IV. RESULTS AND DISCUSSIONS

4.1. Land Cover Change Classification

The large areas of land cover are mapped at 1:50,000 scale using Landsat TM and/or ETM data. The land cover mapping was carried out using the FAO Land Cover Classification System (LCCS), a new methodology especially created for land cover mapping and now used worldwide. The following list describes the main phases applied in the present study, for the creation of the land cover maps:

1. Satellite data selection
2. Satellite data preprocessing
3. Satellite data classification
4. Satellite data interpretation and vectorization of the resulting units
5. LCCS classification
6. Field checking
7. Composition of final land cover maps

4.1.1. Satellite Data Selection

As previously indicated, all areas under study were used in July 1989 for a rapid assessment of local physiographic and of the main land cover classes occurring there. Satellite data were selected on the seasonal based of the crop calendar for the main crops. Although the purpose of the study was to prepare land cover maps and not crop inventories, it was considered of some importance to be able to separate the crops in the field at the time of satellite data acquisition. Consequently, an image acquired in December is included in the wet season, while July and August and September are the dry season. Based on the seasonal
based calendar of the satellite image, we can consider not only permanent land cover changed by human factor but also temporal changed by season. The information of images use in this research is shown in Table (4.1).

<table>
<thead>
<tr>
<th>Types of image</th>
<th>Path row</th>
<th>Date of acquisition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Landsat ETM + T 1220650126034</td>
<td>122-065</td>
<td>December 6, 2003</td>
</tr>
<tr>
<td>Landsat ETM + T 1220650816982</td>
<td>122-065</td>
<td>August 16, 1998</td>
</tr>
<tr>
<td>Landsat ETM + T 1220650919932</td>
<td>122-065</td>
<td>September 19, 1993</td>
</tr>
<tr>
<td>Landsat TM + T 1220650706892</td>
<td>122-065</td>
<td>July 6, 1989</td>
</tr>
</tbody>
</table>

4.1.2. Satellite data Processing

This is the first step prior to the remotely sensed data to be analyzed for removing some errors of satellite imagery. There are two common types of errors, radiometric and geometric, in remotely sensed satellite image to perform for enhancing quality of image for analysis. Fig (4.1) shows the process of image preprocessing for analysis.

![Flow Chart of Image Preprocessing](image-url)
4.1.2.1. Radiometric correction

The effect of atmospheric scattering caused by particles is a problem in imagery that should be removed or minimized to avoid bias to each spectral band. Histogram adjustment is one of the ways to minimize the bias. The radiometric correction algorithm is defined as below:

\[
\text{Output BV}_{ijk} = \text{input BV} - \text{bias}
\]

Where:

- \( \text{Input BV}_{i,j,k} \) = input pixel value at line \( i \) and column \( j \) of band \( k \)
- \( \text{Output BV}_{i,j,k} \) = corrected pixel value at the same location

1989_ radiometric correction
1993_rediometric correction

Fig (4.2): The radiometric correction image of 1989 and 1993

4.1.2.2. Geometric Correction and Rectification

The geometric correction processes is normally implemented as a two-steps procedure. First, those distortions that are systematic, or predictable, are considered. Second, those distortions that are essentially random, or unpredictable, are considered (Lillesand and Kiefer, 1994). In the transformation process there is need to choose the control point type which must be polynomial

---

1. Dilatar meningkatkan dan memperbanyak sebagian atau seluruh RKP ini, tanpa perubahan yang memberikan hal-hal yang nyata dalam masyarakat.
2. Penguraian latar belakang dan penutupan dalam bentuk gambar atau teks dalam bentuk gambar atau teks.
for rectifying the image. Resampling is used to determine the pixel values to fill into the output matrix from the original matrix (Lillesand and Kiefer, 1994).

The image for the year of 1989, 1993 and 1998 need to perform geometric correction in order to create the new dataset in the same geodetic datum (WGS 84) and map project (SUTM 48) as image in the year of 2003. The number and distribution of ground control point will influence the accuracy of the geometric correction and also root mean square error (RMS) should be less than 1.00. Resampling technique chosen is “nearest neighbour” and the cell seize is 30 meter. This process is very important for overlaying simultaneously both of vector and raster images.

Fig (4.3): Images after geometric rectification of the years 1998 and 1993

4.1.3. Satellite Data Classification

For unsupervised classification the ISODATA method was applied, and for supervised classification, the maximum likelihood classification (MLC) was preferred. To identify the sample areas for supervised classification, specific
procedures and information from topographic maps were used together with
thematic maps and expert knowledge of the terrain after field checking.

The objective of these operations is to replace visual analysis of the image
data with quantitative techniques for automating the identification of features in a
scene. This involved the multi spectral image data and the application of
statistically based decision rules for determining the land use identity of each
pixel in the image.

In this classification, the interpreter knows beforehand what classes are
present and whether each is in one or more locations within the scene. These are
located on the image, areas the statistical analysis is performed on the multi band
data for each such class. Instead of clusters then, one has class groupings with
appropriate discriminate functions. It is possible that must be more that one class
if only one band is used but unlikely when more than 3 bands are used because
different classes seldom have similar responses over a wide range of wavelengths.

