International Journal of GEOMATE, Nov., 2017, Vol.13, Issue 39, pp.46-53
Geotec., Const. Mat. & Env., ISSN:2186-2990, Japan, DOI: https://doi.org/10.21660/2017.39.98214

DEVELOPMENT FLOW DURATON CURVE FOR CRITICALITY ASSESMENT OF RIVER BASIN APPLIED AT THE UPPER CITARUM RIVER BASIN, INDONESIA

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*Corresponding Author, Received: 13 April 2017, Revised: 06 May 2017, Accepted: 20 June 2017

ABSTRACT: A river basin is a landscape unit in which a hydrologic cycle completely occurs in every respect. River basins, initially healthy and natural, are slipping into critical conditions, affected by urbanization processes. Hydrologic imbalance happens due to land-use change resulting in increased runoff and reduced soil infiltration capability. The change of a river basin from a fine healthy hydrologic condition into a critical state is shown by flow duration curve and its least square line. Having been applied at the Upper Citarum river basin using ArcSWAT hydrologic model and SWAT-CUP calibration program, the curves could map the health range of the river basin showing wheather the river basin was heading towards a critical condition. Based on modeling of FDC on natural and fully utilized condition, the criticality feature is the increase in high flow and decrease in low flow. The upper Citarum river basin was in criticality process which shown by high flow increases and low flow decreases over the period 1981-2010. Using model of FDC's gradient, the criticality value of the period 1981-1986 was 3.15 and it increased to 3.35 in the period of 2005-2010. The increase is correlated with land use change in increasing settlements, dry crops, barrenland, and forest decline.

Key words: Land use change, River Basin Criticality, Hydrologic Imbalance

1. INTRODUCTION

Across the world human development is a major factor in changing the character of a river flow. It affects the hydrologic conditions of a river basin which is reflected in the characteristics of the streamflow [1] [2]. However, change of land surface due to human activities strongly correlates with the changing character of a river flow [3]. Human development activities dynamically link with urbanization processes in a river basin. Urbanization increases impermeable areas causing increases runoff and reduces the soil's ability to absorb water and therefore affects groundwater recharge and base flow conditions [4].The process works in line with changes in impervious areas in river basins [5]. Impermeability due to land cover change is an important parameter in urban areas that affect flow patterns so that the impact of land cover change can be represented by the degree of impermeability [6].

Change in land use will increase impervious cover and reduces vegetation intensity in river basins, which further causes interference in natural hydrologic. The process is reflected in the change of response of a river basin in transforming rainfall into runoff which the pattern could be indicator of hydrologic criticality in a river basin.

The criticality refer to situation where emerging environmental degradation may lead to loss capabality to survive. Much of the change inflicted by human pressure on the environment may impose cost on future generations that must be included in approach to endangerment and criticality [7]. The Critical environment condition is a situation where widespread increase of environmental degradation prevents sustainable human utilization of the environment that further causes a disturbed health levels requiring adaptive measures and specific capacity response.

Hydrologic criticality in river basin is part of the criticality of environment. Therefore, it is important to understand the process of criticality relating to hydrologic imbalance in a river basin which caused by the effect of land use change.

The flow duration curve (FDC) is an important tool to understand how the river basin runoff response due to land use change [8]. FDC is also useful to describe the daily flow in the context of long-term planning [9]. It is also an easy method to show the range and change in flows due to various land use changes. Therefore, by constructing 2 FDCs in one graph, this method can be used for analyzing pre- and post changes in flows by reviewing shifts that allegedly were caused by the change in land-use [10]. Changes of FDC, due to the land use changes effect could be used for assesing a river basin criticality. Based upon problem statement, the research objective was to develop Flow Duration Curve for assesing hydrologic criticality in river basin due to land use change.

