Analysis of Bekasi watershed erosion and sedimentation problem

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Abstract. The flood incident of Bekasi City was caused by the flow of run-off from the upstream Bekasi watershed and the limited capacity of Kali Bekasi River. The amount of flow caused by changes in land and also erosion in the upper of Bekasi watershed. The amount of erosion that occurred not only resulted in lower water absorption capacity, but also the erosion carried to Bekasi river and settle which ultimately reduce the flow capacity of Kali Bekasi. Several efforts are needed to overcome erosion problems in the upper of Bekasi watershed, thus indirectly reducing flood problems in Bekasi City.

1. Introduction

Bekasi River is one of the rivers that passes through Bekasi City sourced on two rivers that is Cileungsi and Cikeas Rivers. In the middle of Kali Bekasi there is Bekasi weir which intersects with the West Tarum Channel. Bekasi weir serves to maintain the water level elevation of Bekasi River in order to deliver raw water to Jakarta and irrigation.

In line with the development of settlements in Jabodetabek, there is a change of land use in the Bekasi River Watershed which was able to absorb rainwater and turned into a surface stream that burden the capacity of the river. This condition is exacerbated by decreasing the flow capacity of Bekasi River as a result of sedimentation due to erosion in the upper watershed.

The flood of Bekasi City began in February 2002 which inundated several settlements area about 0.5 to 2.0 meters for several days. The settlement is located in Jati Asih, South Bekasi and Bekasi Timur sub-districts in the housing complex of Bekasi River such as Depnaker Complex, Pondok Gede Permai, Kemi Ifi, Jati Asri Permai, Kemang Pratama, Jaka Setia, Jaka Kencana, Villa Kartini, Villa Nusa Indah and others. The floods also caused avalanche slopes on several sections of the river due to scouring at the bottom and riverside. The daily rainfall recorded in Bekasi Regency amounted to 250 mm resulting in flow discharge reaching 578.63 m³/s and the water level at Bekasi weir reaching +18.75 m.

The flood occurred again in Bekasi back in March 2005, as a result of daily rainfall recorded on 3-5 March 2005 at Bendung Bekasi equal to 127 mm and at Cibinong Station equal to 88 mm. The flowing flow discharge is 545 m³/s and the water level at the water gate reaches +18.75 m.

2. Description of Bekasi Watershed
2.1. Rainfall
Average annual rainfall in the Upper Bekasi watershed is based on statistical data in the lowlands + 1800 mm and for mountain areas + 2500 mm. In January and December rainfall in mountainous areas is quite heavy. The highest rainfall occurred in February and the most rainy days in December. The air temperature of the Upper Bekasi watershed ranges from 28°C - 32°C, while for the mountain zone 18.9°C - 25.2°C. The largest daily rainfall of 8 stations spread from upstream to downstream of Bekasi watershed during the period 1974 to 2016 is presented in Table 1. Based on this data the largest daily rainfall is 250 mm recorded at Bekasi station in 2002.

| Station          | Max daily(mm) |
|------------------|----------------|
| Cariu            | 245            |
| Gadog            | 202            |
| Cibinong         | 157            |
| Gunung Putri     | 133            |
| Cileungsi        | 146            |
| Depok            | 208            |
| Halim P Kusuma   | 165            |
| Bekasi/ Tambun   | 250            |

The design discharge was calculated using the design rain fall using HEC-HMS hydrology simulation model based on the watershed biophysical data in 2016 obtained the peak discharge quantities and concentration times as in Table 2.

| Return Period | Design Rainfall (mm) | Discharge (m³/dt) |
|---------------|----------------------|-------------------|
| 2             | 108.1                | 341.2             |
| 5             | 115.2                | 372.9             |
| 10            | 134.3                | 459.5             |
| 25            | 168.3                | 614.9             |
| 50            | 204.5                | 780.0             |

2.2. Soil Taxonomy
Based on detail map scale of 1: 50,000 for Bekasi and surrounding area and report by soil research center (1981), found soil types: alluvial, rensina and litosol, low humus glei, gray hydroflor, gramusol, Latosol, and Podsolic. Based on certain soil properties (texture, drainage), shape of area / physiography, and the soil forming material, it can be derived as much as 20 kinds of soil with fine texture to coarse, rapid drainage.

