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SOIL EROSION MODELING USING GIS AND RUSLE ON THE EURAJOKI WATERSHED FINLAND

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ABSTRACT

This thesis study applied Geographical Information System (GIS) and the Revised Universal Soil Loss Equation (RUSLE) to predict the annual average soil loss rate from the Eurajoki watershed (South-West Finland). To achieve the goals of the thesis, the RUSLE factors were calculated using the local data that was collected from National Land Survey of Finland and Finnish Metrological Institute. The soil survey data were used to develop the soil erodibility factor (K), and a digital elevation model of the catchment was used to generate the topographic factor (LS). The values of cover-management (C) factor and support practice (P) factor were collected from literature due to lack of satellite image and soil index map. Usually C and P factors determine from land cover and land use classes respectively. The rainfall–runoff erosivity (R) was derived from monthly rainfall data and Fournier index.

The results indicate that the average annual soil loss (A) within the catchment is about 5 Mg/ha/yr (5 metric ton per hectare per year). This is highly depend on R value which ranges between 299 and 307 MJ/ha.mm/h with the highest values being in the lower part of the catchment and the lowest values in the higher part of the catchment. Slopes in the catchment varied with steep slopes having higher values of slope length and mean LS factor is 1.34.

It is also important to note that the steepest slopes show high risk of soil erosion, it is therefore recommended that further study be undertaken to establish the suitable soil and water conservation measures that should be implemented in these areas as well as the whole catchment.

Keywords: Soil Erosion, RUSLE, GIS, Eurajoki Watershed

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LIST OF SYMBOLS AND ACRONYMS

A	RUSLEs Equation Average Annual Soil Loss
AAP	Average Annual Precipitation
C	RUSLEs Equation cover-management factor
DEM	Digital Elevation Model
E	Storm Energy
EI	storm erosivity
EI_{30}	30-min storm erosivity
Elsat	Elevation of station from sea level
GIS	Geographic Information System
Grlat	Grid 27E coordinates of the station, latitude
Grlon	Grid 27E coordinates of the station, longitude
I	precipitation intensity (mm/h)
I_{30}	maximum 30-min intensity (mm/h)
K	RUSLEs Equation soil erodibility factor
L	RUSLEs Equation slope length factor
Lat	Latitude, degrees*100 + minutes
Lat-sec	Lat_sec= latitude seconds
Lpnn	Number of the Station
LS	Slope length and steepness factor
MAR	Mean Annual Rainfall
MFI	Modified Founier Index
OM	Organic matter
P	Support Practice Factor
R	RUSLEs Equation Rainfall-runoff erosivity factor
Rrmon	Monthly Precipitation
RUSLE	Revised Universal Soil Loss Equation
S	RUSLEs Equation slope steepness factor
USLE	Universal Soil Loss Equation

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1 INTRODUCTION

According to recent assessments over 80% of the world's agricultural land suffers from moderate to severe erosion which induced loss of productivity. Because of this and population growth, the global per capita food supply is currently declining. In many areas of the world, on-site impacts of increased soil loss are frequently coupled with serious off-site impacts related to the increased mobilization of sediment and its delivery to rivers. These off-site impacts include water pollution, reservoir sedimentation, the degradation of aquatic habitats and the increased cost of water treatment. (Ritchie et al., 2003)

1.1 Background

The limitations of current measurement techniques and models to provide information on the spatial and temporal patterns of soil and water degradation across catchments restrict ability to develop cost-effective land management strategies. However, the advent of new techniques of erosion assessment and recent developments in the application of remote sensing and geographic information systems (GIS) to the study of erosion and sediment delivery offer considerable potential for meeting these requirements.

Since disturbed lands in watersheds are significant source of sediment, a systematic rating of their potential for erosion would be useful in soil conservation planning. Most importantly mapping and assessment of erosion prone areas enhances soil conservation and watershed management. Maps showing the spatial distribution of natural and management related erosion factors are of great value in the early stages of land management plans, allowing identification of preferential areas where action against soil erosion is more urgent or where the remediation effort will have highest revenue. (Mbugua W. 2009)

1.2 Problem Statement

Lake Pyhäjärvi is a large (155 km^2) but shallow mesotrophic lake in southwest Finland has a great meaning locally, nationally and internationally and also considered as the most important lake in terms of water supply, recreational use. The two rivers Yläneenjoki and Pyhäjoki and the four main ditches, which are a part of Eurajoki watershed, discharge into Lake Pyhäjärvi. The soils in the river valley are mainly clay and silt, whereas tills and organic soils dominate elsewhere in the catchment. (Tattari and Rekolainen, 2006)

The soil erosion in the vicinity of Lake Pyhäjärvi and its main tributaries is the major cause for the degradation land and loss of its fertilities. For example, over 60% of the external nutrients into the Lake Pyhäjärvi come from Eurajoki catchment. Erosion rates in Yläneenjoki area vary owing to local natural conditions and management practices. Agricultural field plots and catchments dominated by agriculture produce higher erosion rates than forested areas. The clayey soil of the south-western coastal plains is more susceptible to erosion than inland predominantly sandy and till soils. (Tattari and Rekolainen, 2006)

Therefore, the aim of the thesis is to use GIS techniques to determine RUSLE’s parameters and to estimate the annual average soil loss by erosion from the entire watershed.

1.3 Objective of the Study

The overall objectives of the thesis are:

- To evaluate the application of Geographic Information System (GIS) and Revised Universal Soil Loss Equation (RUSLE) to determine the soil loss.
- To predict the amount soil loss from the Eurajoki watershed by using ArcGIS and Revised Universal Soil Loss Equation.

Its specific objectives are:

- To identify and describe the six components of the RUSLE soil loss equation.
- To familiarize with the digital elevation model (DEM) to generate the slope length and steepness of Eurajoki watershed

2 LITERATURE REVIEW

The subject of soil erosion has been a global concern and numerous research works have been undertaken. In this chapter, soil erosion has been discussed briefly including the model that has been preferred in its assessment and the importance of GIS application

2.1 Soil Erosion

Soil erosion is a three phase phenomena consisting of the detachments of individual soil particles from the soil mass and their transport by erosive agents, such as running water and wind. When sufficient energy is no longer available with erosive agents to transport the particles then the third phase is called a 'deposition' takes place. The potential for soil erosion varies from watershed to watershed depending on the configuration of the watershed (topography, shape), the soil characteristics, the local climatic conditions and the land use and management practices implemented on the watershed (Arora K. 2003 and Suresh R. 2000). The removal of topsoil by water is takes place in the following ways:

- Sheet erosion
- Rill erosion
- Gully erosion
- Stream bank erosion
- River erosion

2.1.1 Sheet Erosion

Sheet erosion is more or less is the removal of a uniform thin layer or ‘sheet’ of soil by flowing water from a given width of sloping land. The amount of soil removed by this type of erosion is small, but as it flows down the slope, it increases in size and develops into rill erosion. (Arora K. 2003 and Suresh R. 2000)

2.1.2 Rill and Gully Erosion

With rill erosion the erosive effect of flowing water suddenly increases at a location where a confluence of surface water occurs. Due to low infiltration rates and the occurrence of rainfall, the excess water collects very slowly over the land surface and into the rill. As this gathering of water continues the depth of water together with the velocity, kinetic energy, and the soil particle carrying capacity of the water increases. Then the rill erosion develops into gully erosion. (Arora K. 2003 and Suresh R. 2000)

2.1.3 Stream Bank Erosion

The removal of soil from the stream of the stream bank occurs due to either water flowing over the sides of the stream from overland runoff or the water flowing in the stream and scouring the banks. Stream bank erosion is a continuous process in perennial streams and is caused by the souring and undercutting of the soil below the water surface caused by wave action during normal stream flow events. (Arora K. 2003 and Suresh R. 2000)

2.1.4 River Erosion

This type of erosion occurs particularly in rivers in which permanent water flow takes place, usually with varying rate. River erosion is likely to be more effective in the water courses of smaller catchment area and those having less favorable conditions for draining discharge. (Arora K. 2003 and Suresh R. 2000)

Figure 1 shows the development or stage of soil erosion by water (Sharma, Partha Das. 2009)

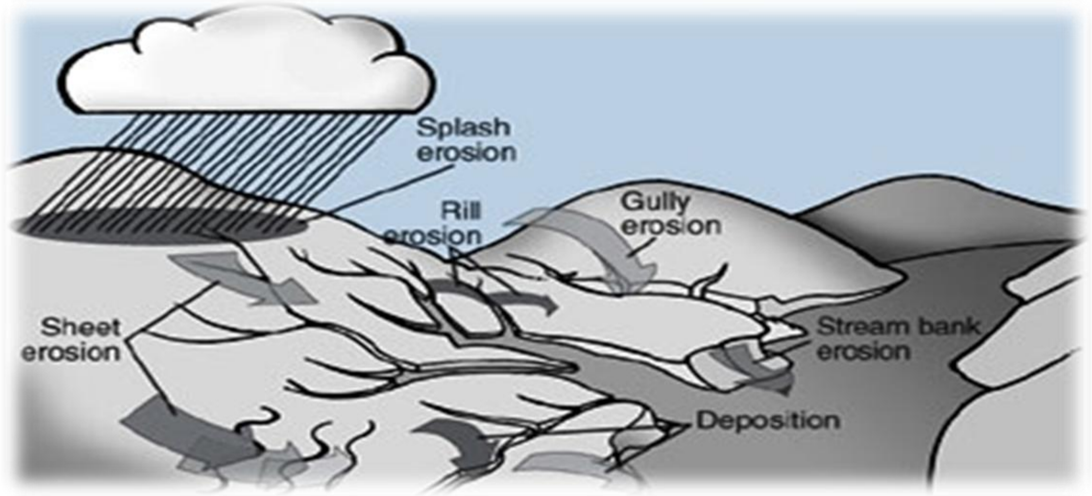


FIGURE 1. Soil erosion process (Sharma, Partha Das. 2009)