2. MATERIALS AND METHOD

2.1 Data and Location

The research was conducted in Upper Citarum river basin, in West Java Province Indonesia where Bandung City, Bandung Regency and West Bandung Regency are located and known as the Bandung Metropolitan Area. Upper Citarum river basin spans an area of approximately 175,000 hectares with Citarum River as the main river flowing from east to west through Nanjung outlet (see figure 1). The research used observed daily rainfall and daily streamflow data of 1981-1986, 2005-2010 and land use conditions of year 1986 and 2010.

Table 1 Landuses change 1986-2010 in %

Land Uses	1986	2010	change
Settlement	13.9	18.7	+
Bush	19.2	7.0	-
Estate	4.6	5.4	+
Forest	17.2	13.4	-
Dry crop/ Barrenland	14.3	25.9	+
Rice	30.3	29.2	-
Water	0.5	0.3	-
	100	**100**	

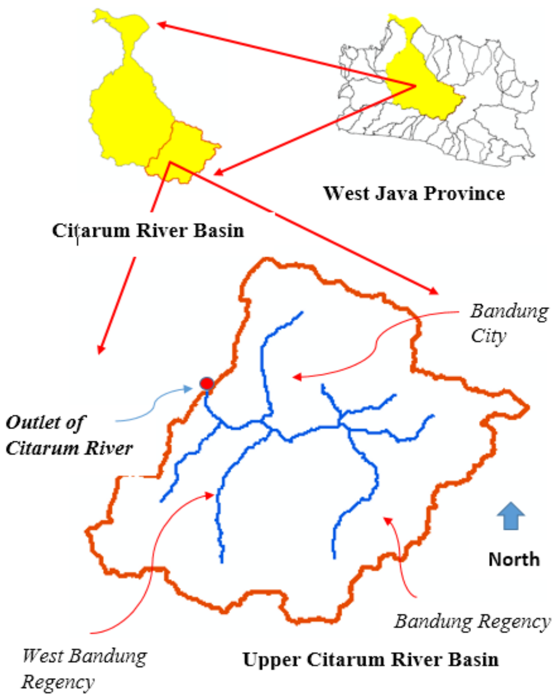
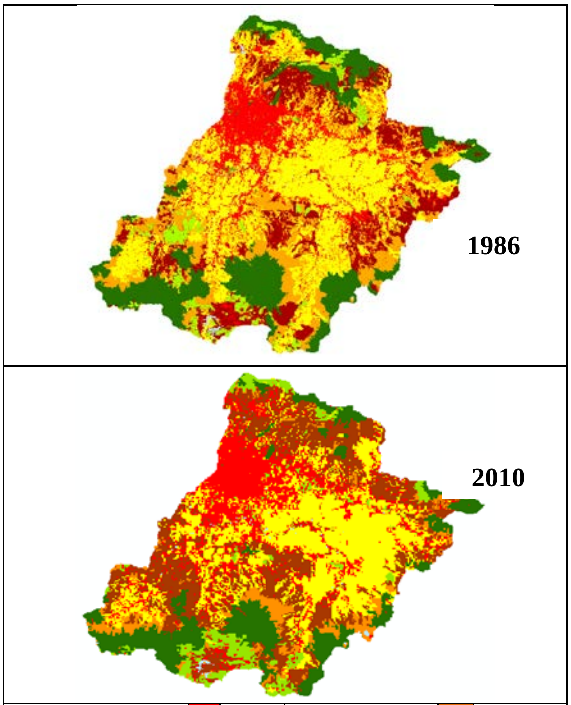


Fig.1 Upper Citarum river basin

The land-use changes in figure 2 and table 1 show an increase in settlement, dry crops, estate, barrenland and a decrease in forests, rice fields and bush. Changes in land use in the period 24 years is a reflection of the increase in impermeability that will be the basis of hydrologic modeling to understand the behavior of stream flow changes.