All pixels in the image which lying outside training sites are then
compared with class discriminate, with each being assigned to the class it is
closest to – this makes a map of established classes (with a few pixels usually
remaining unknown) which can be reasonably accurate but classes present may
not have been set up; or some pixels are misclassified. In this research primary
image classification into (5) class, i.e., (1) forested area (2) agricultural area (3)
industrial area (4) settlement (5) Bush/grass land.
4.1.4. Satellite Data Interpretation and Vectorization of the Resulting Units

Landsat TM enhanced false color composites RGB (red, green, blue) 4,5,3; 5,3,2; 4,5,7 and 4,3,2 were used for the interpretation and delimitation of the land cover classes.

4.1.5. LCCS Classification

The Land Cover Classification System (LCCS) is a comprehensive, standardized a priori classification system, independent of the scale or method used to map. The classification uses a set of independent diagnostic criteria that allow correlation with existing classifications and legends, consequently the system could serve as an internationally agreed reference base for land cover. The methodology is applicable at any scale and is comprehensive in the sense that any land cover identified anywhere in the world can be readily accommodated. In this research, take the LCCS classification into (10) classes which include (1) primary forest (2) Secondary forest or reforestation (3) mixed vegetable growing area (4) plantation (5) paddy field (6) bare land (7) bush land (8) extensively dense settlement (9) less dense settlement and (10) industrial area. Then extract the classified layer from the supervised classification image by using scatter gram. After doing limit to actual to the scatter gram, the classified layer appear as shown in Fig (4.4).
Fig (4.4): The scatter gram layer of each class of classified image

It is need to make region to the classified scatter gram pixel, for extracting the classified layer. The following region represents the classification layer “forest” and all the forest land use classification turned to the selected color. Save the image as visual dataset then change to vector format.

Interpretation and vectorization on the screen, available in ArcView format was the preferred methodology because polygons created have vector format and can be directly transformed to a land cover map.

4.1.6. Field Checking

Field visits were undertaken in all areas under study to collect terrain information and interpretation keys useful for image interpretation. Later, field checking was carried out to test accuracy of image interpretation at selected sites and to clarify interpretation assumptions.
4.1.6.1. Accuracy of Land Use and Cover Mapping

The accuracy of the map was assessed by making use of ground truth samples that were collected during the fieldwork. Using the location information of these samples, a point map was created in Arc View. This map was rasterized and then combined with the land use/cover map created from Landsat ETM, acquisition date 6 December, 2003. This gave rise to confusion matrix (Table 4.2) giving information on the overall accuracy of the land use/cover map. The overall accuracy of the map was 74.5% which was considered to be satisfactory for the purpose of this study (Table 4.4). The map was imported into raster format and each class on the map was assigned a unique identifying number.

Table (4.2): The Accuracy assessment of each class of land cover classification (2003)

<table>
<thead>
<tr>
<th>Class</th>
<th>Overall accuracy (%)</th>
<th>Average accuracy of each class (%)</th>
<th>Average error reliability (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>100</td>
<td>83.4</td>
<td>72.5</td>
</tr>
<tr>
<td>2</td>
<td>90</td>
<td>79.2</td>
<td>68.0</td>
</tr>
<tr>
<td>3</td>
<td>80</td>
<td>73.5</td>
<td>63.0</td>
</tr>
<tr>
<td>4</td>
<td>95</td>
<td>90.4</td>
<td>75.6</td>
</tr>
<tr>
<td>5</td>
<td>90</td>
<td>85.4</td>
<td>70.0</td>
</tr>
<tr>
<td>6</td>
<td>85</td>
<td>80.0</td>
<td>65.0</td>
</tr>
<tr>
<td>7</td>
<td>90</td>
<td>85.0</td>
<td>70.0</td>
</tr>
<tr>
<td>8</td>
<td>95</td>
<td>90.0</td>
<td>75.0</td>
</tr>
<tr>
<td>9</td>
<td>85</td>
<td>80.0</td>
<td>65.0</td>
</tr>
<tr>
<td>10</td>
<td>90</td>
<td>90.0</td>
<td>75.0</td>
</tr>
</tbody>
</table>

4.1.7. Composition of Final Land Cover Maps

Vector shape files were created manually, in ArcView using both the original image and the results of the supervised classification in the background to provide a basis for visual interpretation. The result of land cover classification map of the year 2003, 1998, 1993 and 1989 is shown in Appendix (6) to (9).
4.2. Determining RUSLE factors

4.2.1. Rainfall Erosivity (R factor)

The generation of the rainfall erosivity layer is based on daily rainfall amounts for Bandung regency was aggregated into annual rainfall amount, and the isohyet map of West Java. As is common to many weather stations in developing countries, the rain gauges measuring precipitation in the vicinity of rainfall station and automated rain gauge station do not collect data pertaining to rainfall intensity. The weather stations at Bandung regency which is included in upper Citarum watershed daily recorded rainfall amounts, but storm duration data as well as storm power needed to calculate rainfall intensity were not available. Because of this limitation, a relational equation that estimates rainfall erosivity using annual rainfall totals was applied.

