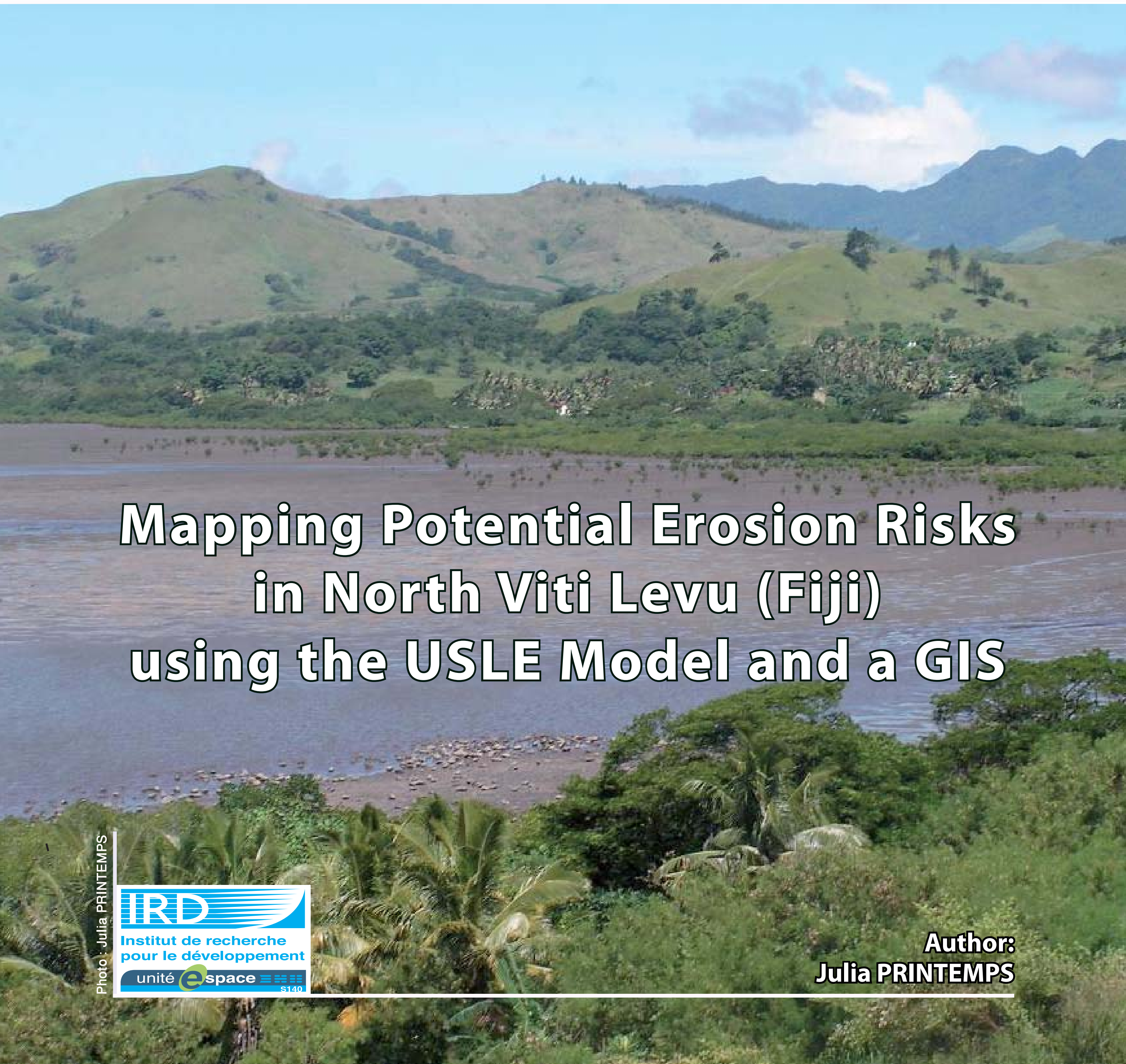
COMPONENT 1A - Project 1A4

Integrated Coastal Management - GERSA Project
Spatial Approach - Remote Sensing

September 2008

CRISP
Coral Reef InitiativeS for the Pacific
Initiatives Corail pour le Pacifique

TECHNICAL REPORT



Mapping Potential Erosion Risks in North Viti Levu (Fiji) using the USLE Model and a GIS

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The CRISP programme is implemented as part of the policy developed by the Secretariat of the Pacific Regional Environment Programme for a contribution to conservation and sustainable development of coral reefs in the Pacific.

CRISP

Coral Reef InitiativeS for the Pacific
Initiatives Corail pour le Pacifique

The Initiative for the Protection and Management of Coral Reefs in the Pacific (CRISP), sponsored by France and prepared by the French Development Agency (AFD) as part of an inter-ministerial project from 2002 onwards, aims to develop a vision for the future of these unique eco-systems and the communities that depend on them and to introduce strategies and projects to conserve their biodiversity, while developing the economic and environmental services that they provide both locally and globally. Also, it is designed as a factor for integration between developed countries (Australia, New Zealand, Japan and USA), French overseas territories and Pacific Island developing countries.

The CRISP Programme comprises three major components, which are:

Component 1A: Integrated Coastal Management and Watershed Management
- 1A1: Marine biodiversity conservation planning
- 1A2: Marine Protected Areas (MPAs)
- 1A3: Institutional strengthening and networking
- 1A4: Integrated coastal management

Component 2: Development of Coral Ecosystems
- 2A: Knowledge, monitoring and management of coral reef ecosytems
- 2B: Reef rehabilitation
- 2C: Development of active marine substances
- 2D: Development of regional data base (ReefBase Pacific)

Component 3: Programme Coordination and Development
- 3A: Capitalisation, value-adding and extension of CRISP activities
- 3B: Coordination, promotion and development of CRISP Programme

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COMPONENT 1A - PROJECT 1A4 (GERSA)

Integrated Coastal Reef Zone and Watershed Management

The purpose of GERSA is to foster the emergence of an integrated cross-cutting approach based on public policy tools and monitoring methodology and local-scale stakeholder dynamics. Ultimately, the goal is to have a scientific foundation and indicators suited to Pacific Island settings so as to set up country sustainable development observatory networks as part of the introduction of MPAs. GERSA is then a cross-cutting project relating also to project 1A2 (MPAs).

The project 1A4 is composed of 4 main activities:

- *ACTIVITY 1*: ***SPATIAL APPROACH***
- *ACTIVITY 2*: ***TERRITORIALITY AND SOCIO-ECONOMIC VALUES***
- *ACTIVITY 3*: ***ENVIRONMENTAL INFORMATION SYSTEMS AND MODELISATION***
- *ACTIVITY 4*: ***DYNAMICS AND MODELISATION OF WATERSHED***

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INTRODUCTION

Soil erosion is a natural process which is accelerated by land use. Steep slopes, high intensity storms and natural geologic process set the stage for high natural erosion rates. Natural erosion rates are high in tropical landscapes on a worldwide basis (Nelson, 1987). Streams in tropical areas have up to 15 times the natural sediment loads as comparable streams in temperate areas (Simonett, 1968). Within the South Pacific Region, particularly on the high islands, soil erosion is a marked feature of the landscape. After each storm, rivers change colour and much material is carried away towards the sea (Eyles, 1987), bringing very abundant sedimentary contributions that induce changes in the profile and degrade coastal reefs fringing (Dumas, 2004).

In order to spatialise and quantify the erosion hazard in Fiji, it is an approach based on modelling which has been chosen. In this way, the Universal Soil Loss Equation - USLE (Wischmeier and Smith, 1978) - was used because on the one hand, it is the model that requires less data-source and on the other hand, it has already been widely applied to many environments and for all scales. The USLE is a simple empirical model designed to estimate annual rates of soil loss over the long term in agricultural areas. Despite the flaws and limitations of this equation, it is widely used, because of its relative simplicity and reliability (Desmet and Govers, 1996). Furthermore, coupled with GIS, it allows producing documents which serve as decision-making tools for management.

