Mindanao Journal of Science and Technology Vol.12 (2014) 51-67

Assessment of Soil Erosion, Sediment Transport and Deposition along Cagayan de Oro River

Ruth G. Cabahug* and Belma M. Villanueva
College of Engineering and Architecture
Mindanao University of Science and Technology
Cagayan de Oro City, 9000 Philippines
**ruth_gc@yahoo.com*

Date received: July 1, 2013
Revision accepted: April 1, 2014

Abstract

The study focuses on soil erosion and the transport and deposition of eroded sediments along Cagayan de Oro River. Its main thrust is to assess the extent of soil erosion considering rainfall pattern and vegetation growth and on sediment transport and deposition considering the turbidity of the water, river velocity and the type of soil extracted at certain parts of the river. Rainfall data is taken from the hydrologic records of PAG-ASA-DOST at El Salvador City. Site visit and inspection were conducted to determine the abundance or scarcity of vegetation growth. Soil extracted from the channel bed and water samples taken from the river were brought to laboratories accredited by the Department of Public Works and Highways for grain-size analysis and turbidity tests. River velocity was determined by crude method. The results of the study revealed that the riverbanks of Cagayan de Oro River are moderately eroded. Turbidity of the water is a positive indicator that quite a large amount of fine-grained sediments are present and transported by Cagayan de Oro River. Settlement of large sediments occurs at the upstream part of the river in Cala-Cala, Macasandig. Silt and sand settled at the area near Marcos Bridge and at Isla Bacsan.

Keywords*:* soil erosion, sediment transport, sediment deposition, Cagayan de Oro river

1. Introduction

Soil erosion is the removal of soil particles by water or wind. It follows three phases, namely: detachment, transport and deposition. Agriculture, climate change, urbanization and construction of infrastructure are some of the factors that cause soil degradation. As population increases rapidly, sustaining the resources like water and soil for man's day to day activities becomes more important (Bhattarai and Dutta, 2005). Because of erosion, most of the fertile portion of the soil is lost and nutrients are transported and deposited in lakes, estuaries and riverbanks. This loss results to the reduction of surface water quality and to agricultural productivity which in turn cause high economic costs for the society (Rosenmund *et al*., 2005).

The amount of soil that water can carry away is influenced by speed and plant cover. The faster the wind or water moves, the more soil it can erode away. Plants protect the soil and in their absence wind and water can do much more damage. The presence of vegetation prevents or reduces the likelihood of soil erosion. Plant roots that bind soil particles together form a complex arrangement in the organic (O) and the surface soil (A) horizons. Therefore, in areas where vegetation is sparse or absent, such as in arid or cleared areas, wind or running water can easily erode soil. The canopy of leaves provided by vegetation can also decrease the erosive force of impacting rain on soil. Plants can also reduce wind velocity near the ground surface, thereby lessening the ability of winds to erode and transport soil particles. Doten *et.al.* (2006) stressed that vegetation removal increases the rates of surface erosion and mass wasting, either temporarily until vegetation is reestablished or permanently depending on the type of vegetation established.

An important first step in the erosion of soil is its detachment by the impact of raindrops which causes the breaking up of soil clumps. This is known as ‘rainsplash erosion” (Favis-Mortlock, 2005). The lighter materials such as fine sand, silt, clay and organic material, that are detached by raindrops are more readily carried away by runoff, leaving behind larger sand grains, pebbles and gravel. According to Morgan (1995), the severity of erosion depends on the quantity of soil detached and the capacity of the wind or water force to transport it. As both detachment and transport require energy (deposition occurs when energy is no longer available), the ability of soils to erode is based on ‘erosivity’, the energy of the eroding agent (i.e., wind or water), and ‘erodibility’, the soil’s susceptibility to erosion (McCauley, 2005).

