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SEDIMENTATION RATE ESTIMATION FROM COMMUNITY LAND USE IN MAMASA WATERSHED

(Pendugaan Laju Sedimentasi dari Setiap Penggunaan Lahan oleh Masyarakat di Daerah Aliran Sungai Mamasa)

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Abstract

In the last few years, the hydrology function of Mamasa Watershed could not be performed optimally in maintaining sustainability of Bakaru Dam, it is indicated by the occurrence of floods in the rainy and contrary water shortage in dry season. To prevent further damage the land-use management is needed in the watershed. Geographical Information System (GIS) has ability to process and analyze data/information, by combining the data/information in form of map/digital picture, thus an analysis of watershed degradation could be done. For erosion impact study on the increasing of sedimentation rate, the estimation of soil loss capacity could be obtained by calculating and overlaying maps of MUSLE components. Using GIS method, it was found that sedimentation rate from forest land use was 46,55 m^3/km^2/year, paddy field 10,26 m^3/km^2/year, underbush 1934,28 m^3/km^2/year, mixed agriculture 66,42 m^3/km^2/year and dry land agriculture 954,18 m^3/km^2/year.

Keywords: Erosion, Sedimentation, Land Use, Mamasa watershed

Abstrak

Dalam beberapa tahun terakhir, fungsi hidrologi Daerah Aliran Sungai (DAS) Mamasa tidak dapat bekerja secara optimal dalam memelihara kelangsungan fungsi dam Bakaru, hal ini ditandai dengan terjadinya banjir pada musim hujan dan kekeringan pada musim kemarau, sehingga untuk mencegah kerusakan lebih lanjut diperlukan pengelolaan DAS di wilayah tersebut. Sistem Informasi Geografis (SIG) mampu mengolah dan menganalisis data/informasi, memadukannya dalam bentuk peta/gambar digitasi, sehingga analisis terhadap degradasi wilayah DAS dapat dilakukan. Untuk studi erosi yang memberikan dampak pada peningkatan laju sedimentasi, estimasi besarnya kehilangan tanah dapat diperoleh dengan mengkalkulasi dan mengoverlay peta yang merupakan komponen Modified Universal Soil Loss Equation (MUSLE). Dari hasil aplikasi GIS diperoleh laju sedimentasi yang berasal dari penggunaan lahan hutan adalah 46.55 m^3/km^2/thn, persawahan 10.26 m^3/km^2/thn, semak belukar 1934.28 m^3/km^2/thn , kebun campuran 66.42 m^3/km^2/thn dan penggunaan lahan tegalan 954.18 m^3/km^2/thn.

Kata Kunci: Erosi, Sedimentasi, Penggunaan Lahan, DAS Mamasa

BACKGROUND

Mamasa watershed is characterized with unstable soil and geological conditions, due to destruction of forest vegetation by illegal logging, moving farming systems and use of land without any conservation by some people these situation is a major cause of erosion which increase of sedimentation rate in the area. The increasing complexity of the problems in the watershed area calls for the complete and accurate data to the characteristics of the watershed in order to control and manage the area.

Assessment of watershed areas or sub-watersheds could cover the areas in which the condition is varied. It requires a series of data in considerable time and relatively long analysis. Therefore, a method or tool that could access and analyze data in relatively shout period of time with a high accuracy is required. The GIS is able to process and analyze data and information on climate, regional characteristics and land, incorporating in the form of digital maps / images. Based on those reason, the analysis of the degradation of watershed areas could be carried out

The need for GIS technology is based on reasons that volume of data handling and environmental resources are generally very large, in which the conventional method is difficult to handle. Data collection is usually complex and complicated, demanding the use of effective data management system. Besides that, the current GIS development has been supported by many things like urgency to do the repair process (refinement) of cartography, the increasing ability of computerized systems in line with the ever-expanding hardware and software, and the revolution quantitative analysis of spatial information is generally used in planning of environmental management.