2.3. Land Use
Based on satellite Imagery data from Bakosurtanal and field survey results indicate that land use in the Bekasi watershed is water bodies, forests, settlements, plantations, irrigated rice fields, rainfed rice fields, scrub, vacant and moorlands. During the period of 19 years (1998-2016) there has been a significant change of land use in the upper watershed. The proportion of each type of land use in the Bekasi Hulu watershed is presented in Table 3.

The data shows that land use change in Bekasi watershed is: the decrease of land use for water 0.82%, forest 4.58%, plantation 11.39%, irrigated rice field 2.11%, rainfed rice 3, 25% and 1.72% respectively, while the increase of land cover for settlements 13.90%, 4.87% shrubs and vacant land 5.09%.
Table 3. Land use change in Bekasi watershed (1998-2016)

| No | Land Use         | Area(1998) | Percentage | Area(2016) | Percentage | Change (%) |
|----|------------------|------------|------------|------------|------------|------------|
| 1  | Water Body       | 764.4      | 2.0        | 443.8      | 1.1        | -0.82      |
| 2  | Forest           | 4,052.3    | 10.4       | 2,264.4    | 5.8        | -4.58      |
| 3  | Settlement       | 1,715.2    | 4.4        | 7,142.9    | 18.3       | 13.90      |
| 4  | Farming          | 12,313.2   | 31.5       | 7,864.9    | 20.1       | -11.39     |
| 5  | Irrigated rice fields | 3,292.4 | 8.4    | 2,471.3    | 6.3        | -2.10      |
| 6  | Rainfed rice fields | 1,665.4 | 4.3    | 3,944.4    | 1.0        | -3.26      |
| 7  | Shrubs           | 3,244.6    | 8.3        | 5,148.8    | 13.2       | 4.88       |
| 8  | Land             | 1410.0     | 3.6        | 3,396.9    | 8.7        | 5.09       |
| 9  | Moor             | 10,587.2   | 27.1       | 9,917.4    | 25.4       | -1.72      |
|    | Total            | 39,044.6   | 100        | 39,044.6   | 100        |            |

The increase of the settlement area about 13.90% is a widespread change other usage changes which is specially the water body and others, the forest area decrease from 4,052.3 ha to 2,264.4 ha or decreased by 4.58% within 19 years.

2.4. River

In Bekasi watershed, there are eight main rivers are Bekasi, Cikeas, Cileungsi, Citeurep, Cikeruh, Cihera, Cibadak and Cijanggel River. The Bekasi River flow data is presented in Table 4. The data shows that the minimum and maximum discharge fluctuations are very large in February (rainy season) the ratio of maximum and minimum discharge is almost 60 times and in September (dry season) the ratio of maximum and minimum discharge has been reached 36 times. This fluctuation indicates that Bekasi watershed is in the worth condition.

Table 4 Discharge of Bekasi River

| Month       | Discharge (m³/s) | Maximum | Minimum | Average |
|-------------|------------------|---------|---------|---------|
| January     | 507.3            | 9.7     | 58.9    |
| February    | 585.6            | 8.9     | 104.3   |
| March       | 487.4            | 9.7     | 53.0    |
| April       | 358.8            | 6.4     | 73.5    |
| May         | 157.4            | 9.7     | 23.9    |
| June        | 182.6            | 7.9     | 19.3    |
| July        | 372.9            | 7.9     | 34.6    |
| August      | 250.2            | 6.2     | 16.5    |
| September   | 47.3             | 1.3     | 4.5     |
| Oktober     | 66.0             | 2.5     | 7.4     |
| November    | 349.5            | 7.4     | 28.4    |
| December    | 259.8            | 6.5     | 28.3    |

2.5. Land Management
Farmers in the Bekasi River Watershed have a habit of intensive soil cultivation before the planting season arrives. This action will directly make the soil loose and easily eroded. Processed soils will be left open until the rain comes and the land is planted with plantation crops. The time interval from the soil to the canopy of the plant may close the soil, is a critical time for erosion.

