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# Hydrologic Alteration in Watershed Using Flow Duration Curve, Case Study Upper Citarum Watershed, Indonesia

Hadi Nurcahyo [1 +], Indratmo Soekarno [2], Iwan K. Hadihardaja[2], and Arief Rosyidie[1]

1 School of Architecture, Planning, and Policy Development, Institut Teknologi Bandung, Indonesia
2 Faculty of Civil and Environmental Engineering, Institut Teknologi Bandung, Indonesia

**Abstract.** Watershed is the basic unit of landscape particularly to assess hydrological processes. Urbanization and agricultural activities influence landscapes that affect hydrological processes through water demand and uses of space in the watershed. Utilization of space and water by human activities in watershed can alter the composition of the water through increasing the runoff, reducing the flow into the ground and in some cases, move the ground water, into runoff.
Human affect hydrological processes due to: (i) the need of water for domestic and commercial activities whether to use ground water and surface water (ii) the need of space for living, activities, which implicate converting natural vegetation into built up area, which improved impervious area, lessen the soil's ability to infiltrate and absorb water, and thereby reduce groundwater recharge that affects the base flow.
The river is where the accumulation of runoff, waste water from urban activities which is also affected groundwater through seepage from the aquifer, thereby, any changes on watershed as human activity will be reflected in the character of stream flow.
The paper is a part of study the characteristics of streamflow, in relation to hydrological alteration in watershed. Research was conducted in upper Citarum watershed, Indonesia where the metropolitan of Bandung located. By using FDC (Flow Duration Curve) analysis, was able to know the changes pattern of stream flow especially in low-flow that can detect symptoms of a decrease in capacity of base flow due to changes in land use in the upstream area as well as an increasing a return flow due to the impact of the withdrawal of groundwater as result urban activities.

**Keywords:** Flow Duration Curve, Stream Flow, Ground Water Discharge, Watershed Development, Hydrologi Alteration, Urban Activities

## 1. Introduction

Urbanization in watershed will increase impervious area which can increase runoff, lessen the soil's ability to infiltrate and absorb water, and thereby reduce groundwater recharge that affects the base flow condition [1]. This process works in line with the increase in the proportion of impervious area in the watershed [2]. Hydrological alteration on watershed was reflected in the character of stream flow and Human development is clearly altering the natural characteristics of streamflow around the world [3], [4].

However, others believe urbanization may stabilize or increase base flow due to leaks from water infrastructure and septic systems [5] as well as decreases in evapotranspiration which result from replacing vegetative cover with impervious surfaces. Many studies have focused on analyzing the relationship between impervious cover or other land use changes to hydrologic alteration without considering other effects such as reservoir storage and water withdrawals [6], [7]. There is little question that water withdrawals and discharges will have an impact on the amount of water in a basin. In fact, many models directly calculate water availability by subtracting withdrawals and/or adding discharges [8].

+ Corresponding author. Tel.: +62-818201954; fax: +62-22-252271
*E-mail address*: Hadi_Nurcahyo@yahoo.com

The Hypothesis of research is the growth of Bandung metropolitan has influenced an increasing of extraction of groundwater and also increasing an impervious area on the upper Citarum river basin and consequently affecting streamflow characteristic through increased of runoff, decreased base flow and increased of ground water withdrawal as result of urban activities.

This paper is a part of our research work on characteristics of streamflow using flow duration curve method in relation to hydrological alteration in watersheds which caused by urban development and its implication in human usages of water and increase of impervious area. Research was conducted in upper Citarum watershed, Indonesia where the metropolitan of Bandung reside on.

In previous research [9], by analyzing correlating of rainfall patterns, land use changes by flow duration curve which measured with single gauge station at outlet of watershed that conclude the change in land use on upper citarum watershed correlate to changes in the response of a watershed in producing runoff. However, in this paper research, we develop it, with using two gauge stations to represent the different characteristics of upstream and downstream with a focus on analyze of low flow due to changes in land use and a return flow effect due to the impact of the withdrawal of groundwater as result of urban activities.