Settlement		Forest	
Bush		Rice	
Estate		Water	
Dry crop/ Barrenland			

Fig.2 Landuse 1986 and 2010

2.2 Develop Health Range Of The River Basin Based On Extreme Land-Use

To analyze the critical pattern of a river basin involves mapping a range bounded by two limits each representing extreme land use condition. The first limit is the extreme condition when the river basin is still in a natural state without any significant land use change caused by human activity. The second limit is the extreme condition when the entire river basin area is in a maximum full utilized condition due to human activity.

A river basin in its natural condition without impact of human activity has the most natural hydrologic cycle. In contrast when a river basin is in fully utilized condition due to urbanization which the hydrologic cycle is in a disturbed stage. The two conditions creates health ranges of river basin spanning from the healthiest status to the most criticality. The river basin criticality ranges can be seen on Fig. 3.

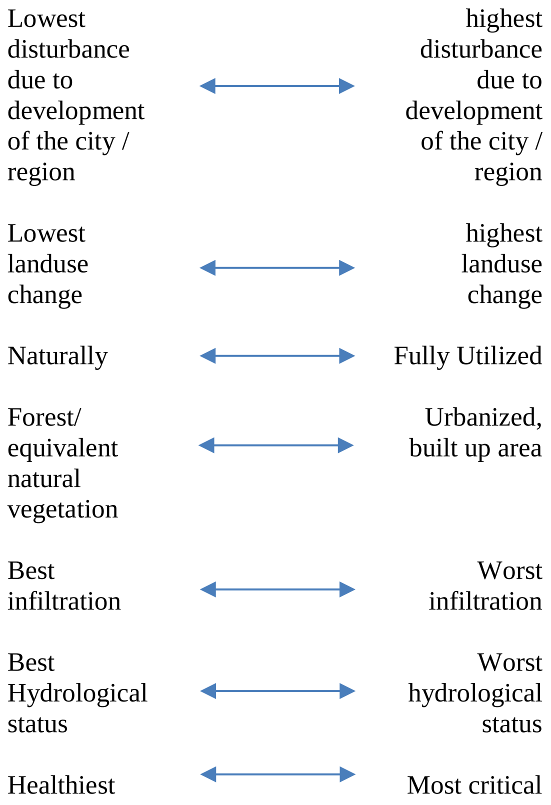


Fig.3 River Basin Criticality Ranges

2.3 Develop FDC and its Least Square Line

FDC describes flow regimes in relation to frequency showing exceedance probability. FDC is influenced by rainfall patterns, size and physical characteristics of a river basin, water resource development and land use [11]. FDC is a stochastic representation of the variation is due to run off the transformation of rainfall which is affected by the physical character of the watershed [12].

The formula of FDC is as follows: [8]

$$F = 100\frac{\mathrm{R}}{\mathrm{N}+1} \qquad (1)$$

where:

F = frequency of occurrence, expressed as a percent value and will be equal to or exceed
R = the rank
n = the number of data

For analysis FDC curve in frequency is divided into intervals in several categories, or zones. FDC is divided into five zones representing high flow in the interval of 0 to 10%, wet conditions at intervals of 10 to 40%, the flow of the middle (mid range flow) at intervals of 40% to 60%, dry condition at intervals of 60 to 90% and, low flow at intervals of 90% to 100% [10].

Further, a trend line of the FDC can be drawn using the least squares line so a single numerical value is obtained based on the value of the gradient line. This value represents the streamflow as the river basin's response to its physical characteristics and land use status, which is a form of transformation of rainfall into runoff after having passed the river basin surface through the hydrologic process. The lines and gradient shifting over land use change can be used as indicators of the river basins health level or its criticality level condition.

2.4 Modeling, Calibration & Validation

To formulate, the health ranges of river basin, requires hydrological modeling using ArcSWAT. The hydrograph as output of model after having calibrated, validated afterward was converted to FDC and least square lines .