The influence of rainfall on soil erosion is closely related to the general grain size of soil. The mineral particles comprising the soil can range from gravel and sand to silt and clay. Soils that are abundant in coarse grain materials mixed with organic debris have a large volume of pore spaces that allow a large amount of rainwater to infiltrate into the soil before it begins to run off at the surface. Thus, a smaller amount of runoff occurs and thereby, the less chance that erosion in this type of soil will occur. However, only a smaller volume of pore spaces is present in soils with abundant amount of fine-grained particles, thus, only a small amount of rain can be absorbed by the soils which in turn results to a large volume of runoff. Because runoff occurs sooner, finer-grained soils are more susceptible to erosion than coarser-grained soils. Soils that have good structure resist erosion when they are not disturbed. Good cohesiveness between soil particles and soil cemented by organic matter may resist water and wind erosion (Hillel, 1998).

Soil erosion is also influenced by the intensity of rain, i.e., the amount of rainfall in a given amount of time. Rainwater can infiltrate and percolate into the ground when a “gentle” rain is falling over an area for a long period of time. However, if the rain falls at a higher intensity, a considerable quantity of soil is removed. On level or less sloping areas, as the raindrops hit bare soil, their kinetic energy is able to detach and move soil particles a short distance and its effects are solely on-site and the soil is merely redistributed back over the surface of the soil (Favis-Mortlock, 2005). Because rainsplash requires high rainfall intensities, it is most effective under convective rainstorms in the world’s equatorial regions, an area where the Philippines is situated.

When soil particles are dislodged by raindrops on the soil surface, sheet erosion occurs. Sheet erosion most of the time develops into rill erosion whereby small channels form which serve as passageway of slow-moving water. Rills are shallow drainage lines less than 30cm deep which are develop when surface water concentrates in depressions or low points through paddocks and erodes the soil (Jenkins, 2013). Once, these channels are developed, gully erosion occurs. Gullies are channels deeper than 30cm that occur when smaller water flows concentrate and cut a channel through the soil (Jenkins, 2013).

Soil erosion by water increases when water at the soil surface exceeds water infiltration (Hillel, 1998). When rain falls rapidly the water cannot enter the pores in the soil fast enough and surface runoff occurs. If rain falls over an extended period of time, all of the pore spaces in the soil may become filled with water so additional moisture will run off at the surface. Under these conditions, the presence of running water at the surface increases the likelihood of soil erosion.

Sediment is used to describe loose particulate material at the Earth’s surface that has been produced by weathering of rocks and then transported by wind or water or ice. Sources of eroded sediments includes agricultural lands, forests, upland gullies, stream channels, roads and highway ditches and canals, construction sites, and surface mined areas. The United Stated Department of Agriculture classifies soil into three types namely silt, sand and clay. Sand which is larger in size feels gritty, silt which is moderate in size has a smooth or floury texture and clay, the smallest among the three, feels sticky. Considering grain size, the USDA classifies sand as having a diameter ranging from 0.05 mm to 2mm. Silt, on the other hand, has a grain-size diameter ranging from 0.002 mm to 0.05 mm. Any soil with a diameter lesser than 0.002 mm is classified as clay.

Sediment load of a river can be classified as dissolved load, suspended load, intermittent suspension (saltation) load, wash load and bedload (Hickin, 1995). Hickin describes dissolved load, as material in solution that becomes part of the stream water moving through the channel and suspended load comprises mainly of silt and sand that are kept in suspension by the turbulence generated at the channel bed. He further differentiated intermittent suspension load from wash load and bed load. According to him, intermittent suspension load bounces along the channel bed, partly supported by the turbulence in the flow and partly by the bed, wash loadis part of the suspended-sediment load that is so fine (in the clay range) that it is kept in suspension by thermal molecular agitation and tends to be uniformly distributed throughout the water column while bed load is the particulate material, mainly sand and gravel, that moves through the channel fully supported by the channel bed itself and they are kept in motion (by rolling and sliding) by the shear stress acting at the boundary.

According to Perlman (2013) fast-moving water can pick up, suspend, and move larger particles more easily than slow-moving waters making the rivers more muddy-looking during storms since they are carrying a lot more sediment than they carry during a low-flow period. This cloudiness, commonly known as turbidity, of the river water is due to suspended sediments. Turbidity is also the measure of the amount of light that is scattered by these suspended particles. In fact, so much sediment is carried during storms that over one-half of all the sediment moved during a year might be transported during a single storm period (Perlman, 2013). Human activities that reduce the amount of vegetation, increase land slope, or prevent soil from soaking up water serve to increase soil erosion. The more soil eroded the greater amount of soil to be transported.