METHODOLOGY

Data Collecting and Processing

Stage One: Conducting observations of biophysical conditions and collection Mamasa watershed secondary data, such as: administrative maps, soil types map, slope class maps, land use maps and precipitation map with a scale of 1: 300,000. Combination of these maps is a map which is used as a working map.

Stage Two: Collecting data on hydrological/climatologically Mamasa catchment area during the last 10 years these data were tabulated and analyzed to obtain the average daily, monthly and yearly hyrological and climatological condition.

Stage Three: The Clarification of location and wide of area for identification in the process of land units map

Stage Four: Scanning maps for digitation Mamasa watershed, interpretation and analysis of computational maps of biophysical conditions of the watershed (software applications MapInfo / Arcview) to define land units. Thematic maps were used to obtain parameters on MUSLE (Modified Universal Soil Loss Equation), namely rain aerosivity factor (R), soil aerodibility factor (K), length and steepness of factor slope (LS), crop factor (C) and management factors plant and soil conservation (P). Calculating the total area of the river basin by computing and calculating the sedimentation rate

MUSLE Model

Soil Erosion prediction calculated by the equation:

$$A = R \text{ x } K \text{ x } L \text{ x } S \text{ x } C \text{ x } P \qquad (1)$$

Rain Erosion factor (R) is calculated with the equation proposed by Bols (1976) in Suripin (2004):

$$R = \sum_{i=1}^{n} EI_{30},_{m} \qquad (2)$$

$$EI_{30,m} = 6{,}119 R_m^{1{,}211} N^{-0{,}474} R_{MAX}^{0{,}526} \qquad (3)$$

Where: EI30, m = monthly Erosion (KJ/ha), Rm = monthly rainfall (cm), N = number of rainy days per month (days), RMAX = maximum daily rainfall (cm). Erosion factor (K) obtained from the analysis of soil samples. As a comparative value of K could also be obtained with the help of monographs' presented by Wischmeier (1978) is by knowing the soil texture, soil structure, organic matter and soil permeability. Factors of Slope length and steepness (LS), were calculated based on the formula proposed by Williams and Berndt (1972) in Suripin (2004):

$$LS = \sqrt{\frac{L}{22{,}13}^{2}}\,(0{,}065 + 0{,}0453s + 0{,}0065s^2) \qquad (4)$$

Where: L Length of slope (m), S slope steepness (m/m), L is determined from $L = \frac{0{,}5A}{LCH}$ where the total length of LCH is the channel/river (m) and A is the catchment area (m^2).

Crop factor (C) was determined based on the values expressed by the River Research Agency (Arsyad, 2006). Mamasa watershed land cover with the scale of 1: 100,000 was used to represent land use of the watershed. Value of C varies between 0.001 to 1.0 where vacant land or fallow land is 1 and lowest in forest-covered organic mulch materials or cover enough ground, namely 0.001. Management factors Crop and Soil Conservation (P), is the ratio of the amount of erosion of land with specific conservation measures to the amount of erosion of standards of land without conservation measures. Input values for the soil conservation measures factors were determined based on research that has been done in Indonesia. For plants without soil conservation measures, the value of factor P = 1.

Estimation of sedimentation rate

Comparation of sediment mass in outlet basin (Sy) to the total mass sediment resulting from the erosion (E), is known as sediment delivery ratio (SDR), which is calculated as (Lin, et al. 2002):

$$SDR = \frac{Sy}{E} \quad (5)$$

SDR values are extremely varied to each of basin; a few studies which have been made to estimate SDR could than correlate empirically to Basin area (Robinson, 1979 in Arsyad, 2006):

$$SDR = \alpha A^{\beta} \quad (6)$$

Where A : Basin area (km^2), α : 36 and β : -0,20, are empiric constant from the regression equation.