2.4.1 Produce Hydrograph Usung ArcSWAT

ArcSWAT is the development of the SWAT GIS-based model. SWAT stands for Soil and Water Assessment Tool, a river basin-based model developed by the USDA (United States Department of Agriculture). SWAT was developed to predict the impact of water management, sediment, agricultural chemical yields at river basin scale with variations in soil type, land use, and management conditions over long periods of time. SWAT is a physically based, semi-distributed, continuous time model operating on a daily time step at basin scale as well as subbasin [13].

ArcSWAT uses a digital elevation model (DEM) to delineate river basin boundaries and splitting into subbasins, using hydrologic response unit (HRU) as transformation mechanisms rainfall into streams and based on curve number methods.

The formula of water balance in ArcSWAT is as follows:

$$SW_i = (SW_o + R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw})_i \qquad (2)$$

Here:

t = the time in days
SW = ultimate value of water conditions on the ground (mm)
SW_o = the initial value of the water conditions on the ground (mm)
R_{day} = the amount of rainfall in a single day (mm)
Q_{surf} = The amount of evapotranspiration in one day i (mm)

E_a = The amount of evapotranspiration in one day i (mm)

W_{seep} = the amount of water entering the vadose zone in one day i (mm)

The ArcSWAT model produced a hydrograph for the periods 2005-2010 and 1981-1986 showing the hydrologic processes that had occurred in the river basin, using observed daily rainfall and discharge data of 1981-1986, 2005-2010, land use conditions of 1986, 2010, including soil type and slope.

2.4.2 Calibration and Validatiom Using SWATCUP

SWATCUP SUFI-2 (sequential uncertainty fitting type 2 version) program was applied for calibration of the SWAT model for this research. This program allows for analyzing uncertainty that might occur in the structure of the model and data input errors. More detailed explanation is given in [14]. Eighten hydrologic parameters were used for modelling. However initial range values of parameters were used as referred to the SWATCUP user manual

Further, the period 1981-1986 and 2005-2010 were calibrated. Sub period 1981-1986 to predict the river basin in its most natural condition and sub period 2005-2010 to predict the river basin in its most critical condition. To calibrate and validate a split sample test was carried out to devide evenly the duration of each sub period.

Calibration and validation results are shown in table 2 and table 3. Calibration and validation values meet the requirements for use with of value NS, R2. Adequate level of coherence between simulation and observation curve shape appears on the similarity of the two curves (see figure 4 and 5)

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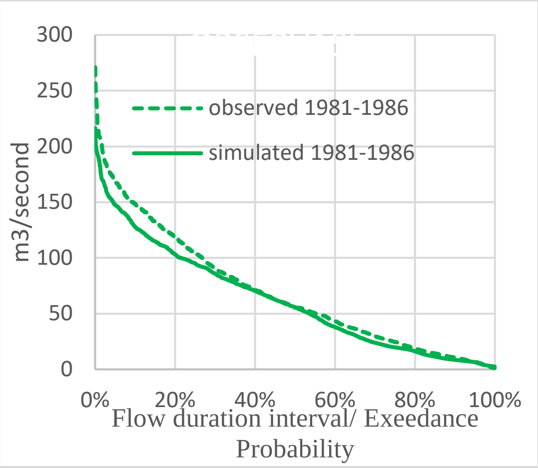

Fig 4 FDC simulation-observation of period of 1981- 1986

Table 2 The Best value parameters of calibrated

Parameter	Period	
	1981-1986	**2005-2010**
v__ESCO.hru	0.99	0.80
v__EPCO.hru	0.03	0.13
v__CANMX.hru	50.30	51.70
v__SOL_BD().sol	24.20	12.59
v__SOL_K().sol	0.65	0.46
v__SOL_AWC().sol	470	1030
v__SHALLST.gw	40850	22950
v__GW_DELAY.gw	20.5	0.50
v__ALPHA_BF.gw	0.95	0.35
v__GWQMN.gw	2895	4755
v__GW_REVAP.gw	0.13	0.17
v__RCHRG_DP.gw	0.14	0.20
v__CH_K2.rte	50	402
v__CH_N2.rte	0.1	0.01
v__REVAPMN.gw	24.5	483.5
v__SURLAG.bsn	464.50	13.10
v__CNCOEF.bsn	0.98	1.02