The process of erosion stops when the transported particles fall out of the transporting medium and settle on a surface, a process called deposition (Pidwirny, 2006). The rate of deposition depends on the size, shape and density of the materials. All other things being equal, the more spherical a particle, the faster it will settle. Moreover, materials with a higher density will settle faster compared to materials which are less dense.

Deposition may also be temporary or permanent on the channel bed. Sediments may be moved again when the flow of water is high but when it's low, landforms such as floodplains and point bars on the inside of meander bends may result.

Deposition, which is also called sedimentation, is a process in which particulate matter is carried from its point of origin, by either natural or human-enhanced processes then deposited elsewhere on land surfaces or in bodies of water. As the river flows near the ocean or it meets either standing water or nearly flat lying ground, it deposits more materials than it erodes. Deposition of materials usually occurs along the inside edges of meanders.

The Cagayan de Oro River basin covers an area of about 1,520 square kilometer comprising mostly of forested areas, agricultural farming, large-scale plantations and mining areas (Quiaoit, 2011). Cagayan de Oro River has its headwaters originating from Kitanglad Mountain Range, in Bukidnon. It traverses the plains of the watershed for a distance of 90 kilometers with its six major rivers, six creeks, four streams and eight watershed divides (Quiaoit, 2011).The river discharges at Macajalar Bay in Cagayan de Oro City.

Figure 1. Cagayan de Oro River

When heavy rainfall occurs in Bukidnon and Cagayan de Oro City, especially at the river's drainage basin, muddy water which is an indication of the transportation of a large amount of fine-grained sediments can be observed. The same was also seen right after the tragedy that struck Cagayan de Oro City on December 2011 due to storm Washi (Sendong) at the estuary of Cagayan de Oro River, where river water meets seawater.

Assessing the state of soil erosion and sediment transport in the river and determining if certain factors could have caused changes in the amount of sediments along Cagayan de Oro River are therefore very important. The findings of this study will make the community, especially the people who still choose to live along the banks of Cagayan de Oro River, more aware of what might affect their lives and properties in the event of future catastrophe. The data and results of this study can also provide new knowledge and information regarding the extent of soil erosion and deposition of Cagayan de Oro River, which can be used by local and national government officials and other stakeholders as bases in planning and in implementing programs related to watershed management and protection. Local government authorities can also use the data in planning strategies for the safety of residents especially those who live along the river.

The main thrust of the study, therefore, is to assess the extent of soil erosion and sediment transport along Cagayan de Oro River considering rainfall pattern, vegetation growth, turbidity of the water, river velocity and the type of soil extracted at certain parts of the river. Specifically, the study seeks to answer the following questions:

1. What is the rainfall pattern in Cagayan de Oro for the last five years?
2. What is the extent of soil erosion along the riverbank of Cagayan de Oro River as determined in terms of vegetation cover?
3. What is the extent of soil erosion along Cagayan de Oro River as determined by the turbidity of the river water?
4. What is the extent of sediment transport and deposition in terms of velocity in certain areas of the river?
5. What is the extent of soil erosion and deposition along Cagayan de Oro River based on soil type?

2. Methodology

This is a descriptive type of research designed to assess the extent of soil erosion and sediment transportation and deposition along Cagayan de Oro River. The setting of the study is focused along Cagayan de Oro River and its banks, within the perimeter starting from Cala – Cala Section up to the estuary at Barangay Bonbon.

The study needed hydrologic and hydraulic information of Cagayan de Oro River. River water samples were taken two (2) meters from the river bank at Barangay Macasandig, Barangay Balulang, Barangay Consolacion and Barangay Kauswagan where hydraulic quarrying activities are conducted. The samples were stored in clean plastic water bottles and were immediately taken for turbidity testing to F. A. S. T. Laboratory, a laboratory duly accredited by the Department of Public Works and Highways (DPWH).

The soil samples were also obtained two (2) meters away from the river bank at the following five sections: a) Cala-cala in Brgy. Macasandig, b) near Carmen Bridge, c) near Marcos Bridge, d) at Isla Bacsan, and, e) at the mouth of the river in Brgy. Bonbon. Each sample was placed inside clean plastic bags and then brought for grain-size distribution and analysis to TestLab Engineering and Geotech, also a DPWH-accredited laboratory. The test method used by TestLab conformed to ASTM C136.

