An Erosion Model for Monitoring the Impact of Mining in New Caledonia

Printemps J[1], Ausseil, A-G[2], Dumas P.[1,3], Mangeas M.[1], Dymond J.R.[2] and Lille D.[1]

1 US 140 ESPACE / Institut de Recherche pour le Developpement, BP A5 98848 Noumea
New Caledonia
2 Landcare Research Ltd, Private Bag 11052, Palmerston North, New Zealand
3 Equipe CNEP - ETAPP / University of New Caledonia , BP15466, 98804
Noumea, New Caledonia
(Email: AusseilA@LandcareResearch.co.nz)

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EXTENDED ABSTRACT

Mining is the major economic activity in New Caledonia, which contains 25% of the world's nickel ore reserves. With so much land disturbance associated with mining, it is important to minimise the off site impacts of sediment deposition in waterways and lagoons. An erosion model that relates off-site deposition to mining activities is needed to help plan the mitigation of erosion.

We used the Universal Soil Loss Equation (USLE) to estimate the soil loss per unit area coming from surficial erosion. GIS maps were derived for each of the factors involved in the USLE, including rainfall, slope length and steepness, soil erodibility, and cover.

Data limitation has hindered the calibration of the estimation of soil loss. However, initial results show a strong soil loss at the top of the mountain, mainly due to high precipitation and steep slopes. These areas correspond to the mining activities. Mitigation work can be prioritised by using the model to identify sources of sediment that make large contributions.

The cover factor was derived from a thematic land cover map, but it is intended in the future to use a sequence of satellite images to map the land cover as input to the model. We also intend to use available data on sediment traps to calibrate soil loss estimation. The GIS framework will then allow comparison of different land covers and mitigation scenarios by varying the cover factor and a sediment delivery ratio.

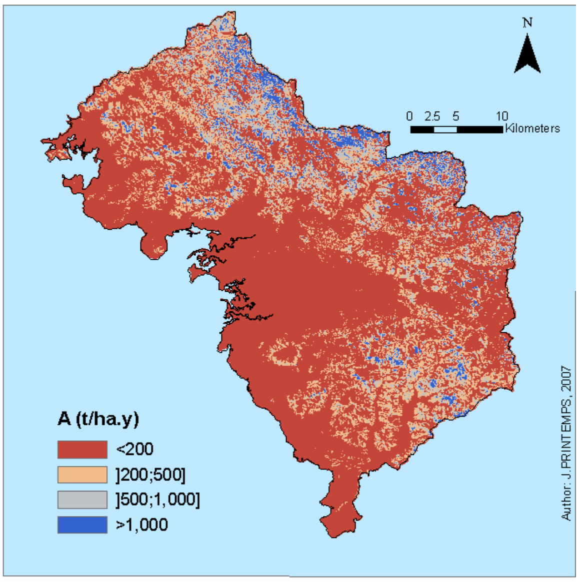

Figure 1: Soil loss erosion rate (t/ha/yr) for the Voh, Koné and Pouembout catchments.

1. INTRODUCTION

Mining is the major economic activity in New Caledonia, which contains 25% of the world's nickel ore reserves. In the Koniambo mountain a new mine is proposed which will be one of the largest nickel mines in the world. The mining activities impact on the environment through soil erosion. Sediment loads in the rivers are a major threat in the aquatic ecosystems, especially the coral reefs that surround the New Caledonian coast. It is important to minimise the off site impacts of sediment deposition in waterways and lagoons. An erosion model that relates off-site deposition to mining activities is needed to help plan mitigation of erosion. No previous study in New Caledonia has attempted to quantitatively estimate soil loss.