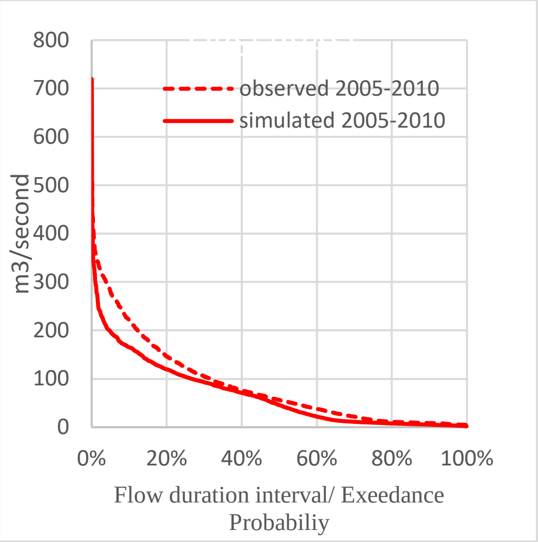

Fig 5 FDC simulation-observation of period of 2005-2010

Table 3 Calibration-Validation Performance in sub period 1981-1986 and sub period 2005-2020

1981-1986 period			
Calibration		Validation	
1981-1983		1984-1986	
NS	0.53	NS	0.41
R^2	0.6	R^2	0.5
2005-2010 period			
Calibration		Validation	
2005-2007		2008-2010	
NS	0.4	NS	0.6
R^2	0.49	R^2	0.64

3. RESULTS

3.1 Long Term Criticality Range Using FDC

River basin in natural condition is assumed that it is at its best infiltration capacity otherwise a river basin in fully utilized is assumed when it is at its worst infiltration capacity. These could be represented with FDC using Curve Number method [15] lowest value in 30 represent a pristine forest and highest value in 98 represent built up area.

For this purpose, the modeling was performed using ArcSWAT based on calibration of 2005-2010, 1981-1986 period simulation. The result are two curves extreme FDC representing river basin in naturally conditions and at fully utilized condition , as seen in Figure 6. The curves represent long term river basin critical ranges.

