Evaluation of Natural Flood Management using Curve Number in the Ciliwung Basin, West Java

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Abstract

This paper describes the application of a Natural Flood Management approach in a tropical environment. It examines the impacts of land use changes on Curve Number as an indicator of water runoff, in the context of wide scale changes from agricultural to residential land uses. CN value is a function of soil type, hydrological conditions, land use, and Antecedent Moisture Condition (AMC). To model the formation of runoff which will later turn into flood, a Natural Flood Management approach was applied to try to improve the catchment management in the study area. The NFM approach evaluated here was to use riverside woods and strip buffers. Large changes in CN were identified suggesting the effectiveness of NFM, but such strategies have to be considered alongside social and economic factors. A number of areas of further work are identified.

Keywords: Curve Number (CN), Natural Flood Management (NFM), Ciliwung

1 Introduction

Runoff water analysis is an essential activity of water resource and flood management. Runoff is determined by environmental conditions such as slope, land use, soil type, and rainfall. In developing regions, land use change makes a significant contribution to changes in surface water because it alters infiltration and flow (Paul and Meyer, 2001). One method that describes the effect of land use on the formation of runoff is the Curve Number (CN) method. The Soil Conservation Service Runoff Curve Number (SCS-CN) is a method for estimating water runoff with a lumped model using an empirical equation to estimate system responses. CN values indicate the catchment area characteristics as a function of soil type, hydrological conditions, land use, and Antecedent Moisture Condition (AMC) (Bondelid, McCuen and Jackson, 1982). It indicates the value of runoff on a scale of 30-100 where 30 has almost no runoff, and 100 is entirely become runoff.

Natural Flood Management (NFM) is an emerging flood management approach based on the concept of working with natural processes. The primary aims of NFM are to postpone the arrival of the flood peak downstream by increasing water storage and soil infiltration, slowing water by increasing resistance to its flow and reducing water flow connectivity (Dadson *et al.*, 2017). NFM techniques that can be used in a catchment include planting riverside woods to slow the water and create a buffer strips of grass or trees to reducing water flow connectivity (POSTNOTES, 2011). The impacts of potential changes in land use, especially from agricultural to urban land, can be evaluated using simple multi-criteria analysis to support NFM techniques. Criteria can be evaluated through the Curve Number parameter in order to examine how different NFM practices may reduce runoff through the CN value. NFM approaches have been extensively applied in temperate countries (Burgess-Gamble *et al.*, 2017) with some success like for the catchment restoration in Eddleston, Scottish Borders (Werrity *et al.*, 2010). They have not been extensively applied in tropical environments which is the objective if this paper.

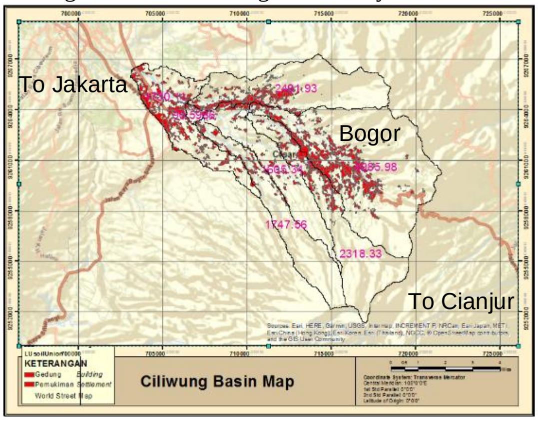
2 Material and Methods

2.1 Study area

The research location is in the catchment (basin) area of the Ciliwung River in the Bogor Regency, West Java, Indonesia. Figure 1 shows the sub-basin of the Upper Ciliwung River. This is segmented using elevation to quantify the catchment drainage patterns (in this case using the ArcHydro toolkit). There are 7 sub-basins resulting with a total area reaching 149,698 Km^2. The Ciliwung catchment contains the main highway connecting Jakarta City with Cianjur Regency. Much prior research has been undertaken examining runoff and land use changes upstream in the Ciliwung River catchment because of the flood risk to downstream Jakarta. The Ciliwung Basin region, like other tropics area, generally has only two seasons, namely dry and rainy season. The Ciliwung Basin has a very high average rainfall of 303 mm / month (Rusdiana *et al.*, 2003) compared to average rainfall in the UK (temperate country) of 52 mm / month in 2018 (Metoffice, 2019). During the rainy season, almost every day in one month the Ciliwung Basin area always experiences rain.

