An Iteractive Landscape Planning Process for Sustaining Flood Regulation in the Ci Kapundung Upper Water Catchment Area, Bandung Basin, Indonesia

Medria Shekar Rani[1], Eckart Lange[2], Ross Cameron[2], Olaf Schroth[3]

[1]The University of Sheffield, Sheffield/UK · msrani1@sheffield.ac.uk
[2]The University of Sheffield, Sheffield/UK
[3]Weihenstephan-Triesdorf University of Applied Sciences, Freising/Germany

Abstract: Simulations and modelling are often used in many studies to assess and visualise the effects of landscape changes on environment. However, only a few studies have been conducted to assess landscape interventions to sustain ecosystem services, including hydrological processes. This paper presents an iterative and interactive process to generate landscape planning for the Ci Kapundung upper water catchment area, Bandung Basin, Indonesia, based on two development scenarios. The land change model was coupled with a hydrological model to assess the influence of land cover changes on flood risk in Bandung Basin. The result shows that the overland flow at three observation points is affected by the land cover, topography, and soil properties. Outputs from the iterative hydrologic simulations suggested that conifers could be planted in the proposed river buffers in the case study area to reduce the volume of runoff flowing to the Ci Kapundung River.

Keywords: Scenarios, landscape planning, flood regulation, hydrologic modelling

1 Introduction

Geodesign can be seen as a medium for practitioners and scientists to propose spatial arrangements of landscape elements to support ecosystem services. To assess and visualise the effects of landscape changes on environment, simulations and modelling are often used in many studies (NASSAUER & OPDAM 2008). Increasing awareness of environmental problems, including climate change, has led to the growing number of environmental management plans and policies. However, research to assess landscape patterns to sustain ecosystem services is still required (COSTANZA 2008 cited in JONES et al. 2012). Specifically, a study on the impact of land use changes on hydrological processes is needed (DEFRIES & ESHLEMAN 2004 cited in AMATYA et al. 2013). Only a few studies have assessed the alternative landscape patterns to sustain streamflow regimes (WU et al. 2015).

This study focuses on the assessment of potential landscape planning strategies for the Ci Kapundung upper catchment area to regulate flooding in Bandung Basin, Indonesia. The land cover compositions in 2015 are developed areas (13.48 %), grassland and cultivated land (40.09 %), natural forests, forest plantations and scattered trees (46.42 %), and water bodies (0.0001 %). Landscape elements, such as patches of specific types of vegetation, and river buffers as green corridors, were proposed in the planning process. The novelty of the research is in coupling a land use model with a hydrological model, so that the two interact.

Journal of Digital Landscape Architecture, 4-2019, pp. 33-41. © Wichmann Verlag, VDE VERLAG GMBH · Berlin · Offenbach. ISBN 978-3-87907-663-5, ISSN 2367-4253, e-ISSN 2511-624X, doi:10.14627/537663004.

Flood regulation refers to the ecosystem service to reduce flood risk prompted by rainfall events with high precipitation rates (STÜRCK et al. 2014). According to the data from Citarum-Ciliwung Watershed Management Agency/BPDAS (2002), floods occurred in Bandung Basin almost every year within the period of 1990-2002. The occurrence of floods is affected by the flow discharge from main rivers, and the increasing rainfall rates in the region. During La-Nina event in 1998, the total flooded area in the basin was more than 6,000 Ha (LASCO & BOER 2006).

The analysis on land use changes in Bandung Basin (1983-2002) suggested that Ci Kapundung had the highest runoff coefficient among all water catchments in the basin (HARYANTO et al. 2007). Landsat 5 and 8 satellite images of the upper catchment in 1990 and 2015 respectively indicate the land cover change from natural landscapes to developed areas in 25 years (red boxes in Figure 1).