## 2. Data and Methods

FDC (Flow Duration Curve) is a method to represent stream flow which relate to its frequency which is influenced by rainfall pattern, size and physical characteristics of the catchment, water resource development and land use [10]. FDC is an easy way to describe the range of flows and how it change due to various land use changes. This method can use "post and pre alteration" analysis by reviewing shift of two FDC that allegedly caused by the change of land uses [11].

FDC is a key tool for the sustainable management of water resources [12]. It has been used in numerous hydrological applications as a part of water resources planning and environmental studies, flood and lowflow frequency analyses [13], reservoir and sedimentation studies [14], in-stream flow assessment [15] and impacts of land use changes [16].

The benefits of using FDC is to analyze trends of eco deficit and eco surplus by comparing, natural and altered FDCs [17].Eco surplus is a condition when the FDC shifted upward while eco-deficit if FDC shifted downward. The shift can occur in a certain range whether in high flow zones, medium or low. The area under the curve line represents a total volumetric of flow, upward shift increase volumetric of flow while shifting downwards reduces volumetric of flow.

The paper uses a comparative analysis of FDCs, using data from two gauge stations daily discharge in the watershed (see Figure 1). The first on Nanjungs gauge station representing the hydrological changes that occur in the watershed as a whole. The second on Dayeuhkolots gauge station representing a catchment area of watershed on the middle and upstream. Since, the constellation positions the two gauge stations was in same river channel, the shape of FDC of Nanjung will correlate with the shape of FDC of Dayeuhkolot and it also was influenced by a characteristic of land uses on each catchment area. Nowadays, downstream areas is dominant as urban area, but in upstream areas, more developed as agricultural activities.

The FDC is formulated with the following formula:

$$F = 100\frac{\mathrm{R}}{\mathrm{n}+1}$$

F = frequency of occurrence which expressed as % of time a particular flow value is equaled or exceeded or stated as $Q_{\%}$

R= the rank

n = the number of data

The research was conducted in Indonesia, at upper Citarum watershed where Bandung City, Bandung Regency and West Bandung Regency located and known as the Bandung Metropolitan Area. Upper Citarum watershed has an area of approximately 175,000 hectare with Citarum River as the main river that runs from east to west flow out through the outlet of Nanjung (see Figure 1).

The research used daily discharge measured at Nanjung and Dayeuhkolot gauge stations on sub periods of 1981-1986 and 2005-2010 by which a long term 24 years is expected resulting a different patterns of FDC due to changes in land use and water usage, significantly.