Rainfall data from January 2007 to December 2011 was obtained from the Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAG-ASA), an agency under the Department of Science and Technology (DOST). The data obtained was used to determine the rainfall pattern of the City.

An ocular inspection of the study area was conducted to assess the state of the river in terms of vegetation cover and degree of erosion. Pictures were taken to show the present state of the river bank and to identify areas with abundant or sparse vegetation growth.

Due to unavailability of a flow meter, river velocity was obtained by crude method. This was done by floating an orange fruit from a selected spot of the river, five (5) meters away from the riverbank, for a distance of 10 meters. The time taken by the floating orange to travel from the starting point to the 10-m mark was recorded. The velocity is obtained by dividing the distance traveled (10 m) by the measured time. Three trial runs were obtained for each selected section or area.

3. Results and Discussion

Figure 2 shows the rainfall data recorded by PAG – ASA from January 2007 to December 2011. Rainfall depth in Cagayan de Oro has changed for the last three years. It can be seen that the highest peak of rainfall was on January 2009 with more than 450 mm depth of rainfall. Flooding along certain areas of the floodplains of Cagayan de Oro River occurred during this time. Nevertheless the damage was just minimal compared to the December 2011 flood, which, from the same chart, had a rainfall depth of about 325 mm. Depth has increased and such had cause saturation of soil, and as a result moderate degree of soil erosion occurred in the riverbanks.

Heavy rainfall usually indicates large amount of eroded materials. Thus, the above data shows that a large volume of sediment may have been eroded from the drainage area and transported along and deposited in the channel bed of Cagayan de Oro River and to the ocean.

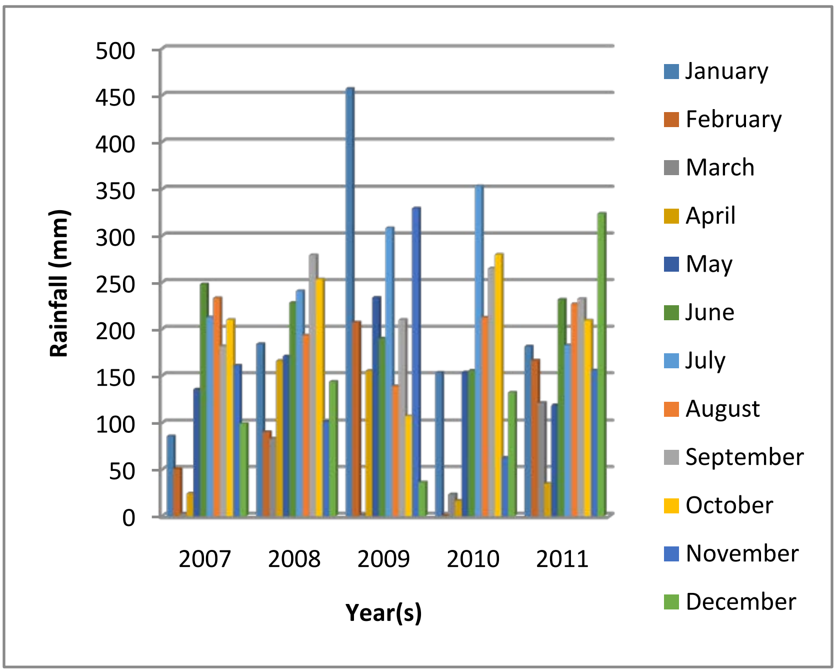

Figure 2. Annual rainfall pattern of Cagayan de Oro for the last five years

The velocity of flowing water determines which particles will be suspended in the water. Fast flowing water can hold or carry very heavy objects while slow water only holds very light particles.

Figure 3 shows Hjulstrom's Diagram, a graph that describes the relationship between stream flow velocity and particle erosion, transport, and deposition (http://www.physicalgeography.net/fundamentals/10w.html). The two curves in the graph represent the minimum stream velocity ("erosion velocity" curve) required to erode sediments of different sizes from the stream bed and the minimum velocity ("settling velocity" curve) required to continue to transport these sediments of varying sizes. Particles tend to be influenced by a variety of factors that changes from stream to stream. Entrainment of silt and clay needs greater velocities then larger sand particles. This situation occurs because silt and clay have the ability to form cohesive bounds between particles. Because of the bonding, greater flow velocities are required to break the bonds and move these particles.

