Sediment control analysis due to erosion and sediment in Cipunagara watershed, Indonesia, using SWAT model

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Abstract. Erosion and sediment are parameters that describe the critical level of a watershed. Cipunagara watershed is one of the most critical watershed in Indonesia. Therefore, we need a study of sediment control due to erosion and sediment. This study aims to determine the level of erosion in Cipunagara watershed, find out sediments in Cipunagara River, and determine the sediment control structure that can be applied in Cipunagara River. The method used in this research is quantitative descriptive method with modelling on SWAT. The analysis was performed using secondary data in 2005-2014. Modelling in SWAT divides Cipunagara watershed into 33 Sub Watersheds. The highest erosion value during years data occurred in Sub-watershed 18 of 654,402 tons/ha/ year with very severe erosion criteria and the lowest in Sub-watershed 5 of 1,075 tons/ha/ year with very mild erosion criteria. The highest sediment value is in River 25 which is 1754758.30 tons/year, and the lowest in River 7 which is 7174.40 tons/year. Sediment control in Cipunagara watershed can use check dams that place on River 18 and River 25.

1. Introduction
Area of critical land in the Cipunagara watershed was increasing. The southern Cipunagara watershed has been converted from forest land into agricultural and residential areas. The northern Cipunagara watershed is dominated by residential, industrial and shopping areas [1]. For an effective and efficient implementation of watershed management practices, identification of these critical areas is vital. The SWAT model could successfully be used for identifying the critical sub-basins in a watershed with imprecise and uncertain data for management purposes [2]. SWAT was developed to predict the impact of land management practices on water, sediment and agricultural chemical yields in large complex watersheds with varying soils, land use and management conditions over long periods of time [3].

The identification of critical areas can be verified by analyzing the relationship between the variations of the land use and sediment discharge [4]. Transition of other land use categories to cropland was the most detrimental to watershed in terms of soil loss while forest acted as the most effective barrier to soil loss. The spatial location of land use with respect to terrain and associated soil properties should be an important consideration in soil erosion assessment process [5].

Sediment yield is likely to increase due to the existing human activities in the watersheds. Sediment yield may also increase due to the necessity of bringing more area under cultivation by felling of tress to meet the demand of food for the growing population. Hence, those areas of the watershed need to be treated. Depending upon priority levels, the watershed area should be treated with suitable vegetative
and structural measures. For effective watershed planning, there must be a close coordination of vegetative and structural control measures and best combination should be decided to tackle the problems of watershed in an integrated manner [6].

Check dams are efficient sediment control measures [7]. Without dam intervention, the percentage of agricultural land flowing directly into the river system has increased [8].

2. Research methods

2.1. Study area
Most of the Cipunagara watershed is included in the Subang Regency and the rest is in the Sumedang and Indramayu Regencies. The Cipunagara River flows from the south (from the Situ Pabeasan spring in Cipunagara Village, Cisalak District, Subang Regency) to the north and ends in the Java Sea (in Patimban Village, Pusakagara District, Subang Regency). The Cipunagara River has several large tributaries, including S. Cikandung, S. Cilamatan, S. Cigadung. The watershed outlets in this study are AWLR Kiarapayung at 6.46 ° South and 107.89 ° East.

Figure 1. The Cipunagara Watershed.
2.2. Data
The data used in this research is secondary data. Input data for the SWAT model in the form of soil, land use, climate and DEM data are prepared in a database format.
- Rainfall data taken from the Cisalak rain station for 10 years (2005-2014) shows an annual average of 68.41 - 334.12 mm.
- Based on the 2018 land use map, the Cipunagara watershed consists of 13 land covers.
- Soil type map shows the Cipunagara watershed consists of 6 types of soil.
- The slope data based on the 30 m DEM SRTM is grouped into five classes, 0-8% (flat), 8-15% (sloping), 15-25% (bumpy), 25-45% (hilly), and > 45% (steep).

2.3. Delineation and formation of HRU
The delineation is processed in SWAT using the Watershed Delineator. The output of this process is the sub-basin and river network for the Cipunagara Watershed.

HRU focuses on adding information on land use and land characteristics. HRU was formed using Multiple HRU's criteria with a land cover threshold value of 10%, soil type 5%, and slope 5%. The number of HRUs formed was 482 in 33 Sub-Watersheds. Each HRU formed is a special combination of sub-watersheds, land use, soil type and slope range.

2.4. Model calibration and validation
Calibration was carried out using data from January 2006 to December 2009. While the validation process was performed with data from January 2010 to December 2013. Calibration was done manually, by matched parameter values by trial and error on several parameters that effect. The results of the validation showed a coefficient of determination (R²) of 0.80, indicating that there was a close relationship between the value of the simulation with the value of observation, and included in the criteria of high influence (0.7 < R² < 1.0). Nash-Sutcliffe (NSE) efficiency was 0.71, included in the fulfilment criteria (0.36 < NSE < 0.75), where the resulting simulation value was acceptable.