A range of models exists for use in simulating sediment transport and associated pollutant transport (Merritt et al. 2003). These models differ in complexity, processes considered, and data required for model calibration and model use. Because we don't have enough information on the physical processes of erosion involved in New Caledonia, we chose to apply an empirical model. One of the most widely used empirical soil erosion models is the Universal Soil Loss Equation (USLE) (Wischmeier and Smith 1978). It predicts the average annual soil loss rate, and it is simple to use. In this paper, we evaluated the USLE to estimate the average annual soil loss rate over a study area in northern New Caledonia. The five major factors involved in the USLE were derived using a GIS framework from input data which included a Digital Elevation Model (DEM), a soil map, a land cover map and precipitation data.

2. STUDY AREA

New Caledonia has a tropical climate. During the warm season (mid-November to mid-April), frequent tropical depressions and cyclones produce much precipitation, which is the main driving factor for soil erosion. The topography of New Caledonia is dominated by a chain of high mountains (Central Chain) running along the entire length. These mountains strongly influence precipitation patterns, generating high levels of orographic rainfall when the dominant winds are from the ENE to SE sector. Precipitation is highest along the windward, eastern slope, where annual totals range from nearly 2,500 mm to over 4,000 mm.

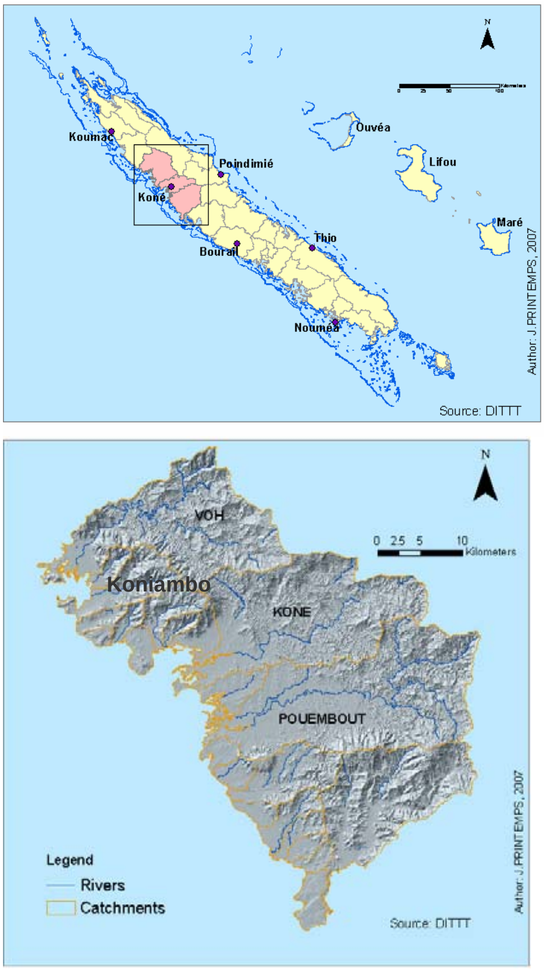

Figure 2: Location of the study area in New Caledonia.

The study area is located in the north of New Caledonia, in the provinces of Voh, Koné and Pouembout (Figure 2). There are several old mines (stopped before 1975) in this area that haven't been revegetated and are still contributing to soil losses, as well as a new mining project on the Koniambo Mountain.

3. METHODOLOGY

3.1. Universal soil Loss Equation (USLE)

The Universal Soil Loss Equation USLE (Wischmeier and Smith 1978), later revised as the RUSLE (Renard et al. 1997), is the most widely used model for prediction of water erosion hazards and planning of soil conservation measures. The USLE/RUSLE was statistically derived from a large database generated from plot experiments in the United States. It estimates long-term average annual soil loss rate using a factor-based approach with rainfall, soil, topography, land cover and management practice as inputs. It calculates mean annual soil loss (A in tons/ha/year) as a product of five factors:

A = R xK x (LS) xC xP (1)

where

A is soil loss in tons/ha/yr,
R is rainfall and runoff erosivity factor in MJ.mm/(ha.h.yr),
K is soil erodibility in t.h/(MJ.mm),
LS is slope length and slope steepness,
C is cover management, and
P is support practice.