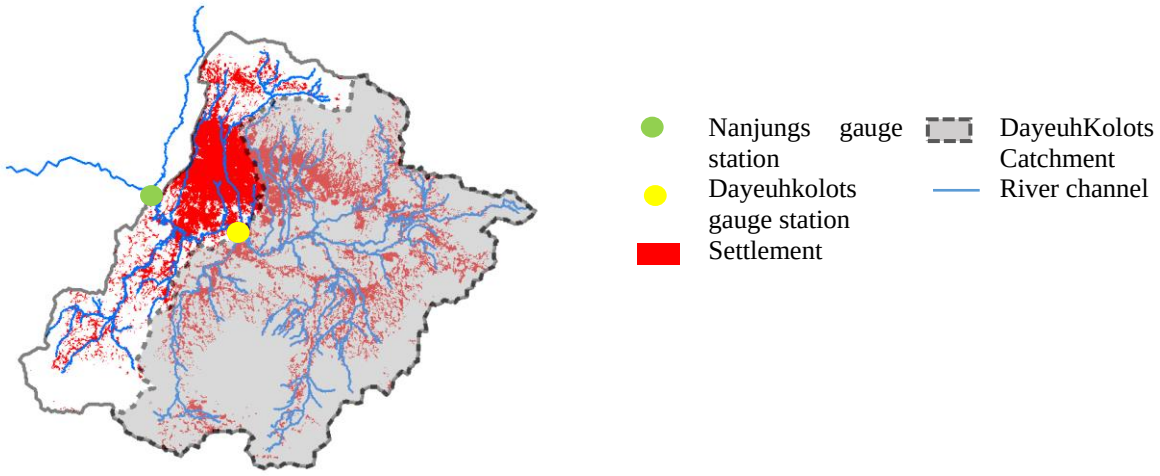



Fig. 1: Upper Citarum Watershed, catchment and sub catchment based on position of gauge station and spatial pattern of settlement of Bandung Metropolitan Area.

## 3. Results

**FDC Comparison Between Sub Periods:** By comparing FDC on sub period 1981-1986 and sub period 2005-2010 as measured in Dayeuhkolot gauge station, there had been an eco surplus in the range Q0 to Q15, and an eco deficit in the range Q15 to Q100 (see figure 2a), while on FDC measured at Nanjung's, that located further downstream had similar pattern but shifted with the increase eco surplus in broader range at Q0-Q50 and eco deficit in the range of Q50-Q100 (see figure 2 b). By using a logarithmic scale on discharge for more sensitive to the low flow measurement was obtained a different pattern between both gauge stations. (see Figure 2c and 2d). The both had a similar pattern in an increases of high flow, however in low flow, FDC of Dayeuhkolot had decreased while FDC of Nanjung conversely.

**FDC Comparison Between Gauge Stations:** Basically, the area under the line of FDC is represents of a volumetric flow of river over the sub period. For that purposes, discharge in M3/sec is converted to volumetric in M3 (see Figure 3). The extent of curve, representing a number of production of runoff and groundwater seepage due to the results of the hydrological processes**.** on watershed. Naturally, a volumetric flow of Nanjungs FDC was greater than a volumetric flow of Dayeuhkolots FDC since the location of Nanjung gauge station more downstream than Dayaeuhkolot gauge station.

If FDC of Nanjung and FDC of Dayeuhkolot were coupled in one graphic on the same sub period, it will form the difference of both (see Figure 3) which representing the difference of volumetric runoff of both. The higher the area of difference, the higher the production of runoff. Based on this, it can be analyzed increase of runoff which produced in downstream area.

By comparing the area of difference in period 1981-1986 and period 2005-2010 (see Figure 3a and 3b), there were an increase in volumetric flow with pattern extends ,widens and thicken indicating an hydrologic alteration with a different pattern between upstream and downstream which influenced by landuse changes occurred in it. Changes in land use with the dominance of settlements in the downstream area and changes in land use with the dominance of agriculture in upstream had affected the pattern of FDCs.

## 4. Discussion

Generally, the volumetric flow of Citarum river had increased based on comparing FDC sub period 1981-1986 and FDC sub period 2005-2010, that could be occur due to two causes. Firstly, as a result of changes the infiltration capacity of watershed due to changes in land uses which strongly correlated with the increase of impervious area. Secondly due to increased rainfall intensity is likely due to climate changes.

Whatever the causes of its influence. it had indicated a hydrologic alteration condition in upper Citarum watershed with different patterns between downstream and upstream area.

An increasing high flow and decreasing low flow based on shifting of FDC of Dayeuhkolot between sub periods (see Figure 2a, 2c) in line with previous research [9] which conclude the changes in land use in the upper Citarum watershed between 1986 and 2010 had an effect on streamflow characteristics. It also confirm and in line with the view of some researchers that the effects of urbanization on watershed alter the flow characteristics with improved peak flow and lower the base flow [1].

However on FDC of Nanjung, there had been anomalies which there was an increase in low flow (see Figure 2d). The condition appears and measurable in the dry season in position Q 95 with minimal rainfall (see figure 2 d). It could be caused by two factors Firstly, ground water seepage has occurred in river channel between stations of Dayeuhkolot and Nanjung. Secondly, there was an increasing a return flow due to the impact of the withdrawal of groundwater as result urban activities.