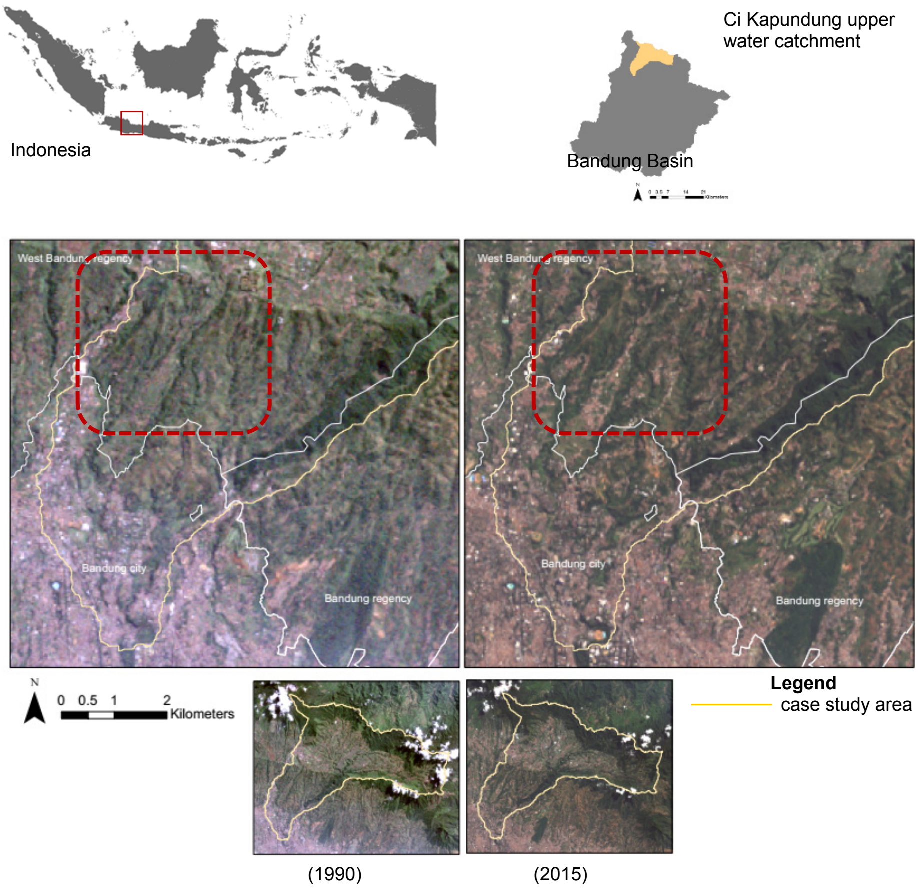


Fig. 1: Landsat imagery of the case study area in 1990 and 2015 (Source: United States Geological Survey/USGS)

2 Methods

The methodology used in this study is shown in Figure 2. Land cover maps of the Ci Kapundung upper water catchment area (102.86 sq. km) in 2013, 2015, and 2017, were derived from SPOT 6 and 7 satellite imagery. The 2013 and 2015 land cover maps were used to simulate the future land cover composition and distribution using the Land Change Modeller (LCM) module of Terrset software, based on different development scenarios (RANI et al. 2018). The model projected the 2017 land cover composition and configuration, which was validated using the actual 2017 land cover map. Then, the future land cover map in 2030 was simulated.

LCM integrates Cellular Automata and Markov model (CA-Markov) to simulate land changes based on their surrounding and previous states of pixels, and uses multilayer perceptron (MLP) neural networks to generate transition potential maps (EASTMAN 2006). A set of constraints maps, showing the area restricted to be built according to each scenario, was developed as one of the required input data for the modelling.

This paper presents an iterative and interactive process to propose large-scale landscape interventions, based on the Ecological Design (ED) development scenario (i. e. protection to the river using buffer and restriction to build in the forests and protected area). A Status Quo (SQ) scenario, showing the current development trend in the area, was also developed as a comparison to the preceding scenario.