Intensive cultivation of soils in blocky structures will lead to the destruction of soil particles or in other words soil particles dislocate each other in the event of rain, the soil will be dispersed by the kinetic energy of rain (splash erosion). If this condition occurs on flat soil, there will be sheet erosion which is visually difficult to determine in the field. The dispersed soil particles will cover the pores of the soil that will inadvertently decrease the soil infiltration capacity and ultimately increase the flow of the surface both in intensity and strength.

If the above conditions occur on sloped soils, it will result in massive land erosion from erosion of the grooves to gully erosion and this is the cause of the high level of sedimentation.

3. Potential of Erosion in Bekasi Watershed

The erosion is the event of the transport of soil or part of the land from one place to another by natural media. In the event of erosion, soil or part of the soil from a site eroded and transported which is then deposited elsewhere. Transportation or removal of the land occurs by natural media in the form of water and wind [1].

Factors affecting erosion can be expressed in the following descriptive equation:

\[ E = f (C, T, V, S, H) \]

with \( C = \) climate, \( T = \) topography, \( V = \) vegetation, \( S = \) soil, and \( H = \) human.

Among the five factors mentioned above, then the human factor determines most whether the land is cultivated will be damaged and not productive or be good and productive in a sustainable manner. Many factors that determine human influence on the land or land are cultivated are: (1) farming area, (2) land tenure system, crop type and harvesting method, (3) technological tenure status, and (4) price results of farming [1].

Based on the above descriptions, the potential for erosion of Bekasi watershed can be known from the factors causing erosion. The five causes of erosion as previously described are represented by the following values: (1) R factor (rain erosivity); ie the ability of rain to cause erosion; (2) K factor (soil erodibility); ie the ability of the soil to erode; (3) LS factor (slope); ie the length and slope of the slope; and (4) CP factor (management); namely the management of land and plants. Below are described two main factors: rain erosivity and soil erodibility.

3.1. Rain Erosivity Factor (R)

Rainfall erosivity factor (R) is the unit of rainfall erosion index which is a function of total rain energy (E) with maximum rain intensity of 30 minutes (EI30). The R value represents the multiplication of the amount of rain energy by I30 for one year.

The potential for monthly erosion to occur in the Bekasi Hulu Watershed varies, depending on the monthly R value. The trend of the monthly R value in the Upper Bekasi watershed is presented in Figure 1.
3.2. Erodibilitas Soil Factor (K)

The value of K is carried out on five types of potential land use that occur erosion, ie forest, plantation (mixed garden), shrubs, land and moor.

Table 5. Erodibilitas value in several land use

| No. | Land Use  | %Sand | %Dust | %Soil | a   | b   | c   | K   |
|-----|-----------|-------|-------|-------|-----|-----|-----|-----|
| 1   | Forestry  | 9.95  | 35.72 | 63.54 | 2.16| 3   | 4   | 0.17|
| 2   | Plantation| 22.14 | 30.86 | 40.72 | 1.29| 3   | 4   | 0.26|
| 3   | Shrubs    | 11.28 | 33.41 | 52.91 | 1.52| 3   | 4   | 0.21|
| 4   | Land      | 8.16  | 35.18 | 35.83 | 1.47| 3   | 4   | 0.28|
| 5   | moor      | 20.28 | 37.67 | 51.98 | 1.36| 3   | 4   | 0.26|

Table 5 shows that the K value ranges from 0.17 tons / joule for forest land use up to 0.28 tons/ joule for empty land use. The greater the value of K, the erosion potential is also greater because the soil erosion is directly proportional to the value of K, meaning that the greater the value of K the greater the erosion will occur and vice versa. The value of K as listed in Table 5 above shows that the sensitivity of soil erosion in Bekasi watershed ranges from low to medium. The K value for forest land use (0.17) means that the erosion sensitivity on forest soils is low (K = 0.11 - 0.20), while other land uses have moderate erosion sensitivity with a range of 0.21 - 0.32.

