CHAPTER 4 EROSION SOURCES AND SEDIMENT YIELD FROM THE WONOGIRI DAM WATERSHED

4.1 Erosion Sources of Sediment Deposits in the Wonogiri Reservoir

Almost all sediment deposits in the Wonogiri reservoir have entered the Wonogiri reservoir as a consequence of land surface erosions due to heavy rain in its watershed and subsequent transport by all the inflowing tributary rivers. Eroded sediments are flushed downstream through stream channels over some period. There is a close relationship between watershed erosion and reservoir sedimentation.

Sediment Deposits at the old bridge on the Reservoir Arm of Alang River

Under the current study, erosion sources of the sediment deposits in the Wonogiri reservoir might be classified according to the erosion sites. The visible erosion sites are; i) soil erosion from land surface, ii) gully erosion, iii) landslide (slope failure), iv) riverbank erosion, and v) slope erosion of road side. Soil erosion from land surface normally occurs due to sheet erosion of the land which includes the cultivation areas, uplands, home-yard areas as well as forest areas. Sheet erosion is defined as detachment and transport of soil particles due to rainsplash and shallow pre-channel flow. Sheet erosion normally predominates where the land surface has been denuded and disturbed, such as by grazing and cropped lands. Considering the current intensive land use of dry-land farming over the Wonogiri dam watershed, it is expected that soil erosion from the land surface is predominant as the source of sediment in the Wonogiri catchment.

Silt/Clay Sediment Deposits in the Reservoir

Total erosion or gross erosion within a watershed is the sum of all types of erosion above. The relative importance of different types of erosion varies from place to place. Erosion rate is expressed in terms of mass of soil removed per unit of time, e.g. 50 ton/km^2/year or 50 ton/ha/year. Erosion rate per year is the so called "annual erosion rate". It may also be expressed as the denudation rate of the earth's surface, measured in soil depth per unit of time, e.g. 2 mm/year. Denudation rate per year is the so called "annual denudation rate".

Sediment yield is defined as the amount of eroded sediments discharged by a stream at any given point. It represents the total amount of fluvial sediments exported by the watershed tributary to a measurement point, e.g. a reservoir. Sediment yield per year is the so called "annual sediment yield". Because much eroded sediment is re-deposited before it leaves a watershed, the sediment yield is always less than, and often much less than, the erosion rate within the watershed. Further sediment from the distant source will typically encounter more opportunities for re-deposition before the watershed outlet. The ratio between the erosion rate and sediment yield is the "sediment delivery ratio (SDR)". Under the Study, the sediment yield from the Wonogiri dam watershed at the Wonogiri reservoir is expressed by the following equation in terms of types of erosion:

Sy = A x SDR1 + Gl x SDR2 + Rb x SDR3 + Ls x SDR4 + Rs x SDR5

where,

Sy:	Sediment yield from watershed
A:	Soil erosion from land surface
SDR1-5:	Sediment delivery ratio for each erosion source
Gl:	Gully erosion
Rb:	Riverbank erosion
Ls:	Landslide
Rs:	Slope erosion of road side

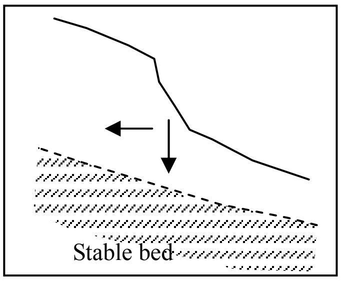
In general, the delivery ratio is higher for sediments derived from erosions of riverbank, landslide and road slope which tend to be almost immediately exported to streams, as compared to sheet erosion on land surfaces. Respective delivery ratios for erosions of riverbank, landslide, gully and road slope are herein assumed to be 100%. Generally the sediment delivery ratio cannot be measured directly as the gross erosion is never measured in a watershed. Under the Study, the sediment delivery ratios for the Wonogiri dam watershed as well as the major tributaries are directly extrapolated by using the measured sedimentation volume in the Wonogiri reservoir which is directly surveyed by the Study.

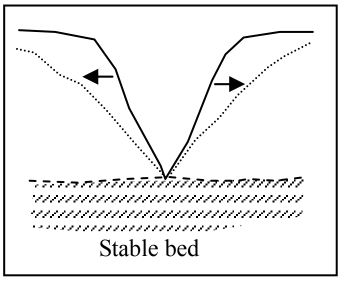
Preliminary estimation of the annual sediment yield for all types of erosion is undertaken under the Study. Erosions of riverbank, landslide, gully and road side slope are estimated based on field investigations, as they are widely distributed over the Wonogiri dam watershed.

4.2 Sediment Yield from Erosions of Gully and Landslide

4.2.1 Gully Erosion

(1) Erosion Process





Gully erosion is an advanced stage of rill erosion where surface channels have been eroded to the point where they cannot be smoothed. Active gullies are characterized by a steep or vertical erosional scarp. In general a gully becomes deeper and wider through the following processes:

<u>Gully head erosion</u>

A gully will advance upward and progress until it reaches a stable bed. If there is no stable bed, the gully continuously become deeper.

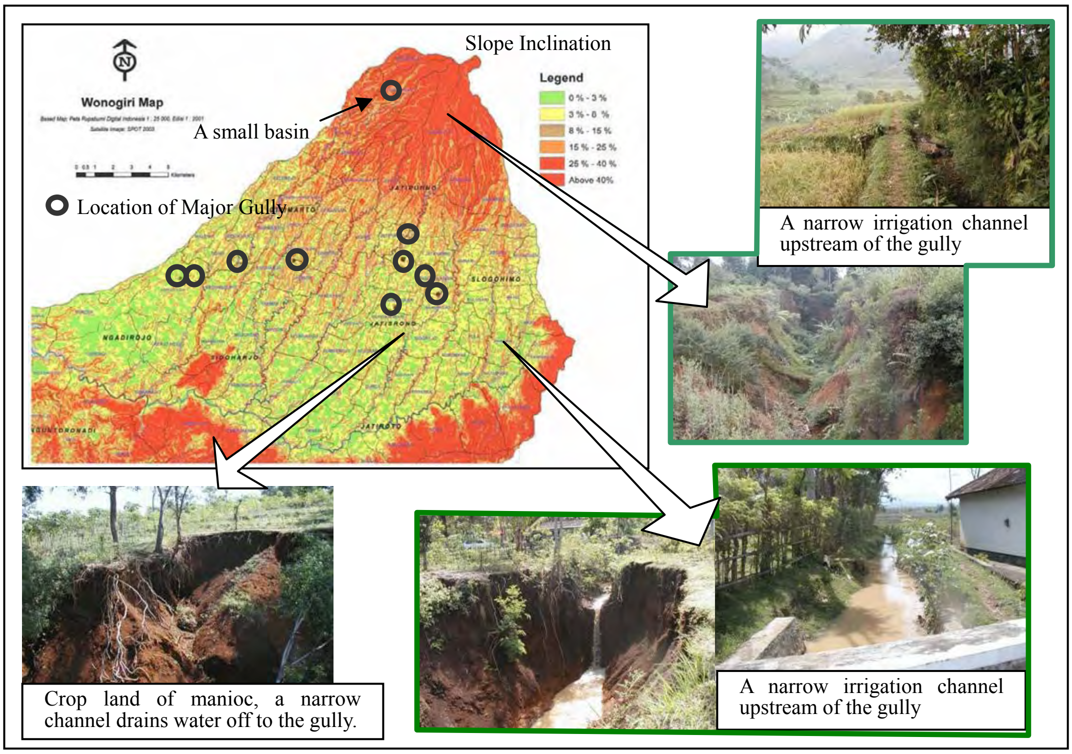
<u>Lateral erosion</u>

After attaining a stable bed, the gully will become wider until the slope inclination reaches its repose angle.