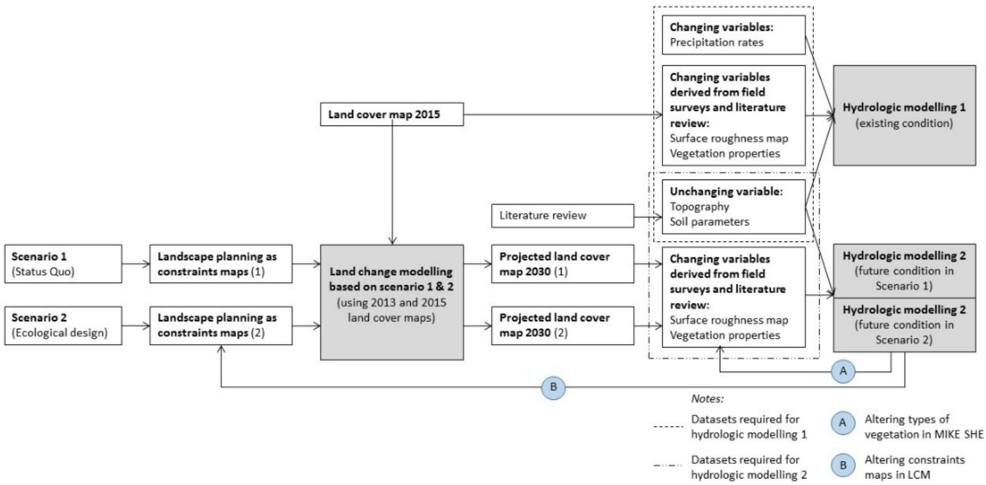


Fig. 2: Methodology used in this study

In this study, MIKE SHE hydrologic model was used to assess the impact of land cover changes to the flood regulation in Bandung Basin; high runoff volume from the catchment will increase the river discharges during extreme rainfall events. MIKE SHE is a physically based hydrologic model, which was developed by the Danish Hydraulic Institute (DHI). The model works based on the hydrological cycle, which simulates water movements, including the evapotranspiration process, overland flow, river flow, unsaturated flow, and the saturated flow (DANISH HYDRAULIC INSTITUTE 2017).

Previous studies have been conducted to assess the influence of land cover changes on hydrological process using Cellular Automata (CA) and hydrological models. However, only a few studies have used a coupled CA-Markov and MIKE SHE model (e. g. WIJESEKARA et al. 2012, FARJAD et al. 2017), and none of them were conducted using a case study in Indonesia.

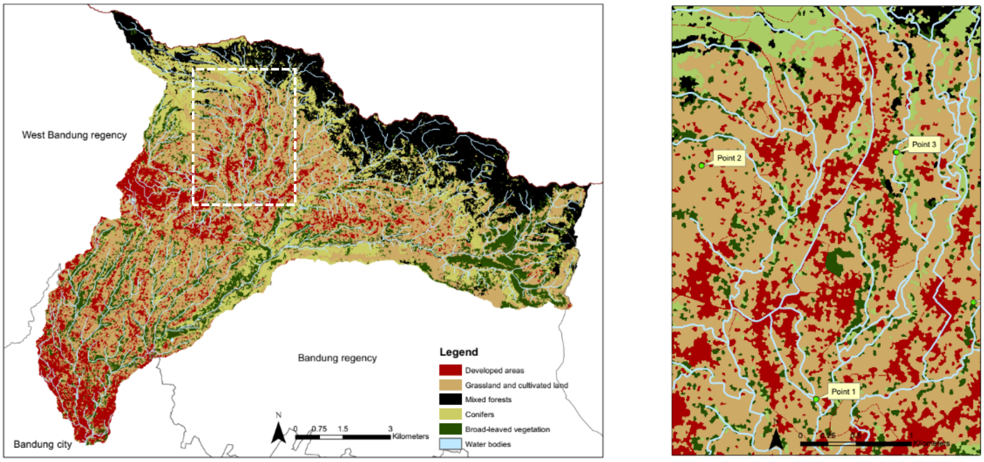
The MIKE SHE model requires various datasets, such as land cover maps, precipitation rates, surface roughness maps, and vegetation properties (e. g. Leaf Area Index (LAI), crop coefficients, and root depth) as changing variables, as well as digital elevation model (DEM) and soil parameters as unchanging variables. All datasets were retrieved from various resources. The DEM of the case study area was retrieved from the Indonesian Geospatial Information Agency/ BIG. The DEM was resampled from the original resolution of 8.34 metre to 6 metre, to match the spatial resolution of satellite imagery. Precipitation data (2013-2015) and soil maps were collected from Water Resource Management in West Java Province/ PSDA and Soil and the Agroclimatic Research Centre respectively. Manning's M number of each land cover type, ranging between 10 for thickly vegetated surface, and 100 for smooth surface, was required to developed the surface roughness maps. LAI was estimated using allometric equations, which were derived from other studies conducted in Indonesia or other tropical countries. Crop coefficients and root depth of vegetation in the site were retrieved from ALLEN et al. (1998) and DJAENUDIN et al. (2011) respectively.