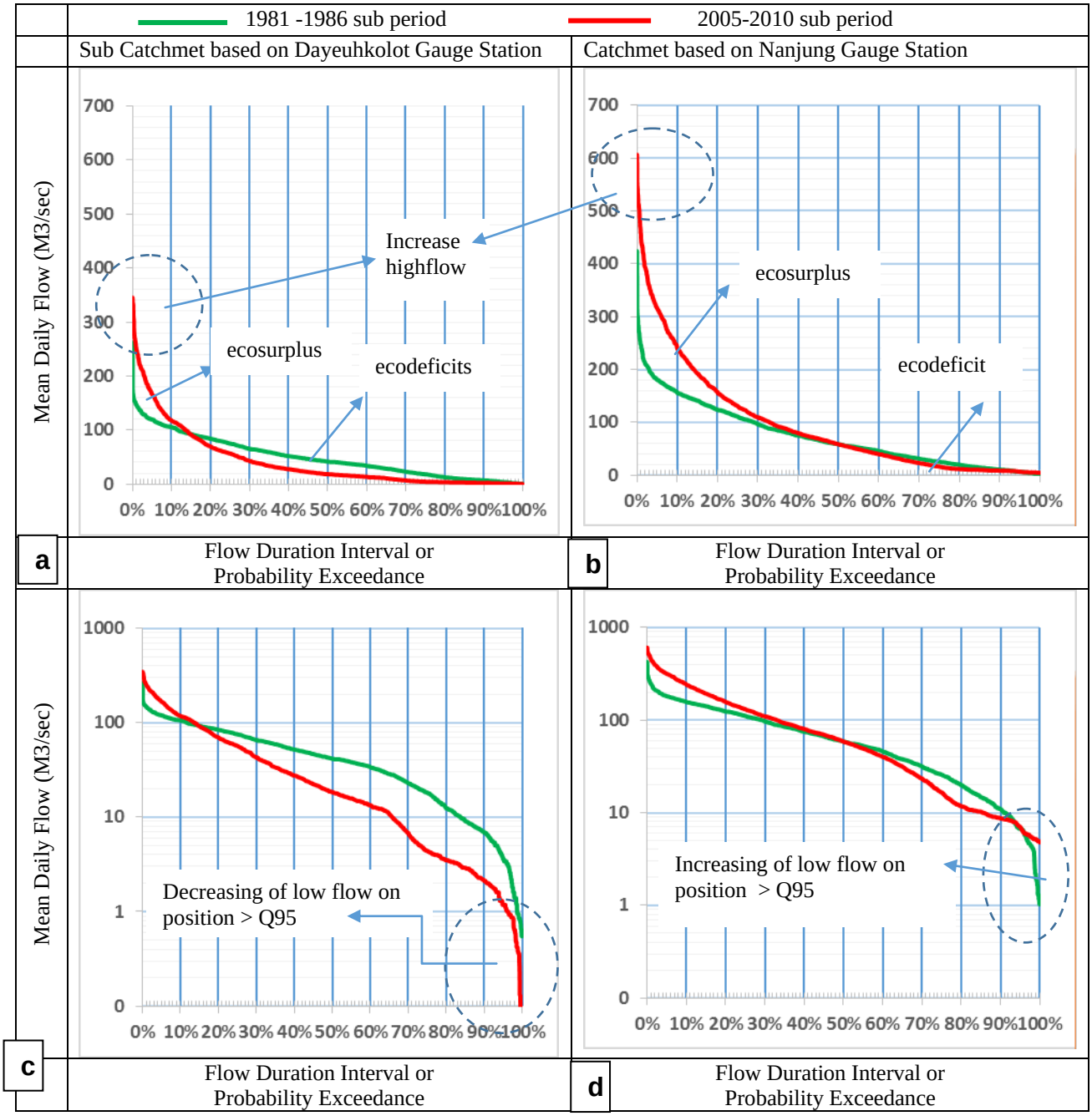
