International Journal of Engineering and Innovative Technology (IJEIT)
Volume 2, Issue 6, December 2012

Soil Erosion in the Urban Catchment Area of Baubau City, Indonesia

Mz. Amirul Tamim*, Saleh Pallu**, Shirly Wunas[#], dan Sumbangan Baja[$]
*Ph.D Candidate, Dept of Civil Engineering, Hasanuddin University, Indonesia; **Dept of Civil Engineering, Hasanuddin University, Indonesia (Ph/Fax: +62-411-580505); #Dept of Architecture, Hasanuddin University, Indonesia (Ph/Fax: +62-411-586036); [$]Dept of Soil Science, Hasanuddin University, Indonesia

Abstract -- To date, soil and water conservation and land degradation in many different environments have always been placed in the framework of development, both for rural and urban areas. Soil erosion is influenced by a considerable number of factors (including climate, soil, topography, land use and types of land management), so that the information on the quantity and spatial distribution of soil erosion and its related effects can be effectively employed as a baseline data for urban catchment management. The principal aim of this paper is two-fold: (i) to develop techniques based on a raster GIS in the parameterization of a soil erosion model, which is designed for use at a large scale assessment; and (ii) to assess and map the spatial distribution of average annual rate of soil losses in the study area based on the updated land use information. This research is conducted in Baubau City, with Baubau catchment area within the area. It is implemented using fundamental principles of the USLE (Universal Soil Loss Equation), and its revised version, RUSLE (Revised USLE) in GIS environment. The results of the study shown that urban environments in the lower parts of the catchment area undergoes less erosion rate compared to rural area where scarce vegetation exists. The uppermost catchment area where protected forest exists soil loss rate was very low, although the facts that such parts of the catchment are steeper that the middle and lower parts of the region. The area around the buffer zone undergoes considerable variable annual soil loss rate. This study is useful for devising soil erosion protection and urban land management in the catchment of Baubau.

Key words: **Erosion, Baubau Catchment Area, Catchment Management, USLE/RUSLE, Baubau Catchment.**

I. INTRODUCTION

Knowledge of erosion and sedimentation in the urban catchment is useful for design of land management and conservation as well as for modeling non-point source pollution. An urban catchment area can be broadly considered to be made up of three types of surface (see Boyd *et al.,* 1993): (i) impervious areas which are directly connected to the drainage system, typically roads, buildings, and parking lots; (ii) additional impervious areas which are not directly connected, runoff from which flows over pervious surfaces before reaching the drainage system; (iii) the remainder, pervious or semi-pervious area consisting of lawns, gardens and parklands, forested land, agriculture area, etc. The first and second points together make up the total impervious area in the urban environments. In the context of city in Indonesia, the latter category of surface may be predominant, especially in a newly developed city.

Baubau City, is a small newly developed city that has recently undergone considerable land use change in many parts, as a result of population growth. Agricultural areas are found in the uppermost parts of the catchment, while construction for residential and infrastructure is concentrated on the lower parts. However, development has now tended to shift on the upper catchment area, and this will bring about increasing rate of erosion and sedimentation. BAPPEDA Kota Baubau (2009) has found that water quality has considerably declined in the past five years due to sedimentation in the main river of Baubau.

In the context of urban land and water management, soil erosion by water is considered as one of the most significant forms of land degradation that affects sustained land use. Important factors related to soil erosion by water include climate, soil, topography, and land use and types of land management. As some of these factors are dynamic, and changing in time and space, frequent updating of the rate and distribution of soil erosion is required, particularly in the regions where intensive use of land exists (Baja *et al.,* 2002).

There are two approaches commonly in use in the estimation of soil erosion. The first is the assessment of soil erosion on the basis of a point or a single plot, and the second approach takes into account the geographical patterns of the area of interest. The limitation of the first approach is the difficulty of understanding the erosion phenomena in terms of spatial patterns and relationships between units of the land under study, especially at the large area such as a catchment. Accordingly, in the planning perspective the second strategy is the preferred one, and spatial analysis techniques in GIS (Geographic Information Systems) play an important role as effective strategic analytical tools (see Boggs *et al.,* 2001; Halim *et al.,* 2010; Kheir, 2008; Ries, 2010).