The parameters selected for calibration and the final results are presented in the following table.

| Parameter          | Definition                                           | Selected value |
|--------------------|------------------------------------------------------|----------------|
| CN2.mgt            | SCS curve number                                    | 95             |
| CH_K1.sub          | Hydraulic conductivity is effective on the main channel | 250            |
| CH_N1.sub          | Manning values on river branching channels           | 15             |
| SLUSUBBSN.hru      | Slope length of surface flow (m)                     | 50             |
| OV_N.hru           | Manning roughness coefficient                        | 0.4            |
| ESCO.hru           | Change factor in soil evaporation                    | 0.95           |
| EPCO.hru           | Change factor of plant canal                         | 1              |
| SURLAG.hru         | lag runoff surface                                   | 19             |
| HRU_SLP.hru        | Surface flow slope                                  | 0.1            |
| CH_N2.rte          | Manning roughness coefficient on the main channel    | 0.2            |
| CH_K2.rte          | Hydraulic conductivity is effective on the main channel | 300            |
| ALPHA_BNK.rte      | Alpha factor for surface runoff at river banks (days)| 1              |

3. Results and discussion

3.1. Erosion and sediment values in the Cipunagara watershed
SWAT analysis gives the amount of erosion that varies from 1,075 tons/ha/year to 654,402 tons/ha/year. Erosion values and class in each sub-watershed are presented in the following table.
Table 2. Erosion value and rating of each sub-watershed.

| Watershed | Erosion (tons / ha / year) | Erosion Classa |
|-----------|----------------------------|-----------------|
| 18        | 654,402                    | Very Heavy Erosion |
| 25        | 519,593                    | Very Heavy Erosion |
| 32        | 458,403                    | Heavy Erosion     |
| 14        | 456,198                    | Heavy Erosion     |
| 33        | 352,325                    | Heavy Erosion     |
| 10        | 337,692                    | Heavy Erosion     |
| 22        | 234,135                    | Heavy Erosion     |
| 15        | 193,387                    | Heavy Erosion     |
| 24        | 189,992                    | Heavy Erosion     |
| 31        | 176,096                    | Medium Erosion    |
| 11        | 167,668                    | Medium Erosion    |
| 27        | 154,202                    | Medium Erosion    |
| 19        | 151,249                    | Medium Erosion    |
| 23        | 139,164                    | Medium Erosion    |
| 21        | 122,952                    | Medium Erosion    |
| 30        | 122.02                     | Medium Erosion    |
| 13        | 102,335                    | Medium Erosion    |
| 28        | 98,661                     | Medium Erosion    |
| 17        | 96,983                     | Medium Erosion    |
| 20        | 93,727                     | Medium Erosion    |
| 6         | 92,399                     | Medium Erosion    |
| 29        | 91.19                      | Medium Erosion    |
| 3         | 85.49                      | Medium Erosion    |
| 8         | 72,882                     | Medium Erosion    |
| 26        | 72,535                     | Medium Erosion    |
| 7         | 61,329                     | Medium Erosion    |
| 12        | 33,897                     | Light Erosion     |
| 2         | 21,968                     | Light Erosion     |
| 9         | 17,267                     | Light Erosion     |
| 16        | 14,342                     | Very Light Erosion|
| 1         | 5,049                      | Very Light Erosion|
| 4         | 2,749                      | Very Light Erosion|
| 5         | 1,075                      | Very Light Erosion|

a based on the Republic of Indonesia's Ministry of Forestry Regulation Number: P.39/Menhut-II/2009 concerning Guidelines for Preparation of Integrated Watershed Management Plan [9]

After obtaining erosion in each Cipunagara watershed, the sediment yield in the river was calculated for each sub-watershed. Sediment yield in Cipunagara Sub-watershed starts from 0.172 tons/h/year to 102,590 tons/ha/year. Sediment yield classes vary widely, and there are 16 sub-watersheds classified as very high sediment yield classes. Sediment yield was illustrating the amount of land that transported by water to rivers. Sediment yield also illustrates the amount of sediment at the outlets of each Cipunagara watershed. Values and classes of the sediment yield in each sub-watershed and river are presented in the following table.
Table 3. Sediment yield value.