In this study, water movement in the saturated zone (i. e. geological layer underneath the soil layer) and the river flow were excluded in the hydrologic simulations. At this stage, no future precipitation trend was projected and used in the simulation. Therefore, the results from MIKE SHE modelling should be interpreted only based on the available datasets, which were used in the simulations.

The projected land cover maps (2030) used the first iteration of hydrologic simulations were previously developed using LCM, based on the Status Quo (SQ) and Ecological Design (ED) scenarios (RANI et al. 2018). Outputs from the LCM modelling showed that the percentages of three land cover types in the two scenarios in the future (e. g. developed areas, conifers, and mixed forests) are almost similar. However, the distribution of land cover differs with each scenario. The predicted land cover composition in 2030 for developed areas, grassland and cultivated land, mixed forests, conifers, and broad-leaved vegetation in the SQ scenario are 17.586 %, 33.950 %, 16.008 %, 16.012 %, and 16.444 % respectively, whereas the land cover compositions in the ED scenario are 17.583 %, 31.407 %, 16.256 %, 16.009 %, and 18.744 % respectively. If the MIKE SHE model predicted a high volume of runoff (i. e. the landscape planning could not support the flood regulation in the future) in the ED scenario, then, the second iteration of hydrological simulation was conducted by changing the land cover map as the input data for MIKE SHE, to retrieve the most effective land cover scenario of case study area, which can benefit flood regulation in Bandung Basin.

In the beginning of the second iterative landscape planning process, the capacity of different landscape elements to reduce runoff in the case study area was assessed. Firstly, a series of flood risk simulations using the future land cover maps with different plants in the river buffers (e. g. conifers, broad-leaved vegetation, and mixed forests) was performed in MIKE SHE (process A in Figure 2). Secondly, river buffers as green corridors (minimum width of 25 metre and 5 metre in the rural and urban areas respectively) were proposed in the simulation of future land cover maps under the ED scenario (process B in Figure 2). The aims for these processes are to retrieve information regarding the suitable types of vegetation in the river buffer for reducing runoff in the case study area, and to simulate how river buffers can potentially improve the flood regulation. The results were considered in the subsequent land change simulations; river buffers with specific width and type of plant were included as part of the proposed landscape elements in the Ci Kapundung upper water catchment area.

Three observation points (Figure 3b) were assigned in the model to record the depth of overland flow (as an initial phase of runoff) in 2013-2015 based on the existing land cover map as a baseline, the simulated future land cover maps in the Status Quo (SQ), as well as the Ecological design (ED) scenarios in the two iterative planning processes.