2.2 Soil Erosion Measurement

The adverse influences of widespread soil erosion on soil degradation, agricultural production, water quality, hydrological systems, and environments, have long been recognized as severe problems for human sustainability. However, estimation of soil erosion loss is often difficult due to the complex interplay of many factors, such as climate, land cover, soil, topography, and human activities. Accurate and timely estimation of soil erosion loss or evaluation of soil erosion risk has become an urgent task. (Mbugua W. 2009)

In many situations, land managers and policy makers are more interested in the spatial distribution of soil erosion risk than in absolute values of soil erosion loss. To address this need the combined use of Geographic Information System (GIS) and erosion models has been shown to be an effective approach to estimating the magnitude and distribution of erosion (Mitasova et al., 1996; Yitayew et al., 1999). Among numerous mathematical models used to estimate, or, simulate soil erosion, the Revised Universal Soil Loss Equation (RUSLE) is widely used and accepted model to predict the average soil erosion rate from certain area.

2.3 Revised Universal Soil Loss Equation (RUSLE)

The RUSLE is a revision of the Universal Soil Loss Equation (USLE) which was originally developed to predict erosion on croplands in the US. Following the revision, the equation can be employed in a variety of environments including, agricultural site, rangeland, mine sites, construction sites, etc. (ENVIRONMENTAL GIS: Lab 10)

The Revised Universal Soil Loss Equation (RUSLE), which is greatly accepted and has wide use, is simple and easy to parameterize and requires less data and time to run than most other models dealing with water erosion. GIS on the other hand facilitates efficient manipulation and display of a large amount of geo-referenced data. (ENVIRONMENTAL GIS: Lab 10)

The model represents how climate, soil, topography, and land use affect rill and gully soil erosion caused by raindrop impact and surface runoff. It has been extensively used to estimate soil erosion loss, to assess soil erosion risk, and to guide development and conservation plans in order to control erosion under different land-cover conditions, such as croplands, rangelands, and disturbed forest lands. The RUSLE is expressed as:

$$A = R\ K\ LS\ C\ P \qquad (1)$$

Where;

A = Average annual soil loss in in Mg/ha/yr
R = Rainfall/runoff erosivity (MJ.mm.ha^{-1}.h^{-1}.yr^{-1})
K = Soil erodibility (Mg h/MJ/mm)
LS = Slope Length and Steepness Factor
C = Cover-management
P = Support practice factor

Source: (ENVIRONMENTAL GIS: Lab 10)

2.4 RUSLE Factors

Rainfall erosivity factor (R), Soil erodibility factor (K), Slope Length and Steepness Factor (LS), Cover-management (C) and Support practice (P) factor are the major parameters in the application of RUSLE.

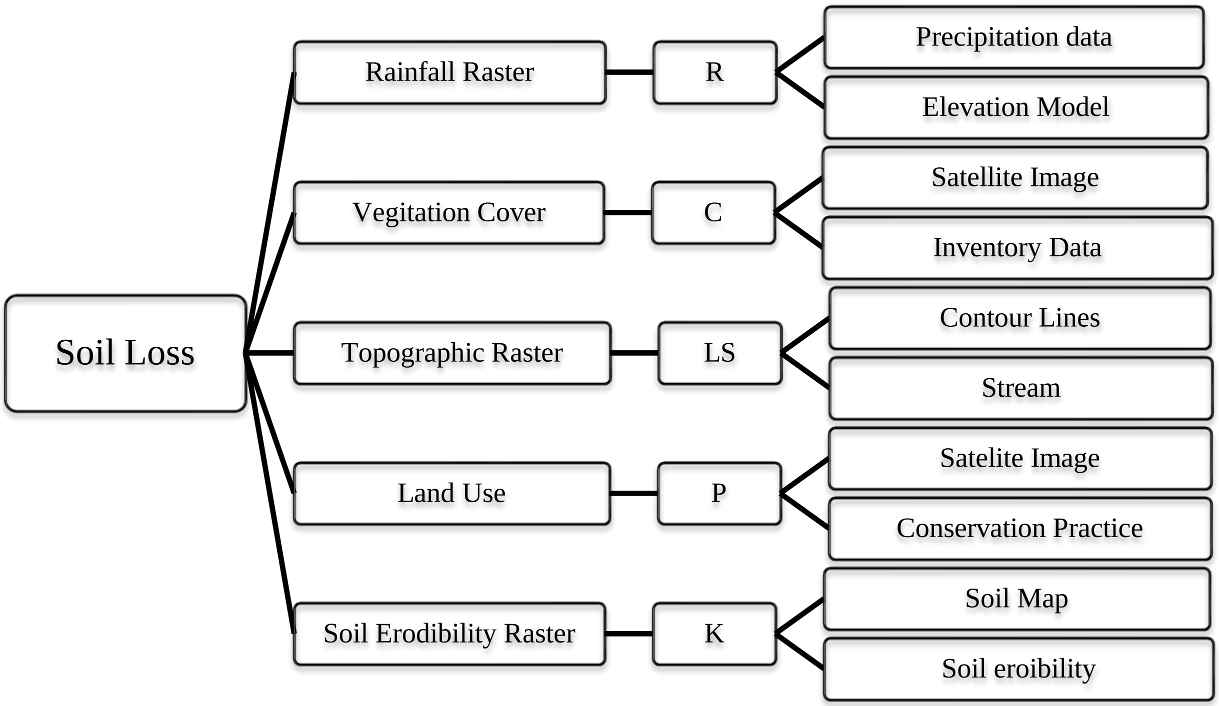


FIGURE 2. Flow chart for modeling of soil erosion loss caused by water

2.4.1 Rainfall/runoff erosivity (R-factor)

R is a measure of erosivity of rainfall which is the product of storm kinetic energy and maximum 30-minute intensity EI_{30}. When other factors are constant, storm losses from rainfall are directly proportional to the product of the total kinetic energy of the storm (E) times its maximum 30-minute intensity (I_{30}). (Arnoldus, 1978)

Most of the time rainfall intensity and storm kinetic energy data are not available at national meteorological stations. By the absence rainfall intensity and storm kinetic energy data for this study area, mean annual and monthly rainfall data have been used to estimate the R factor. (Arnoldus, 1978)

2.4.2 Soil Erodibility Index (K factor)

Soil erodibility factor represents both susceptibility of soil to erosion and the rate of runoff, as measured under the standard unit plot condition. The value of this factor is affected by infiltration capacity and structural stability of the soil. So, the K values run from 1.0 to 0.01 with the highest values for soils with high content of silt or very fine sand. For example, soils high in clay have low K values, about 0.05 to 0.15, because they resistant to detachment. Coarse textured soils, such as sandy soils, have low K values, about 0.05 to 0.2, because of low runoff even though these soils are easily detached. Medium textured soils, such as the silt loam soils, have a moderate K values, about 0.25 to 0.04, because they are moderately susceptible to detachment and they produce moderate runoff. Soils having high silt content are most erodible of all soils. They are easily detached; tend to crust and produce high rates of runoff. Values of K for these soils tend to be greater than 0.4. (Weesies A.)

2.4.3 Slope and Slope Length (LS) Factors

L and S are factors representing the topography of the land and they define the effects of slope length and slope angle on sheet and rill erosion. The slope length factor L is defined as the distance from the source of runoff to the point where deposition begins, or runoff becomes focused into a defined channel. The interaction of angle and length of slope has an effect on the magnitude of erosion. For example, soil losses from plots on irregular slopes may be dependent on the slope immediately above the point of measurement. As a result of this interaction, the effect of slope length and degree of slope should always be considered together. (Edwards, 1987)

2.4.4 Cover management factor (C)

Cover management factor is the crop or land cover management factor and measures the combined effect of all the interrelated vegetative cover and management variables. In other word, this factor measures the protection of the soil surface from raindrop impact by vegetative material at some height above the soil surface and the additional protection from raindrop impact and overland flow by cover in contact with the soil surface (surface cover). It is defined as the ratio of soil loss from land maintained under specified conditions to the corresponding loss from continuous tilled bare fallow. Values can vary from 0 for very well protected soils to 1.5 for finely tilled, ridged surfaces that produce much runoff, leaving it susceptible to rill erosion. (Van der Knijff et al., 2000)

2.4.5 The Support Practice (P Factor)

The Support Practice is the support or land management practice factor. In RUSLE, the support practice factor is generally applied to disturbed lands and represents how surface and management practices such as contouring, terracing and strip cropping are used to reduce soil erosion. For areas where there is no support practice the P factor is set to 1.0 (Simms A.D 2003)