| Watershed | SDR  | Sediment Yield (ton/ha/year) | Sediment Yield Classa |
|-----------|------|------------------------------|------------------------|
| 18        | 0.157| 102,590                      | Very high              |
| 25        | 0.152| 79,039                       | Very high              |
| 14        | 0.160| 72,959                       | Very high              |
| 32        | 0.156| 71,690                       | Very high              |
| 33        | 0.151| 53,263                       | Very high              |
| 10        | 0.158| 53,242                       | Very high              |
| 24        | 0.237| 44,987                       | Very high              |
| 22        | 0.158| 37,097                       | Very high              |
| 21        | 0.302| 37,089                       | Very high              |
| 19        | 0.218| 32901                        | Very high              |
| 20        | 0.332| 31,160                       | Very high              |
| 15        | 0.153| 29,547                       | Very high              |
| 23        | 0.197| 27,415                       | Very high              |
| 11        | 0.158| 26,457                       | Very high              |
| 27        | 0.155| 23,928                       | Very high              |
| 31        | 0.134| 23,527                       | Very high              |
| 13        | 0.191| 19,576                       | High                   |
| 17        | 0.185| 17,979                       | High                   |
| 30        | 0.141| 17,242                       | High                   |
| 28        | 0.149| 14,714                       | Low                    |
| 6         | 0.153| 14,166                       | Low                    |
| 3         | 0.163| 13,937                       | Low                    |
| 29        | 0.152| 13,836                       | Low                    |
| 26        | 0.157| 11,414                       | Low                    |
| 8         | 0.150| 10,948                       | Low                    |
| 7         | 0.148| 9,074                        | Low                    |
| 12        | 0.168| 5,704                        | Low                    |
| 2         | 0.196| 4,308                        | Very low               |
| 9         | 0.150| 2,598                        | Very low               |
| 16        | 0.138| 1979                         | Very low               |
| 1         | 0.195| 983                          | Very low               |
| 4         | 0.163| 448                          | Very low               |
| 5         | 0.160| 172                          | Very low               |

a based on the Republic of Indonesia's Ministry of Forestry Regulation No: P.61/Menhut -II/2014 concerning Monitoring and Evaluation of Watershed Management [10]

3.2. Analysis of sediment control structure

Determination of the location of the sediment control structure consider: placed in the location that has the highest soil and sediment erosion; placed on a degraded riverbed; if there is a waterfall on the river channel, the sediment control structure is placed before it falls; sediment control structures are not placed on a water gap.

The analysis shows that the location with the highest erosion and sediment is in the sub-watersheds and rivers number 18 and 25.
The position of the structure in the river channel is determined by analyzing the long-section of each river channel. After obtaining long-section for Rivers 18 and 25, an analysis of the river slope is carried out to obtain a degraded riverbed. Long-sections of river channels 18 and 25 are presented in the following figures.

Next is a cross-sectional analysis to get a cross-section view of the river bank at the location of the sediment control structure. The results of the river cross-section analysis are the structure placement point for river 18 at coordinates 6°41'46.78" S, 107°46'37.15" E, while for River 25 it is at 6°42'17.15" S, 107°50'08.85" E.

4. Conclusion
Based on the analysis results, there are several conclusions, including:

- The highest erosion value during the data year was in Sub-watershed 18 of 654,402 tons/ha/yr with very heavy erosion criteria, and the lowest in Sub-watershed 5 of 1,075 tons/ha/yr with very mild erosion criteria.
- The highest sediment value in River 25 is 1754758.30 tons/year, and the lowest in River 7 is 7174.40 tons/year.
- Sediment control in the Cipunagara watershed can use check dams placed on River 18 and River 25.
References

[1] Andika L D 2016 Analisis lahan kritis di Daerah Aliran Sungai (DAS) Cipunagara (Bogor: IPB University)

[2] Besalatpour A, Hajabbasi M, Ayoubi S and Jalalian A 2012 Identification and prioritization of critical sub-basins in a highly mountainous watershed using SWAT model Eurasian Journal of Soil Science 1 64

[3] Neitsch S L, Arnold J G, Kiniry J R and Williams J R 2011 Soil and Water Assessment Tool theoretical documentation Version 2009 Texas (Texas Water Resources Institute) 1

[4] Chen L, Qian X and Shi Y 2011 Critical area identification of potential soil loss in a typical watershed of the three gorges reservoir region Water Resour. Manage. 25 3445

[5] Sharma A, Tiwari K N and Bhadoria P B S 2011 Effect of land use land cover change on soil erosion potential in an agricultural watershed Environ. Monit. Assess. 173 789

[6] Pandey A, Chowdary V M and Mal B C 2007 Identification of critical erosion prone areas in the small agricultural watershed using USLE, GIS and remote sensing Water Resour. Manage. 21 729

[7] Zhao G, Kondolf G M, Mu X, Han M, He Z, Rubin Z, Wang F, Gao P and Sun W 2017 Sediment yield reduction associated with land use changes and check dams in a catchment of the Loess Plateau China Catena 148 2 126

[8] Bellin N, Wesemael B V, Meerkerk A, Vanacker V and Barbera G G 2009 Abandonment of soil and water conservation structures in Mediterranean ecosystems a case study from south east Spain Catena 76 114

[9] Republic of Indonesia's Ministry of Forestry Regulation Number: P.39/Menhut-II/2009 concerning Guidelines for Preparation of Integrated Watershed Management Plan

[10] Republic of Indonesia's Ministry of Forestry Regulation No: P.61/Menhut -II/2014 concerning Monitoring and Evaluation of Watershed Management