4. Erosion And Sedimentation Analysis

4.1. Estimation of Bekasi Watershed Erosion

The level of erosion in Bekasi watershed is calculated based on the type of potential land use that is eroded, ie forest, plantation, shrub, vacant land and moor. Each type of land use has different degrees of erosion. The average erosion value of each type of land use in the Bekasi watershed is presented in Table 6.

Table 6 shows that the highest average erosion rate occurred on empty land use with an average erosion of 1,599.0 tons/ ha/year. Furthermore, the use of plantation land reached the second highest after vacant land with an erosion value of 701.5 tons /hectare/year. Furthermore, the moor has average erosion of 679.5 ton /ha/year, this figure is higher than the average erosion of scrub and forest with average erosion of 159.3 ton /hectare /year and 10.5 ton/ha/year.
Based on the level of soil erosion, the average rate of erosion occurring in Bekasi watershed is relatively mild (<16 tons /ha /year) for forest land use, heavy (80-480 tons/ha/year) ie for shrubs land use and very heavy category (> 480 tons/ha/year) ie for other land use.

Table 6 shows that an increase in total erosion of the Upper Bekasi watershed is 11.21 million tons per year in 1998 and increased to 18.53 million tons per year. Increased total erosion of Upper Bekasi watershed is caused by changes in land use, especially lands that potentially lead to heavy erosion. The above results also show that total forest erosion decreased from 0.04 million tons in 1998 to 0.02 million tons in 2016. This decrease was due to a decrease in forest area from 4,052.3 ha in 1998 to 2,264.4 ha at 2016.

### 4.2. Sedimentation in the River

The soil and part of the soil that is transported from an erosion site and settles into a place is called the sediment. Some of the sediments will reach and enter the river. The ratio of sediment carried by the river from an area to the eroded amount of soil from the area is called the sediment delivery ratio (SDR).

Two factors that greatly affect the amount of sediment and sedimentation in the river are the amount of eroded soil and widespread watersheds. The count of sediments produced throughout the Bekasi River Watershed will go into rivers, reservoirs, places and other flat places using a total erosion and SDR approach.

The sediment delivery ratio (SDR) for the border watershed which has an area of about 39.045 ha is 9.75%. This means that about 9.75% of the total eroded soil will become sediment. So the value of sediments to the river can be calculated:

\[
\text{Sediment Yield} = \text{Total erosion} \times \text{SDR} = 18.53 \text{ million tons} \times 9.75\% = 1.81 \text{ million tons per year.}
\]

So the total sediment that will reach the river and other deposition places is estimated at 1.81 million tons annually. This figure is very large if seen the capacity of the river and other deposition places other than the river, such as rice fields, ponds, situ, river mouth and others. This phenomenon needs to be anticipated to prevent more severe adverse impacts in the future.

### 4.3. Bekasi River Flow Capacity

As previously explained that the sediment produced by the erosion process and carried by a stream will undergo a deposition process so that the sediment will be deposited at a place where the water velocity is slower or the water flow is stopped. This process is known as "sedimentation" or precipitation. The river is a means of shelter and drainage of rainwater and other materials carried by erosion process. The resulting erosion when settling in the river will reduce the capacity of flow and river catchment.
Whereas from hydraulic simulation results obtained Bekasi River largest flow capacity at Sta 65 of 764 m$^3$/s and the smallest at Sta 45 Pekayon of 462 m$^3$/s. Based on these calculations can be determined the maximum flow capacity of the entire Bekasi River is taken based on the smallest ability or equal to 462 m$^3$/s. This count uses the assumption of riverfront elevation based on the elevation of the dike that was built in 2003.