3 MATERIALS AND METHODOLOGY

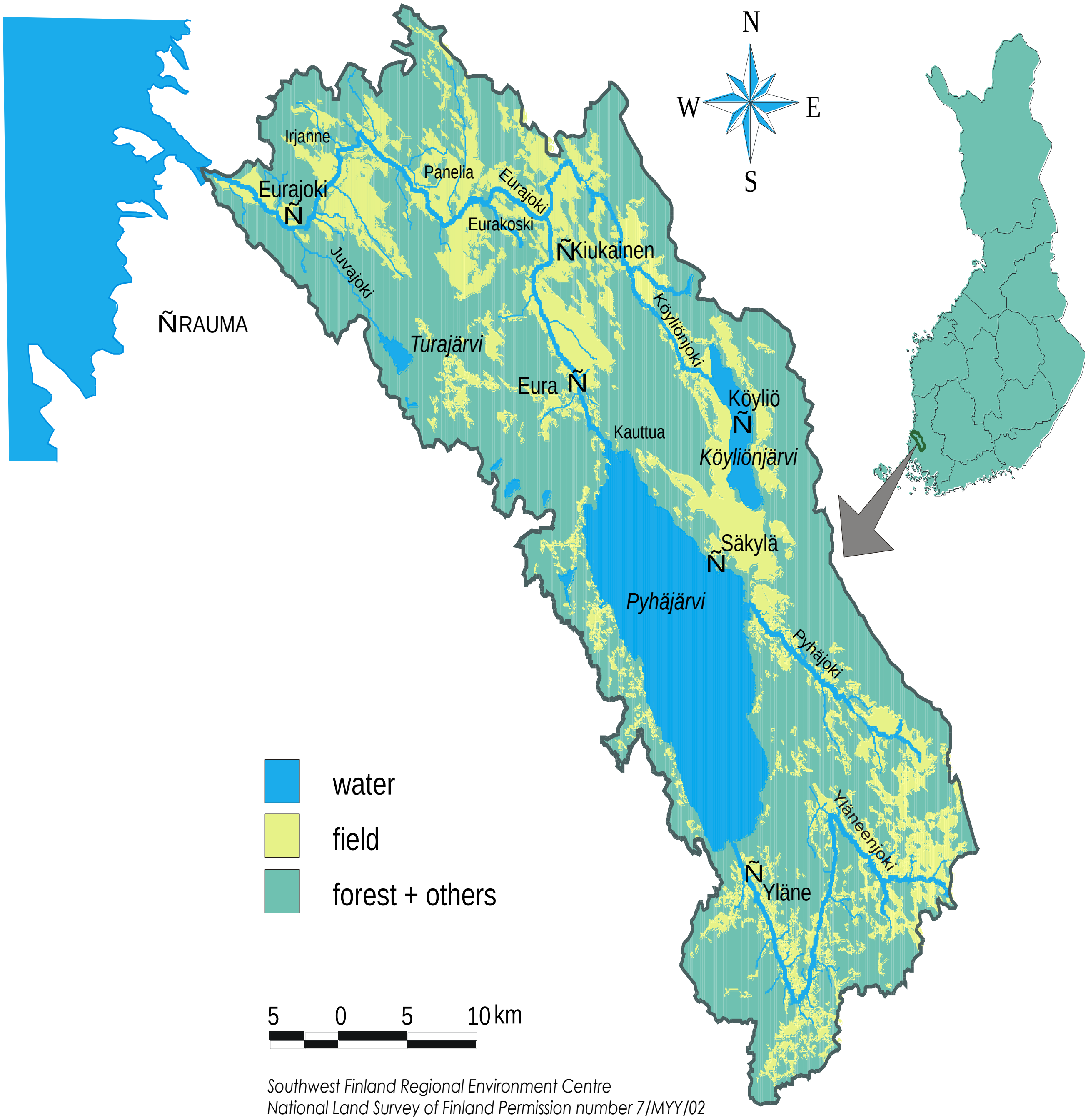
Determining the intensity, amount and distribution of erosion has a big import for environmental management specialist to make an informed decision on the suitable soil and water conservation measures that should be installed in a given area. The Universal Soil Loss Equation (Wischmeier, 1978) or the Revised Soil Loss Equation (Renald et al., 1997) is often used to predict rainfall erosion in landscapes/watersheds using GIS.

3.1 Site Description

3.1.1 Location and Extent

The site is situated at latitude of 61, 2000 (6112'0.000"N) and longitude of 21, 7333 (2143'59.880"E) in the region of Satakunta which is located in the province of South-Western Finland. The total area of the catchment, which includes: lake Pyhäjärvi, area between the lake and the sea, and the two major rivers (Yläneenjoki and Pyhäjoki), is 1336 km^2 (figure 3). From this the municipality and the lake covers 643.78 km^2 and 154 km^2 respectively. The two rivers and the four main ditches (catchment areas between 6-20 km^2), which is located in the nearby catchment area, flow directly into the lake Pyhäjärvi. (Lepistö 2010)

Yläneenjoki river basin is considerably larger (233 km^2) than that of Pyhäjoki River (78 km^2). The river mouths of both Yläneenjoki and Pyhäjoki have been regularly monitored and hence the loading estimates to the lake are easily available. On the contrary, the diffuse load from direct, nearby catchments is much more difficult to assess due to the contingency of water level, sediment and nutrient measurements. (Lepistö 2010)



Southwest Finland Regional Environment Centre
National Land Survey of Finland Permission number 7/MYY/02

FIGURE 3. Eurajoki watershed together with its 306-km^2 catchment, serves as the pilot area of the project (Lepistö 2010)

3.1.2 People, Topography and Climate

The estimated population density for entire municipalities partly extending outside catchment is 63,300 inhabitants. The average annual precipitation is estimated to be 599 mm (1990-2000). Ten years (1991–2000) average discharge measured in the Yläaneenjoki main channel is 2.2 m^3/s and 0.7 m^3/s in Pyhäjoki, respectively. The highest discharges typically occur during the spring and late autumn months. The portion of groundwater flow is not measured but according to typical annual water balances groundwater accounts for less than 20% of annual rainfall. (Hyvärinen, 2003)

The total number of lakes which are included in the study catchment is about 23. The stream network density is 0.58 km/km^2. (Hyvärinen, 2003)

3.1.3 Land Cover and Soil Types

The predominantly soil types of the area are clay and moraine. For example, the soils in the Yläneenjoki river valley are mainly clay and silt. Forests and natural wetlands cover 65% of the catchment the rest being agricultural (34%) and urban (1%) of the entire catchment (fig. 4& 5).

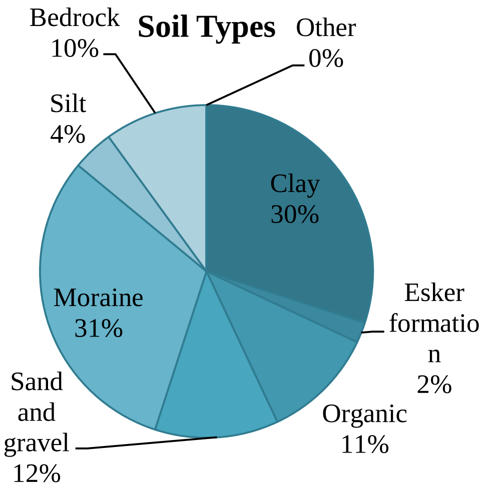


FIGURE 4. Main soil types in the Eurajoki catchment

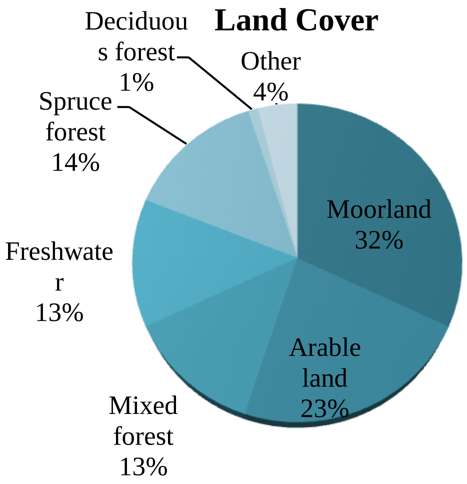


FIGURE 5. Main land use classes in the Eurajoki catchment

The land cover of the study area is mainly moorland (uncultivated hill land), unmanaged grassland, arable land and agricultural land which cover an area of 308.4 km^2 (Kronvang 2003).

3.1.4 Agricultural System

Agriculture in the catchment area consists mainly of cereal production and poultry husbandry and is relatively intensive for Finland (Pyykkönen et al., 2004). According to surveys performed in 2000–2002, 75% of the agricultural area is planted for spring cereals and 5–10% for winter cereals (Pyykkönen et. al. 2004). The livestock of the study area is: 7,260 cattle, 64,200 pigs and 2,316,000 poultry (Kronvang 2003).

3.2 Data Sources

The quantitative evaluation of the soil erosion loss by RUSLE is based on its component factors; such as: rainfall data, digital elevation model (DEM), soil type map, land cover map, and satellite map. Those data were obtained from Meteorological Institute, Environment Institute and National Land Survey of the country. For example, all precipitation data are obtained from metrological institute; topographic maps from national land survey and all results of other relevant studies are from Environment Institute. These different data sources may have different data formats, projections, data quality, and spatial resolution. The use of GIS provides the tools to manage and analyze these data. However, the evaluation of these data is necessary before they are used. The uncertainties regarding data sources may introduce larger uncertainties in soil erosion estimates. Great attention should be paid to the evaluation and preprocessing of data sources, such as data interpolation, conversion, and registration.