There are (7) rainfall stations situated in upper Citarum watershed which lie around the study area. The location of the rain gauge station is presented in (Appendix -1). The resulted map of rainfall erosivity (R) factor is presented (Appendix-2).

4.2.2. Soil Erodibility (K factor)

According to the soil classification map, scale 1:50,000 (Soil Research Center,1976) the study area is covered by six soil types, i.e: Alluvial Eutric, Andosal Distic, Gelosols Humus , Lithosol, Regosol Audic and Podzolic. These soil types generally are characterized by silty clay to sandy loam texture, low to high permeability, and low to very high erodibility. The soil depth is more than 90 cm, only in the small part of the area the soil depth of less than 30 cm.
4.2.2.1. Entisols

In the study area of Bandung regency Entisols include two types of FAO soil classification (1) Lithosol and (2) Regosol. Lithosol profile can be found in the area of rocky mountain especially on steep slopes, actively eroded slopes and receiving frequent deposits from flooding. This type of soil classification can be found near Lembang fault of the study area. Regosal profile can be found in the area of volcanic ash deposits and river sedimentation. These types of entisols consist of over sand deposits. The fertility of regosal varied from very low to very high depending on the situation.

4.2.2.2. Gelisols

Gelisols is shallow soil with dark organic surface layers on top of mineral layers. The fertility of soil is quite high and consists of high organic matter content.

4.2.2.3. Ultisol

Ultisol are mature soils with profiles formed by a sol formation process called podzolization, typically in cool humid regions under a coniferous or mixed conifer-hardwood vegetation. The fertilization is medium and highly productive soil for crop production.

4.2.2.4. Andisols

The original andisols are volcanic ash soils rich in organic matter. The color of the soil is dark brown and very fertile soil. This type of soil is the key factor in many successful horticultural and agricultural crop productions. The best tea plantations in the study can be found in Andisols soil type classification.
Alluvial fans occur at the base of steep slopes where streams discharge into an area having a more subdued relief. The fans are built of coarse-textured materials eroded from the higher elevations and transported down slope. Slopes on the alluvial fans are in the 2 to 15 percent range, with steeper slopes at the head of the fan and gentle slopes near the base. The texture material of alluvial fans is principally sand and gravel, with some silt. The surface water percolates very well into the ground and the porous soil mass acts as an underground storage reservoir.

Based on USGS soil texture and survey manual book and monograph, the characteristics of soil can be classified as shown in Table (4.2).

**Table (4.3): The Physical Characteristics of the Soil Types in the Study Area**

<table>
<thead>
<tr>
<th>No.</th>
<th>Soil Types</th>
<th>Texture</th>
<th>Permeability</th>
<th>Erodibility</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Andisols Alluvial Eutric</td>
<td>Sandy loam</td>
<td>High</td>
<td>Very high</td>
</tr>
<tr>
<td>2</td>
<td>Andisols Andosal Distic</td>
<td>Loam</td>
<td>Moderate</td>
<td>High</td>
</tr>
<tr>
<td>3</td>
<td>Gelisols Gelosol</td>
<td>Loam</td>
<td>Moderate to high</td>
<td>High</td>
</tr>
<tr>
<td>4</td>
<td>Entisols Lithosol</td>
<td>Clay loam</td>
<td>Moderate</td>
<td>High</td>
</tr>
<tr>
<td>5</td>
<td>Entisols Regosol Audic</td>
<td>Sandy loam</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>6</td>
<td>Inceptisol Podsolic</td>
<td>Clay loam</td>
<td>Moderate</td>
<td>Moderate</td>
</tr>
</tbody>
</table>

a. Sandy loam

Sandy loam can be classified into:

- Coarse sandy loam: 25% or more consist of very coarse and coarse sands and less than 50% consist of small sands
- Sandy loam: 30% or more consist of very coarse, coarse, and medium, but less than 25% consist of very coarse sands and less than 30% is very small and small size of sands.
- Small sandy loam: >=30% of small sand or < 30% of very small sand or 15% - 30% of very coarse, coarse, and small sands.
- Very small sandy loam: >= 30% very small sand or > 40% very small and small sands.

b. Loam

Soil texture that contents 27% clay, 28-50% is silt and less than 52% is sand.

c. Clay loam

Soil texture that contents >= 27%-40% is clay and 20-45% is sand.

d. Loamy sands

Loamy sands can be classified as:

- Coarse loamy sands: 25% or 25% consist of very coarse and coarse sands. Less than 50% consist of other size of sands.

- Loamy sands: 25% or more consist of very coarse, coarse, and medium. Less than 50% consist of small and very small sands.

- Small loamy sands: 50% or more consist of small sands and less than 25% consist of very coarse, coarse and medium sands then less than 50% consist of very small sands.

- Very small loamy sands: 50% or more consist of very small sands.

Based on soil texture classification, USGS hydrologic soil group can be classified in Table (4.2).