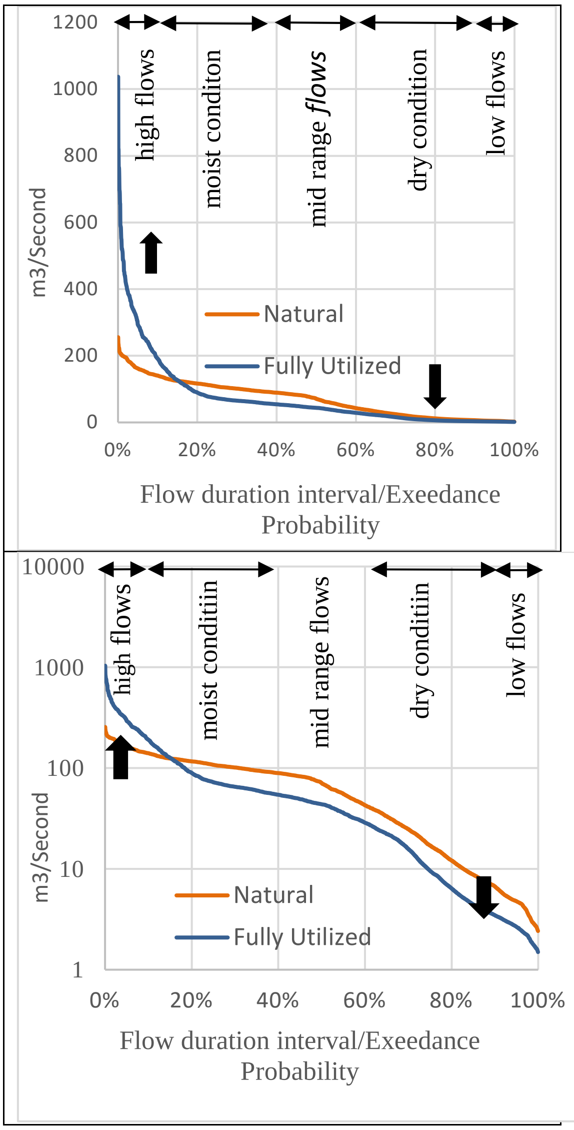

Fig. 6 Long term river basin critical ranges based on FDC's natural and fully utilized in normal and log scale

Based on the pattern of two FDC extreme curves, a visible difference showed between the curve in natural condition and the curve in full utilized condition, where the head of the full utilized curve was fatter and wider than the natural condition curve, whereas the tail end was thinner. The inflection point was in the range of 15% percentile when high flow and low flow were 0 to 15% where the full utilized curve line was far above the natural curve line.

While in contrast in the range between percentile 15 % to 100% it was in the reverse position. When analyzed on logarithmic graph for more sensitivity in low flow shifts, it showed also that the lowest value point of the full utilized curve was lower than that of the natural curve.

The slope of FDC can be represented by trend line line using least square method. With this method, the criticality status can be represented only on a single value based on the gradient line.

Using least squares line, the natural and fully utilized FDC's were converted into two trend lines forming a range of gradient values that consisted of all possible gradient values that had ever occurred or will occur. Changes in gradient values can be considered representing the changes of the river basin's health or criticality status in long term due to land use changes.

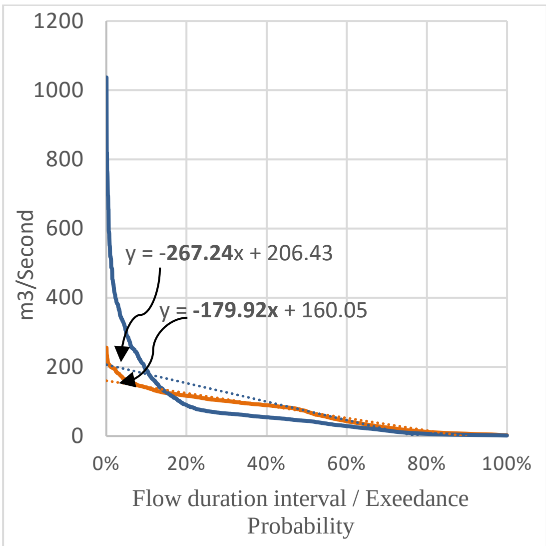

Fig. 7 FDC's natural-fully utilized converting to trend line by least square method

3.2 Position of Short Term Periods on Long term Criticality Ranges

Comparing the FDC on 1981-1986 period with FDC on 2005-2010 period showing a similar pattern to the FDC's in natural and fully utilized condition. They both showed increased high flow and decreased low flow over time. It means that the changes from 1981-

1986 to 2005-2010 in short term was part of the changes in the long-term health of the river basin. If the symptom of increased high flow and decreased low flow can be considered as a declining process it means that the river basin in is changing into a critical condition**.**

When the least square lines of land use of 1986 (1981-1986 period) and of 2010 (2005-2010 period) were positioned at the least square lines of natural-full utilized condition, their relative position at the long- term range showed up. The gradient values are shown in table 4. It shows an increasing value proportional to the age of the older. The 1986 's land use represented by gradient value 3.15 and the 2010's land use represented by gradient value 3.35. The future curve and its gradient could represent future critical values to be in the range of 3.35 to 10