Since all factors in the USLE have a spatial distribution, a GIS based evaluation of the different factors is possible by overlaying the layers and multiplying them on a grid basis.

3.2. Rainfall and runoff factor: R

The rainfall and runoff factor (R) represents two characteristics of a storm determining its erosivity: amount of rainfall and peak intensity sustained over an extended period. Research showed that soil losses are directly proportional to the total storm energy (E) times the maximum 30-min intensity (Brown and Foster 1987). R was computed as:

$$R = \frac{1}{N}\sum_{i=1}^{k}\left(E \times I_{30}\right) \quad (2)$$

where
R is in MJ.mm/(ha.h.yr),
N is number of years,
K is number of rainy events,
E is total storm energy in MJ.mm/(ha.h), and
I_{30} is the maximum 30 minutes intensity of rain in mm/h.

R was calculated on eight weather stations spread across the study area (Table 1). A rainfall factor layer was then generated over the whole study area by using a spline interpolation on a 10-m resolution DEM.

Table 1: R-factor estimated for eight weather stations.

Weather Station	N (yr)	Elevation (m)	R
KONE	10.5	7	4747
KONIAMBO	6.5	895	5881
POUEMBOUT	13	27	3198
VAVOUTO	5	93	1743
TANGO	8	341	8035
ODHAVI	5	45	4066
NEPOUI	13	79	2815
OUATIALO	4	120	4461

The R values range from 1743 to 4747 MJ.mm/(ha.h.yr), which is compatible with other estimations in the litterature. For example, R=1690 in Toulouse (France) for an average oprecipitations of 664 mm/yr (Morschel et Fox, 2004), R=8098 in Haïti for average precipitations around 1900 mm/yr (Délusca, 1998).

3.3. Slope length and slope steepness factor: LS

The length and slope steepness factor (LS) represents the effect of topography on erosion, as increases in slope length and slope steepness produce higher overland flow velocities and therefore higher erosion (Haan et al. 1994).

LS was derived from Wischmeier and Smith (1978):

$$LS = \left(\frac{\lambda}{22.13}\right)^{m} \times (65.41\sin^{2}\theta + 4.56\sin\theta + 0.065) \quad (3)$$

where

λ is the slope length in meters,
θ is the slope angle in degrees, and
m is a slope angle contingent variable ranging from 0.01 to 0.56 (McCool et al. 1997).

λ and θ were calculated using a 10m resolution DEM and an AML script under ArcInfo developed by Van Remortel (2003). LS values vary from 0 to 104, with an average of 6.4. These values are compatible with previous studies, for example 0 to 88 in Morocco for slopes between 0 and 60% (Sadiki et al., 2004), 0 to 102 in Haiti for slopes between 0 and 60% (Délusca, 1998).

3.4. Soil erodibility factor: K

The soil erodibility factor (K) represents the susceptibility of a soil type to erosion. The USLE monograph (Wischmeier and Smith 1978) estimates erodibility as:

$$K = 2.1 \times M^{1.14} \times 10^{-6}(12 - MO) + 0.0325 \times (b-2) + 0.025 \times (c-3) \quad (4)$$

where

M = (%silt+%very fine sand)(100-%clay),
MO is the percent organic matter content,
b is soil structure code, and
c is the soil permeability rating.

Table 2: K-factors for the study area.

Soil	Usda class	K
Altered ferritic and ferrallitic soils	Sandy loam	0.013
Tropical eutrophic brown soils, hypermagnesic, on ultrabasic rocks	Clay	0.022
Desaturated fersiallitic soils	Loam	0.03
Little developed soils of alluvial contribution, modal with variable texture	Sandy loam	0.013
Tropical eutrophic brown soils, little developed and modal on basalts	Clay	0.022

The soil erodibility K was derived from a soil map of Pouembout at 1;50,000 scale (Denis and Mercky 1982). The study area was divided into five major soil classes. They had K factors ranging from 0.013 to 0.03 (Table 2). These values are compatible with other studies for example K ranged from 0.004 and 0.15 inn the Bouyaha catchment in Haiti (Durosier, 1990), and 0.026 to 0.052 on the Balan gully in Haiti (Delusca 1998), for a similar ferrallitic soil.