(a) (b)

Fig. 3: (a) Land cover map of case study area in 2015 (Source: object-based image classification using SPOT6 satellite images from ©Airbus DS (2015)); (b) the location of three observation points in the case study area

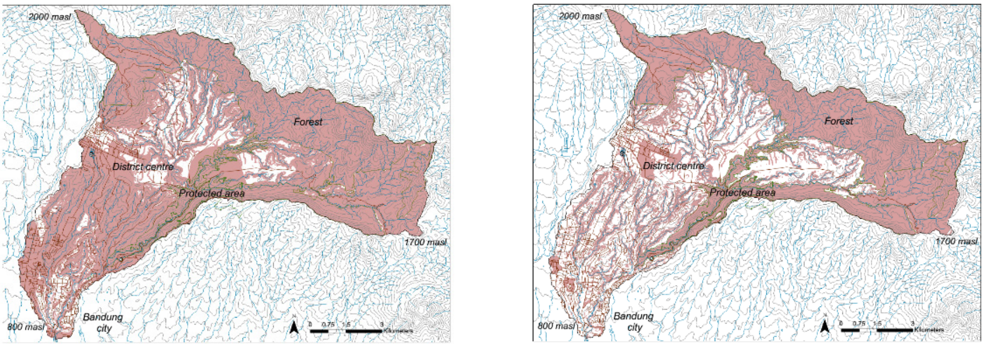
3 Results and Discussion

Constraint maps for the first modelling iteration are presented in Figure 4. In the first iteration of landscape planning for the case study area, a protected area, existing forests, areas with steep slopes and areas near river networks are restricted to be built in the future (areas presented with brown colour in Figure 4) (Rani et al. 2018). However, existing buildings, which were constructed before 2015 in the riparian, still remain unchanged in the future, as has been previously specified in the LCM modelling process.

Preliminary results from the first hydrologic simulation showed that the volume of runoff generally increases at the three observation points in 2030. The simulated depth of overland flow during the day with the highest precipitation rate in 2013-2015 at the first observation point is 14.584 mm. This value is similar to the predicted runoff volume at the same point using the projected 2030 land cover based on the Status Quo (SQ) (i. e. 14.576 mm), and is higher than the volume from the 2030 land cover in the Ecological Design (ED) scenarios

(i. e. 11.697 mm). At the second point, the overland flow in 2015, in the SQ and ED scenarios is estimated at 11.764 mm, 11.511 mm, and 12.244 mm respectively. The depth of overland flow at the third observation point is also slightly similar; flow in 2015, in the SQ and ED scenarios are 17.863 mm, 16.463 mm and 17.146 mm.

From the initial results, it can be seen that the higher value of overland flow at the third observation point in 2015 and 2030 (both scenarios) can be caused by the steeper slope in the area (12.65^0), compared with the other two points. The third observation point is located in the area with high soil composition of clay (52.07 %). The lower overland flow at the first point in the ED scenario can be caused from the land cover in the area (i. e. broad-leaved vegetation). In the ED scenario, river buffers were proposed, and it is expected that the land cover would change from grassland and cultivated land, to broad-leaved trees in 2030.



(a) (b)

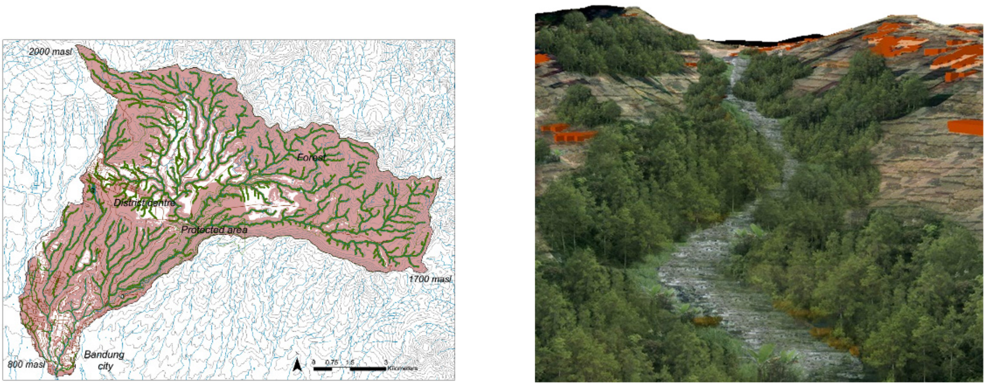
Fig. 4: (a-b) Constraints maps showing areas restricted to development of new settlements and agriculture in the first iteration (RANI et al. 2018)