Erosion in Fiji is not a recent phenomenon. It has exceeded ‘natural’ rates wherever human populations have exerted pressure on the environment, and wherever land management techniques not attuned to the environment, have been introduced (Eyles, 1987). Brookfield (1981) and Latham (1983) from studies on the eastern Fiji Islands of Labeka, Anatom (Vanuatu) and Tikopia (French Polynesia) consider that there is evidence of human induced erosion dating from as early as 3000 years ago. In Fiji, since 1950, the expansion of the sugarcane cultivation from the alluvial flats to the rolling and hill country resulted in soil erosion becoming severe (Eyles, 1987).

From these observations, a set of studies on erosion have been led in Fiji. The most known are those of Morrison (1981, 1987), Liedke (1984, 1987) and Nelson (1983, 1987), who have calculated soil losses using USLE from instrumented parcels under specific conditions of rainfall, soil type, slopes and land use. This report presents the combination of the model USLE with GIS software allowing spatializing and quantifying potential soil loss on a large area. It constitutes a document which can be used as a decision tool for a better land management planning.

1. PRESENTATION OF STUDY AREA CONTEXT

1.1. PHYSICAL FBEATURES OF THE FIJI ISLANDS

The Fiji Islands consist of 322 islands (of which 106 are inhabited) and 522 smaller islets, having a total area of about 18,300 km² and lying between 15 and 22°S latitude and 177°W and 175°E longitude. The two most important islands are Viti Levu and Vanua Levu.

Our area of interest is situated on Viti Levu so we will focus on this island. Viti Levu hosts the capital city of Suva, and is home to nearly three quarters of the population. Other important towns include Nadi (the location of the international airport), and Lautoka (the location of a large sugar mill and a sea-port) (Figure 1).

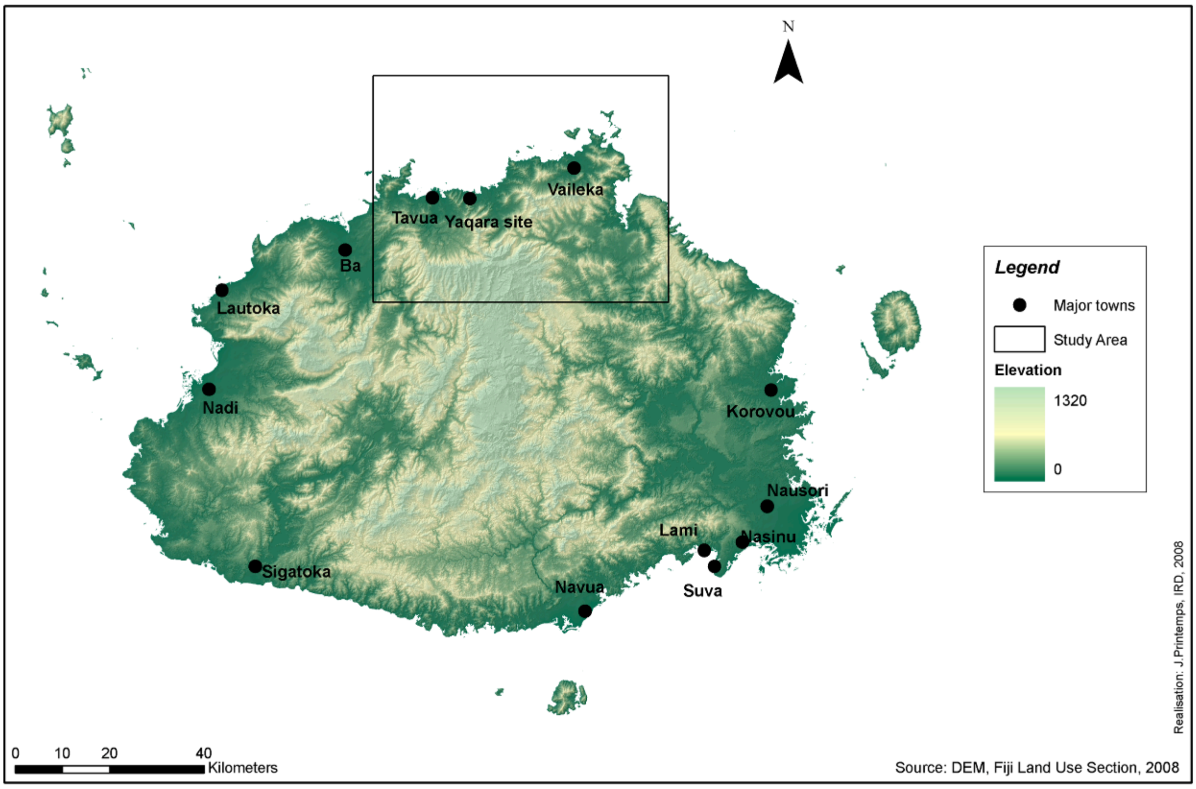

Figure 1: Viti Levu and localisation of the area of interest

- ### Topography

Fiji is dominated by steep, mountainous country deeply incised by rivers and streams and peaks up to 1,320 metres (Figure 1). 67% of Viti Levu is steepland (slopes > 18°) while much of the remaining land is rolling and hilly land (slopes 3-18°) (Morrison & Clarke, 1990).

- ### Climate

The climate of the Fiji Islands is humid tropical and mainly dominated by the Southeast trade winds. Average annual rainfalls range from 1,800 to 3,300 mm/yr but are highly variable and strongly influenced by topography, with the winds bringing moisture onshore and causing heavy showers in the mountain regions. As a result, the west coast is drier than the east coast (Figure 2).

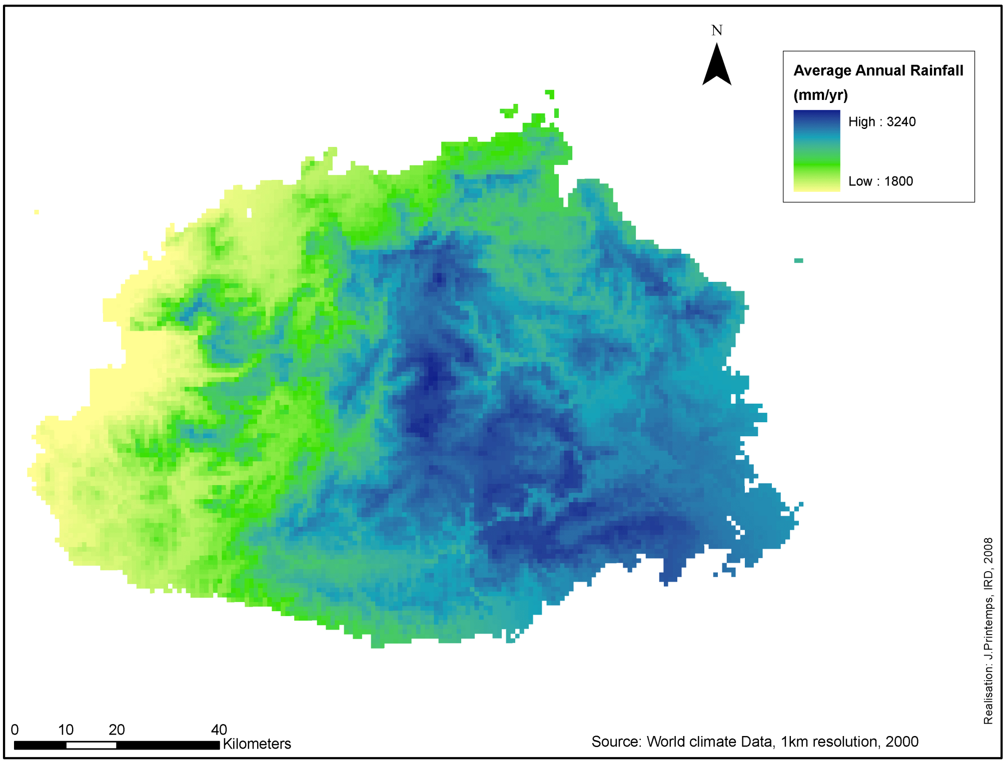

Figure 2: Average Annual Rainfall in Viti Levu

- **Soils**

The general soil pattern partially reflects the climatic zonation described above with a strong correlation occurring between the broad soil pattern and the topographic and climatic pattern (Morrison & Clarke, 1990). It can be best described by separating soils into topographic groups and superimposing on this a subdivision based on altitude and climate as it has been done in the Fiji Soil Taxonomic Unit Description Handbook (Leslie & Seru, 1998).
But there are a lot of soils in Fiji, which particularities so we will take into account the texture of each soil on the study area.