Gully erosion occurs where erodible soil is exposed to concentrated runoff from rainfall, and may be initiated by enlargement of aril, when flow is concentrated by a structure such as a trail, road, ditch or drain, or when runoff is increased by a change in the use of the upstream land. Photos below show typical gullies in the Keduang River basin. As shown below, discharged water from narrow channels or drains causes gully erosions in many cases.

Large Gully in Keduang Area

Large Gully in Keduang Area



Source: JICA Study Team

Figure 4.2.1 Typical Gullies on the Keduang Watershed

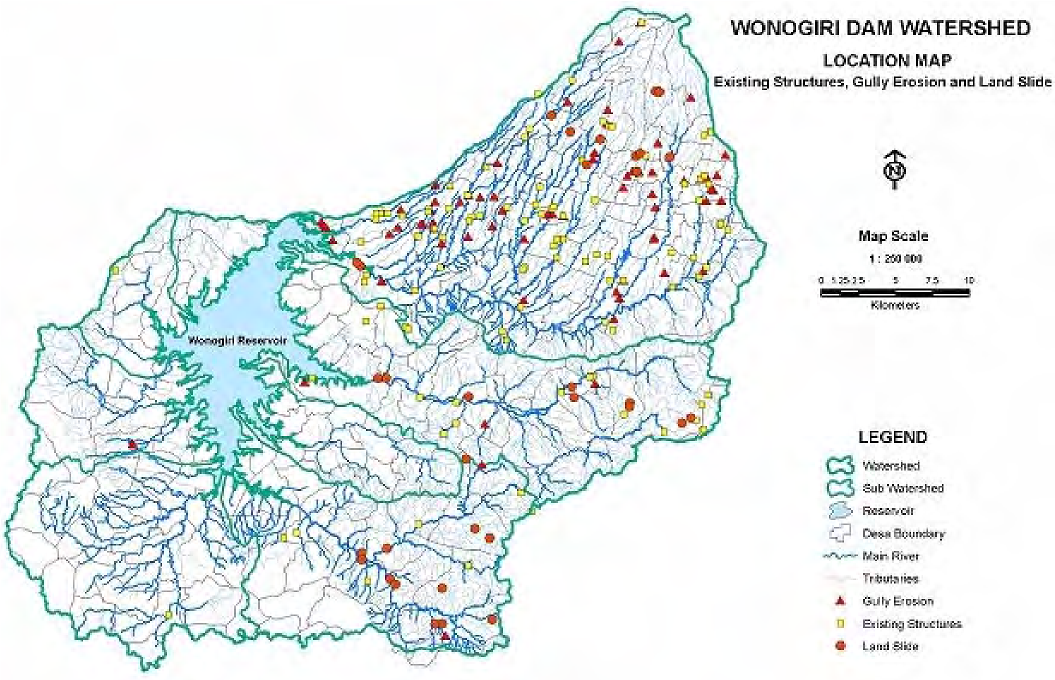
(2) Field Investigation

Gully locations were investigated over the entire Wonogiri dam watershed. In total, 71 gully locations were identified. The location map of the existing gullies is shown below. Major findings are summarized below:

i) Many gullies are concentrated in the Keduang watershed, although almost of them are very small (less than 2-3 m in height) and might be negligible. The largest gully observed in this watershed is 5-8 m high, 15-20 m wide and 200 m long.

ii) In the Keduang area, major gullies are located on the mountainside of average slope inclination of less than 15% where there is a transition zone from a gentle slope terrace or terrain to a relatively steep slope with 5-8 m thick erosive soil. Although slope inclination is one of most important factors for gully erosion, the highland area is covered by relatively dense forests and no large-size gullies were detected.

iii) Several gullies were observed on the tributaries of the Tirtomoyo and Upper Solo Rivers.



Source: JICA Study Team

Figure 4.2.2 Location Map of Existing Gullies, Landslides and Sediment Related Structures

(3) Existing Sediment Related Structures

There are many sediment related structures such as sabo dams, check dams, gully plugs (small, medium and large scales), gully head structures and small sand trapping reservoirs. The location map is shown in Figure 4.2.2 above.

Large Gully Plug in Keduang Area

Large Gully Plug in Keduang Area

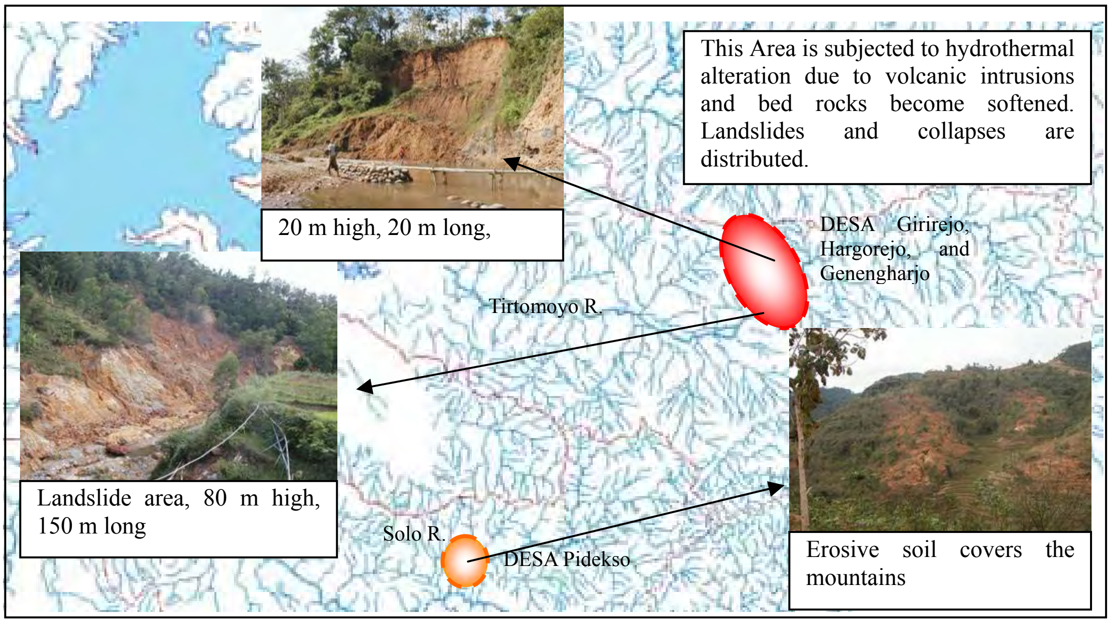
Check Dam in Alang Area

Small Gully Plug in Keduang Area

4.2.2 Landslides

Landslides are a source of sediment in the watershed. Landslides are normally difficult to quantify because they tend to occur episodically and in response to extreme events. In total 25 existing landslide locations were identified. Locations are also shown in Figure 4.2.2 above.