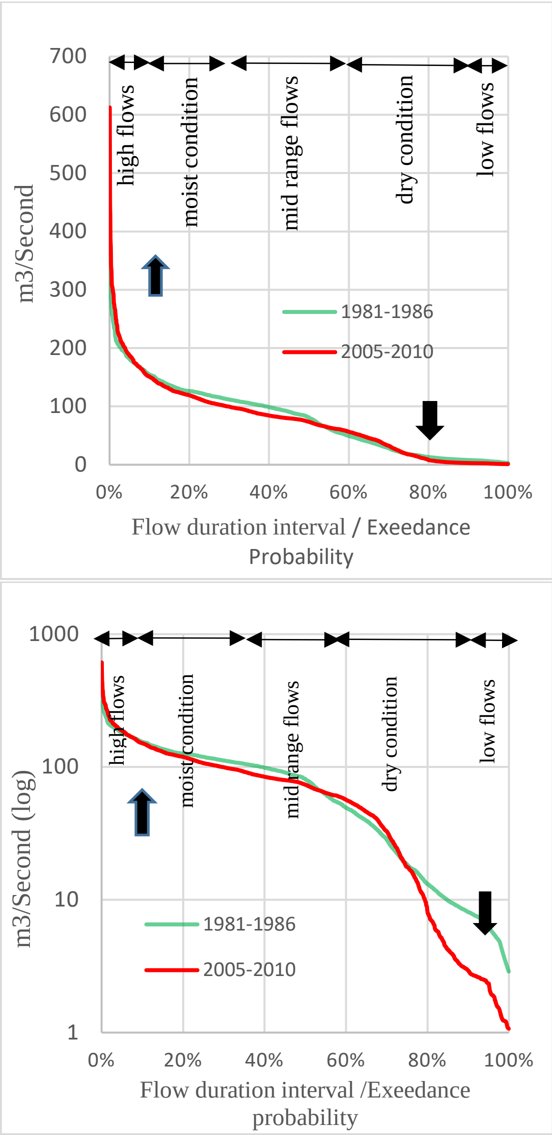

Fig. 8 Short term River Basin Critical Ranges based on period of 1981-1986 until period of 2005-2010

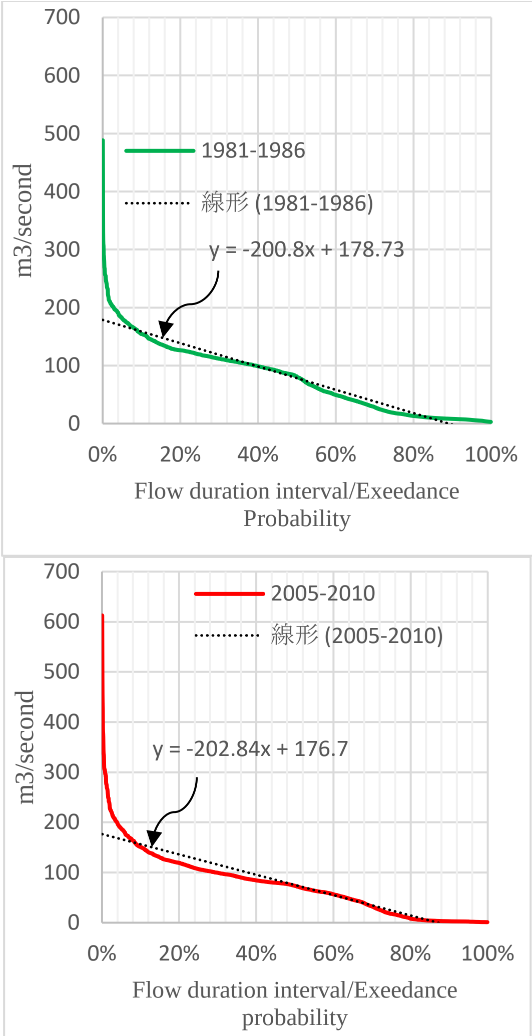

Fig. 9 FDC's periods converting to trend line by least square method

Table 4 Gradient Value as indicator of criticality level

FDC Status	Trend line gradient	Scaling 1-10
Fully utilized	-267.2	10
2005-2010 period	-202.8	3.35
1981-1986 period	-200.8	3.15
Natural	-179.9	1

4. DISCUSSIONS

The criticality assessment method formulated based on the streamflow as a function of rainfall, land use and physical river basin characteristics. Applying the ArcSWAT model, the rainfall variables were manipulated so as to have similar affects. The model after being calibrated by

SWATCUP could show the correlation land use change and streamflow change.