The principal aim of this paper is two-fold: (i) to develop techniques based on a raster GIS in the parameterization of a soil erosion model, which is designed for use at a large scale assessment; and (ii) to assess and map the spatial distribution of average annual rate of soil losses in the study area based on the updated land use information. This research is implemented using fundamental principles of the USLE (Universal Soil Loss Equation) (Wischmeier and Smith, 1978), and its revised version, RUSLE (Revised USLE) (Renard *et al.,* 1997) in a raster GIS environment. This study is useful for devising soil erosion protection and urban land management in the catchment of Baubau.

II. STUDY AREA

The Baubau cathment area is situated in the geographical coordinates between 5^0 27' 8" and 5^0 32' 33"South and between 122^0 33' 5"and 122^0 42' 34"East (Figure 1). It covers an area of about 6.160 ha, and includes some parts of five sub-districts (local called: *kecamatan)*: Wolio, Murhum, Betoambari, Batauga and Sampolawa. As the main river flows through the area of Baubau City, and to the the Button Straits, this catchment gives important contribution to the quality of urban environments, as well as coastal waters along the east coast of Sulawesi Island. As will be seen later, forest and shrubs are still the predominant land use in the catchment. Various types of agriculture were found in the southern part of the catchment, while in the northwestern parts residential and other urban facilities are mostly found.

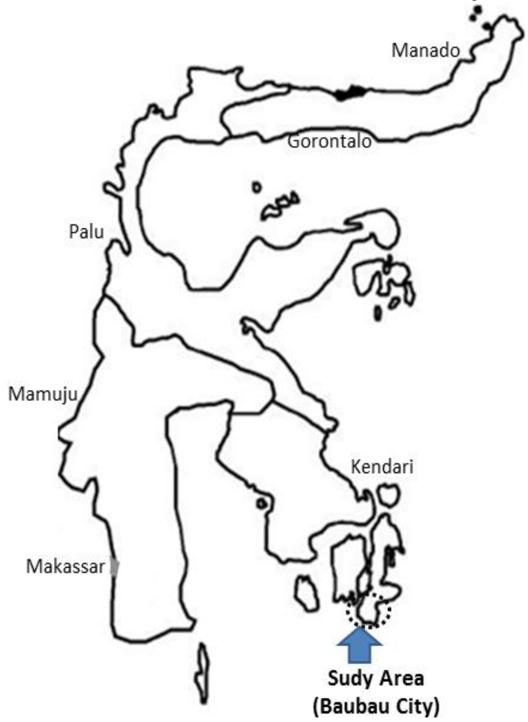

Fig 1. Location of study area (Baubau catchment)

III. METHODOLOGY

A.The USLE model

In this study, USLE (Universal Soil Loss Equation) is used to predict soil erosion by water, *i.e.,* average annual soil losses due to sheet and rill erosion. Although sheet and rill processes are two different forms of erosion, they are usually considered together in the assessment procedure for soil losses. The main reason is that both types of erosion require similar farm management and conservation practices for controlling them. Such premise underlies the establishment of USLE (Wischmeier and Smith, 1978), and its revised version, RUSLE (Renard *et al.*, 1997) with the basic form of equation as follows:

$$A = R \times K \times LS \times C \times P \ldots\ldots\ldots \quad (1)$$

Where, A = average annual soil loss (t/ha/y), R = index of rain erosivity, K = index of soil erodibility, LS = slope factor (L = length, and S = gradient), C = land cover and management factor, and P = conservation practice (support) factor.