- **Land Cover**

The main part of the Fiji Islands is covered by tropical forests and woodland which represent 65% of the Land Use. Only 15% is suitable for arable farming. The main cultivation is sugar cane which represents 40% of the agricultural economy and gives a job to 25% of the active population. Coconuts, ginger, and copra are also significant.

1.2. LOCALISATION OF THE STUDY AREA

The study area is situated on the North Coast of Viti Levu Island (Figure 1), from Tavua to Viti Levu Bay (Nanukuloa), including the Tikina of Rakiraki, the Nakauvadra Range and the Yaqara Basin. This area is 62 kilometers long and the elevation ranges from 0 to 1,320 meters (Figures 3, 4). There are lots of villages and the major town is Tavua, west of the study area.

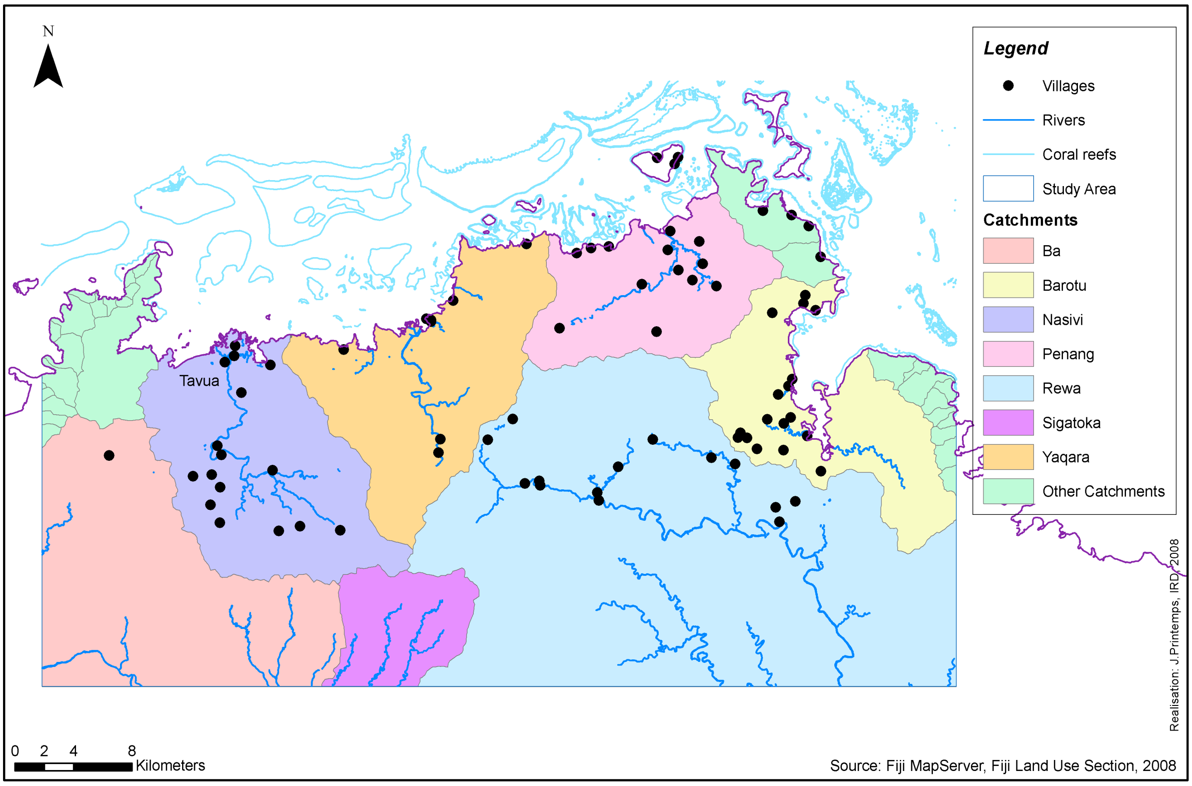

Figure 3: Presentation of the Study area

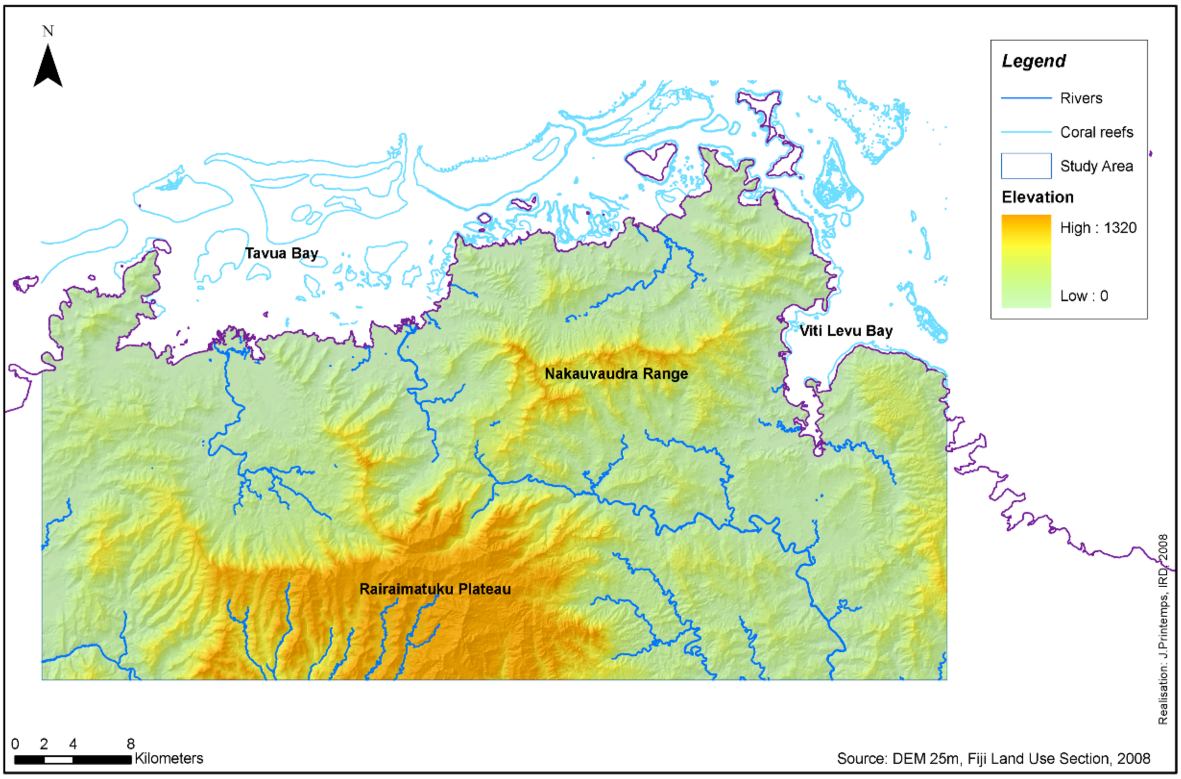

Figure 4: Digital Elevation Model on the Study Area

Off the coast, large coral reefs are a treasure sensitive to erosion and more particularly to the terrigenous contributions. That is why it is so important to analyse and to map the potential erosion on the catchments of this area.

2. METHODOLOGY: MODELING EROSION WITH USLE

The Universal Soil Loss Equation, later revised as the RUSLE (Renard et al., 1997), was developed by Wishmeier and Smith in 1978. The USLE predicts potential erosion and is widely used in the world. Potential erosion, representing by soil losses, has units of weight per unit area per year (t/ha/yr). The equation is:

$$A = R \times K \times LS \times C \times P$$

A = average potential annual erosion (t/ha/yr)

R = rainfall-runoff factor (erosivity)

K = soil erodibility factor

LS = topographic factor (L slope length, S slope gradient)

C = land cover management factor

P = soil conservation practice factor

2.1. RAINFALL FACTOR R

Hudson (1981) defines erositivity as the potential ability of rain to produce erosion, often attributed to its physical characteristics. The amount, intensity, size of raindrops, the size distribution of these drops and the speed of fall are just a few examples. These characteristics are linked. Indeed, the size drops defines the distribution of droplet size and influence the amount of rain fell. In addition, the size of the drop affects its speed fall and is linked to the intensity of rain.