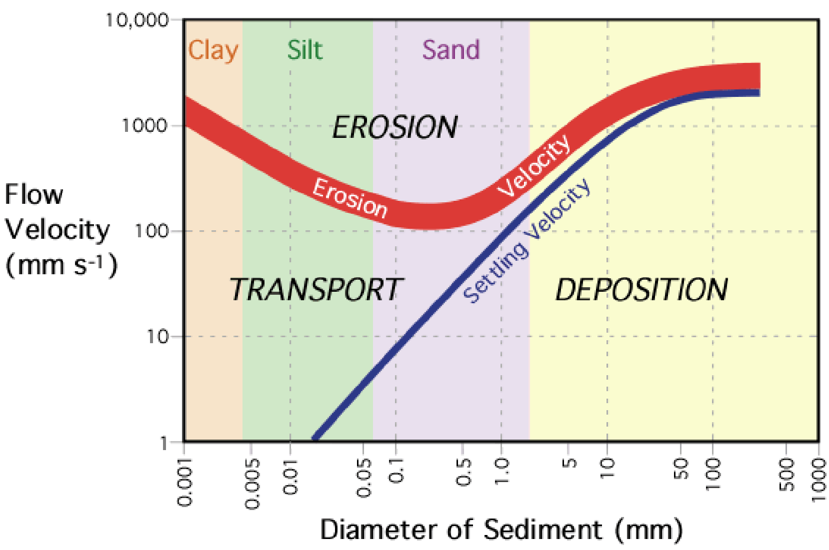

Figure 3. Hjulstrom's Diagram shows the relationship between stream flow velocity and particle erosion, transport, and deposition

The graph also indicates that the transport of particles requires lower flow velocities then erosion. This is especially true of silt and clay particles.

Finally, the line labeled "settling velocity" shows at what velocity certain sized particles fall out of transport and are deposited.

Table 1 and Figure 4 shows the average velocity of the Cagayan de Oro River at specified locations. As indicated in Table 1, the Isla Bacsan section of the Cagayan de Oro River, with an average velocity of 0.1913 m/s, tends to deposit fine grained sediments, particularly sand, because of this slow velocity. The islet itself is a proof of this deposition. At the Carmen Bridge Section, the average velocity of the river is 0.2118 m/s. At this point of the river, medium-sized gravel and sand settle on the channel bed.

Table 1. Trial runs on river velocity measurements

Location	Trial 1 (m/sec)	Trial 2 (m/sec)	Trial 3 (m/sec)	Average (m/sec)
Cala-Cala section	0.7174	0.7893	1.071	0.8592
Carmen Bridge	0.2212	0.2088	0.2053	0.2118
Isla Bacsan	0.1948	0.2004	0.1787	0.1913