B. Data base and analysis procedures

Data base used in this study were stored and processed in a GIS, consisting of: (i) rainfall data for ten years, used for calculating rain erosivity index (R); (ii) soil map with a scale of 1 : 100.000 for estimating soil erodibility index (K); (iii) contour data from topographic map (scale 1 : 50.000), used for generating slope layer that can be used to determine slope gradient and length factor (LS); (iv) land use map, derived from IKONOS image, acquired in 2009, with spatial resolution of 1.0 meter, that is used to calculate crop and conservation effort factor (CP). Such data bases were also supported by vector GIS data base extracted from topographic map.

Soil loss estimation procedure in this study was performed using conventional GIS-based operations. Based on the USLE parameters in equation (1), GIS layers required for the analysis include: rainfall erosivity index (R), soil erodibility index (K), slope factors (LS), and cover and support practice factors (CP).

It should be noted that each of these layers is derived from different sources, and scale and level of observation, as well as time of data acquisition. Therefore, certain procedures were developed GIS packages to ensure all data sets used conformable one to another. In this study, the data sets were analyzed and interchanged in two different formats: raster and vector. Calculation of the USLE parameters was made based on the available guidelines especially those recommended for Indonesian environment, including Bols (1978) for rain erosivity, and Arsyad (2006) for cover types and conservation practices. The LS factor was determined using the RUSLE guideline in RUSLE (Renard *et al.*, 1997).

Furthermore, an analytical procedure for IKONOS image interpretation was developed to produce a land use/land cover map of the study area. Following a site inspection, nine classes of relatively static land use/land cover were defined to establish the map legend: forest, shrubs, grass, dry land agriculture, paddy field, bare land, reclaimed land, water body, and rural residential. Visual analysis of a displayed colour images was performed, with the help of ancillary information. Ground data collection was conducted to study land use patterns and characteristics in relation to their spectral response patterns on the satellite images. Such land use/land cover types and information sets obtained from ground surveys were the used to determine land cover and conservation practices, according to the guidelines provided by Arsyad (2006).

Annual soil loss was calculated on a spatial basis, using multiplication as presented in Equation (1). This is resulted in a map of average annual soil loss in the region. It is important to note that two types of results were obtained: first is potential erosion (potential soil loss rate), calculated from RKLS factors, and second is actual erosion (actual soil loss rate) calculated from RKLSCP factors. The latter indicates the actual condition of soil losses that are now taking place.

IV. RESULTS AND DISCUSSION

A. Land use/land cover

Spatial distribution of land use/land cover in the study area can be seen in Figure 1. Forest is the dominant land use in the area consisting of 2241 ha (or 36% from the total area), and is concentrated on the upper parts of the catchment. It is followed by dry land agriculture, bare land, shrubs, and residential. Residential areas are found in the lower part within the coastal areas. Some settlement areas have occupied land area with steep slope in the middle parts of the catchment.

Table 1. Land Use/Land Cover Types in the Study Region

Land use types	Area (ha)	Percent (%)
Forest	2241.0	36.1
Roads	62.7	1.0
Dry land agriculture	1158.0	18.6
Bare land	1120.5	18.0
Reclaimed land	23.9	0.4
Residential	596.1	9.6
Grassland	5.4	0.1
Paddy field	35.4	0.6
Shrubs	948.1	15.3
Water bodies	18.8	0.3
Total area	6209.9	100.0