So 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.

Wischmeier and Smith (1978) showed that soil losses are directly proportional to the total storm energy (E) times the maximum 30-min intensity. Brown and Foster (1987) computed R as:

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

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),

I30 is the maximum 30 minutes intensity of rain in mm/h.

To calculate R, the rainy events of less than 12.7 mm in a period of 6 hours are omitted. There are considered as no aggressive for soils.

2.2. SOIL ERODIBILITY FACTOR K

The soil erodibility factor (K) represents the susceptibility of a soil type to erosion. This factor reflects the resistance of soil to erosion caused by the precipitation force. Unlike the erosivity of the rain which is directly linked with its physical properties, erodibility of the soil is the result of several variables. Indeed, the physical, chemical and mineralogical properties of a soil and their interactions affecting factor K. To this is added a large spatial variability.

The USLE monograph (Wischmeier and Smith 1978) estimates erodibility as:

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

where

M = (%silt+%very fine sand)(100-%clay),

MO is the percent organic matter content,

b is soil structure code,

c is the soil permeability rating.

To estimate K for different soil, you need a description of the soil composition or you can use a chart if you know the texture of each soil (Table 1).

Table 1: K factor for different soil texture in US units and SI units (Stone and Hilborn, 2000)

Soil texture	K factor (ton.acre.hr/hundreds of acre.ft.tons.in)	K factor (t.ha.h/ha.MJ.mm)
Sand	0,02	0,0026
Loamy sand	0,04	0,0053
Coarse sandy loam	0,07	0,0092
Fine sand	0,08	0,0105
Loamy fine sand	0,11	0,0145
Sandy clay	0,12	0,0158
Sandy loam	0,13	0,0171
Fine sandy loam	0,18	0,0237
Sandy clay loam	0,2	0,0263
Clay	0,22	0,0289
Silty clay	0,26	0,0342
Clay loam	0,3	0,0395
Loam	0,3	0,0395
Organic	0,3	0,0395
Silty clay loam	0,32	0,0421
Silt loam	0,38	0,0500

2.3. TOPOGRAPHIC FACTOR LS

Above a slope of 2%, erosion increases exponentially (McCool et al., 1987) due to the formation of gullies and, with the speed of runoff, rising of diffuse erosion rates.

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 is derived from Wischmeier and Smith (1978):

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

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).

L and S can be calculated separately. Slope length is defined as the distance between the point where the stream begins and the point where deposition begins.

The best way to compute L and S is to use a DEM.

2.4. COVER MANAGEMENT FACTOR C

The cover management factor (C) takes into account land cover (vegetation, facilities and agricultural practices). Indeed, erosion affects more particularly certain types of crops while it is less strong or simply absent for certain activities and facilities.

The type of vegetation cover is essential because it influences the deadening of rain drops, the slowing of the runoff and the infiltration (Roose, 1994).

The factor C depends on:

- the percentage of bare soil, erosion appearing mostly on bare soil during rainy aggressive episodes,
- the height of vegetation, it is interesting to have a cover, but if it is too high, deadening of rain drops will not occur anymore. Indeed, after a first interception, the drops will be further released to the ground,
- the architecture of plants, plants with funnel shape will tend to attract the flow and cause gullies. In contrast, plants called "umbrella" will disperse the drops of water and therefore reduce their energy.

So, factor C 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. There are many references given C for different type of vegetation (Table 2).

Table 2: Some example of factor C for different type of vegetation (Mongkolsawat and al, 1994)

Vegetation type	C
Forest	0.001
Rice	0.28
Cassava	0.6
Sugar Cane	0.45
Fruit trees	0.3
Savannah	0.04
Swamp	0.28
Bare land	1

2.5. SOIL CONSERVATION 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 (Table 3).
If no information on P is available, a value of 1 can be used.

Table 3: Example of Factor P (Stone and Hilborn, 2000)

Support Practice	Factor P
Up and down slope	1.0
Cross slope	0.75
Contour farming	0.50
Strip cropping, cross slope	0.37
Strip cropping, contour	0.25

3. APPLYING USLE ON FIJI

3.1. DATA COLLECTION

Data necessary for applying USLE in Fiji were collected from governmental departments in Fiji and on the Internet (Table 4).

Table 4: Data collected

Data	Scale	Geographical extent	Source
Digital Elevation Model (raster)	25m pixel resolution	Viti Levu	Land Use Section
Geographical shapefiles (contours, hydrologic stream, catchments, roads, towns, …)	1/50 000	Study area	Land Use Section, Mining and Resource Division
Soil map (shapefile)	1/50 000	Viti Levu	Land Use Section
Word Climate Rainfall Data (raster) *(www.worldclim.org)*	1km pixel resolution	World	Hijmans, Cameron and Parra from University of California
Forest Cover (shapefile)	1/50 000	Viti Levu	Fiji Map Server
Satellite image	2,5m pixel resolution	Study area	SPOT Image

3.2. RAINFALL FACTOR R

The mechanics of soil erosion is a natural characteristic of tropical islands high subjected to violent rains (Dumas, 2004). Indeed, rain is the main erosion factor. Soil erosion appears when rainwater can no longer infiltrate into the ground and carry a stream of particles land (Le Bissonnais and al., 2002).

As there are not enough data from weather stations in the study area, we chose to use "Very high resolution interpolated climate surfaces for global land areas" developed by Hijmans, Cameron and Parra in 2004 at the University of California.

"We developed interpolated climate surfaces for global land areas (excluding Antarctica) at a spatial resolution of 30 arc s (often referred to as 1-km spatial resolution). The climate elements considered were monthly precipitation and mean, minimum, and maximum temperature. Input data were gathered from a variety of sources and, where possible, were restricted to records from the 1950–2000 period. We used the thin-plate smoothing spline algorithm implemented in the ANUSPLIN package for interpolation, using latitude, longitude, and elevation as independent variables." (Hijmans and al, 2005).

The data collected on the Internet are on the form of a set of twelve rasters representing average of the monthly rainfall over fifty years. Using a GIS to do the sum of the rasters and an extract with a mask of the study area, we obtain the average annual rainfall on the area of interest (Figure 5).