Table (4.4): The Classification of Soil Group in Hydrology based on Texture

<table>
<thead>
<tr>
<th>Hydrologic Soil Group (HSG )</th>
<th>Soil Texture</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Sandy, loamy sand, or sandy loam</td>
</tr>
<tr>
<td>B</td>
<td>Silt loam or loam</td>
</tr>
<tr>
<td>C</td>
<td>Sandy clay loam</td>
</tr>
<tr>
<td>D</td>
<td>Clay loam, silty clay loam, sandy clay, silty clay, or clay</td>
</tr>
</tbody>
</table>
Group A soils have low runoff potential and high infiltration rates even when thoroughly wetted. They consist chiefly of deep, well to excessively drained sand or gravel and have a high rate of water transmission (greater than 0.30 in/hr).

Group B soils have moderate infiltration rates when thoroughly wetted and consist chiefly of moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures. These soils have a moderate rate of water transmission (0.15-0.30 in/hr).

Group C soils have low infiltration rates when thoroughly wetted and consist chiefly of soils with a layer that impedes downward movement of water and soils with moderately fine to fine texture. These soils have a low rate of water transmission (0.05-0.15 in/hr).

Group D soils have high runoff potential. They have very low infiltration rates when thoroughly wetted and consist chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a clay pan or clay layer at or near the surface, and shallow soils over nearly impervious material. These soils have a very low rate of water transmission (0-0.05 in/hr).

The final result map of soil erodibility (K) factor can be seen at Appendix-4.

4.2.3. Land Cover (C factor)

Using the guidelines for physical and socio-economic suitability developed by FAO (Rossiter, 1994), land suitability analysis was conducted for 10 Land Mapping Units of the study area.

The land cover and land use of the study area was grouped into (5) types i.e. (1) Forested area (2) Horticultural Crops Field (HC) (3) Agricultural land
(Rice field) (4) Settlement area and (5) Industrial area. The forest area can be divided into two, natural forest or conservation area and secondary forest or reforestation.

4.2.3.1. Natural Forest (NF) or Conservation area

The main species in natural forest are rasamala (*Altingia excelsa*), puspa (*Schima noronhae*) and saninten (*Castanopsis Javanicus*). Besides trees, also herbs are found. The trees and plants in the natural forest area create a stratification of canopy that protect the land from the impact of rainfall drops. Interlayered canopies, thus reducing the energy and the amount of rainfall reaching the surface, intercept the rainfall.

The vegetation of natural forests influences the soil conditions in such a way that erosion is reduced. The infiltration capacity of the areas occupied by natural forest is generally higher than of the other areas. Thus, the vegetation causes a decrease in the detachment force of rainfall, it also reduces the rate and amount of surface erosion. Therefore, soil loss in the natural forest area is minimum and the C factor value is 0.005.

4.2.3.2. Secondary Forest or Reforestation

Secondary forest only occupies a small part of the area. The tree species, which can be found, is puspa (*Schima noronhae*). The secondary forest is formed when trees have been cut and harvested. This forest has only one single tree canopy, but still has herbs as a groundcover. Most of the reforestation are pine forest, quinine estate forest and wood land forest. This kind of forest is plantation forest. The canopy coverage is average in reforestation area but the ground cover condition is as good as secondary forest.
4.2.3.3. Horticultural Crops Field

The horticultural crop field can be divided into vegetable growing area and plantation. There are several vegetable crops that are cultivated in that area, i.e: cabbage, cauliflower, tomatoes, chili, cassava, maize, potatoes, strawberries and beans. To cultivate these crops generally one of three production systems are used, i.e.

(a) Monoculture
(b) Mixed crops
(c) Crop rotation

The horticultural crops usually cultivated by using monoculture production are: tomatoes, beans, potatoes, cabbage/cauliflower, chili, strawberries, cassava and maize.

Mixed crops production usually uses crops combination as follows:

(a) Cabbage/ cauliflower – tomatoes
(b) Cabbage/ cauliflower – tomatoes- chili
(c) Tomatoes – chili
(d) Chili-long bean and
(e) Maize – tomatoes

The crop rotation pattern and crop calendar change year to year and it depend on the season and market demand.

4.2.3.4. Rice Field

Rice field are found in the area of fluvial plains, i.e the river terraced which are close to the water sources and moderately high elevation with leveling area. Rice is cultivated 4 times per year depending on the season.
4.2.3.5. Settlement

The settlements on the study area are grouped into two groups, i.e. extensively dense settlement (city) and less dense settlement area (town). City is defined as the area which is occupied by more than 60% impervious area. The town has been less than 60%.

4.2.3.6. Industrial Area

The industrial area can be found along the Citarum river and surrounding the Lake Ciguling.

4.2.4. Land Management (P factor)

Land management should consider the physical characteristics of the area such as soil properties, landform and climate (rainfall) to keep the sustainability of the high productivity of the land. Land management is directed to maintain the dynamic equilibrium of soil formation and soil loss and to increase the land productivity for long-term purpose.