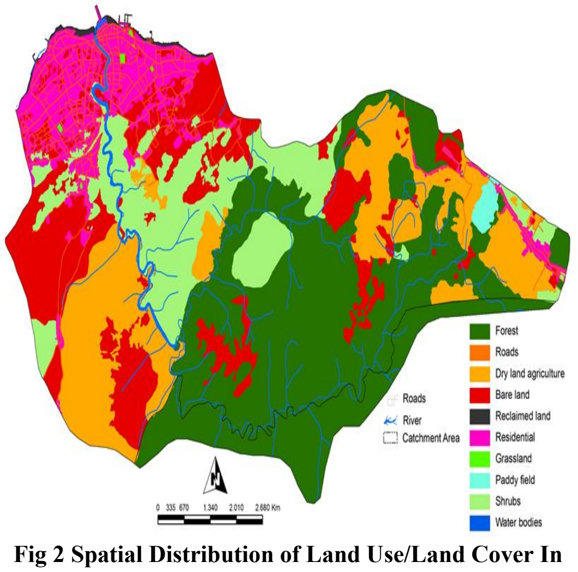

Fig 2 Spatial Distribution of Land Use/Land Cover In Baubau Catchment

B. Soil loss rate

As it equation implies, there are at least five map layers that represent the parameter of USLE. For the simplicity, among the five USLE parameters as given in equation (1), only land use map is presented here (Figure 1). While for predicted annual soil erosion rate, two maps are presented: potential soil loss (Figure 2) and actual soil loss (Figure 3).

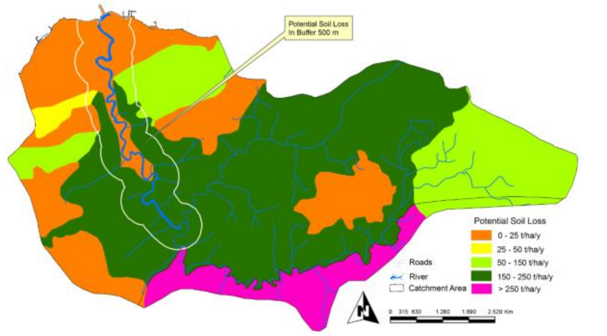

Fig 3 Map of Potential Average Annual Soil Loss in Baubau Catchment

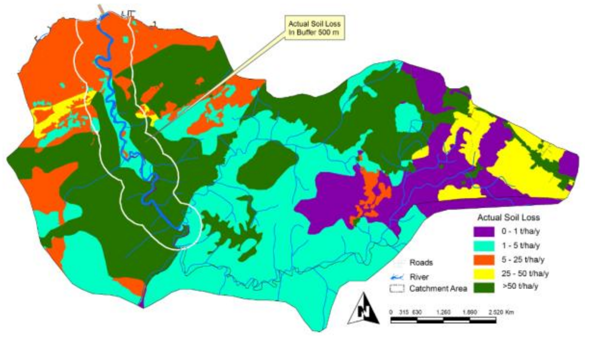

Fig 4 Map of Actual Average Annual Soil Loss in Baubau Catchment

Spatial distribution of soil loss information in GIS is given in categorical basis, and for display purposes the estimated rates of annual soil losses were aggregated into 5 classes (Figure 2 and Figure 3). The map shows that most parts of the study area have a potential soil loss more than 50 ton/ha/year (Figure 2), and the highest level (greater than 150 ton/ha/year) is found in the middle parts of the study area. Such information is useful for development, especially in construction activities and farmland management. During construction activities, soil surface is commonly in bare condition (no soil cover; and in this case C and P factors are not considered). With USLE method, Haile and Fetene (2012) found that erosion rate is higher for the upland areas than the lowlands due to inappropriate soil and water conservation measures, free grazing and conversion of hillside areas into farmlands. The figures imply that soil conservation measures are always needed to control erosion during construction activities in the land areas having a relatively high soil loss rate, and at the same time to protect sedimentation in the water bodies.

Furthermore, subdivision of estimated actual loss rates (Figure 3) is based on that suggested by the NSW Soil Conservation Service (Graham, 1989) for tropical regions, where classes 1, 2, and 3 represent the maximum acceptable soil loss (or erosion tolerance) for soils with shallow, moderate, and deep solum, respectively (DLWC, 1997). Figure 3 shows that varying levels of estimated average annual erosion occur in the study area. Based on the analysis of areal distribution in a GIS, soil loss in the study area gives the following figures: class 1 (< 1 t/ha/y) occupies 11.9% of the area, followed by class 2 (1-5 t/ha/y) with 32.56%, class 3 (5-25 t/ha/y) with 14.85%, class 4 (25-50 t/ha/y) with 5.79%, and class 5 (>50 t/ha/y) with 34.83%. It is interesting to note from Figure 3 that most of the sloping areas have estimated soil losses of 1-5 t/ha/y. This is mainly due to the presence of dense forest cover in those parts of the study region (Figure 1). If this forest cover were removed, such areas would have severe soil losses (generally 150-250 t/ha/y) (potential soil loss). High erosion rates occur mostly on areas with poor land cover. Lako and Marko (2012) found that substantial erosion occur on the area where forest harvesting and construction of forest roads. A study conducted by Loch (2000) concluded that decreasing vegetation cover from 47% to 0% resulted in a 60- to 70-fold increase in soil loss. Such examples indicate the importance of maintaining good land cover in the steeper portions of the study area.