In the Tirtomoyo River basin, relatively large landslides were detected in Desa Girirejo, Hargorejo and Genengharjo as presented below. The landslide high potential zone is probably restricted to the area subjected to hydrothermal alteration due to volcanic intrusions.



Source: JICA Study Team

Figure 4.2.3 Landslide Area of Tirtomoyo River and Upper Solo River Basins

4.2.3 Preliminary Estimate of Sediment Yield from Erosion of Gullies and Landslides

Gross erosion from the existing gullies and landslides within the Wonogiri dam watershed seems to be relatively small based on the results of field investigations. The table below presents a summary of the estimated production volume from the existing gullies and landslides.

Table 4.2.1 Estimated Production Volume of Existing Gullies and Landslides based on Field Investigation

River System	Gully Erosion		Landslide	
	points	Total Volume (m^3)	points	Total Volume (m^3)
Keduang	65	84,626	12	2,026
Tirtomoyo	2	108	8	7,950
Temon	1	30	0	0
Solo	1	270	5	302
Alang	2	9,000	0	0
Others	0	0	0	0
TOTAL	71	94,034	25	10,278

Source: JICA Study Team

The total erosion volume from gullies is estimated at around 94,000 m^3. As shown above, there are more than 90% of the existing gullies and gross erosion volume from them are located in the Keduang watershed. Especially they are intensively distributed on the moderate-to-steep sloping mountain areas of the Keduang River where Latosol soil is widely distributed. The Latosol is quite susceptible to erosion by streams. It appears from the advice of local inhabitants that the gullies have developed over about 4 years for large scale gullies and in 1-2 years for small ones. It is thus roughly estimated that around 30,000 m^3 totally of gully erosion has occurred annually over the Wonogiri dam watershed. Under the Study, it is assumed that annual gross erosion from gullies is around 50,000 m^3 considering there still might be small gullies unidentified by the current field investigation. The assumed gross erosion is distributed throughout each watershed in proportion to its estimated production volume.

As for landslide, a total of 25 sites were observed through field investigation and the total erosion volume from landsides is estimated at around 10,300 m^3. Although a few of them are still active, they are small as a whole. The number of sites is largest in the Keduang, but they are of relatively small scale. On the other hand, large scale landslides are observed in the Tirtomoyo watershed. Photos in the next page, which were taken in August 2001 and in November 2005, compare the state of the largest landslide on the Tirtomoyo River at different times. It seems that this landslide is being stabilized as its vegetation is being recovered. Under the Study, it is assumed that annual gross erosion over the Wonogiri dam watershed is around 10,300 m^3 applying the estimated total erosion volume from field investigation, assuming that from now on small scale landslides will continue to occur.

Comparison of Largest Landslide at Different Times on Tirtomoyo River

In summary annual gross erosion of gully and landslide from respective catchment is as follows:

Table 4.2.2 Estimated Future Annual Gross Erosion from Gully and Landslide

River System	Gully Erosion (m^3)	Landslide (m^3)
Keduang	46,300	2,000
Tirtomoyo	60	8,000
Temon	20	0
Solo	150	300
Alang	5,000	0
Others	0	0
Total	**51,530**	**10,300**

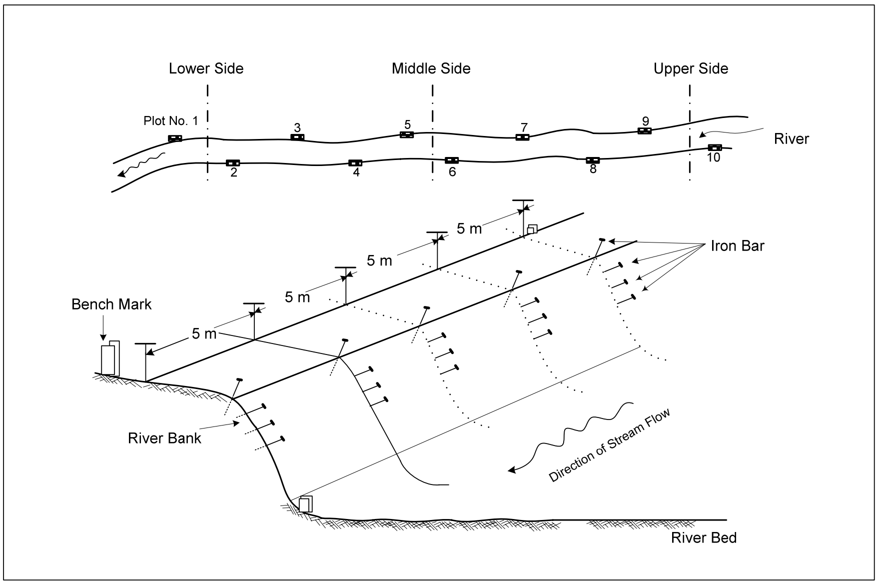
Source: JICA Study Team

4.3 Sediment Yield from Riverbank Erosion

4.3.1 Average Annual Rate of Riverbank Erosion

Channel and riverbank erosion normally occurs along the channel bed and banks of rivers. Almost no bank protection works have been undertaken on major tributaries within the Wonogiri catchment. Only some wet masonry revetment have been provided for protection of bridge abutments. Active eroding banks are readily observed at many locations along tributaries, where riverbanks are often nearly vertical with freshly exposed roots and generally little bank vegetation. The majority of riverbed materials are sand together with cobbles. These coarse materials are conveyed and deposited from upstream to downstream, although very fine materials (wash loads such as clay and silt) are also conveyed with sands to enter the Wonogiri reservoir without deposition on riverbed. Thus, the study focuses on riverbank erosion.

Sediment yield due to bank erosion is governed by the rate of erosion per unit area or length of river channel. Rates of bank erosion were studied by BP2TPDAS[1] (Watershed Management Technology Center of Surakarta, Ministry of Forestry) for both the Keduang and Tirtomoyo Rivers in 1995. This study aimed at evaluation of the effect of the 10 km long riverbank protection and the 80 km long road slope protection which had been constructed under the Upper Solo Watershed management protection Project by IBRD from 1988/89 to 1994/95. The method applied for measuring the rate of erosion was the iron bar observation method which was installed at the selected riverbank locations. The observation was conducted during the wet season from December 20, 1994 to February 20, 1995. The measurement was made at a total of 20 locations along the mainstream of Keduang and Tirtomoyo Rivers. In total, 500 iron bars were installed. Typical arrangement of iron bars on the riverbank is illustrated below.



Source: BP2TPDAS (Watershed Management Technology Center of Surakarta)

Figure 4.3.1 Iron Bar Arrangement for Measurement of Riverbank Erosion

The results of measurement are concluded that the annual erosion rates from bank erosion per meter channel length are 1.13 m^3/m for the Keduang River and 2.30 m^3/m for the Tirtomoyo River, respectively. The average for these two rivers is 1.72 m^3/m. It is noted that BP2TPDAS recommended these erosion rates as the annual erosion rate, although the observation period is only for two months in the wet season. For this Study, the average annual erosion rate is applied as 3.44 m^3/m, which is twice of the average annual erosion rate to allow for the period of the wet season and likely increase of the annual rate.