The hydrograph as a result of model, after converted to FDC were able to map the long term ranges of the river basin at its healthiest condition as well as at its most critical. The change from the healthiest condition to the most critical condition is characterized by increasing in high flow and decreasing low flow.

However the criticality pattern of upper citarum river basin as measured on sub periods 1981-1986, 2005-2010 using FDC have identical patterns with a ranges of long-term criticality based on FDC"s natural and fully utilized

It corresponds with the statement of Increasing high flow means increasing run off and decreasing low flow means a disturbed in base flow, and the proccess works in line with changes of impermeability in river basin [4] [6]. Therefore, this criticality ranges using FDC complies with scientific theory requirement to be further developed into a criticality diagnostic framework.

By using FDC least square lines, long-term criticality ranges is simplified by the existence of two lines with the largest and smallest gradient representing the most critical watershed conditions and healthiest. When the least square lines of 1981-1986 period and 2005-2010 period were positioned at the ranges, the 2005-2010's least square line gradient was highest than 1981-1986's. It means the higher gradient indicates the higher value of critical condition so that the values of gradient can be considered as indicators of criticality.

Looking closer table 4 show a pattern of shifting gradients comparable with the time range of the period that formed it. The position of the 1981-1986 and 2005-2010 of periods show the criticality pattern that had happened within the range and left the future critical range at gradient 3.35 to 10.

In the future, the range of values 3.35 to 10 become the possibility of continuation critical condition when the change in land use continue , however there should be a threshold value within the value range of 3.35 to 10 as a sign that the increase in the change in land use must be stopped for reasons of disaster risk. Identification of threshold values require further research

The critical or health range of a river basin, using FDC and its least squares line was able to describe an orientation travel path of the river basin's development from its healthiest to its most critical condition (unhealthy) that had ever happened or will happen. Therefore it can become as diagnostic check to see whether the shift in land use will or will not head towards the critical condition of the river basin.

Analysis using FDC and least squares line can be used to assess a river basin's critical condition caused by the growth of city / region affecting land use change. The model could be developed using scenarios of future rainfall with future land use base on spatial plan.

This method should become a preliminary to diagnose the critical condition of a river basin and needs to be further eloborated by more in-depth analysis. This approach is simple and easy to understand and contains important information for decision-making in planning and river basin management. It could be applied in developing countries with limited hydrologic data. The research results can become input for the evaluation of policy on integrating regional development, spatial planning with water resources aspects.

5. CONCLUSIONS

The critical process at the Upper Citarum River Basin for the long term periods and short term periods have both simillar patterns in high flow increase and low flow decrease. In short term periods of 1981-2010 high flow increase in 3% and low flow decrease in 63 %. In long term periods from river basin in natural condition to become fully utilized condition, high flow Increase in 80 % and low flow decrease in 44 %.

This result is in line with the theoretical statements in the introduction that increased change in land use increases level of imperviousness which further causes hydrologic imbalance as referred to in the theoretical statement.

Short-term critical range when positioned in long-term critical range showed the relative position of the existing river basin's critical status either in future or thepast. Increasing the criticality value from 3.15 to 3.35 correlated with the increase of 81% mixed crops and barrenlad, 35% increase in settlements and 22% forest decline.

Critical relative position showed a road map for further conditions where future change in critical status will be in proportion with future change in impervious cover.

6. ACKNOWLEDGEMENTS

The authors wish to thank to the Greater Basin Territory Centre of Citarum and the Center for Water Resources Development, Bandung Institute of Technology for supporting the data and we would like to thank all whom involved directly and indirectly in completing this paper.

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