RESULTS AND DISCUSSION

Mamasa Basin Area

Mamasa Watershed is situated in Mamasa, Pinrang and Polewali Regency, which includes 4 subdistricts and 48 villages. Mamasa River has a length of 113.75 km for the main river, while the length of 172.50 km for the tributary, flowing from north to south with the total catchment area 1061.7803 km^2. Mamasa Basin area is has an elevation of about 60 to 2873 m above sea level. Most of this area is a hilly area with gradient 15% to> 45%.

In the downstream Mamasa watershed area there is Bakaru PLTA Dam with an irigated area of 199.85 ha located in the village of Ulu Saddang, Pinrang. This Dam is used as a source of raw water and water irrigation for local communities, as well as hydroelectric power

Erosion Estimation

Aerosivity (R)

Among climate elements which has enormous influenced on the erosion process is rainfall. Based on the kinetic energy of the annual rainfall, Mamasa watershed area divided into five regions of rain which each represented by Lemo, Sumarorong, Mamasa, Mambi and Tuppu Station. Rainfall data was used as inputs, these included the average annual rainfall, which was used to predict the amount of aerosivity. The average annual rainfall at the five stations on the amount between 543 mm - 2127 mm with a 41-day rainy day - 143 days, therefor the annual rainfall value of the Mamasa watershed ranges from 100 to 2800 mm.

Table 1. Region of Rainfall in Mamasa Watershed

No	Rainfall Value (mm)	Area (ha)	Area (%)
1	100 - 500	5863.67	5.52
2	501 – 1010	20513.73	19.32
3	1011 – 1600	22616.89	21.30
4	1601 – 2200	46251.34	43.52
5	2201 – 2800	10935.43	10.29
	Total	106178.03	100

The intensity of rain refers to the number of rain per unit time. The high intensity of rain was said when rainfall occurs a large amount in a short period of time. While the amount of rain refers to the depth of rain water during the rain in a certain period of time. The amount of rainfall may not necessarily lead to erosion if the small intensity, as well as high rainfall, but in small amounts, probably will not cause erosion because not enough water to wash away dirt particles. Erosion could occur if the rain that has occurred in the amount of high intensity. According to Hudson in the Seta (1991), soil erosion will occur if the intensity of rain is greater than or equal to 25 mm/hour.

Aerodibility (K)

Each type of soil has a difference in resistance to erosion. Ease of a soil erosion aerodibility known as the land. Aerodibility value of land mainly influenced by physical factors such as soil texture, structure, permeability and organic matter content in soil, which determined the sensitivity to erosion (Nyakatawa, et al. 2001). Soil order in Mamasa Watershed area are Ultisols and Alfisols, and Sub order Udults and Udalfs. Whereas soil type are Podsolik Browm, Mediteran Yellow Brown and Brown Forest Soil. The value of Mamasa aerodibility (K), are presented in Table 2.

Soil texture with high porosity resulted in water easily seep into the ground, a small surface flow thus reduced erosion. Similarly, land that has a solid structure, not easily destroyed by the rain flowed, this land will be resistant to erosion. On the other hand soil structure was not stable, very easy to be destroyed by the flows rain into fine grains that cover the soil pores. As a result infiltration and inhibited the flow of surface increases, which means an increase in erosion.

Permeability of soil was closely related to infiltration. Infiltration is an event of water entry into the soil through the soil surface. If the infiltration of ground, then the young water to seep into the soil surface so that the flow becomes smaller, the result of erosion that occured will be small too. While soil organic matter content determined the sensitivity of soil to erosion. Soil contained enough organic material generally causes soil structure to be established so that the resistance to erosion. Soil containing < 2% are generally sensitive to erosion (Morgan, 1985).

Topography (LS)

Mamasa Watershed area has a topographic conditions extremely varied, ranging from flat, sloping, a above sea level steep to very steep, with elevation from 60 to 2873 m. Topographical factors that most influence on the long slope erosion and slope. According to Angima, et al., (2003), slope of land will affect the land productivity.