4.3.2 Field Investigation on Existing Riverbank Erosion

Locations of existing riverbank erosion were investigated for major tributaries. The identified locations of existing riverbank erosion along river channels together with field

[1] Kajian Penilaian Laju Erosi Tebing Sungai dan Erosi Tebing Jalan di DTA Waduk Wonogiri, Journal Volume II No.2, 1995 (Study on Streambank Erosion and Roadside Erosion Rate Assessment at the Wonogiri Dam Catchment Area)

photos are shown in Figure 4.3.2. As seen, locations of existing bank erosion are widely distributed over the Wonogiri dam watershed. Progressing bank erosions occur mainly at i) meandering stretches in the main stream ii) confluence points with small tributaries, and iii) downstream bank of river structures such as bridge and irrigation intake.

Most active bank erosions are observed in the Alang River which flows through the large river terrace over the lower land. Along the river terraces there are many small tributaries and the drainage canals causing erosion. Most of terrace deposits seem to be easily eroded by small flush floods. Typically the erosion occurs at the foot of the bank and could cause larger scale bank failure.

The riverbanks of small tributaries in the mountainous area are mainly composed of the compressed cobbles and sands (N-value is 30 to 50) or exposed hard rocks. The total erosion volume from them is considered relatively smaller than the mainstream.

Figure 4.3.3 below presents the comparison of grain size distributions of riverbank materials as they were at the major tributaries in 2004, with the sediment deposits in the Wonogiri Reservoir. Though the grain size distribution of the riverbank in the watershed varies from location to location, typical bank erosion that normally occurs on the banks was composed of fine and soft materials. Considering a grain size of 0.50 mm, which is the upper limit of grain size in the reservoir, could be delivered into the reservoir, around 75% of materials eroded from the riverbanks would be delivered into the reservoir.

Alan River

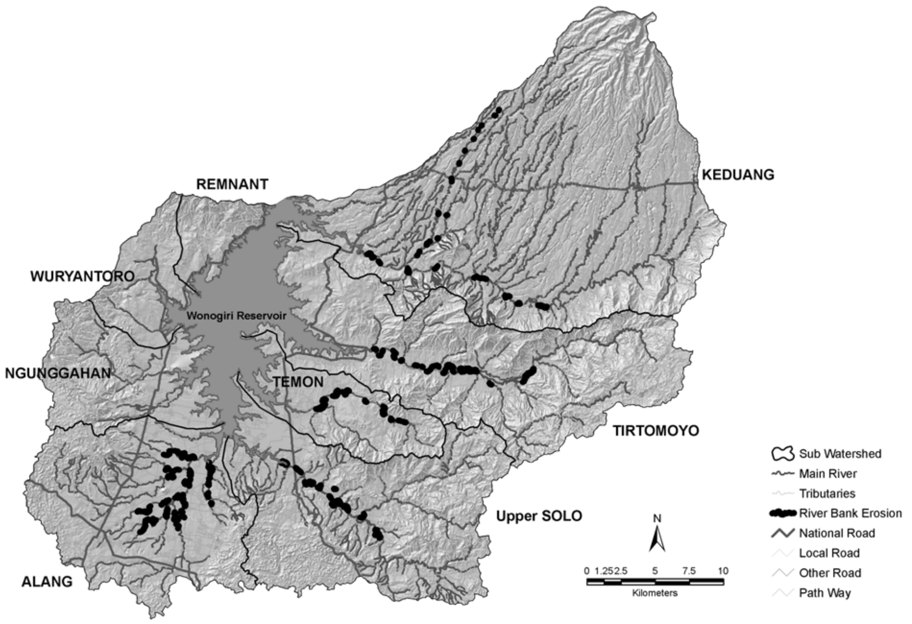
Alang River

Keduang River

Upper Solo River

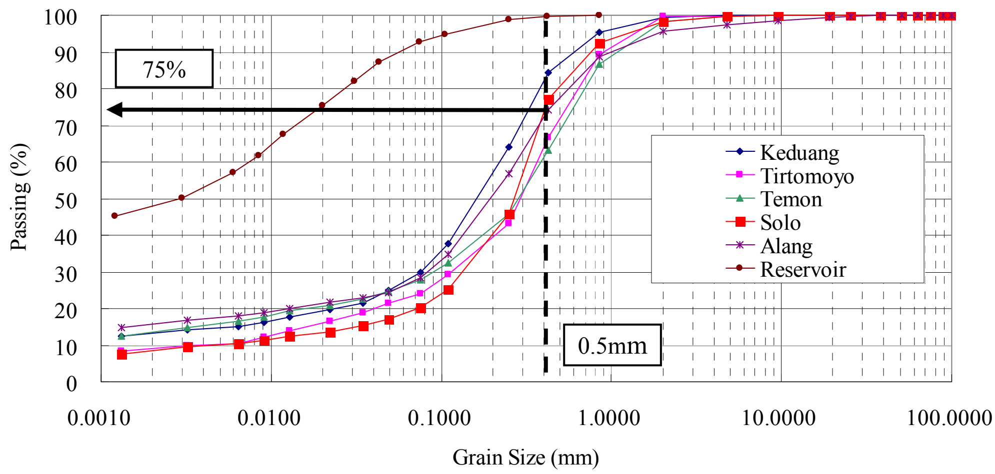
Upper Solo River

Temon River



Source: JICA Study Team

Figure 4.3.2 Location Map of Riverbank Erosion



Source: JICA Study Team

Figure 4.3.3 Grain Size Distributions of Riverbank Materials

4.3.3 Preliminary Estimate of Sediment Yield from Erosion of Existing Riverbanks

Totally 25,860 m of eroding riverbanks were identified in the basin. Multiplying this length and the erosion rate determined by referring to the result of field test by BP2TPDAS as mentioned above, the future gross erosion from riverbanks was estimated as summarized in the table below.

Table 4.3.1 Estimated Future Gross Erosion from Riverbank

River System	Riverbank Erosion		
	points	Total Length (m)	Total Volume (m^3)
Keduang	15	1,940	6,670
Tirtomoyo	29	3,920	13,480
Temon	16	2,250	7,740
Solo	22	2,190	7,530
Alang	42	13,210	45,440
Others	12	2,350	8,080
TOTAL	**136**	**25,860**	**88,940**

Source: JICA Study Team

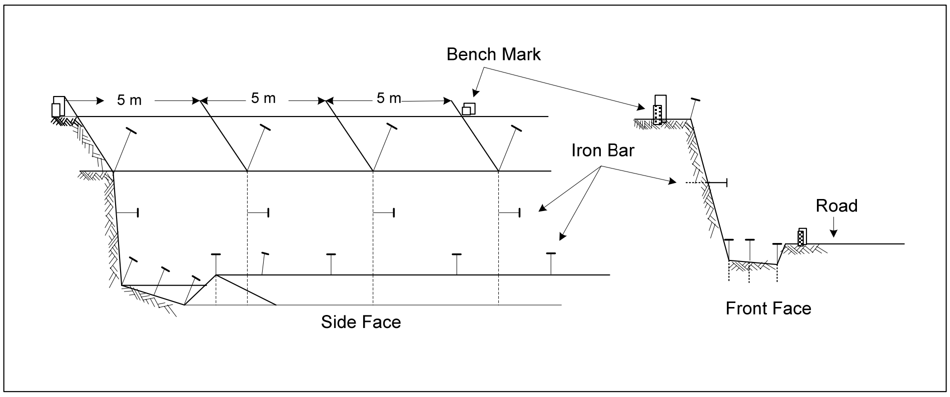
As shown in above table, characteristics of riverbank erosion might be described as follows:

i) The riverbank erosion occurs along the mainstream of major tributaries. Total length of bank erosion in the basin is 25,860 m long and the gross erosion volume from the riverbanks is determined as 88,940 m^3.
ii) The most active bank erosion is progressing in the Alang River and its erosion volume is more than half of the total volume in the whole Wonogiri dam watershed.
iii) In the other basins, the riverbank erosion is relatively smaller.