In the study area many land management systems can be found, i.e: tillage, terracing, fertilization and cropping pattern. Tillage generally is done parallel to the contour but slightly slanting to the slopes or even parallel to the slopes direction.

There are several types of terracing which are used in the study area, i.e: level bench terraces, inward-sloping bench, and outward slopping bench terraces, which is followed by making the ridges parallel to the slope direction. The sloping part of the terraces are usually made vertically, therefore, the landslides occur very often.
Fertilization of the agricultural land is done intensively, but sometimes the effects of fertilization are not effective due to the mis-use of the tillage. The fertilizer was often washed away rapidly by surface runoff.

4.2.5. Slope Length (LS) Factor Classification

An Arc View based technique designed by Bernie (1999) was used. The technique uses DEM as the input layer and the hydrological and spatial analyst extensions in ArcView 3.3 for processing. To estimate LS, flow accumulation and slope layers are required.

The flow accumulation layer was used to estimate slope length (L). The technique is based on the principle that flow algorithm distributes flow according to relative slope of downhill pixels. This layer was calculated from the DEM following logical steps with GIS processing capabilities in the hydrologic extension of ArcView 3.3. From the DEM, depressions and sinks were delineated using the fill sinks option under the hydrologic extension. The operation resulted in a new DEM with depressions or sinks which indicate the route of flow. The new DEM with depressions was used to compute flow direction layer. The flow direction layer was in turn used as an input for computing a flow accumulation layer which shows how much area flows through each grid. The slope layer in degree was directly extracted automatically under the derive slope option on the surface extension. Since RUSLE is suitable for estimating interill and rill erosion processes, there is a limit on the slope length at 150m. Therefore, the flow accumulation map was modified to enforce this limit. To modify the flow accumulation map, a layer was created where value 5 was assigned to all pixels...
that had flow accumulation greater than 5 (150/pixel size (30)). The ArcView 3.3 map calculator was used to derive this layer as below.

\[ ([\text{Flow accumulation}] > 5) \times 5 \]  \hspace{1cm} (4.2)

Another layer was also derived where value 1 was assigned to pixels that had flow accumulation below 12 as follows.

\[ ([\text{Flow accumulation}] < 5) \times \text{flow accumulation} \]  \hspace{1cm} (4.3)

The two modified flow accumulation layers were added together to obtain a new flow accumulation map with a flow accumulation maximum of 5, that when multiplied with the map pixel size of 30 m translates to the RUSLE maximum slope length limit of 150 m. The new flow accumulation layer and the slope steepness layer were then used as inputs for computing LS. The following equation proposed by Moore and Burch (1986) was used to calculate LS.

\[ \text{LS} = (\text{New Flow accumulation} \times \text{cell size}/22.13)^{0.4} \times (\sin \text{slope}/0.0896)^{1.3} \]  \hspace{1cm} (4.4)

Where; Flow accumulation is the grid layer expressed as number of grid cells, and cell size is the length of a cell size taken as 30 m. The slope length (LS) factor map is shown in Appendix-5.

### 4.3. Erosion Potential based on Soil Loss Rate

The estimated annual soil loss rates were classified into 5 severity classes i.e. acceptable level (0-11 t\(^{-1}\) h\(^{-1}\) yr\(^{-1}\)), slight (11-37 t/h yr), moderate (37-60 t\(^{-1}\) h\(^{-1}\) yr\(^{-1}\)), high (60-75 t\(^{-1}\) h\(^{-1}\) yr\(^{-1}\)) and very high (>75 t\(^{-1}\) h\(^{-1}\) yr\(^{-1}\)). According to Morgan (1995), the appropriate measure of soil loss over which agriculturalist should be concerned is 11 t\(^{-1}\)h\(^{-1}\)yr\(^{-1}\). This threshold was adopted as the soil loss tolerance limit for Bandung regency, and was used as the critical value for separation of moderate and high annual soil erosion categories. The term
“soil loss tolerance” denotes the maximum level of soil erosion that will permit to be sustainable environment. The erosion potential map of 2003, 1998, 1993 and 1989 based on soil loss rate can be seen from Appendix-10 to 15, respectively.

4.4. Analysis of Land Cover Changed and Erosion Rate

Sensitivity analysis has been used in several studies (Kadupitiya, 2002b; Renschler, 1996) to evaluate the relative stability of models to parameter change. In this study, factor input parameters that are identical in model namely, cover factor; slope gradient; rainfall amount and soil texture organic matter were considered. Among these (4) factors, land cover factor is chosen for doing sensitivity analysis.

4.4.1. Comparison between Four Different Periods of Landsat Images

From comparison between 3 different years of Landsat images, the land cover change can be observed clearly. The water quality especially sedimentation can be seen clearly in all images. The way of river flow and the condition of lakes are seriously effected by dramatical population increase and industrial activities.
dramatically to industrial and residential areas.

Fig(4.6): Comparison of land cover between 3 different years
Seasonal change of agricultural lands and permanent change of agricultural areas to residential areas can be observed in following figures.