3.2.1 The digital elevation model (DEM)

Digital elevation model (DEM) is a digital file consisting of terrain elevations for ground positions at regularly spaced horizontal intervals. In other word, digital elevation model (DEM) data are digital representations of cartographic information.

The DEM data files of study area are available from National Land Survey of Finland and PaITuli-paikkatietopalvelu – CSC. The DEM data was added to ArcGIS 10 to calculate the flow length and slope steepness.

3.2.2 Soil Data

The soil data for this study is obtained from Finnish Environmental Institute library and information center. The soil types of the study area are Moraine 31%, Clay 30%, Organic matter 11%, Sand and Gravel 12%, Bedrock 10%, Silt 4% and Esker formation 2% (figure 4).

3.2.3 Precipitation Data

The rainfall data used in this study is from two rainfall stations namely Köyliö Yttilä and Pöytyä Yläne Stations. Köyliö Yttilä rain gauge is located at the upper part of the catchment (Grlat: 6786717 and Grlon: 3250885) while as the Pöytyä Yläne rain gauge is located at the lower part of the catchment (Grlat: 6760108 and Grlon: 3249760). In order to increase the accuracy of the result additional rainfall data from eight rain gauge stations, which are not located in the study area but close enough to it, were used. All those precipitation data of these stations were obtained directly from Finland Metrological Institute.

3.2.4 Land use and Land Layer

The role of land use and land cover category has been immense particularly in estimating the C and P factors of the RUSLE model. Thus their influence on soil loss would be to some extent decisive, however, slope length and slope gradient have put strong reflection of their pattern at final result of the RUSLE model. (Hudad B. 2010). Usually, C and P factors determine from satellite map, aerial photos and filed observation. But in this study, due to absence of satellite map and other necessary information, the values of C and P factors were obtained from literatures (previous studies).

4 DATA ANALYSIS

Data analysis was undertaken using RUSLE model, ArcGIS 9.3, Microsoft Office Excel 2007 and different equations proposed by many authors. The slope length and steepness (LS factor) is drived from DEM by application of ArcGIS. In summary figure 6 shows the methodology applied so as to achieve the intended objectives

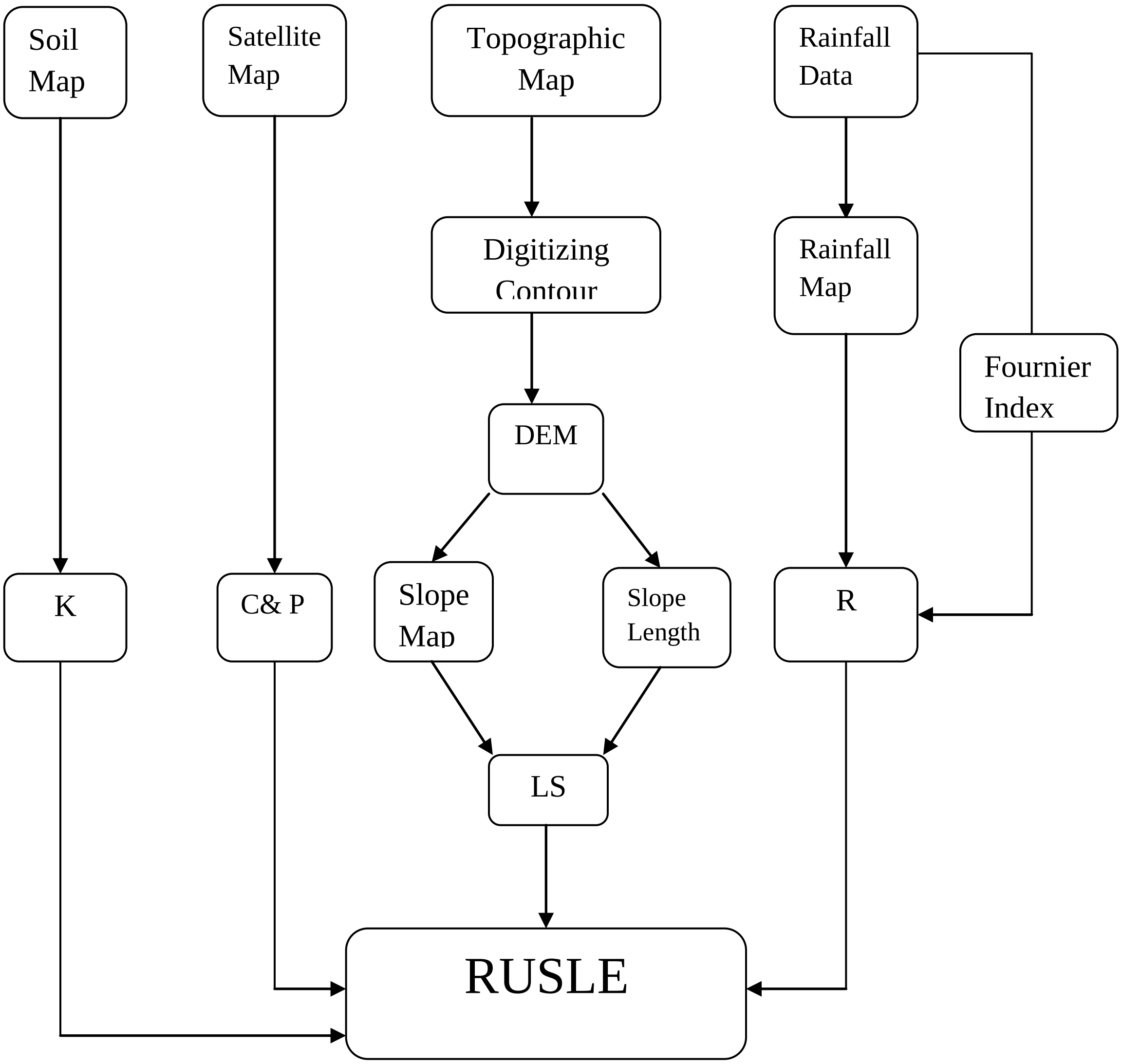


FIGURE 6. Overall Methodology for generating RUSLE factors

4.1 Calculation of RUSLE Factors

4.1.1 Rainfall Erosivity Factor (R Factor)

To calculate the value of R factor of the study area, the relationship between rainfall and elevation of the rain gauge stations was developed from table 1 as shown in figure 7. From the figure, equation 2 was derived in order to interpolating the mean annual rainfall (MAR) values across the catchment

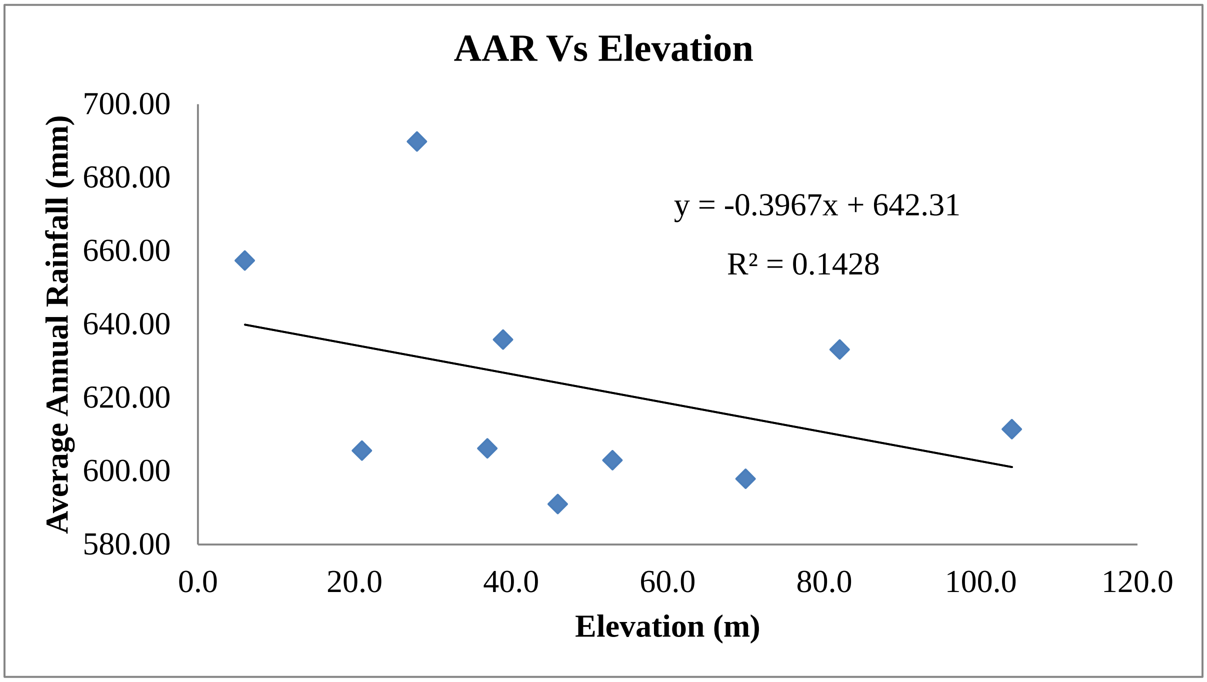


FIGURE 7. The average annual precipitation (AAP) as related to elevation

The derived equation is:

$$Y= -0.3967X + 642.31 \qquad (2)$$

Where;

Y is the mean annual precipitation (MAR) in mm and x is the elevation in meters of the point where the rainfall data is being determined.