4.4 Sediment Yield from Slope Erosion of Roadsides

4.4.1 Average Annual Rate of Slope Erosion of Roadsides

As mentioned in the previous sub-section, rates of slope erosion from existing roadsides are also available in the study report of BP2TPDAS. The same field observation method as the riverbank erosion was applied by use of iron bars. The observation period was also the same. A total of 30 locations were selected for the Keduang, Tirtomoyo and Upper Solo River basins. In total, 720 iron bars were installed with the following typical bar arrangement. The survey report concluded that the annual erosion rates from roadside slope per meter road length are 0.039 m^3/m for the Upper Solo, 0.128 m^3/m for the Keduang and 0.133 m^3/m for the Tirtomoyo. The average of these three basins is 0.10 m^3/m. For this Study, the average annual erosion rate is applied as 0.20 m^3/m, which is twice of the average annual erosion rate to allow for the period of wet season and likely increase of the annual rate.



Source: BP2TPDAS (Watershed Management Technology Center of Surakarta)

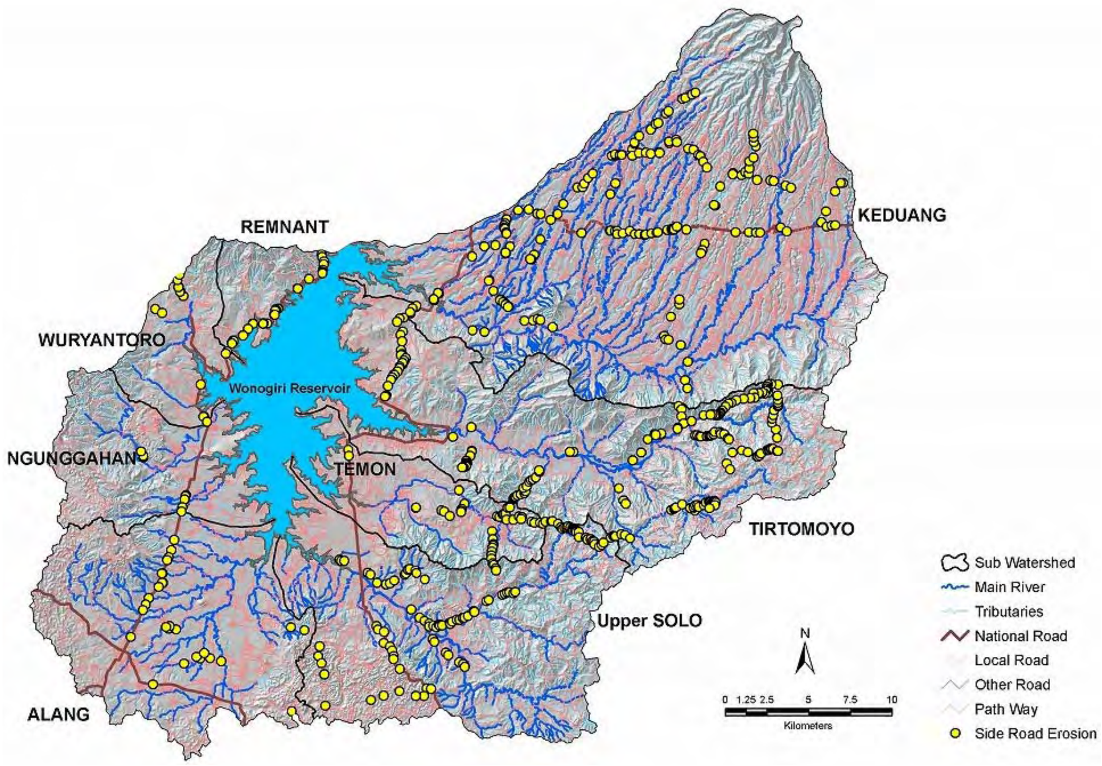
Figure 4.4.1 Iron Bar Arrangement for Measurement of Roadside Slope Erosion

4.4.2 Field Investigation on Existing Locations of Roadside Slope Erosion

The locations of existing roadside slope erosion are investigated for major and local road networks over the Wonogiri dam watershed. The identified locations together with field photos are shown in Figure 4.4.2.

The roadside slope erosions are distributed throughout the entire basin, especially on the steeper slopes of excavated sections. Though sheet erosion is a dominant for the erosion of roadside slopes, slope failures occur in some areas. Protection works by masonry and blocks normally exist on the road slopes in urban areas. Where the excavated roadside slope is gentler, the slope is protected from erosion by covering grasses. Both the protected slopes and gentler slopes were neglected for the estimation.

		
Major Road in Keduang	**Major Road in Keduang**	**Major Road in Keduang**
		
Hedge on the slope of roadside	**Maijor Road in Tirtomoyo**	**Major Road between Solo and Pacitan**



Source: JICA Study Team

Figure 4.4.2 Location Map of Roadside Slope Erosion

4.4.3 Preliminary Estimate of Sediment Yield from Slope Erosion of Roadsides

Estimated future gross erosion from riverbank is presented in Table 4.4.1.

Table 4.4.1 Estimated Future Gross Erosion from Roadside Slopes

River System	Slope Erosion		
	No. of Locations	Total Length (m)	Total Volume (m^3)
Keduang	160	12,595	2,519
Tirtomoyo	192	8,466	1,693
Temon	46	2,055	411
Solo	113	6,817	1,363
Alang	33	2,515	503
Others	40	4,020	804
TOTAL	**584**	**36,468**	**7,294**

Source: JICA Study Team

As is shown in above table, roadside erosion can be characterized as follows:

i) Total length of erosion from roadside slope is 36,500 m and the gross erosion volume from the riverbanks is determined to be around 7,300 m^3 applying the erosion rate of 0.20 m^3/m.

ii) Though roadside slope erosion looks very active, the total erosion volume is smaller than that of riverbank erosion because of the lower erosion rate.

iii) The estimated gross erosions for the river basin are in proportion to the catchment area.

iv) In the Alang River basin, roadside slope erosion is relatively smaller because there are few excavated sections due the land being less hilly.