Mamasa watershed area is dominated by undulating to hilly topography with a width of approximately 42,338.31 hectares or 39.87% of the total watershed area and the topography is quite steep 33,279.70 hectares or 31.34%. Only 1.70% of the river basin which is a plain Mamasa, consequently it is possible the rate of surface flow (runoff). Because the flow process of the faster surface by the growing percentage of slope (Suripin, 2004). The value of topographic factor (LS) based on slope length and slope in the watershed areas ranging from Mamasa 0.10 to 11.78.

Table 2. Soil Type and Aerodibility Value (K) in Mamasa Watershed

No.	Soil type	Erodibilitas	area(ha)	area (%)
1.	Podsolik Brown	0.10	21599.65	20.34
2.	Compleks Yellow Brown	0.15	47072.01	44.33
3.	Brown Forest Soil	0.21	37506.37	35.32
	Total		106178.03	100

Table 3. Slope and slope factor values in Mamasa Watershed

No.	Slope (%)	LS value	Area (ha)	area (%)
1.	0 - 8	0.10	1825.01	1.70
2.	8 – 15	0.88	14058.30	13.24
3.	15 – 25	4.09	42338.31	39.87
4.	25 – 45	8.37	33279.70	31.34
5.	> 45	11.78	14678.71	13.82
	Total		106178.03	100

Table 4. Factor Value Crop and Crop Management in Mamasa Watershed

No.	Land Use	CP value	Area (ha)	Area (%)
1	Forest	0.005	54126.20	50.97
2.	Paddies	0.050	2261.72	2.13