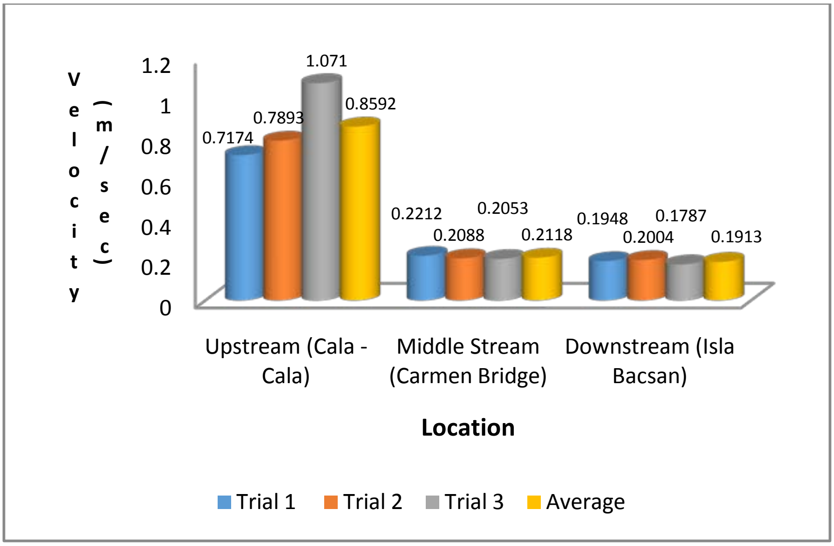

Figure 4. Velocity trial runs at selected areas of Cagayan de Oro River

As water flows with the other suspended sediments, it reaches the section of the river at Isla Bacsan where the average velocity of water is 0.1913 m/s. The suspended load at this point includes not only light particles but also small rocks and pebbles because at this point, the average velocity of the river has decreased. However, at Cala – Cala section where the average velocity is 0.8592 m/s, only very heavy materials are settled and deposited in this area.

Water samples were taken at areas near four quarry sites located along Cagayan de Oro River namely, Macasandig, Balulang Consolacion and Kauswagan. Visual test showed that the water samples were all cloudy. The samples were brought to F. A. S. T. Laboratory for testing. The test results are shown in Table 2.

Table 2. Turbidity test results

Quarry Site	Turbidity Test Result (NTU)*
Macasandig	304
Balulang	106
Consolacion	188
Kauswagan	210

*NTU- Nephelometric Turbidity Units

From Table 2, it can be seen that turbidity levels at Macasandig and Kauswagan are quite high. Higher turbidity values, measured in Nephelometric Turbidity Units (NTU), indicate that more fine-grained sediments are present in the water, making the water cloudy. Cloudiness in the water decreases photosynthetic activity. Moreover, the fine-grained sediments also absorb the heat from the sunlight, making the water warmer than normal. Both conditions decrease the chance of having a thriving underwater flora and fauna.

Figure 5 and Figure 6 show the extent of soil erosion along certain parts of the banks of Cagayan de Oro River. Soil erosion along the river banks at areas where there are less amount or area of vegetation cover could be observed. It can be observed that most areas of the riverbanks are still covered with lush vegetation. This also suggests that erosion, if any, is minimal at these locations. In the moderately and highly eroded sections of the river banks, less or no vegetative cover can be seen. It can be deduced that the type of soil in these areas might not be suitable or appropriate for these vegetation to grow and thrive. Further, since vegetation is non-existent or minimal, and then erosion at these areas is highly probable.

In Cala – Cala Section

Abundant vegetation

Moderately abundant vegetation

Abundant vegetation

Near Carmen Bridge

Abundant vegetation

Abundant vegetation

Moderate vegetation

Near Marcos Bridge

Abundant Vegetation

Sparse Vegetation Growth

Moderate Vegetation

Figure 5. Vegetation growth at Cala-Cala and near Carmen and Marcos Bridges

Isla Bacsan Section

Abundant vegetation

Abundant vegetation

Abundant vegetation

Estuary

No vegetation growth

No vegetation growth

No vegetation growth

Figure 6. Vegetation growth at Isla Bacsan and at the estuary (Brgy. Bonbon)

The gradation or grain-size analysis of the soil is important so that the soil type existing in the area can be identified. The type of soil can then be used as reference in identifying the extent of erosion and sediment transport along the Cagayan de Oro River. In the Unified Soil Classification System (USCS), fine-grained soils are described as soils with 50% or more passing through the No. 200 sieve and are classified as inorganic silt, inorganic clay, and organic silts and clay. On the other hand, coarse-grained soils are soils that are gravelly and sandy in nature with less than 50% passing through the No. 200 sieve and are classified as gravel (G) and sand (S). Moreover, gravel has a grain size between 4.75 mm and 75mm while sand has a grain size between 0.075mm and 4.75mm.

Table 3 shows the results of the grain-sized analysis performed on the collected soil samples from specific areas along the Cagayan de Oro River.