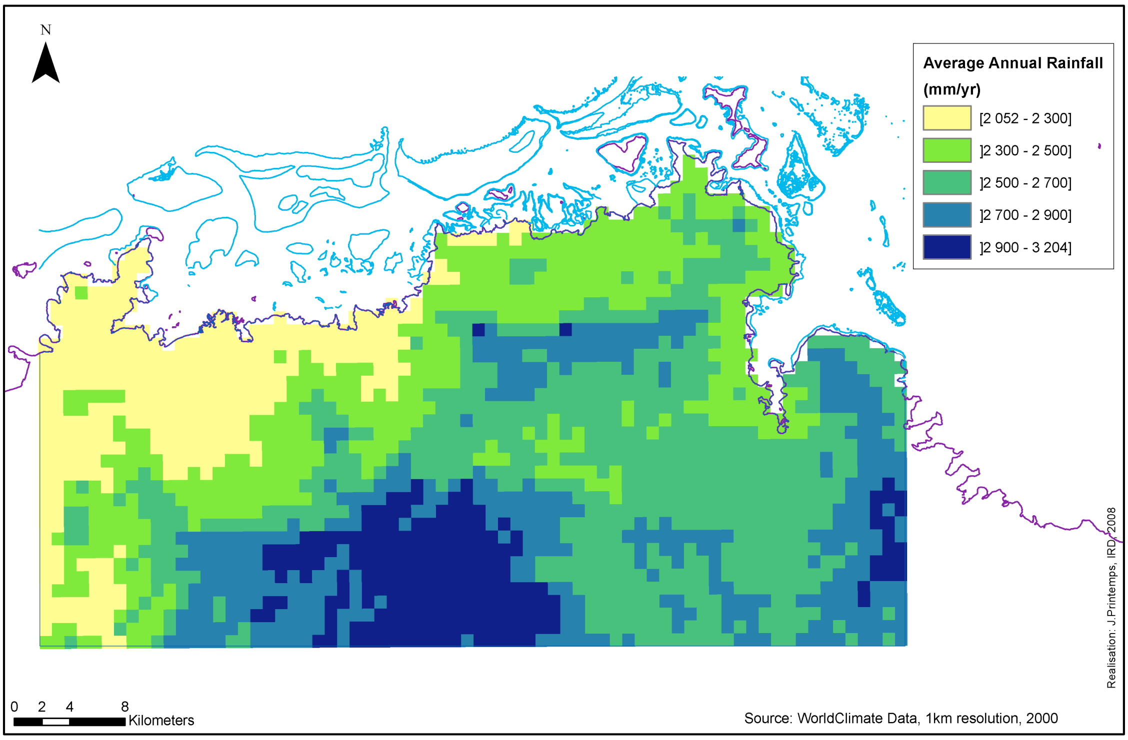

Figure 5: Average annual rainfall on the study area

The average annual rainfall ranges between 2,052 and 3,204 mm/yr with a spatial distribution depending on the topography: rainfall superior to 2,900 mm/yr on mountainous areas and rainfall inferior to 2,300 on the flood plain and particularly on the Tavua and Yaqara catchments.

Because we have no more precise data, we use an approximation given by Roose (1975):

$$\mathbf{R = 0.5 * P * 1.73}$$

where P = average annual rainfalls

which is easy to use with a GIS. We obtain a spatialisation of the R factor (Figure 6). Of course, resulting of a multiplication, the R factor follows the variations of the rainfall and topography. It ranges from 1174 to 2772 MJ.mm/ha.h.yr. These numbers seem to correspond to previous studies:

- R = 885 in the area of Lautoka, west of our study area (Liedke, 1989),
- R = 2,200 in the area of Suva, south of Viti Levu (Liedke, 1987),
- R = 930 near Nadi, and R = 1530 in the east of Viti Levu (Morrison, 1981).

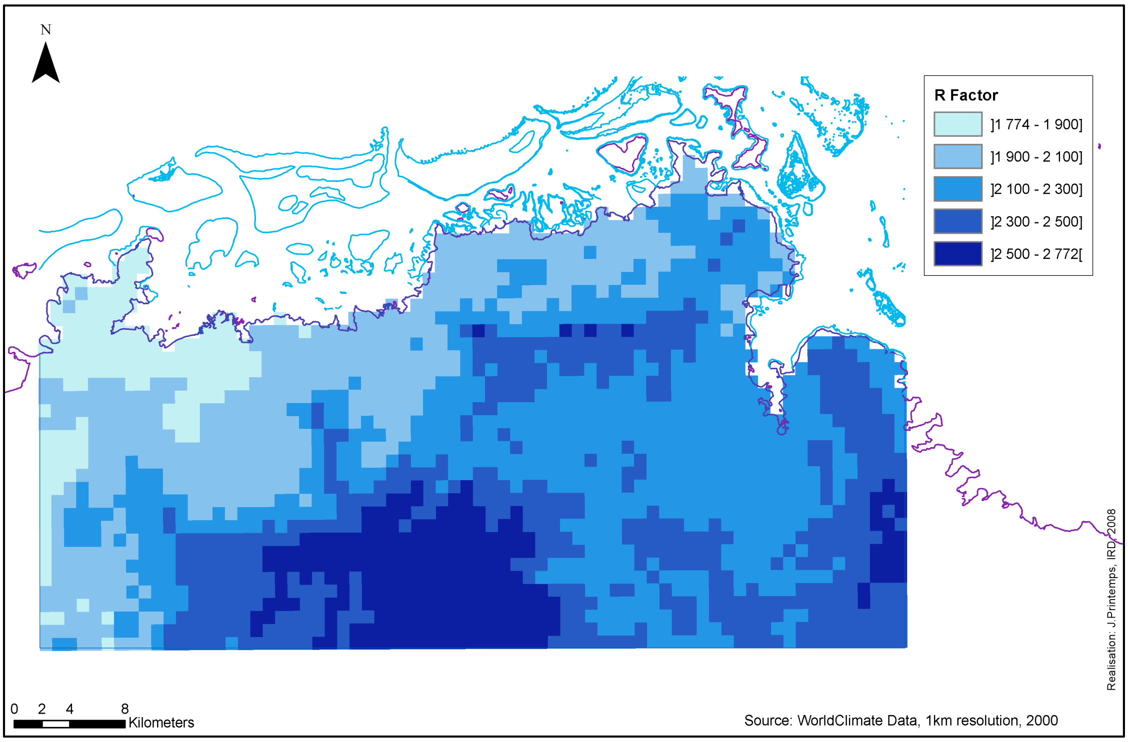

Figure 6: R Factor Map on the Study Area (MJ.mm/ha.h.yr)

3.3. SOIL ERODIBILITY FACTOR K

Nature of soil is a major parameter in erosion since tearing particles depends directly on the properties of soil and subsoil. The soil erodibility factor (K) represents the susceptibility of a soil type to erosion. For mapping this factor, we use the soil map of Viti Levu. There are 83 different soils on the area (Figure 7, the complete legend is given in Annex 1) and we study each to find its texture using the "Fiji Soil Taxonomic Unit Description Handbook" (Leslie and Seru, 1998).

The classification of each soil and its texture are given in Annex 2 but the Table 5 gives three examples of soil description.

Table 5: Description and texture of three soils

Soil Name	***Set***	***Soil Taxonomy***[1]	***FAO***[2]	***Twyford and Wright***[3]	***Texture***
BUA SOILS	Raviravi	Typic kanhaplustalf, very fine, ferruginous, isohyperthermic	Eutric Planosol	Ferruginous latosol with a strong dry season	**Silty clay loam**
BURENITU SOILS	Delaimatai	Typic haplustalf, fine, ferruginous, isohyperthermic	Eutric Nitosol	Humic latosol with a moderate dry season	**Clay**
CUKU SOILS	Vitawa	Typic ustropept, fine-silty, mixed, isohyperthermic	Eutric Cambisol	Steepland soil related or associated with red yellow podzolic soils with a strong dry season	**Silty clay**

[1] Soil Taxonomy Classification System (Leslie and Seru, 1998)
[2] Food and Agriculture Organisation Classification (FAO, 1974)
[3] Twyford and Wright Classification System (1965)

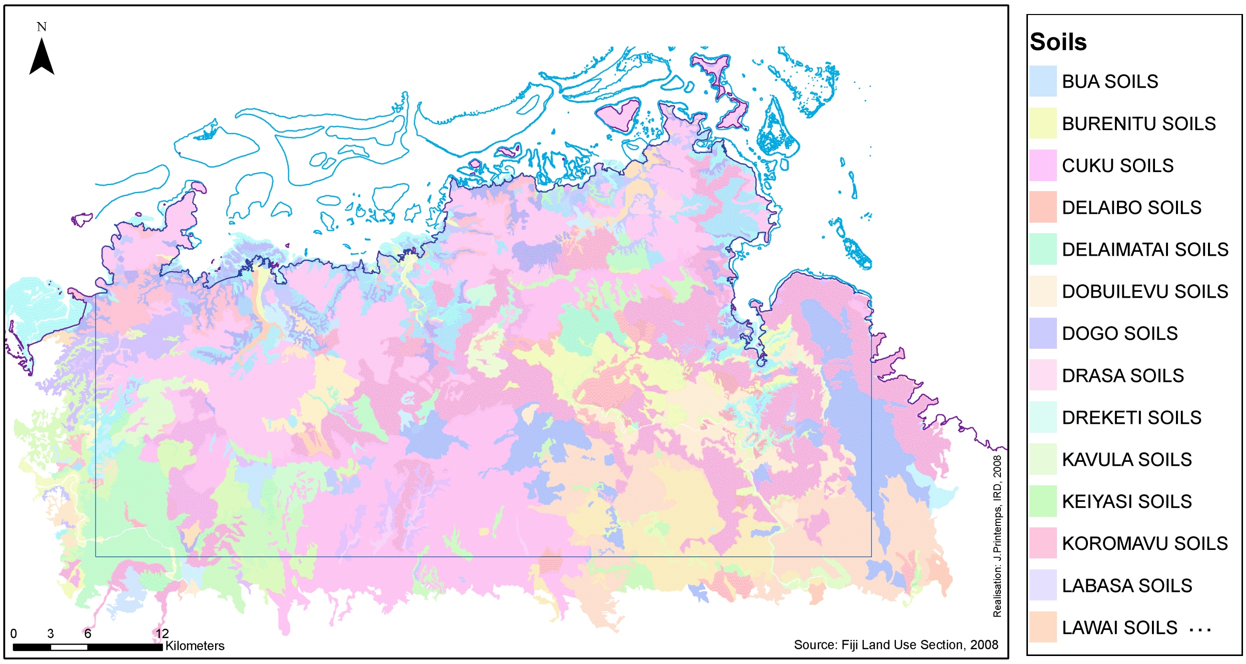

Figure 7: Soil map of the Study Area (incomplete legend)