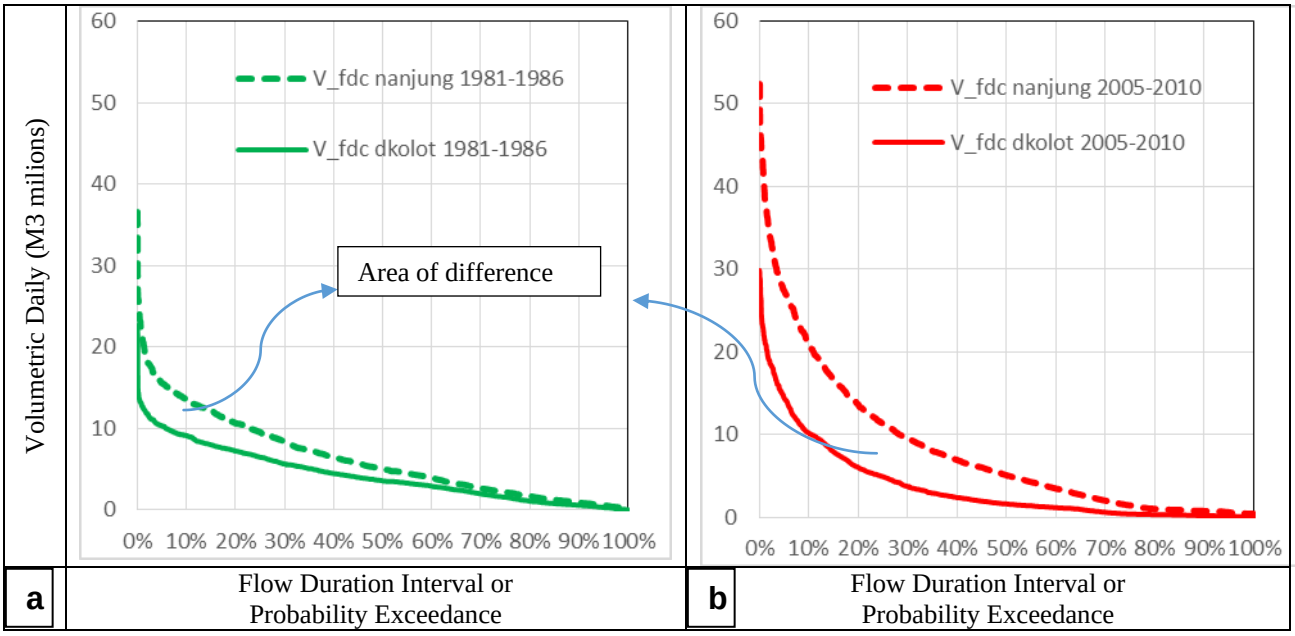