4.5 Sediment Yield from Soil Erosion of Land Surface

4.5.1 Current Soil Erosion on Cultivated Lands

As mentioned later in succeeding subsection 4.5.2, soil erosion from the land results from five factors; i) rainfall, ii) characteristics of soils, iii) topographic conditions (slope length and steepness), iv) the condition of cover and management of the lands, and v) the condition of support practices for prevention of soil erosion.

Average annual rainfall in the Wonogiri dam watershed ranges from about 1,500 mm to 2,800 mm. There is a tendency for the annual rainfall to increase as the elevation becomes higher. The rainfall is erratic. The relation of total annual rainfall (or monthly based rainfall) to soil erosion is relatively high. The rainfall intensity in the catchment area is very high. According to the chart of hourly rainfall records, most of the intense rains is confined to period of only 30 minutes. So both the kinetic energy of rainfall and rainfall intensity are high.

There are four kinds of major soils: Mediteran, Latosols, Grumusols and Lithosols. Except Lithosols, the other three soils (about 80% of the whole Wonogiri dam watershed) are susceptible to water erosion.

It is a feature that the Wonogiri dam watershed is composed of steep lands. Furthermore the land is deeply dissected by the small tributaries in the watershed. The steepness of slopes in the sub-basin is shown below:

Table 4.5.1 Slope Steepness in Wonogiri Sub-watersheds

Name of sub-basin	Proportional % of the area classified steepness				
	Slope steepness (%)				
	0-3	3-8	8-15	15-25	Over 25
Keduang	21	26	20	11	22
Tirtomoyo	13	9	10	15	53
Temon	33	19	14	10	24
Upper Solo	21	11	12	16	40
Alang	44	17	12	10	17

Name of sub-basin	Proportional % of the area classified steepness				
	Slope steepness (%)				
	0-3	3-8	8-15	15-25	Over 25
Ngungganhan	32	13	14	15	26
Wuryantoro	26	27	21	12	14
Entire area	24	18	15	13	30

Source: JICA Study Team

Land having steepness of over 25% occupies about 30% of the total catchment area, especially the Tirtomoyo and Upper Solo basins are steep.

With the present land use, 63% of the total catchment area is used as farmland consisting of 24% in paddy field and 39% in upland field. In addition, dry farming cultivation with cassava is commonly found in the home settlement area. Upland fields extend over the top of the steep mountainous area. On the other hand, the forest area is very small in the catchment area. The state dense forest area is less than 1% and orchard/plantation area is 10%. Accordingly these forest areas do not play a significant role in soil and water conservation.

Annual cropping patterns prevailing in the catchment area are as follows:

Table 4.5.2 Annual Cropping Patterns

Land use	Annual cropping pattern
Paddy field (irrigation water is sufficient)	Irrigation water is availabe1st paddy+2nd paddy
Paddy field (irrigation water is insufficient)	1st paddy + polowijo
Upland field	1st Polowijo + 2nd polowijo

Source: JICA Study Team

The intensity of 2^{nd} polowijo crops in upland area is about 40% at present.

A considerable number of bench terraces are found in upland field. The Upper Solo (Wonogiri) Watershed Protection Project was implemented for 1988/89-1994/95 by Ministry of Forestry under the finance of the World Bank. In this project about 22,000 ha of bench terrace area were made in the upland fields, which is equivalent to about 50% of the total upland field. A considerable portion of these bench terraces are deteriorated at present. However, the terraces of the paddy fields are well maintained.

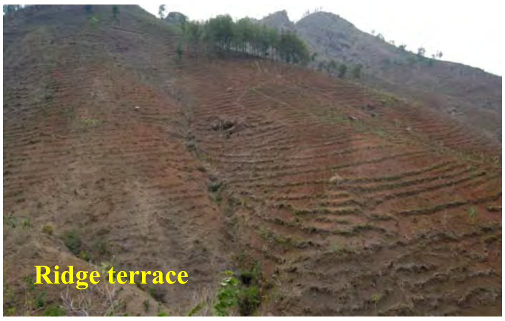
Based on the results of the field survey and analysis of the main sources of soil erosion from the cultivated lands, it may be concluded that the soil erosion sources are as shown below:

i) The main sources of soil erosion are upland fields with no terraces which extend over steep (over 10% in gradient) mountainous areas in the upper streams of the Keduang, the Tirtomoyo, the Upper Solo, the Alang and the Ngunggahan. Also deterioration of bench terrace lands becomes one of the most important factors for acceleration of soil erosions.

ii) Relevant to soil erosions, the home settlement area which occupies about 22% of the total catchment area, features considerable area of upland fields composed of non-terrace and ridge terrace, mainly for cassava cultivation. In case of the Keduang river basin, a lot of rivers run from north to south and deeply dissect the lands. The home settlement area is located at the

back and both sides are generally dissected by rivers. So the slope of the home settlement areas is steep, often over 20%. A lot of roots of the trees are apparent in the home settlement area due to soil erosion.

iii) Intensity of the 2nd cropping season (from middle of February to end of May) in the upland fields is about 40%. So the remaining (60%) areas become bare land. Higher rainfalls still occur in this cropping season and serious soil erosion is expected to result.



iv) About 50% of the total upland field area is covered with bench terrace even though about 80% of the total terraces are poor due to fairly low or no maintenance. The remainders is covered with traditional terraces, ridge terraces, non-terraces, composite of ridge terrace/non-terrace and complex of composite and traditional terrace. Especially, most of the upland fields extending over the steep mountainous areas in the upper reaches of the main rivers in the Wonogiri dam watershed and the most critical upland field areas which are considered as the most serious potential areas for producing sediment yield, are not in bench terraces. Most of these upland fields are covered by traditional terraces, ridge terraces, non-terraces, composite of ridge terrace/non-terrace and complex. Such improper terrace conditions result in acceleration of soil erosion in these critical areas.

4.5.2 Estimate of Soil Loss from Land Surface

(1) General

Land surface soil erosion in the Wonogiri dam watershed area is analyzed by using the Universal Soil Loss Equation (USLE), which is the most widely used method around the world to predict long-term rates of rill erosion from field or farm sized units subject to different management practices. The USLE[2] was developed based on thousands of plot-years of data from experimental plots, and although the initial focus was oriented primarily towards conditions in the middle and eastern United States, the USLE has been extended and applied worldwide. In order to estimate annual sediment production, GIS system was set-up by the use of Arc view Ver.9.0 software. The rainfall erosivity map prepared by rain erosivity index, the soil map with soil erodibility, the topographic factor map with slope length and steepness, the crop management map, and the erosion control practice factor map with terrace condition were prepared and each map was put into the GIS system in the form of a layer. These maps are divided into a grid of 20 m x 20 m.