3.	Underbush	0.300	37254.55	35.09
4.	Mixed Agriculture	0.200	2684.70	2.53
5.	Dry land Agriculture	0.400	9850.86	9.28
	Total		106178.03	100

Crop and Crop Management (CP)

Land use is human activities that give the greatest influence on erosion. Plants or vegetation cover could prevent rain water from falling directly on the soil surface, so that rain water power to destroy the land is reduced, depending on the density and height of plants, plant closer, more effective in reducing erosion.

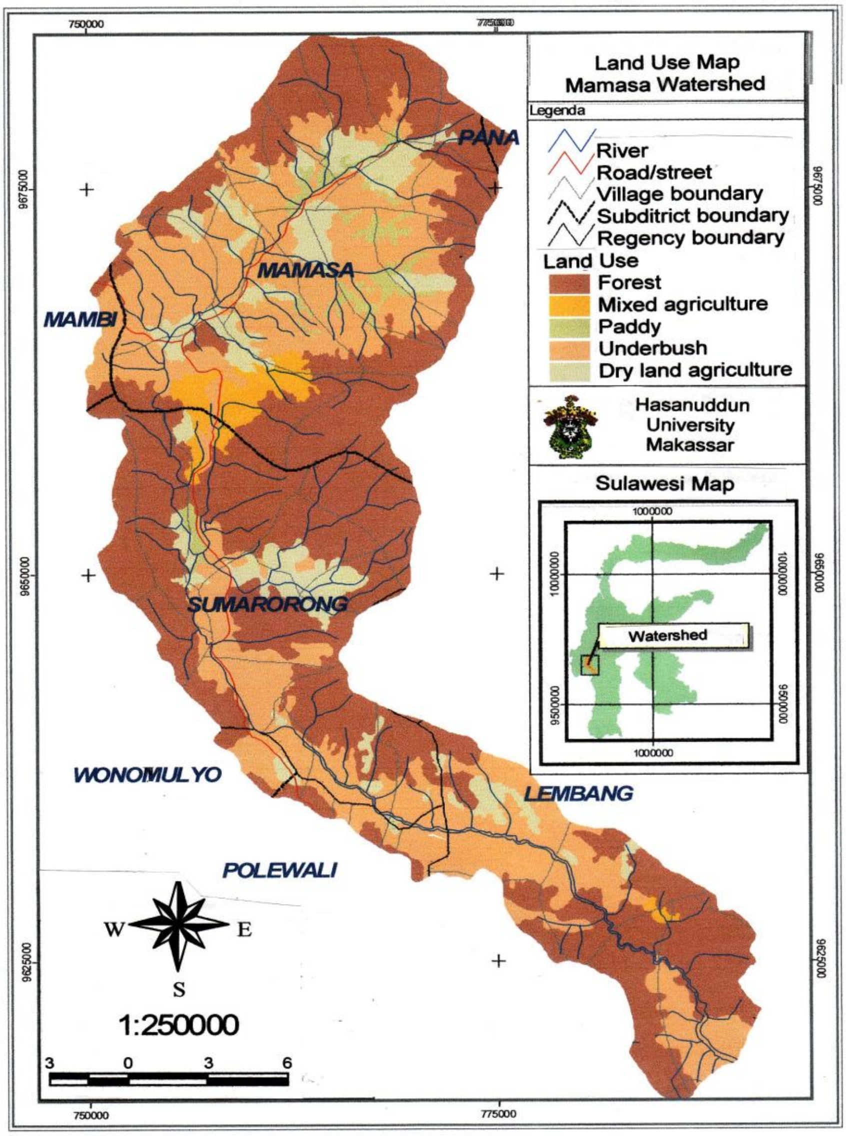
Arsyad (2006) said that, a plant or vegetation cover good ground like thick grass or dense jungle will eliminate the influence of rain and topography of the erosion. Because the human need for food, clothing and housing is increasing, all the land could not be left closed forests and grasslands. Other plants were cultivated by humans play a significant role in the prevention of erosion. In general, the application of conservation in Mamasa watershed areas inadequate, more than 86% of land use is still a forest and underbush. Only about 13.94% of the paddy fields, mixed agriculture and fields by implementing simple conservation methods, such as the use of traditional patio and planting according to the contour on sloping land areas above 20%.