By using equation 2, the values of MAR are calculated for ten rain gauge stations as shown on table 1 below

TABLE 1. Rainfall Data from Different Rain Gauge

No.	***Name***	***Elevation (m)***	***AAP (mm)***	***MAR = -0.3967X + 642.31***
103	KAARINA YLTÖINEN	6.0	657.3	639.9298
1007	LAITILA HAUKKA	21.0	605.47	633.9793
118	TURKU ARTUKAINEN	28.0	689.79	631.2024
1104	KOKEMÄKI PEIPOHJA HYRKÖLÄ	37.0	606.06	627.6321
1106	LIETO TAMMENTAKA	39.0	635.74	626.8387
46	KÖYLIÖ YTTILÄ	46.0	590.88	624.0618
53	PÖYTYÄ YLÄNE	53.0	602.9	621.2849
1111	HUITTINEN SALLILA	70.0	597.81	614.541
1117	ORIPÄÄ TEINIKIVI	82.0	633.05	609.7806
1201	JOKIOINEN OBSERVATORIO	104.0	611.36	601.0532

The following graphs (figure 8 and 9) were developed to show the annual and monthly rainfall data of both Köyliö Yttila and Pöytyä Yläne Rain gauges for a period of 10 years.

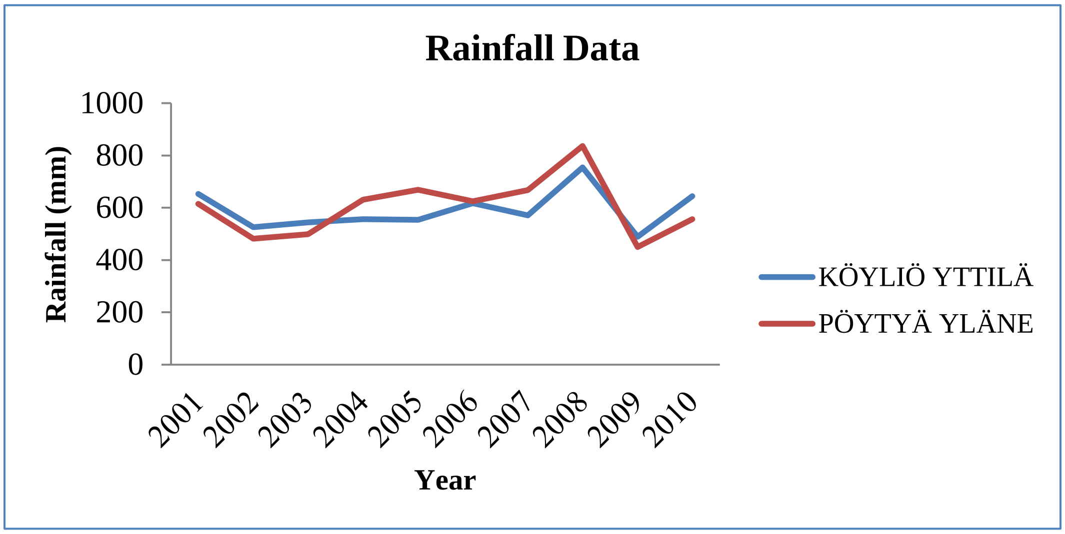


FIGURE 8. Annual rainfall data for both Köyliö Yttila and Pöytyä Yläne rain guage stations

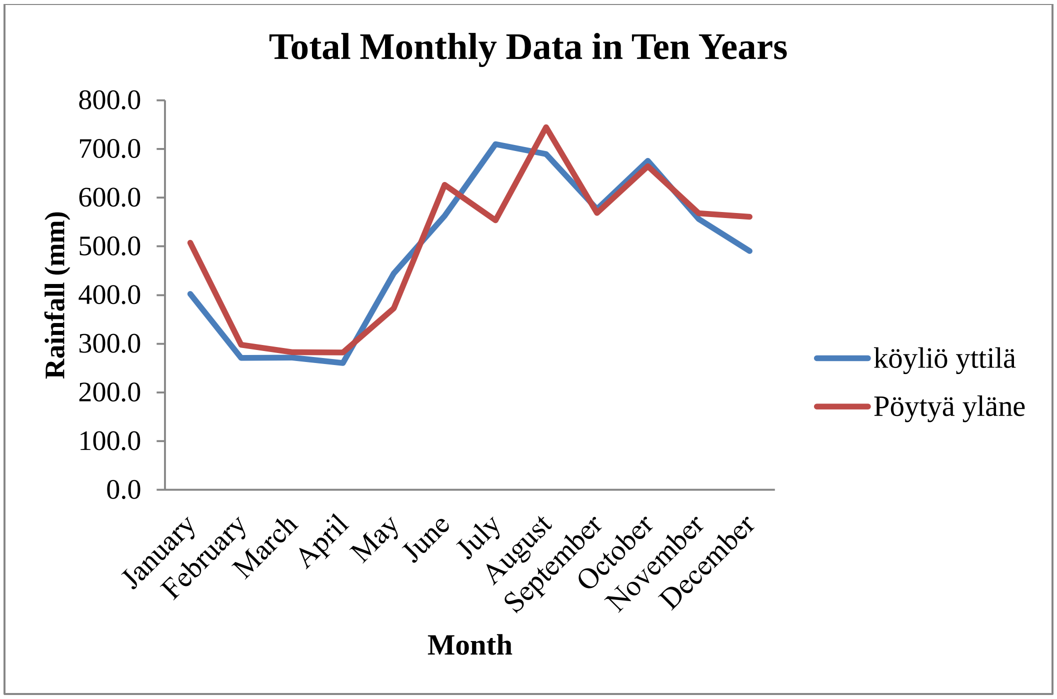


FIGURE 9. Ten years monthly rainfall data for both Köyliö Yttila and Pöytyä Yläne rain guage stations

From the above graphs it is observed that the amount of rainfall vary in both rain gauge stations and throughout the year. This is a clear indication that the rainfall runoff erosivity would also vary from the lower part of the catchment to the upper part of the catchment. Also, it is important to note that the rainfall varies with elevation variation.

Model

The Rainfall erosivity factor R is often determined from rainfall intensity if such data are available. So, the Rainfall-Runoff erosivity (R) can be defined as an aggregate measure of the amounts and intensities of individual rain storms over the year (Hudson 1981; Wenner 1981).

$$\boldsymbol{R} = \frac{\mathbf{1}}{\boldsymbol{n}} \sum_{\boldsymbol{j}=\mathbf{1}}^{\boldsymbol{n}} \left[\sum_{\boldsymbol{k}=\mathbf{1}}^{\boldsymbol{m}} \boldsymbol{E}(\boldsymbol{I}\mathbf{30}) \right] \qquad (3)$$

Where;

R- Rainfall/runoff erosivity ($MJ.mm.ha^{-1}.h^{-1}.yr^{-1}$)

E - Total storm kinetic energy (MJ/ha)

I_{30} - Maximum 30-min rainfall intensity (mm/h)

j - Index of number of years used to produce the average

k - Index of number of storms in a year

n - Number of years used to obtain average R

m - Number of storms in each year

In majority of cases rainfall intensity data are very rare. As such, if there is no station with rainfall intensity data, the R factor is determined using monthly and mean annual rainfall. According to different author, monthly precipitation data p_i, mean annual precipitation data p and Fournier Index F area the basic terms used to calculate erosivity R in the absence of storm kinetic energy and rainfall intensity (Anoldus 1980). Monthly and mean annual precipitation data of the study area is found directly from Finnish metrological institute, but the Fournier Index F is calculated by using equation 4.

$$\mathbf{F} = \frac{\mathbf{1}}{\mathbf{N}} \sum_{\mathbf{j=1}}^{\mathbf{N}} \left(\sum_{\mathbf{i=1}}^{\mathbf{12}} \frac{\mathbf{pi^2}}{\mathbf{p}} \right) \qquad (4)$$

Where:

p_i – Monthly rainfall (mm)

p – Mean annual rainfall (mm)

l – Number of month (which is 12 months)

There are many equations which are derived to determine the value of R for a certain location; but there’s no guarantee that if those equations would work somewhere else. To circuit this problem, several but tested relationships were used and the resulting rainfall erosivity indexes averaged. To determine the suitable equations that could be used at Eurajoki catchment, nine equations given in table 2 were tested based on the relationships between the Mean Annual Rainfall (MAR) and Rainfall Erosivity (R) given by Kassam et al.,1992 (table 3).