The rates of land use change are often high in developing countries. The most common land use changes is from agriculture and forest into settlements (Kuntiyawichai, 2012). An NFM approach was applied to a case study area in Indonesia to examine the impacts of such land use changes on flood risk. It was assumed that any urban and residential land use could not be changed or re-converted into agricultural or forest land. The process of settlement expansion was considered to be the main future land use change through expanded road access.

Figure 1. The Ciliwung Basin study area



2.2 Data Preparation

Table 1 shows the data used for this study and their sources.

Table 1. Data

Data	*Source*
Digital Elevation Model	1:25.000, Indonesia Government
Ciliwung River	1:25.000, Indonesia Government
Land Use	1:25.000, Indonesia Government
Soil type	HYSOGs 250m
CN value	TR-55, USDA
Demographic	Village Map, Indonesia Gov.
Land Value	Village Map, Indonesia Gov.

The CN grid calculation were undertaken using the HEC-GeoHMS extension for ArcGIS with input parameters of soil type, represented using the Hydrologic Soil Group (HSG), and land use divided into four categories of water, residential, forest, and agricultural. The HSG is represented using a percentage of each type soil (A, B, C, D). The CN value for the initial conditions was calculated from this data with resultant values shown in Table 2. The highest CN is 87.25 for Area 3, the lowest is 78.2 for Area 7, a range of 9.05.

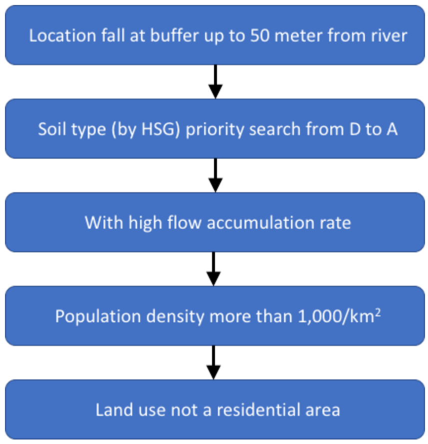
Table 2. Basin CN

Sub-basin name	*CN*	*Area (km2)*
Area 1	86.75	17.60
Area 2	79.86	24.92
Area 3	87.25	0.91
Area 4	80.01	49.86
Area 5	83.99	16.05
Area 6	78.25	23.18
Area 7	78.20	17.47

2.3 Methodology

The CN value indicates the land use specific response related to runoff. In a hydrological model using lumping approaches (such as is supported by the HEC-HMS software), the CN value in the sub-basin represents the entire area of the sub-basin. It can be used as an indicator of the effect of land use change. In this study, land use changes were used as a proxy for a NFM approach. Parameters were chosen to determine locations of NFM implementations using three approaches. The first involves parameters from CN characteristics, which relate to the soil type, land use and hydrologic conditions. The second approach evaluates riparian woodlands and buffer strips as buffer zones typically up to 30m wide on both sides of the river (SEPA, 2015). Here they were set at 50m reflecting Indonesia Government Regulation No. 38 of 2011 describing river border areas in rural areas. The third approach evaluates land use changes. According to (Verburg *et al.*, 2004), these are driven by population growth, migration, and economic factors. Here population density at the village level was used to reflect such pressures. A simple multi-criteria analysis was used to determine the locations of effective NFM approaches through changes in CN are summarised in Figure 2.

Figure 2: Criteria used in the analysis



3 Results

Figure 3 shows areas arising from the criteria described above. The total area identified is 3.73 km^2.