The outputs from hydrologic simulations to test the capacity of the three vegetation types to reduce the runoff, as seen in Table 1, were considered in the second planning iteration. The compositions of vegetation in the simulated future land cover map under the ED scenario have been altered before the maps were used in the hydrologic simulations. In this case, the compositions and distributions of developed areas, grassland and cultivated land, and water bodies were unaltered. Thus, each land cover map only has one type of vegetation (either conifers, broad-leaved vegetation, or mixed vegetation) outside the grassland and cultivated land, in each respective run of the MIKE SHE simulation. The vegetation properties for the newly generated land cover map (e. g. LAI, crop coefficient, root depth) and Manning's M values were assigned based on the existing data. The new land cover compositions for developed areas, grassland and cultivated land, and other vegetation (which could be conifers, broad-leaved vegetation, or mixed vegetation in each simulation run) are 17.583 %, 31.407 %, 51.009 % respectively.

Table 1: Simulated depth of overland flow (mm) from the projected land cover map (2030) with single type of vegetation

Vegetation	**Depth of overland flow (mm)**		
	Point 1	**Point 2**	**Point 3**
Conifers	14.162	11.765	17.148
Broad-leaved vegetation	14.473	11.769	17.339
Mixed vegetation	5.074	11.768	17.265
Dominant soil types:	clay	silt	clay
Slope degree:	4.76°	10.68°	12.65°

The results suggested that conifers could potentially be planted in the proposed river buffers in the case study area, because the overland flow from the site is predicted to be lower than the runoff when broad-leaved and mixed vegetation are assigned as the vegetation in the case study area. Each type of vegetation has different properties, such as LAI, root depth, and crop coefficients, as well as surface roughness, which contribute to its capacity to reduce runoff. For example, conifers have higher LAI (Leaf Area Index) than the broad-leaved and mixed vegetation in the case study area, thus affecting the lower depth of overland flow from the site with conifers as the single type of vegetation (Table 1). According to ZHENG et al. (2018), plants with higher LAI have higher interception loss (i. e. the portion of precipitation that is evaporated to the atmosphere or is absorbed into the plant (MERRIAM 1960)). The information regarding the vegetation type and the width of river buffer, was used in the development of the final stage of landscape planning for the case study area (Figure 5).



(a) (b)

Fig. 5: (a-b) Vegetation with high LAI in river buffer as landscape element in the second planning iteration

4 Conclusion

An interactive and iterative planning process was conducted in this research to assess potential landscape elements, which can effectively reduce runoff in the Ci Kapundung upper water catchment area. In this study, river buffers are proposed in the case study area, as a measure to control the Ci Kapundung River discharges. Conifers are recommended as a type of vegetation in the river buffers because they can effectively reduce the runoff given the existing site characteristics in the case study area (e. g. topography, land cover, and soil properties), and the weather conditions (e. g. precipitation) in the simulation time period. It is suggested that the future precipitation trend in the catchment area is generated based on the historical data and is included in the hydrologic simulations, to provide a better recommendation for landscape planning in the area.

The scale of the case study site, addressing land use change around a watershed, is a typical geodesign problem. The non-linear and iterative process to provide information for the landscape interventions is fundamentally similar to the geodesign framework (BRIAN DEAL & PAN 2017 cited in GU et al. 2018). The novel solution of addressing the problem of land cover changes resulting in flooding through an interactively coupled land change and hydrology model proves a promising planning approach. It is suggested that similar solutions could be adopted for other geodesign processes.

Acknowledgement

This paper was written based on a PhD research, which is funded by the Ministry of Research, Technology and Higher Education of Indonesia. The first author would like to thank Institut Teknologi Bandung (ITB), Indonesia, for the support during the PhD study. All hydrologic simulations were conducted using a sponsored MIKE Powered by DHI software product.