Fig(4.7): Comparison of land cover between 3 different years
- The conservative forest area is converted to residential area
It's generally accepted that ground cover is the most important factor in the soil erosion process. Owing to this importance, it was deemed necessary to evaluate sensitivity of land cover change by years and sensitivity of soil loss to cover (C) factor. According to the following figure, the land cover change pattern can be observed. The variations in sensitivities seem to be more related to site conditions than land cover change over years as a factor.
Fig (4.9): The histogram shown the yearly percentage of land use changed

Between (10) types of land use/cover type’s classification, the cover change was serious in industrial and settlement areas. According to 2003 landsat ETM and 1993 landsat TM image classifications, industrial area increased 17 percent.

For settlement area, the increasing rate was more than 10 percent within five year interval period from 1998 to 2003. Increase of residential, industrial area and agricultural area, the deforestation is shown clearly in histogram chart. The secondary forest area was decreased dramatically between the year of 1993 and 1998 and decreasing rate was 14 percent. In 1998, the percentage of bare land was more than 10%. The acquisition date of 1998 Landsat ETM satellite image was taken in August which is the period of lowest rainfall amount based on
meteorological data. Some of the agricultural fields especially mixed vegetable growing areas were still open land before starting the next cropping. The soil loss rate by erosion according to year is shown in the table (4.5).

Table (4.5): The Yearly Erosion Rate of Study Area by using RUSLE
(Classification based on Morgan, 1995)

<table>
<thead>
<tr>
<th>Erosion Rate</th>
<th>tons/ha/yr</th>
<th>2003 (ha)</th>
<th>2003 (%)</th>
<th>1998 (ha)</th>
<th>1998 (%)</th>
<th>1993 (ha)</th>
<th>1993 (%)</th>
<th>1989 (ha)</th>
<th>1989 (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acceptable Level</td>
<td>0-11</td>
<td>172000</td>
<td>82</td>
<td>199138</td>
<td>94</td>
<td>217000</td>
<td>96</td>
<td>244261</td>
<td>97</td>
</tr>
<tr>
<td>Light</td>
<td>11 to 40</td>
<td>22641</td>
<td>11</td>
<td>10771</td>
<td>5</td>
<td>6678</td>
<td>3</td>
<td>5696</td>
<td>2</td>
</tr>
<tr>
<td>Moderate</td>
<td>40 to 60</td>
<td>12234</td>
<td>6</td>
<td>1201</td>
<td>1</td>
<td>876</td>
<td>0.39</td>
<td>510</td>
<td>0.20</td>
</tr>
<tr>
<td>High</td>
<td>60 to 75</td>
<td>91</td>
<td>0.044</td>
<td>1130</td>
<td>0.531</td>
<td>90</td>
<td>0.04</td>
<td>88</td>
<td>0.03</td>
</tr>
<tr>
<td>Very high</td>
<td>&gt;75</td>
<td>0.89</td>
<td>0.0004</td>
<td>376</td>
<td>0.177</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
</tr>
</tbody>
</table>

Area proportion was tabulated for each soil erosion hazard severity category. In terms of overall erosion distribution by four different period of land cover, the maximum proportion of the study area was 82% with acceptable soil erosion category in 2003, 94% in 1998, 96% in 1993 and 97% in 1989. In 2003, 11% was categorized as light, 6% as moderate, and 0.044% was classified as high. The results, therefore, indicate that the largest proportion of the study area 82% is within the acceptable soil loss tolerance threshold of 0 -11 ton/hectar (ha)\(^{-1}\)yr\(^{-1}\) (Morgan, 1995).

4.4.2. Soil Loss Rate in Each District According to Land Cover Changed

Determining soil loss rates and associated land use types helps to understanding the efforts needed to save the physical quality of land and ultimately hold valuable information for developing necessary conservation strategies. The categorization of RUSLE can be predicted average annual soil loss
rates based on land cover/use types in areas of the respective land uses. Based on the different land cover types of Satellite images for the years (2002, 1998, 1993 and 1998), the analysis of soil loss amount according to district based on land use/cover are as follows.

4.4.2.1. Soil Loss in 2003

Based on the final result of soil loss by using RUSLE which include land cover factor, soil erodibility, rainfall erosivity, land management and slope length factor in Arc View 3.3. The results show variations in average annual soil loss under land use in 2003, with greatest soil loss rates (71 – 85 t/ ha/yr) and lowest rate (14 t/ ha/yr). The annual soil loss was (57 t/ha/yr) for extensive settlement area and less than (14 t/ha/ yr) for tree plantations and degraded secondary forest. The highest soil loss rate was more than (95 t/ha/yr) which occurred in residential area (Fig 4.10).

Fig (4.10): The correlation between land cover and erosion in 2003
The erosion based on soil loss amount between districts in lower portion of Bandung regency during 2003 was compared in following figure (4.11).

Fig (4.11): The total soil loss area in (km square) in each district in lower portion

Most of the eroded area was found in Lembang district and other districts including Cikalongwetan and Cipatat districts. The highest erosion rate was in Batujajar district of the lower portion of Bandung regency in Fig (4.12).