Fig. 2: FDC of Dayeukolot and Nanjung, comparing sub period 1981-1986 and sub period 2005-2010




V_FDC nanjung = FDC based on Volumetric of Nanjung Gauge Station
V_FDC dkolot = FDC based on Volumetric of Dayeuh Kolot Gauge Station

Fig. 3: FDC of Nanjung and Dayeuhkolot, comparing in same sub period, on sub period 1981-1986 and sub period 2005-2010

It is likely the increase in value at a position of more than Q95 at FDCs Nanjung is caused by the return flow resulting urban activity instead of seepage from aquifer. Nowadays the extraction of ground water in metropolitan of Bandung has increased enormously (see Figure 4). eventually having used, some of the water goes back into the body of water adding the volumetric flow of the river. The fact of withdrawal of groundwater discharges that occur in Bandung Metropolitan has a positive correlation to the analysis results.

These findings confirm the results of previous research [5], [6], [7], [8] which states the influence of discharge from groundwater withdrawal could affect to streamflow, therefore need to be taken into account in river water balance.

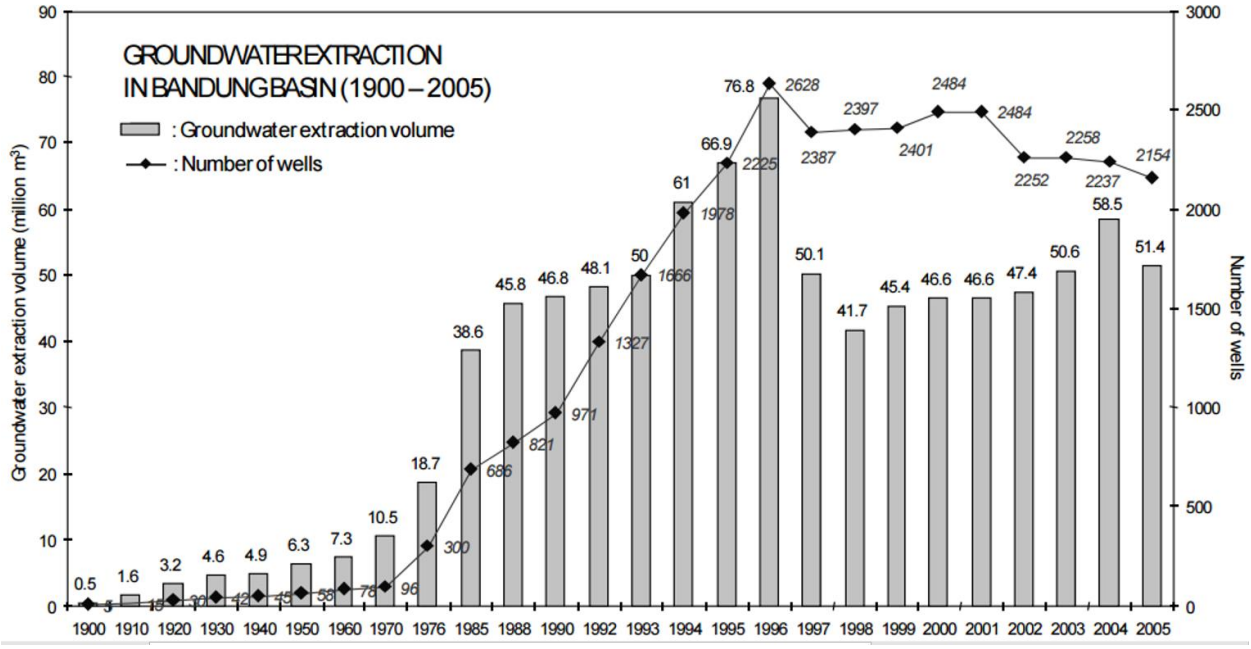



Fig. 4: Registered groundwater extraction in metropolitan Bandung (1900-2005) from the deep aquifer (40-250 m below the surface) adapted from [18].

## 5. Conclusion

FDC in analysis on two gauge stations in river channel on watershed is able to indicate a difference of streamflow characteristics of downstream and upstream due to changes in land use and effect of ground water discharge, but nevertheless it further need analyze, the possibility of seepage in the river channel to ensure that the increase in low flow caused by merely the effects of ground water discharge instead of seepage. These findings need to be confirmed by calculation of ground water withdrawal and loss of water until the water back into the water body. This approach can be accommodated in water balance formula so as the effects of urban waste water which allegedly from groundwater could be accommodated on hydrologic model.

Hydrograph based on modeling, furthermore could be converted into FDC, so that it can be known a shift pattern of FDCs in future, due to urban development with implications of increase in ground water withdrawal and the effect of changes in land use. Furthermore FDC and its modeling, could be useful as a tools for supporting policy in urban development and water resource management in upper Citarum watershed.

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