Table 3. Results of grain-size analysis

Section	Cala – Cala	Carmen Bridge	Marcos Bridge	Isla Bacsan	Estuary (Bonbon)
Standard Size	Percent Passing	Percent Passing	Percent Passing	Percent Passing	Percent Passing
(4”) 100mm	100	100	100	100	100
(3”) 75mm	100	100	100	100	100
(2 ½”) 63mm	100	100	100	100	100
(2”) 50mm	100	100	100	100	100
(1 ½”) 37.5mm	100	95	100	100	100
(1”) 25mm	100	93	100	99	100
(¾”) 19mm	100	90	99	99	100
(½”) 12.5mm	100	85	98	98	100
(⅜”) 9.5mm	100	81	96	97	100
(No.4) 4.75mm	100	73	91	97	98
(No.8) 2.36mm	100	64	80	96	96
(No.16) 1.18mm	98	52	62	96	92
(No.30) 600 µm	90	33	33	94	84
(No.50) 300 µm	62	11	15	91	61
(No.100) 150 µm	21	3	3	79	44
(No.200) 75µm	1	0	0	66	38
D_{60}	0.40	1.90	1.80		
D_{10}	0.10	0.30	0.50		
C_u	4.00	6.33	3.60		
	$C_u < 6$	$C_c = 0.53$	$C_u < 6$		
USCS Classification	Poorly-graded sand	Poorly-graded sand	Poorly-graded sand		
Moisture content (%)	25.2	15.4	18.4	59.5	45.0

The first sample was obtained from Cala - Cala section, 2 meters from the river bank. The sample description is dark brown sandy with some silts and gravel. This soil sample has only 1% passing through the No. 200 sieve and 100% passing through the No.4 sieve. The sample is classified under USCS as coarse-grained soil. Further classification shows that the sample is poorly-graded sand with a uniformity coefficient, C_u equal to 4, which indicates that the soil grains are of the same size. The sediments transported from different locations and deposited in Cala-Cala section might have come from the various quarrying operations at Tibasak, Macasandig and Brgy. Balulang.

The second sample was obtained near Carmen Bridge, 2 meters from the bank of Cagayan de Oro River. The visual description of the sample is dark brown sand with gravel. The soil is classified using USCS as poorly-graded sand with gravel. Since 73% of the sample passed through the No.4 sieve

(4.75mm) and zero in the No. 200 sieve, the sample therefore contains 27% gravel and 73% sand. Since the sample is taken near the river bank, it can be seen that silt has not settled at this site or if there is, then only a small amount of silt is present. Thus, soil erosion cannot be observed at the section but probably sediments that have deposited at the site might have come from quarry operations along the river.

The third sample being tested was extracted near Marcos Bridge, 2 meters from the river bank the sample's description is dark brown sand with gravel. The uniformity coefficient of this sample is 6.33 (Cu > 6), the soil is also classified using USCS as poorly-graded sand with a 0.53 coefficient of gradation (or curvature), Cc. It contains 9% gravel and 91% sand equivalent to the same percentage of the sample passing the No. 4 sieve. It can be seen that silt has not settled at this site where the sample was obtained or if there is, then only a small amount of silt is present. Thus, soil erosion cannot be observed in the section, but probably sediments that have deposited at the site might have also come from quarry operations along the river.

The fourth sample was also obtained 2 meters from the river bank of Isla Bacsan. The visual description of the sample is dark brown sandy with silt and gravel. The sample shows that about 3% gravel is retained in the No. 4 sieve and about 66% passed the No. 200 sieve. This indicates that only 31% of the sample is sand and much of the soil sample is silt or clay. The soil gradation result shows that silt is deposited in this area. This also indicates that soil erosion that has occurred from other areas, especially from the upstream part of Cagayan de Oro River, has been transported by the river and deposited in this location.

The last sample was obtained from the estuary at Brgy. Bonbon and the sample's description is dark brown sandy silt with gravel. The sample shows that although 2% of the sample is gravel, 60 % of the sample is sand and about 38% that passed the No. 200 sieve is silt or clay. It can be said that silt has deposited in this area. This also indicates that soil erosion has indeed occurred in the upstream section, the eroded sediments transported by the river and deposited in this location.

4. Conclusions and Recommendations

Moderate degree of soil erosion occurred along the banks of Cagayan de Oro River, especially at times when rainfall is considered deep.

With regard to the velocity of Cagayan de Oro River, settlements of large sediments occur at Cala-Cala, in Brgy. Macasandig. Silt and sand settled at Marcos Bridge and at Isla Bacsan.