3.5. Cover management factor: C

The cover management factor (C) represents the effect of land use on soil erosion (Renard et al. 1997). It is measured as the ratio of soil loss from land cropped under specific conditions to the corresponding loss from tilled land under continuous fallow conditions (Wischmeier and Smith 1978). By definition, C equals 1 under standard fallow conditions. As vegetative cover approaches 100%, the C factor value approaches 0. In our study area, 6 vegetation types were defined from a 1996 thematic land cover map (DTSI, Direction des Technologies et des Services de l'Information 2003). Cover factor ranged from 0.001 to 1 (Table 3).

Table 3: Land cover types and C-Factor.

Vegetation type	C
forest	0.001
savanna	0.04
mining scrubland	0.25
swamp	0.28
brush	0.72
bare land	1

3.6. Support practice factor: P

The support practice factor P represents the soil conservation operations or other measures that control the erosion, such as contour farming, terraces and strip cropping. Because no information on P was available for this study, a value of 1 was used.

4. RESULTS

Soil erosion loss was estimated by combining GIS layers. The R, LS, K, and C factor layers were multiplied to create a soil loss rate layer. The resulting erosion rate A ranged between 0 and 15,690 t/ha/yr in the study area, with an average of 137 t/ha/yr (Figure 3).

A first visual interpretation of the different factors shows that topography (factor LS) seems to be the dominant driver for explaining the variation in erosion rate. Seventy-four percent of the study area has an erosion rate under 200 t/ha/yr. These areas are the least sensitive to erosion, and correspond primarily to the basin floodplains and flat areas of the Central Chain covered by forests.

Only 6% of the study area is considered to have a high erosion loss (more than 1,000 t/ha/yr). These areas are primarily in the Central Chain and correspond to the association of three factors:

- bare soils due to human activities, such as mining and brush fires (agricultural practices),
- steep slopes,
- high precipitation and altered soils due to tropical climate (~2,000 mm/yr).

These three combined factors explain the very high estimation of soil loss on the top hills of the Central Chain. It shows that the mining activities are located on the most sensitive areas to erosion.

The USLE was able to be applied simply to large regions using GIS. The estimation of soil loss is in the same order of magnitude as other studies: 200 to 500 t/ha.an in the Burundi (Rishirumuhirwa, 1997), 200 to 400 t/ha.an in Tahiti (Servant, 1974). Unfortunately, data limitations currently prevent us from testing the accuracy.