The mineral part of a soil (coming from rock, not from plants) results from the breaking down of the parent material. Texture is the feel of the soil, reflecting the proportion of sand, silt, and clay-sized particles, as well as the amount of organic matter mixed with them (Leslie and Seru, 1998).
That is the reason why we used texture when we don't have the description of the soil in terms of percentages of clay, silt, sand and organic matter.

With the texture and using a table of correspondence between factor K and texture, we obtain the results given by Table 6.

Table 6: Classification of soils and correspondence between texture and Factor K

Soil Name	Burenitu soils Delaibo soils Delaimatai soils Dobuilevu soils Drasa soils Makomako soils Matavelo soils Momi soils Nadruka soils Namalata soils Nanukuloa soils Narewa soils Rewasa soils Sote soils Tabia soils Totoya soils Vaidoko soils Vatukoula soils Veisaru soils Visa soils Vuya soils Wainibuka soils Waisava soils Yako soils	Kavula soils Lewa soils Macuata soils Matawailevu soils Monasavu soils Nabuesa soils Nadarivatu soils Nadroga soils Nairai soils Namosi soils Nasou soils Nausori soils Navai soils Nika soils Qalinaolo soils Raviravi soils Rukuruku soils Sawakasa soils Seatura soils Serua soils Sigatoka soils Tau soils Tavua soils Tiri soils Varaciva soils Vatuma soils Vitawa soils Waibici soils Wailulu soils	Tabuquto soils Taveuni soils	Koromavu soils Lawai soils Navua soils Waidina soils	Cuku soils Dreketi soils Labasa soils Lobau soils Soso soils
Texture	Clay	Clay Loam	Loam	Silt Loam	Silty Clay
Factor K *(t.ha.h/ha.MJ.mm)*	0.0289	0.0395	0.0395	0.05	0.0342
Soil Name	Bua soils Keiyasi soils Nabiti soils Namosau soils Tailevu soils Tamanua soils Tokotoko soils Tuva soils Wainikavou soils Yaqara soils	Yasawa soils	Namuana soils	Dogo soils Savudrodro soils Tagimaucia soils Vatuvonu soils	Ogea soils Rana soils Waibula soils
Texture	Silty Clay Loam	Sandy	Sandy Clay	Sandy Clay Loam	Sandy Loam
Factor K *(t.ha.h/ha.MJ.mm)*	0.0421	0.0026	0.0158	0.0263	0.0171

We can now map the Factor K under a GIS (Figure 8).

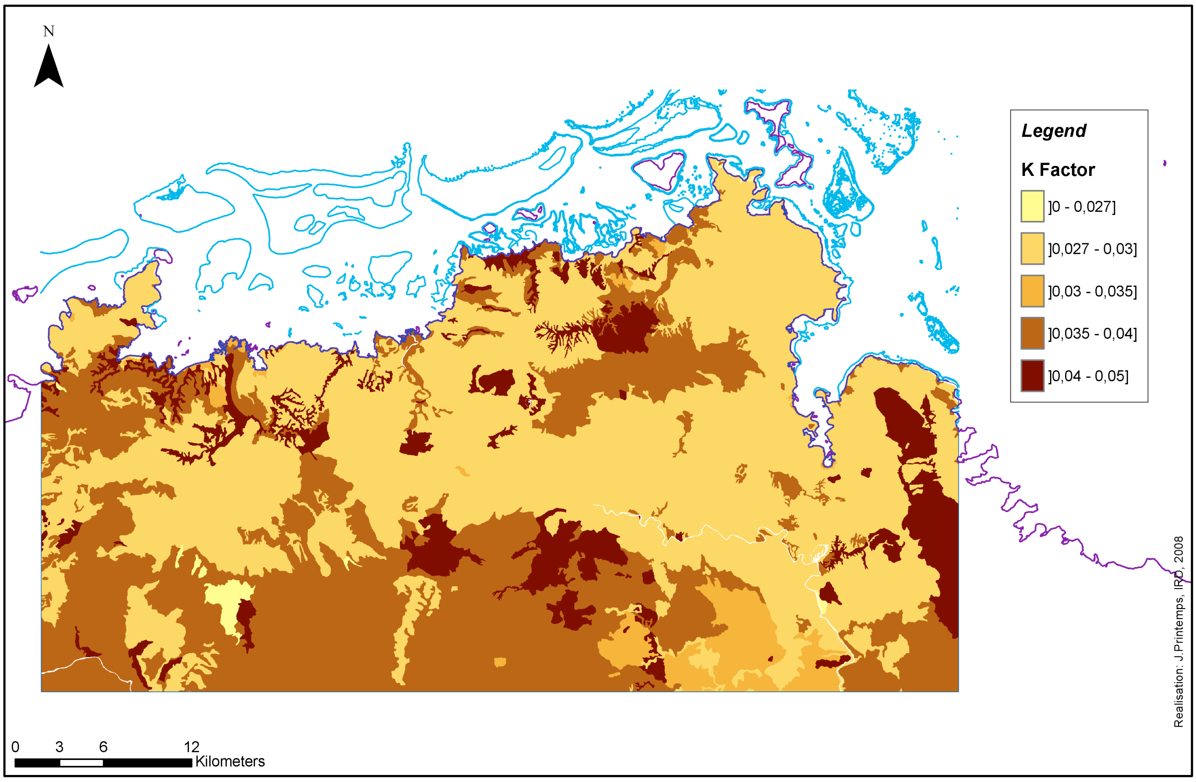

Figure 8: K Factor Map on the Study Area (t.ha.h/ha.MJ.mm)

We can see that most of the study area has a K factor between 0.027 and 0.03 t.ha.h/ha.MJ.mm. Morrison (1981) defined the erodibility factor for Fiji (empirical value) at 0.02634 t.ha.h/ha.MJ.mm corresponding to our values.

3.4. TOPOGRAPHIC FACTOR LS

Topography is the richest source of data about erosion process. To take in account this factor, using a DEM is the best way to integrate water catchments morphology (Guermont, 2005).

The spatial resolution of the Viti Levu DEM is 25 meters. From the DEM, we can obtain the slopes map which represents the first derivation from the elevation (Figure 9).

The average of the elevation is 279 meters and the slopes range from 0 to 88.4° with an average of 25.18°. We can clearly see the Tavua and Yaqara catchments and the mountainous range of Rairaimatuku and Nakauvandra.