(2) USLE Equation

The USLE is an empirical multiple-regression-type equation which incorporates the parameters that influence erosion, and is expressed by the following equation:

$$A = R \cdot K \cdot L \cdot S \cdot C \cdot P$$

[2] Gregory L. Morris, and Jiahua Fan, 1997, "Reservoir Sedimentation handbook", pp. 6.23-6.25

where, A: Average annual soil loss
R: Rainfall erosivity factor
K: Soil erodibility factor
L: Slope length factor
S: Slope steepness factor
C: Crop management factor
P: Support practice factor

(3) Rainfall Erosivity Factor (R)

The rainfall erosivity factor is obtained from the raingall erosivity index (Re). The Re was calculated from the following formula used by the Ministry of Forestry in Indonesia.

$$Re = 2.21 \times \sum_{i=1}^{12} R_i^{1.36}$$

where,
Re: Rain Erosivity Index
Ri: Monthly rainfall (cm)
i: Month (January to December)

Monthly rainfall data for 24 years from 1982 to 2004 colleted from 15 rainfall stations in and around the Wonogiri dam watershed was used. The rainfall erosivity factor "R" is calculated and shown below:

Table 4.5.3 Rainfall Erosivity Index "Re" and Factor "R"

Rain Erosivity Index (Re)	Rainfall Erosivity Factor (R)
1,000-1,100	1,050
1,100-1,200	1,150
1,200-1,300	1,250
1,300-1400	1,350
1,400-1,500	1,450
1,500-1,600	1,550
1,600-1,700	1,650
1,700-1,800	1,750
1,800-1,900	1,850
1,900-2,000	1,950
2,100-2,200	2,150
2,200-2,300	2,250
2,300-2,400	2,350
2,500-2,600	2,550

Source: JICA Study Team

(4) Soil Erodibility Factor (K)

To determine "K" values of the representative soils in the Wonogiri dam watershed, diagnoses of soil profile, soil particle distribution analysis and basic infiltration rate measurement were conducted (detailed in Annex No.9). The K values were determined based on the results of the analysis and monograph for computing the K value of soil erodibility for use in the USLE. The computed "K" values are listed below:

Table 4.5.4 Applied Soil Erodibility Factor "K"

Kind of soils	Soil erodibility factor (K)
Mediteran soils	0.31
Grumsols	0.48
Latosols	0.32
Lithosols	0.015*

* This figure is taken from rehabilitasi lahan dan konservasi tanah daerah tangkapan waduk serbaguna Wonogiri BukuII Lampiran teknik

Source: JICA Study Team

(5) Topographic Factor (LS)

Topographic factor (LS) is calculated based on the following equation.

$$LS = \sqrt{\lambda/22.1} \cdot (65.41 \sin^2\theta + 4.56 \sin\theta + 0.065)$$

where,

LS: Topographic factor
λ: Slope length
θ: Steepness

In this calculation, slope length (λ) was fixed as follows. The slope length of terraces was classified into 5 classes based on the results of the survey on the present terrace condition.

Table 4.5.5 Slope Length for Classified Land Uses

Land Use	Slope Length (m)/Slope(%)
(1) Upland field, paddy field, orchard and plantation area, dry farming land in home settlement area	
a) class-1	8 m /0-8%
b) class-2	8 m /8-15%
c) class-3	4 m /15-25%
d) class-4	3 m /25-40%
e) class-5	2 m /over 40%
(2) Others	50 m

Source: JICA Study Team

Steepness (θ) was calculated based on GIS data prepared by BAKOSURTANAL. The steepness value of 50% gradient is applied for all the upland fields having a steepness of over 50%.

(6) Cover and Management Factor (C)

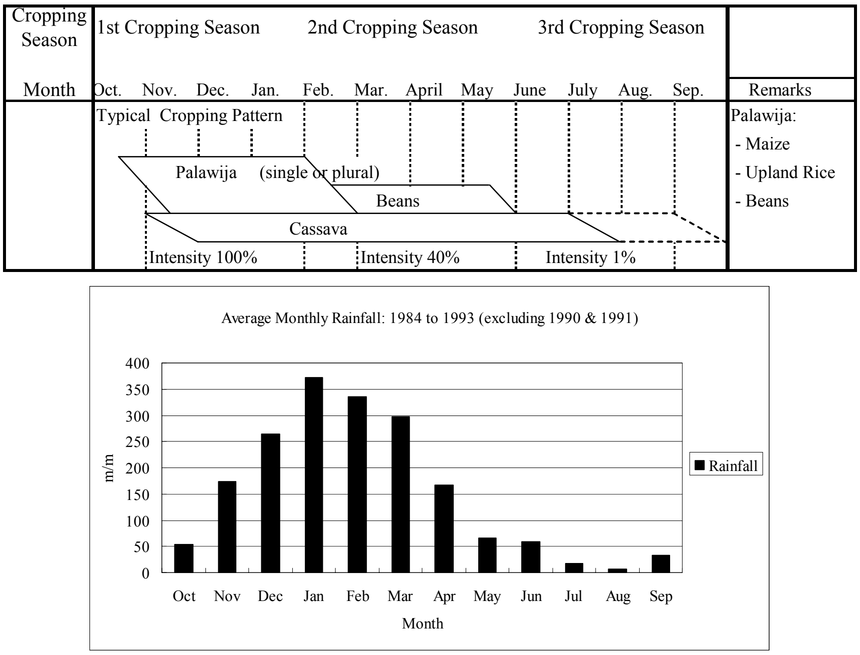
Cover and management factors "C" were generally determined by reference to Badan Penelitian dan Pengembangan Pertanian Departmen Pertanian 1990 and the diagram the reports of Rencana Teknik Lapangan (1985) as presented below:

Table 4.5.6 Cover and Management Factor "C"

Land use	Cover and Management Factor (C)
Paddy field	0.05
Home settlement areas	0.1
Uplands in settlement area	0.7
Uplands	
1-MT-I: average annual crop factor for mixed cultivation of maze and cassava	0.6
2-MT-II: average annual crop factor for mixed cultivation of beans and cassava	0.45
3-MT-III: average annual crop factor for mixed cultivation of beans and cassava	1
Grassland /Bush land	0.02
Forest	0.01
Orchard/Plantation	0.3
Bare lands	1.0
Water body	0

Source: JICA Study Team

In Wonogiri, dry farm lands are largely governed by those of seasonal crops. The overall cropping intensity on the dry farm lands comprises a 1st cropping season for 100%, second cropping season for 40% and third cropping season for 1% as shown below.



Source: JICA Study Team

Figure 4.5.1 Typical Cropping Schedule and Mean Monthly Rainfall in Wonogiri Dam Watershed

As above, the cropping intensity for the second cropping season is about 40%. The remaining 60% becomes bare for February to May when a large rainfall still occurs, which causes serious soil erosion. In order to obtain an accurate value for the crop factor, an overall cover and management factor for upland areas is calculated by the following equation by using cropping intensity data at the Kecamatan level:

$$C = (Ci \cdot Ri + Cii \cdot Rii + Ciii \cdot Riii + \cdot\cdot\cdot\cdot + Ciix \cdot Riix)/Ri{\sim}iix$$

where,

C: Annual overall cover and management factor C

Ci: Average annual crop factor for mixed cultivation of cassava and maize and mixed cultivation of cassava and beans

Ri: Monthly rainfall erosivity factor for i-th month

Ri~iix: Annual rainfall erosivity factor (accumulated Jan. to Dec.)

The cover and management factor C for the upland fields is changed on the basis of cropping intensity in Kecamatan areas.