TABLE 2. Shows the equations and the reference where they can be found

Case	***References/Source of the Equations***	***R and P or F Relationship***
1	Arnoldous (1980)	$R = 4.17F – 152$
2	YU & Rosewell, 1996	$R = 3.82\ F^{1.41}$
3	Arnoldus – Exponential, 1977	$R = 0.302\ F^{1.93}$
4	Renald & Freimun – F, 1994	$R = 0.739F^{1.847}$
5	Renald & Freimun – P, 1994	$R = 0.0483P^{1.61}$
6	Roose in Morgan and Davidson (1991)	$R = P \times 0.5$
7	Kassam et al.,1992	$R = 117.6\ (1.00105^{(MAR)})$ for < 2000mm
8	Singh et al., 1981	$R_{factor} = 79 + 0.363R$
9	Freimund (1994)	$R = 0.6120\ F^{1.56}$; Sicily-Italy $R = 0.264\ F^{1.50}$; the Morocco

Where;

R = rainfall erosivity factor (MJ/ha.mm/h)

MAR = mean annual rainfall (mm)

F = Founier index

P = Mean Annual Precipitation (mm)

TABLE 3. Relationships between the Mean Annual Rainfall (MAR) and Rainfall Erosivity (R) Given by Kassam et al., 1992

MAR (mm)	***R***	***MAR (mm)***	***R***
170	140	913	307
212	146	998	335
256	153	1089	369
302	161	1189	409
350	170	1298	459
400	179	1419	522
453	189	1557	602
508	200	1711	708
566	213	1892	856
628	227	2108	1054
692	243	2376	1188
761	261	2729	1364
835	282	2878	1439

Table 3 shows that for a single value of MAR, there is corresponding value of R factor. The table was used to choose the right equation for the study area.

In this study the F values were calculated for both Köyliö Yttila and Pöytyä Yläne stations and the values are as follows;

- KÖYLIÖ YTTILÄ rain station F = **68.27**
- PÖYTYÄ YLÄNE rain station F = **70.96**

After testing the equations, some of the resulting R factors were found to be close to the values given by (Kassam, 1992) and as shown in table 4. Other models gave too high R values and others gave too low values and hence they were not considered for calculation of the R factor. As a result, the following equations (table 5) that gave results that were within the range of the values given for by Kassan, 1992 were used to determine the R factor for Eurajoki Catchment

TABLE 4. Selected R factor Models

R and P or F Relationship		***References***
R = P x 0.5		Roose in Morgan and Davidson (1991)
R_{factor} = 79 + 0.363MAR		Singh et al., 1981
$R_1 = 0.6120\ F^{1.56}$; Sicily-Italy $R_2 = 0.264\ F^{1.50}$; the Morocco	$R = (R_1 + R_2)/2$	Freimund (1994)

From the above equation, R-factor was calculated on table 5

TABLE 5. Calculation of R-factor

Stations	***F***	***P***	***MAR***	***R = P x 0.5***	***R = 79 + 0.363MAR***	***R = 0.6120 F1.56 Sicily-Italy*** ***R = 0.264 F1.50 Morocco***	***Average***
Köyliö Yttila	68.27	590.88	624.06	295.44	305.53	296.85	299.28
Pöytyä Yläne	70.96	602.87	621.29	301.435	304.53	315.12	307.03
Mean R value of the two stations							**303.15**

4.1.2 K Factors

The soil erodibility factor was calculated using the soil properties obtained from Finnish Environmental Institute library and information center by using equation 5; given by (Wischmeier and Smith 1978). This equation was settled upon due to availability of data on soil structure, organic matter and permeability. The equation reads as shown below:

$$K = 2.1x10^{-6} \, x \, M^{1.14} \, (12\text{-}OM) + 0.025 \, (S\text{-}3) + 0.0325 \, (P\text{-}2) \qquad (5)$$

Where;

K = soil erodibility factor in t.h/MJ.mm

M = (Percentage very fine sand + Percentage silt) × (100 – Percentage clay)

OM = Percentage of organic matter

S = Code according to the soil structure (very fine granular = 1, fine granular = 2, coarse granular = 3, lattice or massive = 4), and

P = Code according to the permeability/drainage class (fast = 1, fast to moderately fast = 2, moderately fast= 3, moderately fast to slow = 4, slow = 5, very slow = 6)

From figure 10 to below, the study area do not have very fine sand; as result the computation of the M was done using sand and gravel, silt and clay contents.

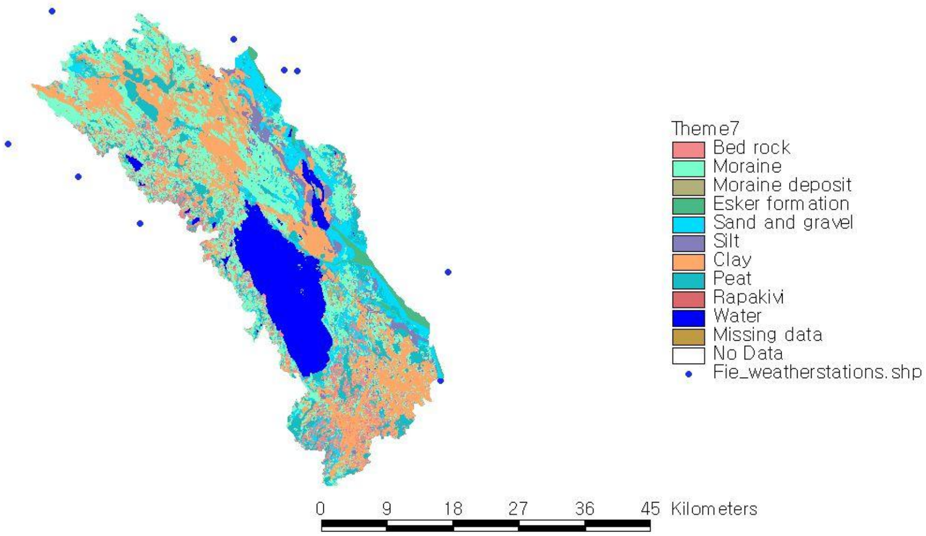


FIGURE 10. Distribution of soil types on the entire study area (Kronvang 2005)

To apply equation 5, soil textural classes were estimated using the textural triangle (figure 11) for the purpose of determining S and P values (Suresh 2000, Arora 2003).

According to the textural classification system, the percentage of sand (size 0.05 to 2.0mm), silt (0.005 to 0.05mm), and clay (size less than 0.005mm) are plotted along the three sides of an equilateral triangle. The equilateral triangle is divided in to 10 zones; each zone indicates a type of soil. The soil can be classified by determining the zone in which it lies.

As it mentioned above, the value of K factor is depend on the percentage of clay, sand and silt available in the study area. The soil samples (clay, sand and silt) obtained for this study were classified according to this textural classification system. A correction factor was used because the study area contained particles larger than 2.0mm size (>sand), moraine, bedrock and water. If a soil contains particles larger than 2.00mm size, a correction is required in which the sum of the percentage of sand, silt and clay is increased to 100%. For example, the soil in which their particle size is less than or equal to 2.00mm of Eurajoki catchment contains 12% sand, 4% silt and 30% clay (chapter one). So, the actual percentage of sand, silt and clay of the study area is 46%. Therefore, each of this percentage would be multiplied by the correction factor of 100/46, and the correction percentage would become 26.09% sand, 8.70% silt and 65.22% clay. The point X falls in to the zone labeled clay as shown on figure 11. Therefore, clay is the majority of soil in the study area.

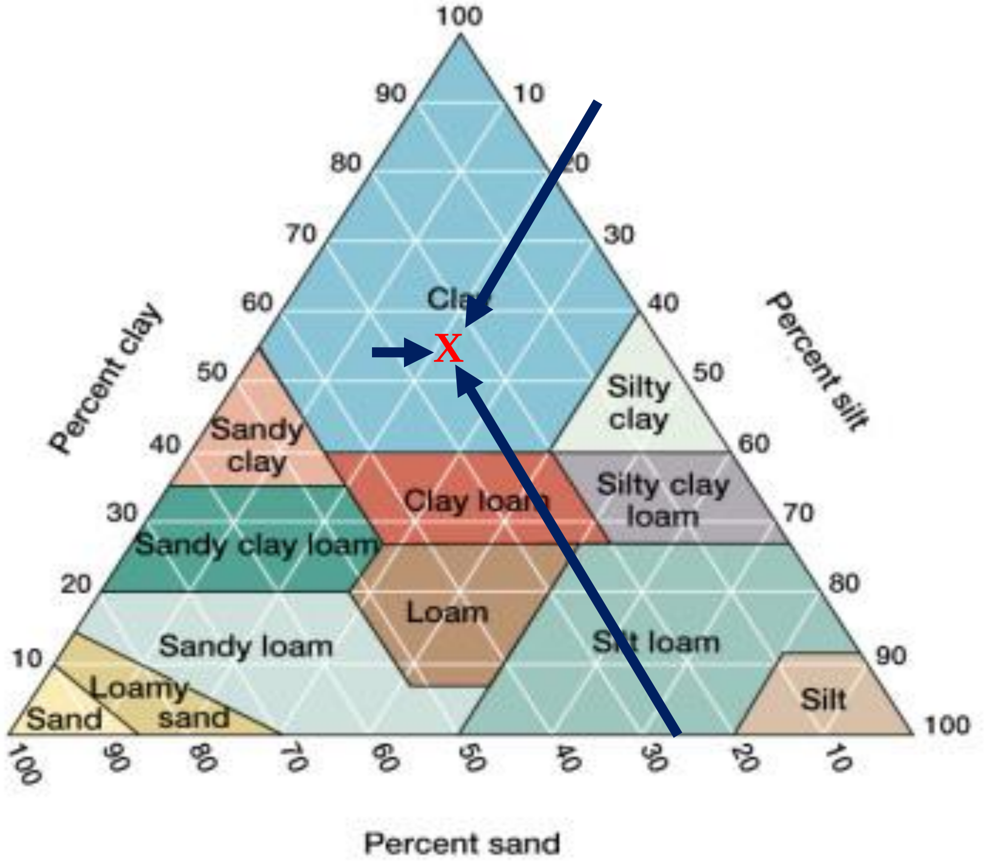


FIGURE 11. Eurajoki catchment soil textural classes (Suresh 2000, Arora 2003)

Since the soil class is clay and the organic matter of the study area is 11%, the codes P and S value is 3 according to permeability and soil structure classes were obtained from the soter database. On average, the approximate value for the soil erodibility (K) factor estimated in the study plots was 0.04 t h/MJ.mm.