Land Unit

Land units is a unit of land that the area relatively uniform erosion over a number of factors. Wischmeier and Smith (1978), stated that an important consideration in the application of erosion prediction models in basin areas is to classify watersheds into sections or areas of land units are relatively uniform over a number of factors of erosion. Unit of land acquired by the map overlay of climate, soil maps, slope maps and land use maps. In the watershed area of Mamasa overlay results yielded 584 units of land in the watershed area of 106178 ha. In GIS analysis, land units were given identity numbers, area information and location of each unit of land in large quantities, integration of watershed area as a whole, which was very difficult to be calculated manually and it takes a long time.

The rate of Soil Erosion

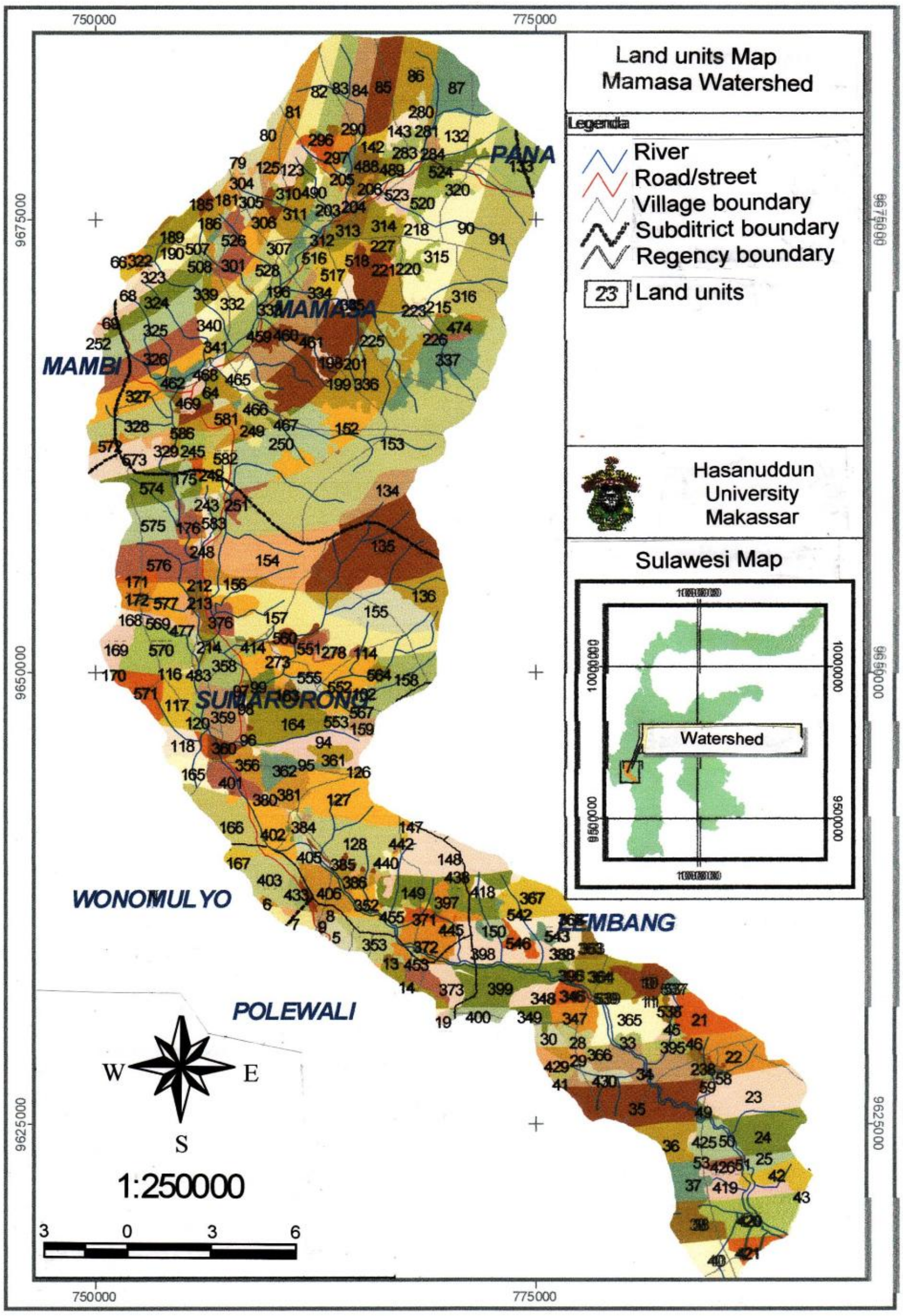
Erosion rate was calculated by using GIS-based MUSLE model, which is based on various factors of erosion. The rate of erosion in the Mamasa Watershed area reach 29.608.797 tons/year or an average of 279 tons / ha / year.