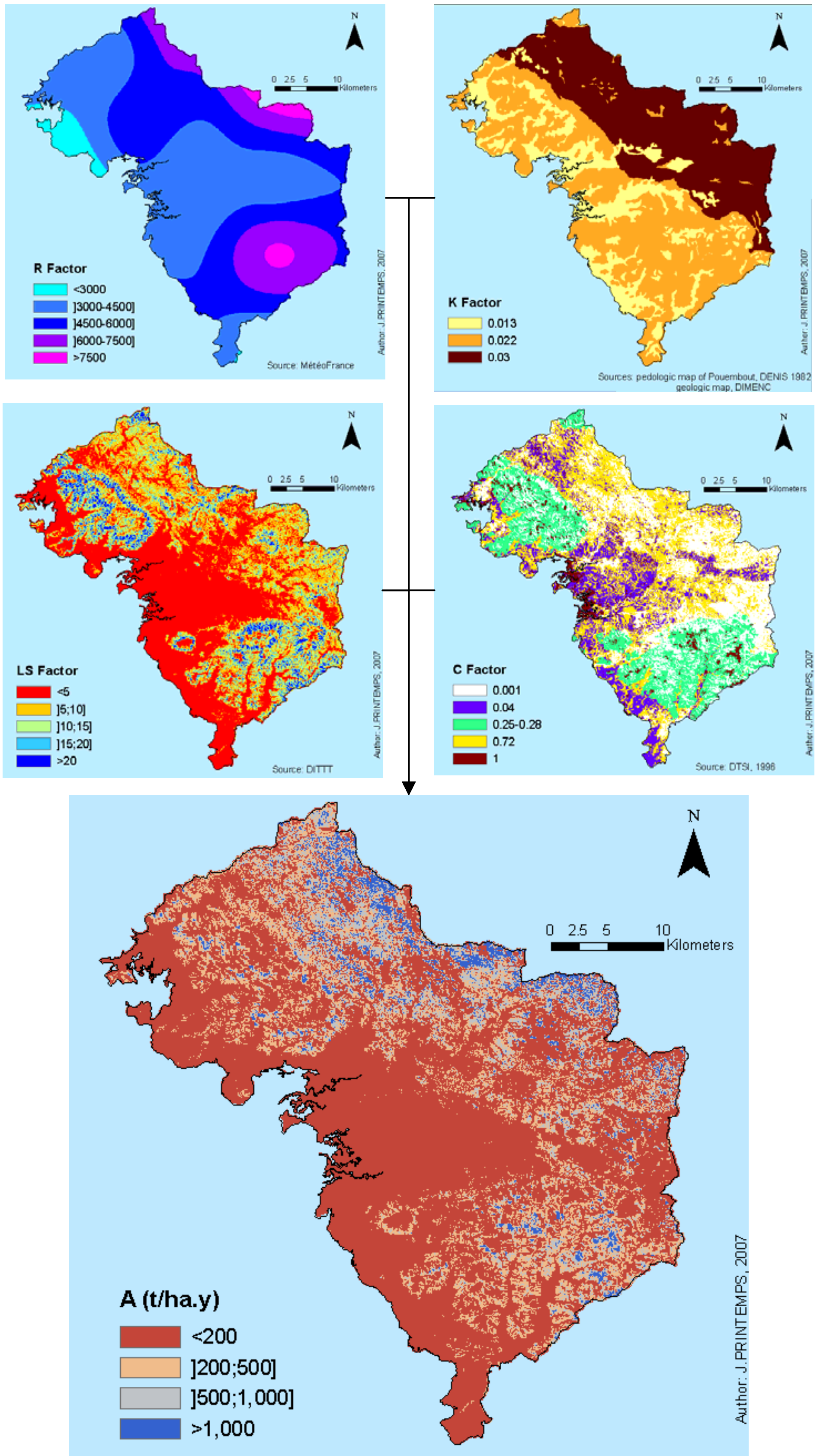

Figure 3: Estimation of sediment rate (t/ha/yr) based on USLE equation.

5. CONCLUSION AND PERSPECTIVES

The use of GIS information has enabled us to estimate the amount of soil loss in the catchments of Voh, Koné and Pouembout in New Caledonia. Results show that the highest soil loss comes from the top of the mountain as a result of intense mining activity (inducing bare soils), high precipitation and slopes.

Data limitation is currently preventing us from assessing the accuracy of the estimated erosion losses in the catchments. The availability of measured erosion data in future will permit accurate calibration of the K factor for a better estimation of erosion loss.

USLE gives the long-term average soil loss resulting from sheet erosion processes. However, soil loss from other types of erosion need to be estimated. For example, gully erosion from lavakas is a common type of erosion found in New Caledonia's landscape. Future research will improve the current model by adding the gully erosion as a separate component. Calibration from existing data on sediment traps in the Koniambo Mountain will help in this regard.

The simplicity of the combination of GIS layers for the USLE equation makes it easy to generate land use scenarios to compare different mitigation strategies. With the availability of on-going satellite imagery, we plan to vary the C factor through an automatic land cover classification. The different land covers will permit monitoring of soil loss changes with land use changes. Moreover, we plan to generate different mitigation strategies by estimating the delivery of sediment to the river with different sediment trap scenarios.

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