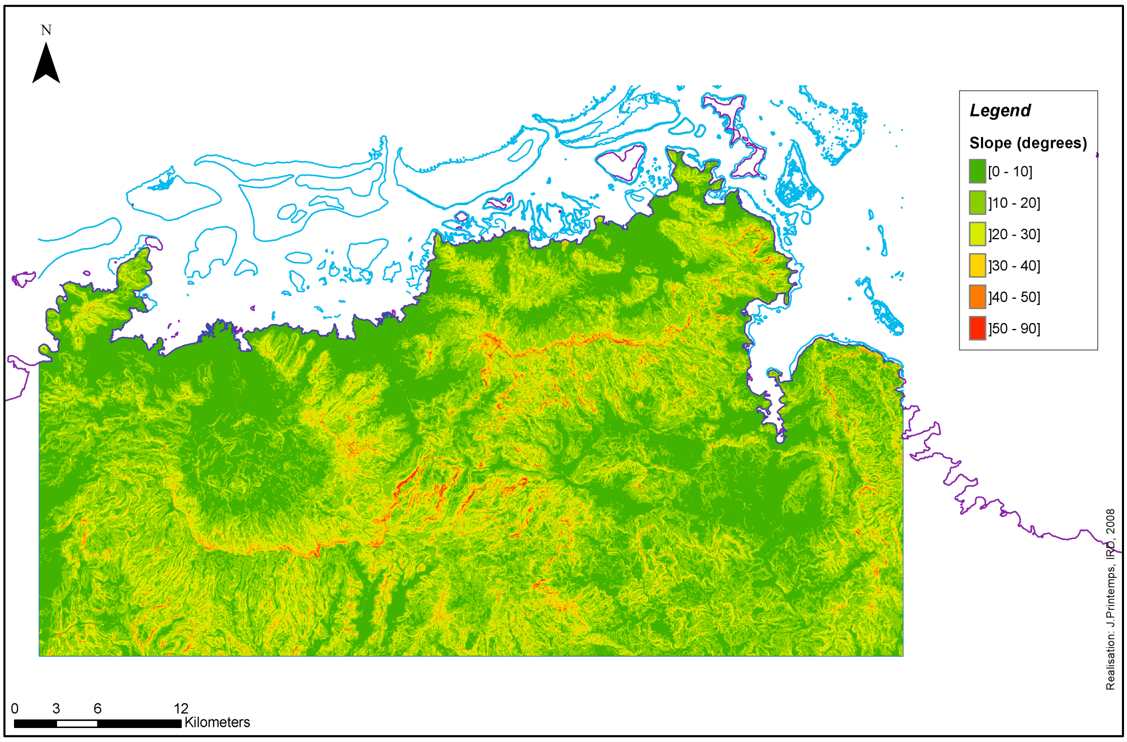

Figure 9: Slopes in the Study Area

The slope length and steepness factor LS represents the effect of topography on erosion. To calculate the LS factor, we use an AML script under ArcInfo developed by Van Remortel (2003). This program needs the DEM and the study boundaries as inputs.

It begins with correcting the DEM in filling the low points. Indeed, the DEM has low points where water can not move virtually. These areas are often caused by inaccuracies in the DEM used. The treatment of these areas is necessary to allow the flow downstream.

The second step is the creation of a raster of flow direction from each pixel to its neighbor with a lower altitude. This helps to calculate the slope length; first for a pixel and then, in aggregate for each pixel.

The third step is the calculation of slopes in degrees for each cell. In function of the slope, the algorithm calculates the value of exposing m (see equation page 9).

Then, it proceeds to calculate S and L and finally, it determines the LS factor.

The figure 10 presents the results on the study area for the LS factor.

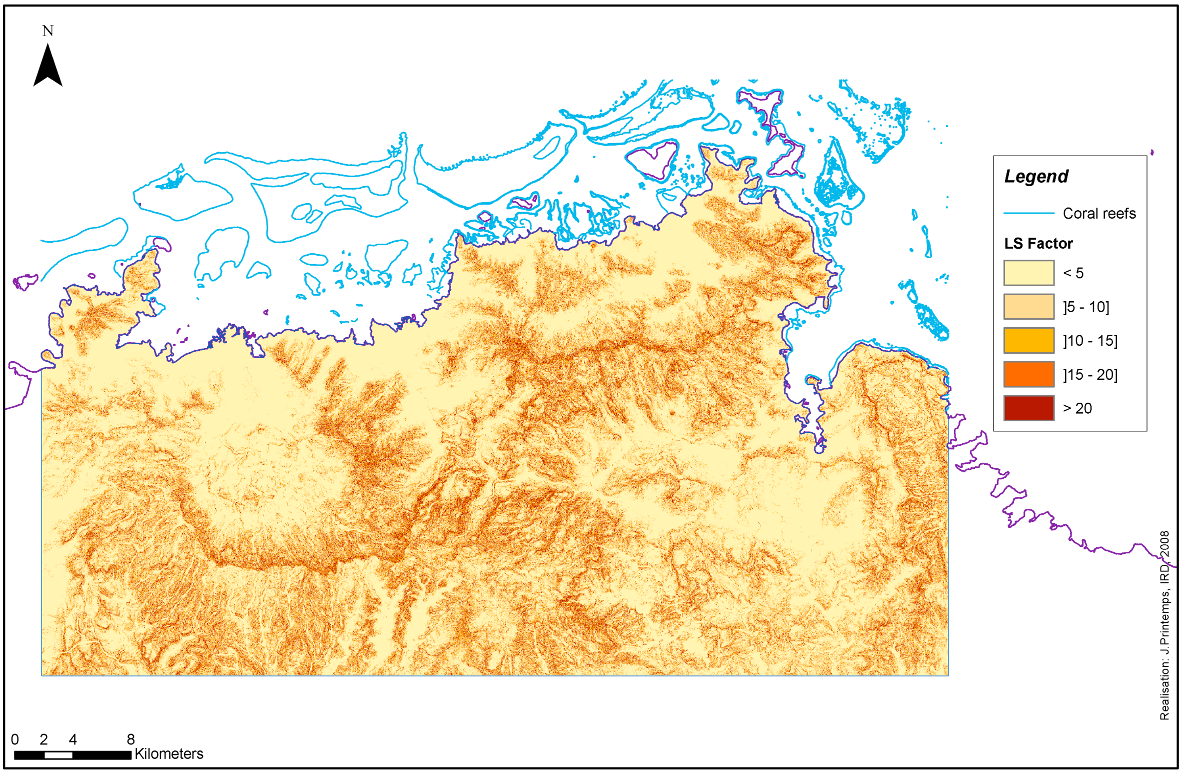

Figure 10: LS Factor in the Study Area

The LS factor ranges from 0 to 119 with an average of 6.79. These values are grouped in five classes (Figure 11).

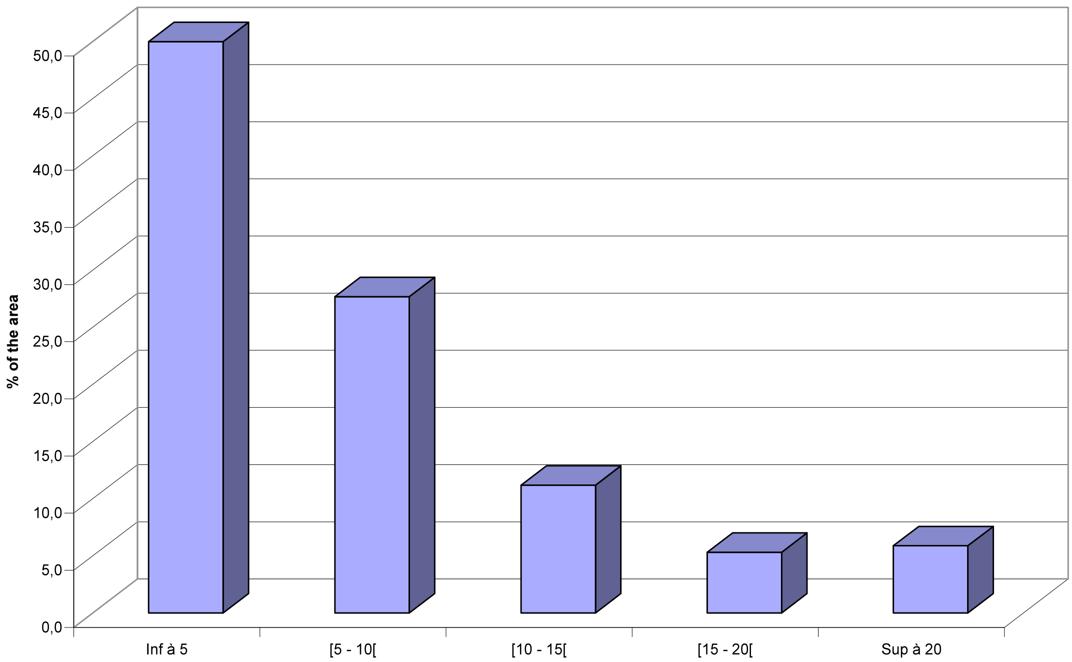

Figure 11: Distribution of the factor LS classes on the study area

Half of the values are under 5 and correspond mostly to plain zones. The high values (superior to 20) correspond to the crests of the mountains, more sensible to erosion. But it represents only 6% of the area.