Figure 3. NFM Target Distribution Area

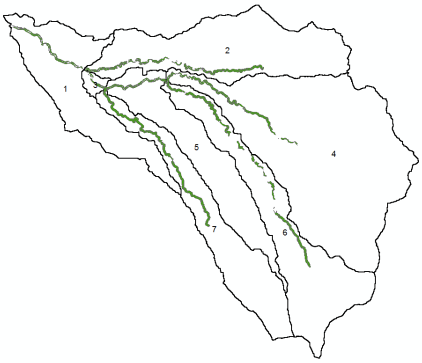


Table 3 shows the results of the CN changes arising in the different areas, comparing the original CN and the modelled CN under land use change scenarios. Area 3 shows the greatest change with a change value of 0.71, followed by Area 7 with 0.49 and Area 6 with the change value of 0.39. The smallest change is in Area 4 with the change value of 0.12. It is instructive to examine the characteristics of each sub-basin area. Area 3 is the smallest area but has the largest ratio of potential locations for applying NFM. Area 7 has a large area of land use suitable for conversion to implement NFM. Area 6 has many residential areas (Figure 1), and still has the potential for land improvement. Area 4 has the greatest residential area but also has other areas suitable for land use conversion to support NFM in its upstream area, where the population density is low.

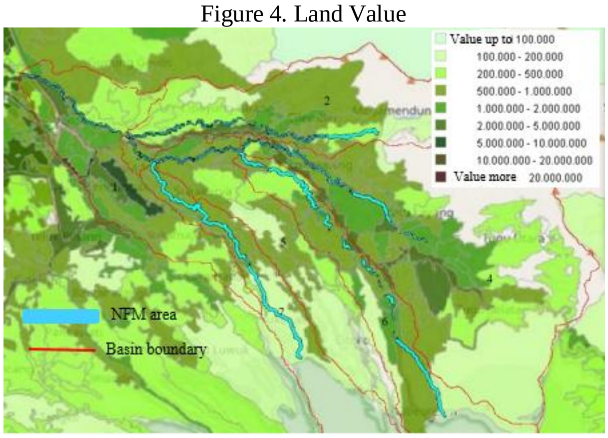
Table 3. New CN and Difference

Sub-basin name	*CN initial*	*CN final*	*Difference*
Area 1	86.75	86.61	0.14
Area 2	79.86	79.59	0.27
Area 3	87.25	86.54	0.71
Area 4	80.01	79.89	0.12
Area 5	83.99	83.85	0.14
Area 6	78.25	77.86	0.39
Area 7	78.20	77.71	0.49

4 Discussion

Although technically the location for the implementation of NFM can be determined using criteria as described above, practically the ability to do this will be limited by other factors, not least of which is land value. Effective NFM strategies must account for land value especially if the land is economically productive (for agriculture) or is for future development and settlement. Owners have to be compensated for their loss if a change of use is enforced. Thus, the interactions between areas suitable for NFM approaches and land value need to be considered. For example, Area 4 which has the smallest change in CN value also has a relatively high land value. This will make it difficult to implement NFM in this area. Land values for the study area from the National Land Agency are shown in Figure 4.

Figure 4. Land Value



The execution of this study has faced a number of limitations. First, the river centerline is used to represent the main river channel, but smaller tributaries are omitted. This means that the effective area modelled as potentially suitable for NFM is smaller than in reality. Second, global soil data from HYSOG was used and in this case shows all areas to be HSG soil types C and D. In reality there are finer soil divisions. Data describing these would allow a more nuanced evaluation of the effect of NFM on runoff through CN changes. Third, this study also uses the assumption that the CN value in residential areas is fixed, and that land cover in settlements cannot be changed. However, sustainable urban drainage system (suds) techniques have been developed that can help slow flow and improve water infiltration and management in residential areas. Examples of suds devices are green roofs, swales and permeable asphalt material. Future work will examine how suds can be represented using the CN approach.

5 Conclusions

The results of this study indicate the potential effectiveness of the NFM approach in surface water management in the Ciliwung catchment case study area. By examining the changes in CN, the effectiveness of the application of the NFM technique can be quantified. In this case, the range of CN values in the study area was found to be 9.05 for initial condition and 8.83 for model scenario (Table 3) as driven by soil types and land use. Here the CN number are high (71 for forest) which means that forest areas are not able to store water effectively. This CN value is similar to those for residential areas condition on different soil types. Here the change in CN value indicates a large effect on the flood risk. Further work is needed to link the formation of runoff water and discharge modeling.

Acknowledgement

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