References

ALLEN, R. G., PEREIRA, L. S., RAES, D. & SMITH, M. (1998), Crop evapotranspiration – Guidelines for computing crop water requirements. FAO Irrigation and drainage paper, 56, 87-158.

AMATYA, D. M., SUN, G., ROSSI, C. G., SSEGANE, H. S., NETTLES, J. E. & PANDA, S. (2013), Forests, Land Use Change, and Water, 116-153.

DANISH HYDRAULIC INSTITUTE (2017), MIKE SHE Volume 1, User Guide. 1-418.

DJAENUDIN, D., MARWAN, H., SUBAGJO, H. & HIDAYAT, D. A. (2011), Petunjuk Teknis Evaluasi Lahan Untuk Komoditas Pertanian. Balai Besar Litbang Sumberdaya Lahan Pertanian, Badan Litbang Pertanian, Bogor. 36.

EASTMAN, J. R. (2006), Guide to GIS and Image Processing. Clark University, Worcester.

FARJAD, B., GUPTA, A., RAZAVI, S., FARAMARZI, M. & MARCEAU, D. J. (2017), An integrated modelling system to predict hydrological processes under climate and land-use/cover change scenarios. Water (Switzerland), 9 (767), 1-23.

GU, Y., DEAL, B. & LARSEN, L. (2018), Geodesign Process and Ecological System Thinking in a Coupled Human-Environment Context: An Integrated Framework for Landscape Architecture. Sustainability, 10 (3306), 1-24.

HARYANTO, E.T., HERWANTO, T. & KENDARTO, D.R. (2007), Perubahan bentuk penggunaan lahan dan implikasinya terhadap koefisien air larian das citarum hulu jawa-barat. Universitas Padjajaran, Bandung, 1-14.

JONES, K. B. et al. (2012), Informing landscape planning and design for sustaining ecosystem services from existing spatial patterns and knowledge. Landscape Ecology.

LASCO, R.D. & BOER, R. (2006), An Integrated Assessment of Climate Change Impacts, Adaptations and Vulnerability in Watershed Areas and Communities in Southeast Asia. A Final Report Submitted to Assessments of Impacts and Adaptations to Climate Change(AIACC), Project No. AS 21,Washington, USA, 115-179.

MERRIAM, R. A. (1960), A Note on the Interception Loss Equation. Journal of Geophysical Research, 65 (11), 3850.

NASSAUER, J. I. & OPDAM, P. (2008), Design in science: Extending the landscape ecology paradigm. Landscape Ecology, 23 (6), 633-644.

RANI, M. S., LANGE, E., CAMERON, R. & SCHROTH, O. (2018), Future Development Scenarios for Adaptation to Climate Change in the Ci Kapundung Upper Water Catchment Area, Bandung Basin, Indonesia. Journal of Digital Landscape Architecture, 3-2018, 23-33.

STÜRCK, J., POORTINGA, A. & VERBURG, P. H. (2014), Mapping ecosystem services: The supply and demand of flood regulation services in Europe. Ecological Indicators, 38, 198-211.

WIJESEKARA, G. N. GUPTA, A., VALEO, C., HASBANI, J.-G., QIAO, Y., DELANEY, P. & MARCEAU, D. J. (2012), Assessing the impact of future land-use changes on hydrological processes in the Elbow River watershed in southern Alberta. Canada. Journal of Hydrology, 412, 220-232.

WU, H., BOLTE, J. P., HULSE, D. & JOHNSON, B. R. (2015), A scenario-based approach to integrating flow-ecology research with watershed development planning. Landscape and Urban Planning, 144, 74-89.

ZHENG, J. et al. (2018), Rainfall partitioning into throughfall, stemflow and interception loss by maize canopy on the semi-arid Loess Plateau of China. Agricultural Water Management, 195, 25-36.