Pic 1. Land Use Map in Mamasa Watershed

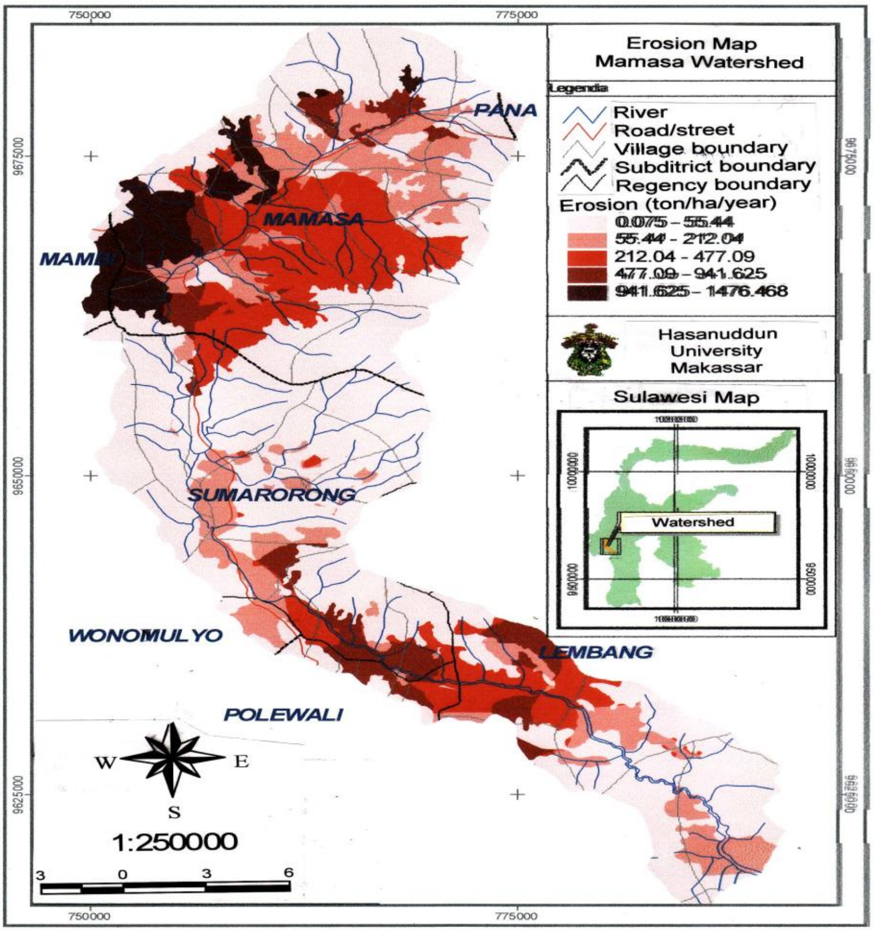
Table 5. The Rate of Soil Erosion From Each Land Use in Mamasa watershed

No.	Land Use	area (ha)	Erosion(ton/ha/year)
1.	Forest	54126,20	4.31
2.	Paddies	2261,72	0.96
3.	Underbush	37254,55	179.10
4.	Mixed agriculture	2684,70	6.15
5.	Dry land agriculture	9850,86	88.36
	Total	106178,03	278.86



Pic 2. Land Units Map in Mamasa Watershed

The highest rate of soil erosion in Mamasa watershed areas, occurred in the area use of underbush; it was 179.10 tonnes/ha/year, and dry land agricultural 88.36 tons/ha/year and, this was caused by land use for these activities, generally performed on cycle region and the lack of public awareness to action in the business of land conservation land use, consequently increasing the surface flow that results in increased erosion rate (see Fig. 2)



Pic 3. The Rate of Soil Erosion Map in Mamasa Watershed

Table 6. The Rate of Sedimentation From Societie's Land Use

No.	Land Use	area (ha)	Sediment (m^3/km^2/year)
1.	Forest	54126,20	46.55
2.	Paddies	2261,72	10.26
3.	Underbush	37254,55	1934.28
4.	Mixed agriculture	2684,70	66.42
5.	Dry land agriculture	9850,86	954.18
	Total	106178,03	3011.69

Sedimentation Rate Estimation

Sedimentation is a further process of erotion. Ratio between sedimen total in river and erotion total in basin was sediment delivery ratio (SDR). SDR value for 106178 ha was 8.97% or 0.09.

Overall sediment total from erosion in Mamasa watershed which enter Bakaru Dam was 3011.69 m^3/km^2/year. This sediment rate was above of Dead Storage Sediment (DSS) value of Dam, i.e. 132.57 m^3/km^2/year, for 50 years technical age. Sediment deposit in dam, river or canal could cause superficiality wich at the end will reduce dam, river or canal function.

The increase of erosion and sedimentation rate due to communites land use which do not consider land conservation cause flood, drought, etc.

CONCLUSION

Sedimentation rate from forest land use was 46.55 m^3/km^2/year, paddy 10.26 m^3/km^2/year, underbush 1934.28 m^3/km^2/year, mixed agriculture 66.42 m^3/km^2/year and dry land agriculture 954.18 m^3/km^2/year, respectively.

Sedimentation rate in Bakaru Dam above Dead Storage Sediment, i.e. 3011.69 m^3/km^2/year.

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