4.1.3 LS Factor

The LS factor (topographic factor) accounts for the effect of topography on erosion in RUSLE. The slope length factor (L) represents the effect of slope length on erosion, and the slope steepness factor (S) reflects the influence of slope gradient on erosion. For this study L is the flow length and S is slope steepness which is given by meter and percent respectively.

Basically, the LS factor can be estimated through field measurement or from a digital elevation model (DEM). With the incorporation of Digital Elevation Models (DEM) into GIS, the slope gradient (S) and slope length (L) may be determined accurately and combined to form a single factor known as the topographic factor LS. The precision with which it can be estimated depends on the resolution of the digital elevation model (DEM). The equation used to determine this parameter was that recommended by (Morgan and Davidson, 1991) given in Equation 6

$$LS = \sqrt{\frac{l}{22}}\,(0.065 + 0.45s + 0.0065s^2) \qquad (6)$$

Where:

L = slope length in m
S = percent slope

From ArcGIS 10, figure 12 was developed by inputting the DEM data (data from National Land Survey of Finland and PaITuli-paikkatietopalvelu – CSC) into ArcGIS that used to determine the mean values of L and S of the study area. The procedure to determine the slope gradient is; Spatial Analyst → Surface Analysis → Slope in degree or percent. In the same fashion, the slope length was calculated as; Spatial Analyst → Hydrology → Flow Length. After that figure 12 was produced for the study area and from its layer properties, the mean, standard deviation, minimum and maximum values slope length (L) and slope gradient (S) were generated from the histogram that produce by ArcGIS.

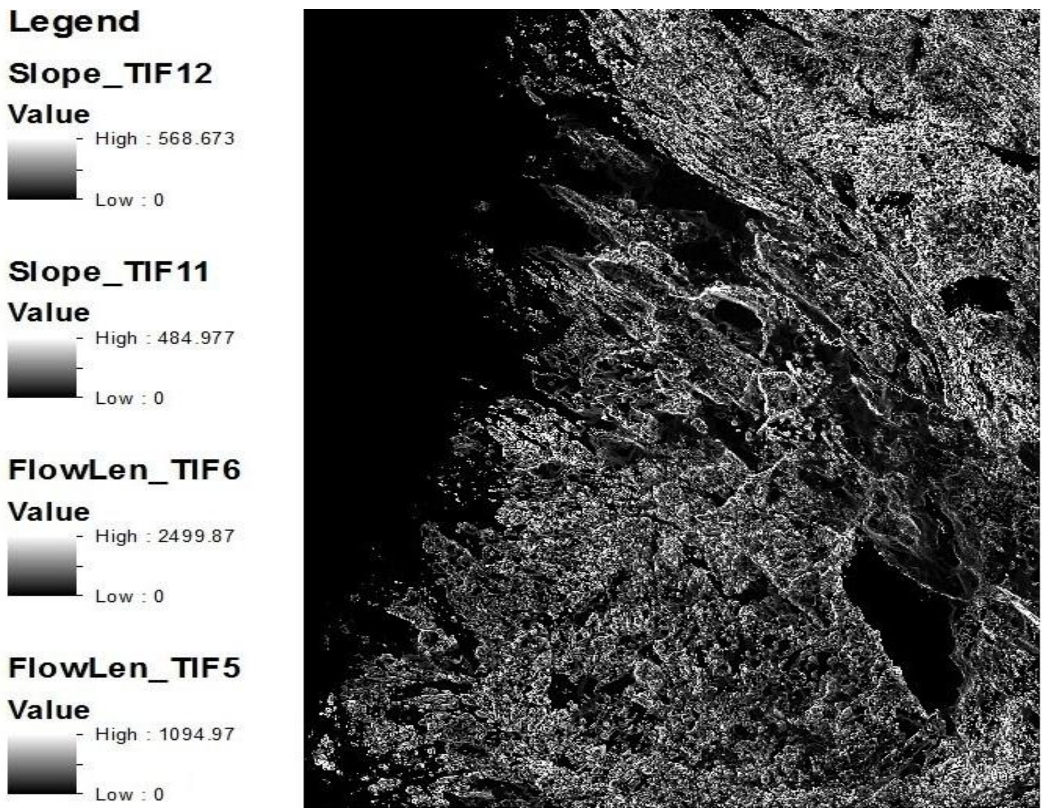


FIGURE 12. 25mX25m DEM of Eurajoki area

The combined topographic (LS) factor was computed rather than the individual slope length and slope angle factors. The inputs for the computation include the slope in percent and the slope length.

4.1.4 Cover (C) Factor

By the help of “Raster Calculator” tool of the “Spatial Analyst” extension of “ArcGIS” software package, the C-factor was calculated from NDVI, a spectral ratio between near infrared and red reflectance, extracted from satellite image (van der Knijff et al., 1999, 2000). In this study, due to the absence of satellite image and other necessary data, the C value obtained from the literature (table 7).

4.1.5 Support Practice (P) Factor

Usually, the P factor is determined from experimental data like satellite images, aerial photos and some field observations. Those data help to recognize the erosion control measures applied on catchment area. Like C factor, the value of P is also obtained from the literature (table 6) due to the absence of necessary information.

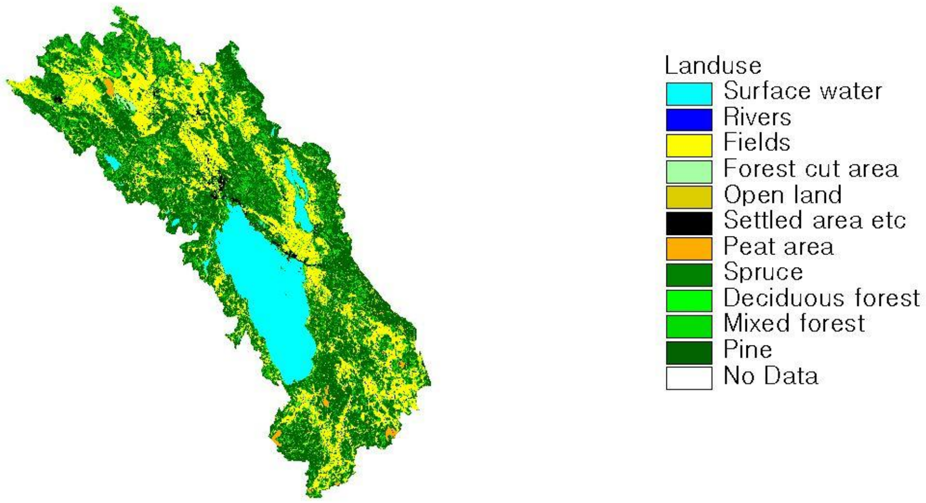


FIGURE 13. Land use map in the Eurajoki catchment (Kronvang 2005)

As you can see from the figure 13 (Kronvang 2005), the major land cover of the study area Pine and Spruce trees, and other part of the study area is open land and fields. It is clear that the soil erosion from the fields and open area quiet much higher than that of land which covered by forest like spruce and pine.

TABLE 6. Land use and C and P Factors

Land Use	***C factor***	***P factor***
Natural Vegetation/Forest	0.001	1.00
Agriculture/Crop	0.128	0.92
Grass	0.003	1.00
Urban	0.030	1.00
Average	***0.31***	***0.96***

Source: Soil and Water Conservation Society 2003

5 RESULTS AND DISCUSSION

Basically, the erosion values obtained through RUSLE is depend upon the above six parameters of RUSLE and their values can vary considerably due to varying weather conditions. The result of RUSLE parameters and average annual soil loss are presented under this chapter as follows.

5.1 Rainfall and runoff erosivity R-factor

The distribution of the average annual rainfall of the study area for 10 years period is different from station to station. This shows that the value of R factor also vary according to rainfall distribution. As it calculated on table 5 above, the average value of R factor for the entire catchment found to be 303.15 MJ.mm./ha.h.yr.

5.2 Soil erodibility K Factor

Usually, soil erodibility factor is obtained from erodibility index map which derived from soil map of the area by the help of ArcGIS. But, due to the absence of erodibility index map, the soil erodibility factor was calculated by using equation 5 and textural triangle (figure 11). So, the final value of K factor is 0.04 t h/MJ.mm.

5.3 Slope Length and Steepness LS Factor

As it mentioned in the chapter 4 and figure 12, the slope angle and slope length (overland flow length) were generated using ARCGIS 10. So, the mean slope length of the study area is 0.36m with standard deviation of 13.32 and the mean slope is 18.27 in percent with standard deviation of 28.45. The LS factor was calculated by using equation 4 and found to be 1.34. For both cases (flow length and slope gradient), the standard deviation is quite high. This shows that there are places where the slope is zero and high slope. The above result is the average of the entire study area

5.4 C and P Factors

As it mentioned above (chapter 4), the value of C and P factors were obtained from literatures depend on land use and land cover of the study area. The study area includes farmland (including grazing) and savanna, settled area, forest, etc (Fig. 12). Therefore, the average value of C and P factors found to be 0.31 and 0.96 (table 7) respectively.