Fig (4.12): The soil loss rate in each district in lower portion
Gunungulu district in Fig (4.13). The most highest erosion rate in the middle portion of study area are Cililin, Gunungalu and Bojongsoang districts suffer high erosion rate between (30 to 45) t/ha/yr in (Fig 4.14).

Fig (4.13): The total soil loss area in (km square) by erosion

Fig (4.14): The soil loss rate by erosion in middle portion

For upper portion of study area in 2003 period, Pasirijambu and Pangalengan had the widest eroded area. All (12) districts in the upper portion of
the study area had erosion rate (30 t/ha/y) in 2003 period. Among them, Kertasari (KTS), Pangalengan (PGLG) and Pasirjambu (PSJ) had soil loss rate up to (45 t/ha/yr).

Fig (4.15): The total soil loss area in (km square) due to erosion

Fig (4.16): The total soil loss area in (km square) by erosion of each district
4.4.2.2. Soil Loss in 1998

By using RUSLE for the year 1998 land cover type, 30% of plantation areas are eroded and the rate of erosion was (11 – 60 t/ha/yr). Paddy fields and mixed vegetable growing area had erosion rate between (11 – 40 t/ha/yr) (Fig.4.17)

This soil loss rate calculated for 1998 period land cover when the satellite image was taken during August. Most of the agricultural areas were in open land before to plan next season crop. The highest erosion rate was around 110 t/ acre/yr in mixed vegetable planning area and plantation area.

![Fig (4.17): The effectiveness of different type of land cover upon soil loss rate](image)

In the lower portion of study area, Cipatat, Lembang, Cikalongwetan and Batujatar districts more than 50 thousand hectare of area were eroded in 1998.
Fig (4.18): The soil loss in area amount in year 1998

Lembang had soil loss rate of 95 t/ha/yr and Batujajar had soil loss rate of 65 t/ha/yr in 1998, respectively. Most of the vegetable growing areas in Lembang consisted of bare land in 1998 land cover scenario so the erosion rate was occurred the highest in Lembang district.

Fig (4.19): The soil loss rate of Lower portion in year 1998

In middle portion of the study area, Gununghalu had the largest eroded area more than 10,000 thousand hectare (fig: 4.20). The erosion rate for Cililin...
and Gununghalu districts were considered serious with soil loss rate more than (90 ton/ha/yr). Cipongkor district also had erosion rate of around (65 ton/ha/yr) in 1998.

Fig (4.20): The soil loss in area amount based on year 1998 land cover type

Fig (4.21): The soil loss in rate based on year 1998 land cover type
Based on 1998 land cover type, the highest erosion rate was occurred in Pangalengan, Pacet, Ciwedy and Kertasari districts at upper portion of study area (Fig:4.22). The soil loss rate was more than (90 ton/ha/yr). The widest eroded area was found in Pangalengan and Pasirjambu districts. In these two districts the eroded area was more than 1600 thousand hectares during August 1998 (Fig:4.23).

![Fig (4.22): The soil loss in area amount in the year 1998 land cover type](image1)

![Fig (4.23): The soil loss rate in the year 1998 land cover type](image2)
4.4.2.3. Soil Loss in 1993

After computing all the factors in RUSLE, results show variations in average annual soil loss under land use in 1993, with greatest soil loss rates (70 t/ha/yr) and lowest rate (14 t/ha/yr). The annual soil loss was (70 t/ha/yr) for orchards (mix vegetable growing area). The largest soil loss area occurred in residential area.

![Histogram of Soil Loss in 1993](image)

**Fig (4.24):** The land cover (C) factor effectiveness on erosion rate in 1993

In lower potion of study area, Cipatat, Batujajar and Cikalongwetan districts had large erosion area according to 1993 land cover classification. Lembang and Cilengkrang districts had highest erosion rate (45 – 67 ton/ha/yr) and Batujajar and Padalarang districts had erosion rate (22 – 45 ton/ha/yr). The highest erosion rate occur in Lambang district because of growing mix vegetable in the area which had LS factor between 3 to 7 and lack of good soil conservation management practice.
Fig (4.25): The soil loss area by erosion in lower portion of study area

Fig (4.26): Soil loss rate in lower portion of study area

In the middle portion of the study area, Gununghalu district had the largest erosion area because of opened land for the purpose of increase settlement in slope percent more than 40 percent.
But the highest erosion rate occurred at Cililin district which situated around the Lake Siguling area. In Cililin district, the soil loss rate by erosion was occurred between 45 to 67 ton/ha/yr because of industrial area, settlement area and opened land for the purpose of growing mix vegetable and incensement of industrial area. Gunanghalu, Cipongko and Sindangkerta districts had erosion rate of 22 to 45 ton/ha/yr according to seasonal land cover changed appeared opened land for the purpose of growing vegetation.
Fig (4.28): Soil loss rate in each district in year 1993

Pagalengan and Pasrijumbu were the widest eroded district in upper potion of the study area because of disturbs the conservative area to agricultural area with high slope length (LS) factor.

