Bad Stabilization (RBS)	4.2	6.3	5.6	3.9	4.5	5.6	2.8		0	0	7.9	6.3	5.5
3	**Utilization Infrastructure (PoU)**		**11.1**		**11.1**	**10**		**11.1**	**7.7**		**11.8**	**7**		**0**	**0**
3.1		Free Intake (Fin)	1.3												
3.2		Weir (Wi)	3.3	8.1	11.1	10	6.2	11.1	7.7	5.3	11.8	7			
3.3		Supply Reservoir (SRv)	3.9												
3.4		Pumping Station (PSt)	2.6												
4	**Flood Control Infrastructures (PoF)**		**44.4**		**44.4**	**34.6**		**44.4**	**22.5**		**47.1**	**37.3**		**50**	**44.8**
4.1		Levee (Lev)	10.6	7.7	16.3	13.8	5.7	19.3	12.2	7.2	16	12.8	8.1	18.8	17
4.2		Revetment/Lining (Rev)	4.0	7.1	15.1	11.8	5.9	7.3	4.8	6	13.4	8.9	7.9	7.2	6.3
4.3		Riverbank Protection (RbP)	5.0	6.2	13.1	8.9	5.4	9.2	5.5				8.2	9	8.2
4.4		Krib - (Kri)	3.7							7.9	17.6	15.5	8.1	6.5	5.9
4.5		Groins/Jetty (Gro)	3.6												
4.6		Side Spillway (SSw)	3.9												
4.7		Flow Regulation structure (FRS)	4.8				4.8	8.7					8	8.5	7.6
4.8		Flood Control Reservoir (FCR)	5.8												
4.9		Hydologic Monitor Equipment(HME)	3.0												
	Sum		100		100	73.87		100	60.53		100	77.31		100	87.78

By using the calculation in Table 3, it can be concluded that the first priority is the improvement in the river with weak performance is Dengkeng River. Priority repairs / maintenance in Dengkeng river can be seen from the low average scores on the respective sub-components. The lowest scores on the river Dengkeng is on the River side slope 3.6 of 9. The lowest score is because that the river bank is situated on black clay so that it is unstable and may not have function properly. Second lowest score is in the river bad stabilization score which only have 4.5 of 9. This score represents many groundsills at downstream of the bridge and the river bad is fail to protect river bad due to physical damage.

The performance assessment is useful in determining the ranking of repairing and maintenance of rivers and river infrastructure. Further analysis can be performed with scores determination to assess the sub-components as an indicator condition that requires improvement. The weakness of this model is the implementation of the assessment system is still highly subjective judgment in defining the scores. Assessment on the field by field personnel needs specific training to standardize the perception giving a score on each river infrastructure function and condition. Furthermore, in order to simplify the applied of assessment method, it needs to make cards describing the condition of river and river infrastructure which is appropriate with the capability field officers.

4. Conclusion

Based on developed model and trials assessment of river performance test at rivers Pepe, Dengkeng, Samin and Jlantah found that the river performance model that developed can help to make priority maintenance order. This result points out that the first priority of rehabilitation or a special maintenance program to restore the drainage function is Dengkeng River.

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