(7) Support Practice Factor (P)

The support practice factor "P" for land use categories of the land use map in the Wonogiri dam watershed is mainly determined in reference to the data and information of the diagram "Parameter of C" in the reports of Rencana Teknik Lapangan (1985) and Risalah Lokakarya Pemantapan Perencanaan Konservasi Tanah dan Evaluasi Tingkat Erosi, Proyek Penelitian Penyelamatan Hutan, Tanah dan Air Pebruari 1990 as follows:

Table 4.5.7 Support Practice Factor "P"

Erosion-control practice	P-factor value
No treatment of soil conservation	0.8
Ridge terrace	
Composite (land of composite of condition of ridge terrace and non-treatment)	
Traditional bench terrace	0.5
Bench terrace for uplands	
(1) Good quality	0.04
(2) Medium quality	0.2
(3) Fair to bad quality	0.4
Terrace of irrigated paddy field	0.02
Orchard/Plantation	0.4
Uplands in settlement area (complex)	0.65
State forest	1
Home settlement area	1
Grass land	1

Source: JICA Study Team

(8) Average Annual Soil Loss from Land Surfaces

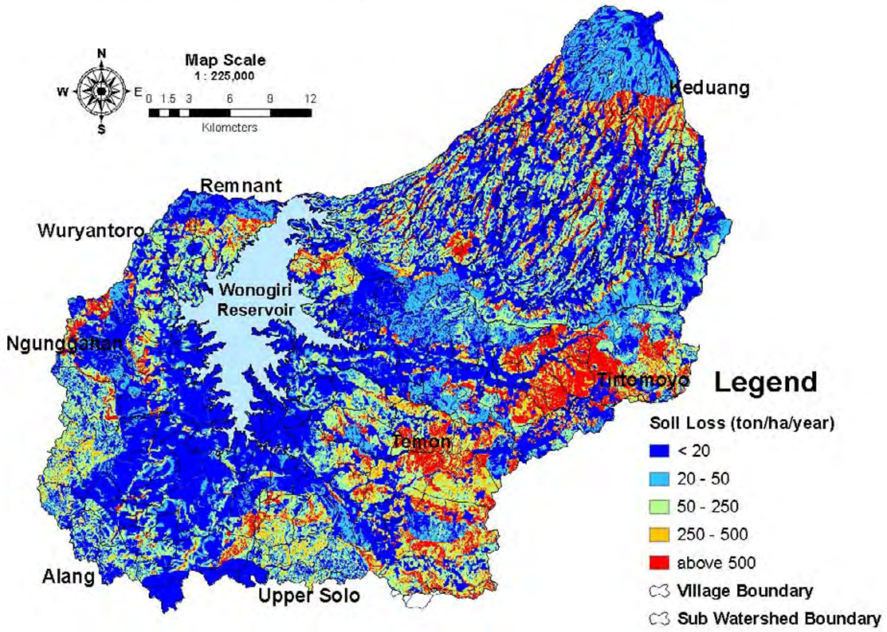
The average annual soil loss in the Wonogiri dam watershed is calculated by use of USLE under the above conditions. It is estimated at about 17.3 million tons/year in the whole Wonogiri dam watershed. The average annual soil loss in the sub-basin is shown below.

Table 4.5.8 Average Annual Soil Loss and Soil Loss per ha in the Sub-Basin in Wonogiri Dam Watershed

Land use	Sub-Basin								
	Keduang	Tirtomoyo	Temon	Upper Solo	Alang	Ngung-gahan	Wuryan toro	Remnant	Total (1,000 ton/year)
1) Paddy field	12	3	0	1	1	1	0	0	18
2) Home Settlement Area									
- housing yard	961	450	39	211	42	27	18	12	1,761
- Upland in settlement area	1,797	732	136	588	245	128	108	58	3,792
3) Upland field	1,726	2,911	660	2,403	521	438	197	264	9,120
4) Orchard and Plantation	363	235	52	298	31	25	35	31	1,071
5) Forest	11	0	0	0	0	0	1	2	14
6) State forest									
- forest	4	8	0	0	0	0	0	4	16
- Other use	234	440	85	299	210	52	1	33	1,454
7) Others	4	7	1	7	6	6	0	1	34
Total	**5,112**	**4,786**	**974**	**3,808**	**1,057**	**777**	**360**	**405**	**17,279**
Catchment Area (km^2)	421	231	63	206	169	82	44	28	1,244
Average annual soil loss /ha (ton/ha/year)	**121**	**208**	**156**	**185**	**62**	**94**	**82**	**146**	**139 (average in all basins)**

Source: Results of JICA Survey

Average annual soil loss from the Keduang basin is the largest, followed by Tirtomoyo, Upper Solo and Alang. Average annual soil loss from the other 5 sub-basins is small, showing less than 1,000,000 tons/year. Keduang has highest value of soil loss in spite of relatively low soil loss/ha because it has the largest catchment area. Though the basins of the Tirtomoyo and Upper Solo are half of that of the Keduang, they have a higher value of soil loss per year owing to the higher value of soil loss per ha. The annual soil loss in the whole Wonogiri dam watershed is illustrated on Figure 4.5.2 below:



Source: JICA Study Team

Figure 4.5.2 Annual Average Soil Loss per Hectare in Wonogiri Dam Watershed

As mentioned in Section 4.1, much of the eroded sediment from soil erosion is re-deposited before it enters the Wonogiri reservoir. Sediment yield from the Wonogiri dam watershed (to the Wonogiri reservoir) is thus estimated by use of the sediment delivery ratio. The process for estimating the sediment yield from all erosion sources of the sediment deposits in the Wonogiri reservoir is discussed in the succeeding section.

4.6 Annual Sediment Yield to Wonogiri Reservoir

4.6.1 Annual Sediment Yield from Erosion of Gullies, Landslides, Riverbank and Roadside Slopes

Although the specific gravity of sediment source materials from gullies, riverbanks and roadside slopes is 2,65 ton /m^3, their bulk densities are generally in the range from 1.2 to 1.8 ton/m^3 because they include both solid grains and voids. On the other hand, the average bulk density of the Wonogiri reservoir sediment is 1.064 ton/m^3 which is the dry weight per unit volume of the bulk sediment deposited in the Wonogiri reservoir. Under the Study, the bulk density of source materials is assumed to be 1.6 ton /m^3 with a void ratio of 40%.The estimated results are summarized below:

Table 4.6.1 Annual Wonogiri Sediment Yield by Source

River System	Gully Erosion	Landslide	Riverbank	Roadside Slope	Surface Soil Erosion	Gross Annual Sediment Yield from Watershed
	(m^3/year)	(m^3/year)	(m^3/year)	(m^3/year)	(m^3/year)	(m^3/year)
Keduang	67,880	2,930	9,780	3,690	1,134,300	1,218,580
Tirtomoyo	90	11,730	19,760	2,480	469,700	503,760
Temon	30	0	11,350	600	61,000	72,980
Solo	220	440	11,040	1,990	591,300	604,990
Alang	7,330	0	66,620	730	326,600	401,280
Others	0	0	11,850	1,170	363,900	376,920
TOTAL	**75,550**	**15,100**	**130,400**	**10,660**	**2,946,800**	**3,178,510**
%	2.4	0.5	4.1	0.3	92.7	100

Source: JICA Study Team