Given the catchment condition as such, the actual soil loss currently taking place is relatively low (Figure 4). About 44% of the catchment experiences a soil loss rate of less than 5 t/ha/yr, and this occurs predominantly on forest and shrub cover types. Urban areas undergo a slightly higher soil loss rate (*i.e.,* 5-25 t/ha/y), because of poor land cover. The rate of erosion as such also brings about off-site effects (Ledermann *et al.,* 2010), especially in the hilly area (see Quine *et al.,* 1999; Sutherland, 1998). This reveals that future land conversion (from forest and shrubs to other uses especially impervious surface) and land management (see Posthumus *et al.,* 2011) on the catchment must be carefully designed and planned to ensure that land degradation due to erosion can be minimized.

C. Soil Loss in the River Buffer Zones

Currently, local government of Baubau City has a program for protecting the main river (lokal: *Kali Baubau*) that flows within the city, from sedimentation to maintain water quality. Based on the analysis of potential and actual erosion rate that occur around the river (river buffer zone), it was found that in the buffer area of 100 m of erosion rate that occupies the largest area (accounted for 132 ha) is in the range of 0-50 ton/ha/year. While for areas within the buffer line of 500 m, erosion rate within the range of 50-150 ton/ha/year occupies an area of 416 ha (see Figure 2). In such a case, riparian vegetation around the buffer zone of river always needs to be maintained, as suggested in a study of Sparovec *et al.* (2002), concerning the definition of the optimal width of riparian forests.

These figures explain that in general, if the vegetation cover and soil conservation efforts are not prepared on a relatively flat area (in the urban center), the sedimentation will occur at a maximum range of 50 ton/ha/year. However, substantial erosion may occur in the upper watershed having steeper slopes, within the areas up to 500 m from river body (see Figure 4). This study indicates the importance of implementation of soil erosion and sedimentation control in every land use activities around the catchment area.

V. CONCLUDING REMARKS

In this study, parameterization of soil erosion has been undertaken in a GIS at a relatively broad scale erosion study. The procedure used has a capability for organizing data bases and thematic layers in effective ways, and signifies the importance of the modeling procedures developed, especially in the context where the spatial pattern of erosion risks over a large area is of the main interest. Given the Baubau catchment condition as such, that most parts of the study area has the potential soil loss of more than 50 ton/ha/year, and the highest level (greater than 150 ton/ha/year) is found in the middle parts of the study area. Actual soil loss that is currently taking place is relatively low, where about 44% of the catchment experiences a soil loss rate of less than 5 t/ha/year, and this occurs predominantly on the shrubs cover type. Good cover type from forested areas signifies such phenomenon.

The procedure developed and the information generated in this study are important for designing the base line physical data set that can be used for future land conversion and land management on the catchment. Soil loss rate presented in this study gives insight into the appropriate land conservation strategies that should be implemented by the local government in the catchment area. Overall, this study reveals that future land conversion (from forest and shrubs to other uses such as agriculture or impervious or semi-pervious areas) and land management on the catchment must be carefully designed and planned to ensure that land degradation due to erosion can be minimized. Availability of base line data sets, in a spatial context, as a reference is equally important to support better urban catchment planning and development in the City of Baubau.

REFERENCES

[1] Arsyad S. 2006. Konservasi Tanah dan Air. IPB Press, Bogor.