5.5 Annual Average Soil Loss

Rainfall erosivity, soil erodibility, slope length and steepness, cover management, and support practice factors were calculated as it shown above. The RUSLE calculated the annual average soil loss (for the basin) from Eq. (1) using the six factors and it is estimated as A= 5 Mg per ha per yr (5 mega gram per ha per yr) which is equal to 5 ton per ha per yr.

The final result of this study was compared to results from different countries (European Communities, Institute for Environment and Sustainability, 1995-2010 database and case study report) and concluded that the overall results of this study is in an acceptable range.

Generally, the estimated value of soil loss in the RUSLE model highly depends on LS factor next to R factor. This implies that the DEM information, which is directly transformed to L and S factors, and rainfall data are crucial in calculating soil loss.

6 CONCLUSIONS

In this study, the importance of the use of revised universal soil loss equation (RUSLE) is well recognized, in which the R factor plays the most important role. The R factor which is the mean annual sum of individual storm erosion index values (EI_{30}) depends on the value of the total kinetic energy of the storm and the I_{30} value, the maximum 30 min rainfall intensity. Since energy of the storm and 30 min rainfall intensity of the study area are not available, an alternate procedure was applied to compute the R factor that could make the RUSLE less effective unless proper procedures are needed.

For reliable estimation of R value, three different modeling approaches were applied by using the relevant data from ten rain gauge stations in which two of them are located in the study area. In these approaches, the combination of regression models between annual rainfall and elevation, monthly and mean annual rainfall and Fournier index were used.

Generally, this study provides an approach for the evaluation of soil erosion loss in Eurajoki watershed based on a combination of RUSLE and GIS. This is an effective way to map and predict the soil erosion loss of certain area. However, an error in a factors value will produce an equivalent percentage error in the soil loss estimation. These errors are mainly due to inaccuracy components in each data and the limitations in the methods used to derive the component factor values. The accuracy of the predicted soil loss can be improved, if each parameter is better estimated. For example, an R value can be better produced by using direct storm energy and 30 min rainfall intensity. The LS factor can be improved by a better generated DEM, maximum downhill slope and infinite flow direction. The C factor can be improved by better estimation of the fractional vegetation cover. To assess the accuracy of the produced maps, validation with independent data is required. This can be obtained from field measurements, surveys, or high resolution image.

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APPENDIXES

A. Precipitation data in mm from Köyliö Yttilä rain station

Months	**Year**									
	2001	***2002***	***2003***	***2004***	***2005***	***2006***	***2007***	***2008***	***2009***	***2010***
January	26.5	76.5	37.8	23.7	67.4	22.5	55.4	55.9	22.3	14.2
February	46.0	43.3	10.6	25.4	15.9	17.9	7.2	40.4	19.0	45.2
March	31.0	32.0	6.5	23.1	6.6	27.2	27.1	41.3	28.8	47.7
April	47.7	2.5	22.2	5.3	12.9	55.1	32.9	38.2	9.8	33.6
May	26.5	60.2	100.1	32.3	32.5	35.5	29.1	9.5	31.1	87.5
June	25.8	76.9	39.7	81.8	42.8	34.1	53.8	89.8	55.7	62.0
July	109.3	102.9	86.6	73.9	48.3	15.7	103.2	36.4	82.3	51.2
August	74.2	41.0	64.1	40.0	129.7	58.5	26.5	169.7	50.4	35.1
September	112.1	14.6	6.7	95.0	39.9	61.7	67.9	26.3	38.1	114.1
October	83.9	23.2	63.0	33.5	43.8	163.7	48.4	123.9	49.3	42.8
November	38.6	45.6	35.8	48.5	88.5	52.9	45.2	74.8	55.1	71.3
December	31.3	7.3	71.5	73.2	25.1	72.9	74.7	48.2	46.8	39.3
Total (p)	652.9	526.0	544.6	555.7	553.4	617.7	571.4	754.4	488.7	644.0
$\sum_{i=1}^{12} pi^2$	46949.83	33448.5	35688.54	34422.03	39021.32	49411.71	34607.66	70160.42	24275.27	42481.46
$\sum_{i=1}^{12} \frac{pi^2}{p}$	71.91	63.59	65.53	61.94	70.51	79.99	60.57	93.00	49.67	65.97
$F = \frac{1}{N}\sum_{j=1}^{N}(\sum_{i=1}^{12}\frac{pi^2}{p})$	**68.27**									

B. Precipitation data in mm from Pöytyä Yläne rain station

Month	**Year**									
	2001	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
January	27.9	84.1	47.8	35.4	84.7	31.4	82.7	77.9	19.9	15.5
February	36.4	51.0	10.0	35.6	23.2	21.1	6.3	57.6	23.1	33.4
March	24.1	35.9	7.1	29.6	8.8	27.8	38.9	43.6	28.0	38.8
April	59.5	2.8	19.3	15.7	13.7	50.9	34.2	41.2	4.6	40.5
May	22.1	25.9	99.2	25.5	31.5	35.7	38.3	5.6	21.0	67.7
June	23.8	88.6	34.0	89.6	53.2	42.5	59.6	107.0	56.4	71.6
July	75.7	89.2	26.6	70.0	67.6	11.9	95.2	38.9	55.2	23.1
August	74.2	22.0	73.9	57.5	195.5	41.9	42.7	152.9	51.6	32.6
September	144.1	10.3	5.7	87.8	27.4	41.8	64.3	41.1	39.6	106.6
October	79.4	26.3	56.0	26.8	41.1	155.7	63.9	132.6	52.5	30.0
November	23.3	37.3	40.1	55.1	88.8	70.9	59.2	83.9	53.7	55.4
December	24.4	7.8	79.1	102.0	33.8	92.8	81.7	53.6	44.2	41.6
Total (p)	614.9	481.2	498.8	630.6	669.3	624.4	667.0	835.9	449.8	556.8
$\sum_{i=1}^{12} pi^2$	46722.83	30181.78	31006.46	42394.92	66057.81	49401.16	43864.44	78540.69	20228.08	32871.00
$\sum_{i=1}^{12} \frac{pi^2}{p}$	75.98	62.72	62.16	67.23	98.70	79.12	65.76	93.96	44.97	59.04
$F = \frac{1}{N}\sum_{j=1}^{N}(\sum_{i=1}^{12} \frac{pi^2}{p})$	**70.96**									

C. Ten years precipitation data from ten different stations

Year/ Stations	Köyliö Yttila	Pöytyä Yläne	Kaarina Yltöinen	Laitila Haukka	Turku TLA	Kokemäki Peipohja Hyrköla	Lieto Tammentaka	Huittinen Sallila	Oripää	Jokioine
2001	652.9	614.9	654.0	659.4	785.8	633.6	682.8	630.7	673.2	652.5
2002	526	481.2	468.8	467.0	559.9	499.2	488.7	518.4	511.2	440.3
2003	544.6	498.8	544.3	512.2	585.7	553.0	450.1	552.5	589.4	584.8
2004	555.7	630.6	840.2	660.9	796.7	612.3	635.9	649.3	647.2	726.4
2005	553.4	669.3	744.9	651.8	739.1	614.3	662.2	615.5	638.5	649.9
2006	617.7	624.4	690.9	625.7	715.5	695.6	746.2	618.0	693.7	586.9
2007	571.4	667	696.6	715.3	720.1	626.7	728.3	602.9	653.2	642.5
2008	754.4	835.9	845.1	771.0	830.6	820.9	870.7	781.5	890.9	760.5
2009	488.7	449.8	532.6	488.3	623.2	438.2	536.3	470.0	498.5	496.2
2010	644	556.8	555.6	503.1	541.3	566.8	556.2	539.3	534.7	573.6

D. Additional information of rain gauge stations

Lpnn	Name	Lat	Lat_sec	Lon	Lon_sec	Grlat	Grlon	Elstat
103	KAARINA YLTÖINEN	6023	12	2233	17	6705580	3254967	6
118	TURKU ARTUKAINEN	6027	16	2210	54	6714565	3234980	8
1007	LAITILA HAUKKA	6049	59	2145	37	6758433	3215199	21
1101	TURKU TURUN LENTOASEMA	6030	55	2216	39	6720950	3240731	49
1104	KOKEMÄKI PEIPOHJA HYRKÖLÄ	6116	15	2215	8	6805090	3245443	37
1106	LIETO TAMMENTAKA	6034	25.5	2226	59.1	6726788	3250627	39
1111	HUITTINEN SALLILA	6101	23.6	2242	7.3	6775868	3267721	70
1117	ORIPÄÄ TEINIKIVI	6054	15	2242	54	6762575	3267553	82
1201	JOKIOINEN JOKIOISTEN OBSERVATORIO	6048	49.9	2330	3.3	6749989	3309619	104
1113	KÖYLIÖ YTTILÄ	6106	36	2222	39	6786717	3250885	46
1130	PÖYTYÄ YLÄNE	6052	16.6	2223	29.1	6760108	3249760	53