4.4. Effort to overcome Bekasi River Watershed Erosion

To overcome the flood problems in Bekasi district, up to 2005, government has been carried out structural efforts by building embankments, normalization and dredging of several segments of Bekasi River. This activity will directly increase the flow capacity of Bekasi River, but this effort has not maximized the flow capacity will continue to decline due to sedimentation, but also land use change will encourage the increase of runoff coefficient in Bekasi watershed.

For comparison to hydraulic analysis based on 2016 watershed condition, the maximum flow rate is 462 m$^3$/s, meaning that the river can only drain 10 year design debit. If there is a change to the above land use and sedimentation in the coming year the capacity of the flow will decrease and flood occurs. Therefore, non-structural efforts are needed to overcome the erosion rate in the upper Bekasi watershed. Efforts to reduce the rate of erosion are essentially efforts to change the factors that influence erosion, including rainfall erosivity (R), soil erodibility (K), slope length (LS), plant management (C) and management factors soil or conservation measures (P). The latter two factors (C and P) are often incorporated into a management factor (CP).

Conceptually, all the factors that influence the erosion above, only the management factor (CP) that allows to be changed, because other factors are very difficult to be manipulated considering those factors highly depend on the behavior and nature.

The decrease in erosion rate in principle is to reduce erosion rate to equal or less than the tolerable erosion by way of treating CP value (management factor) to less than the maximum CP value.

The non-structural approach in soil and water conservation is identical with vegetative conservation methods. This approach is considered less effective because of how it works slowly but in fact many advantages. This approach is basically the use of plants or plants and their residues to reduce the falling power of falling rain, reducing the rate and damage of surface runoff and reducing erosion.

This method has the function of: (1) protecting the soil against the destructive power of falling rain falling grains, (2) protecting the soil against damaged watercourses over the soil surface, and (3) improving the capacity of soil infiltration and water containment directly affecting the magnitude surface flow.

Non-structural approaches that can be carried out include: (1) planting of plants or plants that cover the soil continuously, (2) planting in strips, (3) crop rotation with green manure crop or ground cover crop, (4) ) agroforestry systems, (5) utilization of residue management, and (6) the planting of vegetated waterways.

5. Conclusion

Floods that occur in Bekasi watershed are relatively bigger than year to year, one of them is caused by erosion condition in upstream part of Bekasi watershed causing large flow discharge and sedimentation at Bekasi River.

At present, the average erosion rate occurring in Bekasi watershed is mild for forest land use, heavy (ie for scrub land use and very heavy category ie for other land uses. To overcome the flood problem, government has already made structural efforts but has not given maximum results, so that structural efforts need to be combined with non-structural efforts based on vegetative conservation methods.
References
[1] Arsyad S 2000 *Konservasi Tanah dan Air* Bogor: Institut Pertanian Bogor.

[2] Fongers D 2002 *A Hydrologic Study of the Ryerson Creek Watershed*. Michigan: Hydrologic Studies Unit, Land and Water Management Division Michigan Department of Environmental Quality.

[3] Kadri, T 2004 *Sistem Monitoring dan Evaluasi Pengelolaan DAS* Jurnal Sipil Vo; 4 no.1 September 2004, Universitas Trisakti.

[4] Pemerintah Propinsi Jawa Barat 2012 *Rencana Tata Ruang Wilayah Propinsi Jawa Barat 2020* Bapeda Propinsi Jawa Barat.

[5] Pistocchi A, Mazzoli P 2011 *Use of HEC-RAS and HEC-HMS model with ArcView for Hydrologic Risk Management* Forli : Italy

[6] Sinnakuadan S, Gani A, Ahmad M, Zakaria N 2001 *Pendefinisian Dataran Banjir Secara Tepat Bagi Analisis Risiko Banjir Secara Mampan*. Malaysia: Pusat Pengkajian Kejuruteraaan Awan, Universiti Sains Malaysia.