Fig (4.29): The soil loss rate in area by erosion in lower portion of study area
Ciparay, Majalaya, Katapang and Pameungpeuk districts have high erosion rate in the upper zone of study area. The soil loss rate was 22 to 45 ton/ha/yr. For the increase settlement and agriculture area purpose, the soil loss occurred at the open barren land in such district.

![Histogram of Soil Loss 1993: Value in Upper Portion of Study Area](image)

**Fig (4.30):** Soil loss rate amount in study area at 1993

### 4.4.2.4. Soil Loss in 1989

After computing all the factors in RUSLE, the correlation of soil loss rate and land use type (LUT) can be seen in following figure.
The soil loss occurred in each district (lower portion) of Bandung regency can be seen in following figure. Batujajar district happened the highest soil loss rate in 1989 because of increase settlement and industrial area caused open land. Also mix vegetable growing agricultural area around Lake Segulin in the Batujajar district. The second highest soil loss rate happened in Padalarang district because of the increased population turned conservation area to settlement area. Mix vegetable growing area in Lembang district was happened the third highest rate of soil loss in 1989.
According to figure (4.23), the middle portion except Cililin district was safe from serious soil loss in 1989.

All the districts in the upper portion of study area were safe from serious erosion in 1989 except Pacet.
4.5. Summary of Soil Loss Rate between Different Time Series

The soil loss rate due to erosion in the whole study area based on four different period of land cover condition, ie. 2003, 1998, 1993 and 1989, Paronpong, Cisarua and Lembang districts are in lower portion of study area had moderate eroded condition between (30-50 ton/ha/yr). Padalerang, Batujajar, Cililin and Gununghulu district had continuously soil loss by erosion with very serious rate (50-90 ton/ha/yr). Pasirjambu, Pangalengan, Pacet and Kertasiri districts suffered light and moderate soil loss rate (30-40 ton/ha/yr) which was started at the year of 1998.
Table (4.6): The Erosion Rate in Bandung Regency

<table>
<thead>
<tr>
<th>Name of District</th>
<th>LUT</th>
<th>Value of LS factor</th>
<th>Erosion (tones/ha/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parongpong</td>
<td>Highly dense settlement, industrial area and mix vegetable</td>
<td>0.6 – 0.8</td>
<td>&gt;50</td>
</tr>
<tr>
<td>Cisarua</td>
<td>Disturb the conservative area by settlement area</td>
<td>0.4 – 0.5</td>
<td>&gt;30</td>
</tr>
<tr>
<td>Lembang</td>
<td>Highly dense settlement and mix vegetable garden</td>
<td>0.3 – 0.6</td>
<td>40 - 50</td>
</tr>
<tr>
<td>Padalerang</td>
<td>Highly dense settlement and industrial area</td>
<td>0.5 – 0.6</td>
<td>70 – 90 *</td>
</tr>
<tr>
<td>Batujajar Cililin</td>
<td>Highly dense settlement and industrial area</td>
<td>&gt;0.7</td>
<td>50 – 60</td>
</tr>
<tr>
<td>Gununghalu</td>
<td>Highly dense settlement, Mix vegetable growing</td>
<td>&gt;0.7</td>
<td>50 – 60</td>
</tr>
<tr>
<td>Pasirjambu</td>
<td>Highly dense settlement Mix vegetable growing</td>
<td>0.5 – 0.7</td>
<td>30 -40</td>
</tr>
<tr>
<td>Pangalengan</td>
<td>Substitute the conservative forest with settlement area</td>
<td>&gt;0.7</td>
<td>20 - 30</td>
</tr>
<tr>
<td>Percet Kertasari</td>
<td>Substitute the conservative forest with settlement area</td>
<td>0.5 – 0.7</td>
<td>30- 40</td>
</tr>
</tbody>
</table>

* = Highest erosion rate for 2003 land cover condition.

4.6. Future Management for Study Area

The forested area with the slope gradient above 40 % (LS factor value >0.5) should be classified as highly conservative value forest (HCVF) area, in which no agricultural activities and increase of settlement were permitted. This management practice includes Pangalengan, Pasirjanbu and Gununghalu districts (Appendix-15). If land cover of highly slope gradient area in those districts continuously shift to residential area, the soil loss rate must seriously increased. Some agro- forested area, mostly pine forest must be reforested after clear cut.
In Lembang district, most of the agricultural land is grown without soil mulching type in high elevated area where the erosion rate must be high at the time of heavy raining period. Land management factor is the effective measure for reducing erosion in agricultural land. So land management in the district need to consist of contour tillage, good terracing practice and good mulching practice. Contour cultivation is highly recommended for elevation more than 1000 meter because contouring reduces soil erosion and increases soil moisture by reducing runoff losses. The effectiveness of contouring is also impaired by changes of infiltration capacity of the soil owing to surface sealing.

The area around the lake Saguling which include Batujajar, Cililin and Pajalenjan districts must be maintained as soon as possible because of high rate of erosion around that area caused by agricultural intensification and dense industrial area. The erosion has resulted in the loss of fertile top soil, the formation of rills and even gullies in some parts of the area.