Turbidity of the water is a positive indicator that fine-grained sediments are present and transported by Cagayan de Oro River.

Settlement of fine-grained sediments occurs beside the river bank which shows that soil erosion has occurred in some areas along the river bank.

The following are recommended to control soil erosion along some areas of the river bank of Cagayan de Oro River.

a) Temporary Silt Fence which is used to hold back sediments should be placed 2m from the river bank.

b) Rock Silt Screen (Rip-Rap) must be placed below any construction area located near the river so that sediments will be filtered out of the water.

c) Vetiver grass, a strong fiber grass that can sustain and can hold soil erosion, should be planted at the eroded parts of the river in areas where there is less vegetation cover. To maintain and lessen the presence of sediments in the river, Vetiver grass is an appropriate recommendation because it has fiber roots which are suitable in holding erosion.

d) The local government should relocate the various communities residing near the river banks which already have shallow depths and are prone to flooding and at areas which are highly eroded.

e) Cagayan de Oro residents must be encouraged to help maintain the cleanliness of the river to avoid contamination and pollution which can cause acidity and alkalinity of the river that can harm the residents living near the river.

6. Acknowledgement

Many thanks to Rhey Yecyec, Richard Roxas, Ruben James Ajoc and Jay Louie Magdales for their undergraduate thesis entitled Soil Erosion and Sediment Transport Along Cagayan de Oro River: An Assessment and to Emae Lou Intong, Miraflor Tabamo, Isabel Tagalog and Ma. Neziel Taylaran for their undergraduate thesis entitled “Risk Assessment on the Effects of Quarrying in Cagayan de Oro River”.

7. References

Bhattarai, R. and Dutta, D., (2005). Analysis of Soil Erosion and sediment yield using empirical and process based models. In Proceedings of the Modelling Tools for Environment and Resources Management (MTERM) International Conference, 6-10 June, Thailand, pp. 215-226.

Doten, C. O., Bowling, L. C., Lanini, J. S., Maurer, E. P. and Lettenmaier, D. P., (2006). A Spatially Distributed Model for the Dynamic Prediction of Sediment Erosion and Transport in Mountainous Forested Watersheds, Water Resources Research, Vol. 42, W04417.128.from http://onlinelibrary.wiley.com/doi/10.1029/2004WR003829/abstract

Favis-Mortlock,D., (2005). Water Erosion. From http://www.soilerosion.net/doc/water_erosion.html

Hickin, E. J. (1995). River Geomorphology. From http://www.sfu.ca/~hickin/RIVERS/Rivers4%28Sediment%20transport%29.pdf.

Hillel, Daniel. (1998). Environmental Soil Physics.Academic Press. San Diego. From http://books.google.com.ph/books?id=tP__y5xRd0oC&printsec=frontcover#v=onepage&q&f=false.

Jenkins, A. From http://www.dpi.nsw.gov.au/__data/assets/pdf_file/0003/255153/fact-sheet-1-types-of-erosion.pdf).

McCauley, A., (2005). Soil Water, Management module 3, Managing for soil erosion, Soil Scientist and Clain Jones, Extension Soil Fertility Specialist. From http://www.agronomy.org/cca/exam_pdf/55.pdf#search=%22%20%22Soil%20Erosion%22%20%22Soil%20Erosion%20Processes%22%22

Morgan, R.P.C., (1995). Soil Erosion and Conservation. 2nd Edition, Longman Group Unlimited, London, U.K 198p.

Perlman, H. (2013). From http://ga.water.usgs.gov/edu/sediment.html

Pidwirny, M. (2006). Erosion and Deposition. Fundamentals of Physical Geography, 2nd Edition http://www.physicalgeography.net/fundamentals/10w.html

Roa-Quiaoit, H. A. (2011) Linking the Reefs to the Ridges: The Macajalar Bay Experience". Ridge to Reef in the Philippines: A Showcase of Nine Emerging and Merging Initiatives. Cagayan de Oro City: Xavier University Press.

Rosenmund, A., Confalonieri, R., Roggero, P.P., Toderi, M. and Acutis, M., (2005). Evaluation of the EUROSEM Model for Simulating Erosion in Hilly Areas of Central Italy. RivistaItaliana di Agrometeorologia (2): 15-23.