[2] Baja, S., Chapman, D. M., and Dragovich, D. 2002. A conceptual model for defining and assessing land management units using a fuzzy modeling approach in GIS environment. Environmental Management, 29: 647-661.

[3] BAPPEDA Kota Baubau. 2009. Kajian Pengelolaan Daerah Sungai Baubau. Pemerintah Kota Baubau, Baubau.

[4] Boggs, G., Devonport, C., Evans, K., and Puig, P. 2001. GIS-based rapid assessment of erosion risk in a small catchment in the wet/dry tropics of Australia. Land Degradation and Development, 12: 417-434.

[5] Bols, P.L. 1978. The Isoerodent Map of Java and Madura. ATA 105. Lembaga Penelitian Tanah, Bogor.

[6] Boyd, M.J., Bufill, M.C., and Knee, R.M. 1993. Pervious and impervious runoff in urban catchments. Hydrological Sciences Journal, 3: 463-478.

[7] Haile, G.W., and Fetene, M. 2012. Assessment of soil erosion hazard in Kilie catchment, East Shoa, Ethiopia. Land Degradation & Development, 23 (3): 293–306.

[8] Halim, R., Clemente, R.S., Routray, J.K., and Shrestha, R.P. 2010. Integration of biophysical and socio-economic factors to assess soil erosion hazard in the Upper Kaligarang Watershed, Indonesia. Land Degradation & Development, 18 (4): 453–469.

[9] Kheir, R.B. 2008. A conditional GIS-interpolation-based model for mapping soil-water erosion processes in Lebanon. Land Degradation & Development. 19 (2): 122–135.

[10] Lako A, and Marko, O. 2012. The impact of soils erosion caused by forest harfesting and the construction of forest roads. International Journal of Forest, Soil and Erosion, 2 (2): 85-88.

[11] Ledermann T., Herweg, K., Liniger, H.P., Schneider, F., Hurni, H., and Prasuhn, V. 2010. Applying erosion damage mapping to assess and quantify off-site effects of soil erosion in Switzerland. Land Degradation & Development, 21 (4): 353–366.

[12] Posthumus, H., Deeks, H.K., Fenn, I., and Rickson, R.J. 2011. Soil conservation in two English catchments: Linking soil management with policies. Land Degradation & Development, 22 (1): 97–110.

[13] Quine, Ta., Walling, D. E., and Zhang, X. 1999. Tillage erosion, water erosion and soil quality on cultivated terraces near Xifeng in the Loess Plateau, China. Land Degradation & Development, 10 (2): 251-274.

[14] Renard, K.G., Foster, G.R., Weesies, G.A., McCool, D.K. and Yoder, D.C. 1997. Predicting Soil Erosion by Water: A guide to Conservation Planning with the Revised Universal Soil Loss Equation (RUSLE). USDA Agriculture Handbook No 703, Washington D.C.

[15] Ries, J.B. 2010. Methodologies for soil erosion and land degradation assessment in mediterranean-type ecosystems. Land Degradation & Development, 21 (2): 171–187.

[16] Sparovec, G., Beatriz, S., Ranieri L., Gasner, A., deMaria, I.C., Schnug, E., and Joubert, A. 2002. A conceptual framework for the definition of the optimal width of riparian forests Agriculture, Ecosystems and Environment, 90: 169–175.

[17] Sutherland. R.A. 1998. Rolled erosion control systems for hill slope surface protection: a critical review, synthesis and analysis of available data. I. Background and formative years. Land Degradation & Development, 9 (6): 465–486.

[18] Utomo, W.H. 1989. Konservasi Tanah di Indonesia: Suatu Rekamandan Analisa. Rajawali Press, Jakarta.

[19] Wischmeier, W.H. and Smith, D.D. 1978. Predicting Rainfall Erosion Losses: A Guide to Conservation Planning. USDA Agriculture Handbook No 537. U.S. Department of Agriculture, Washington D.C.