3.5. COVER MANAGEMENT FACTOR C

No land cover map already exists on our area of interest. However, the erosion process depends on the land cover and is particularly important on areas with bare soils.

To obtain a land cover map, we use two tools. On one hand, we use Google Earth to digitalize the culture areas; on the other hand, we use remote sensing to make a classification from a satellite image.

Step 1: Digitalization from Google Earth

With screen shots from Google Earth, it is possible to digitalize culture areas and burnt zones on a GIS (Figure 12 – extract of the zone).

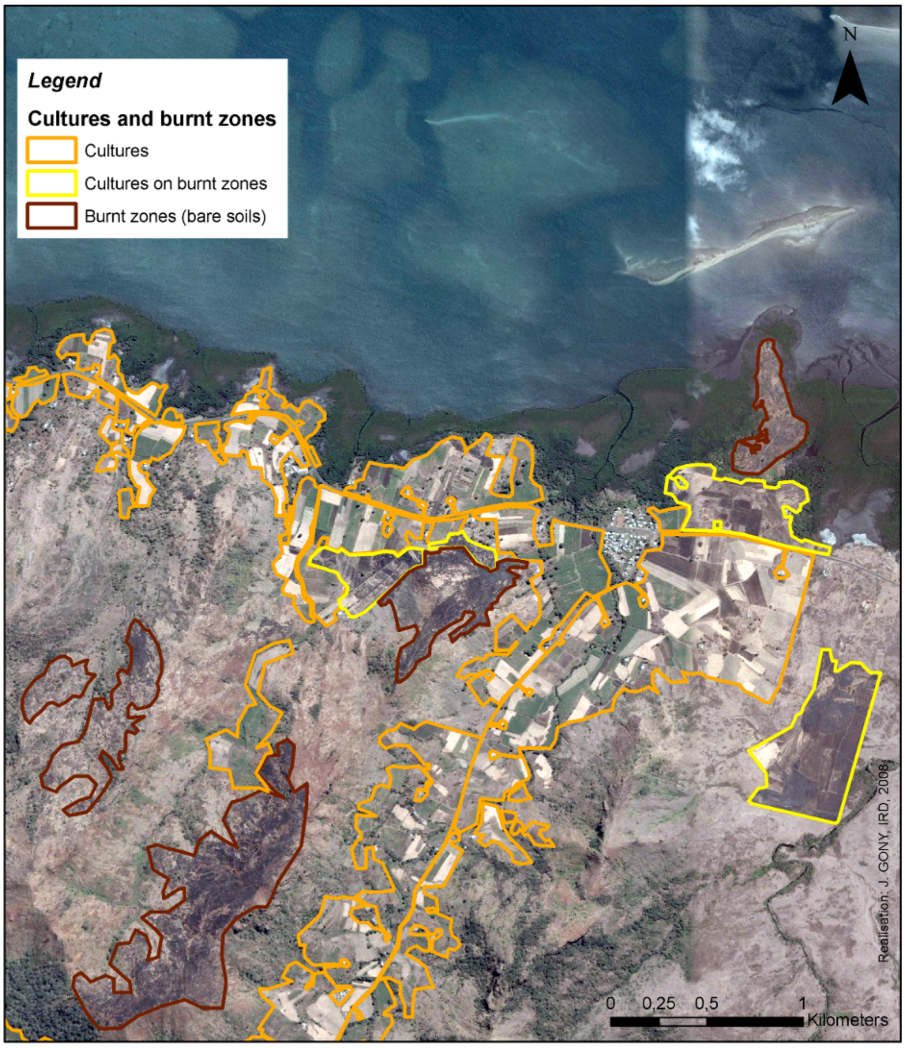

Figure 12: Example of Digitalized cultures and burnt zones in the area of interest

Step 2: Supervised Classification from SPOT Image

Using remote sensing and particularly supervised classification, we obtain a land cover map in our area of interest. We use a SPOT Image of 2007 with a pixel resolution of 2.5 m and add the polygons already digitalized to the classification. We obtain a complete land cover map of our area of interest (Figure 13).

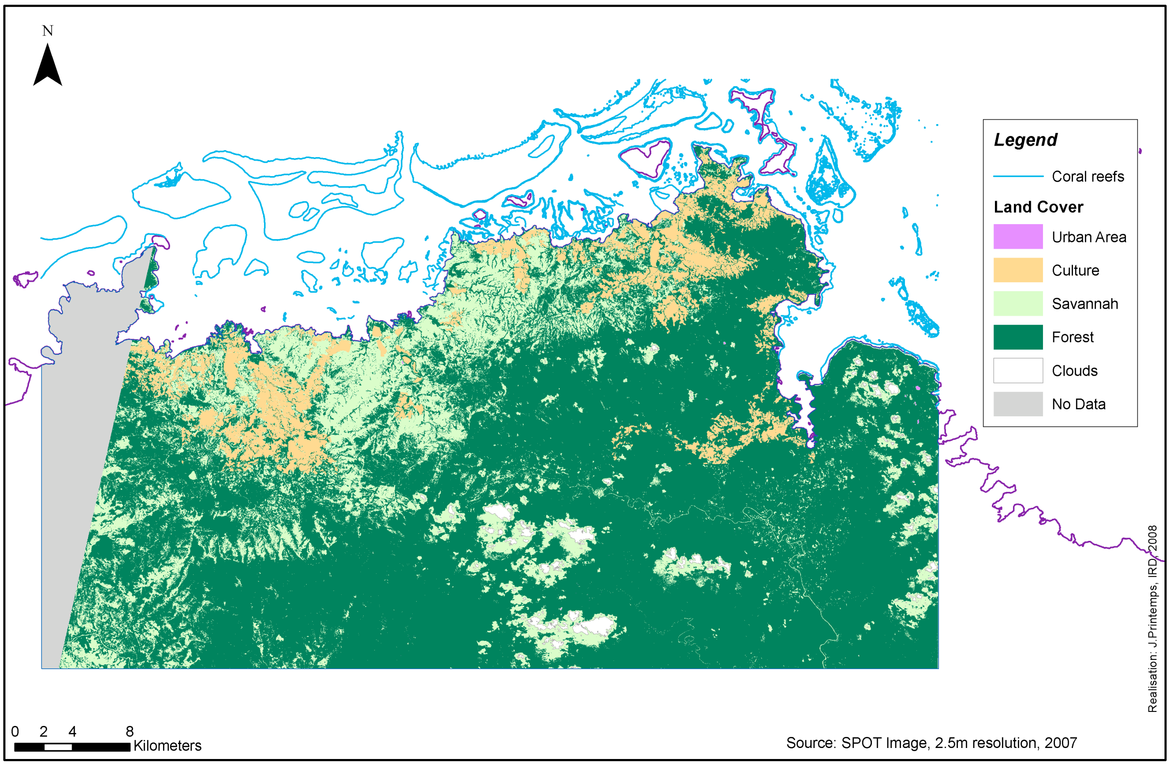

Figure 13: Land Cover Map of the study area

We can notice three main types of vegetation in our study area:

- cultures, near urban areas, mainly in the plains,
- savannah, mainly in the plains and low hills,
- and forest particularly in the mountain zones. It is the main type of vegetation in the zone.

Step 3: Mapping the Factor C

Now, we can map the factor C. We have chosen to give these values:

- 0.45 for cultures, because we have considered that all the cultures were sugar canes (Mongkolsawat and al, 1994),
- 0.04 for savannah,
- 0.001 for forest, value usually given for dense rainforest.

With these values, we obtain a map of factor C. We make the map with a resolution of 25m to allow the cross-cutting of all the layers (Figure 14). In this new map, the urban areas are too small to appear.

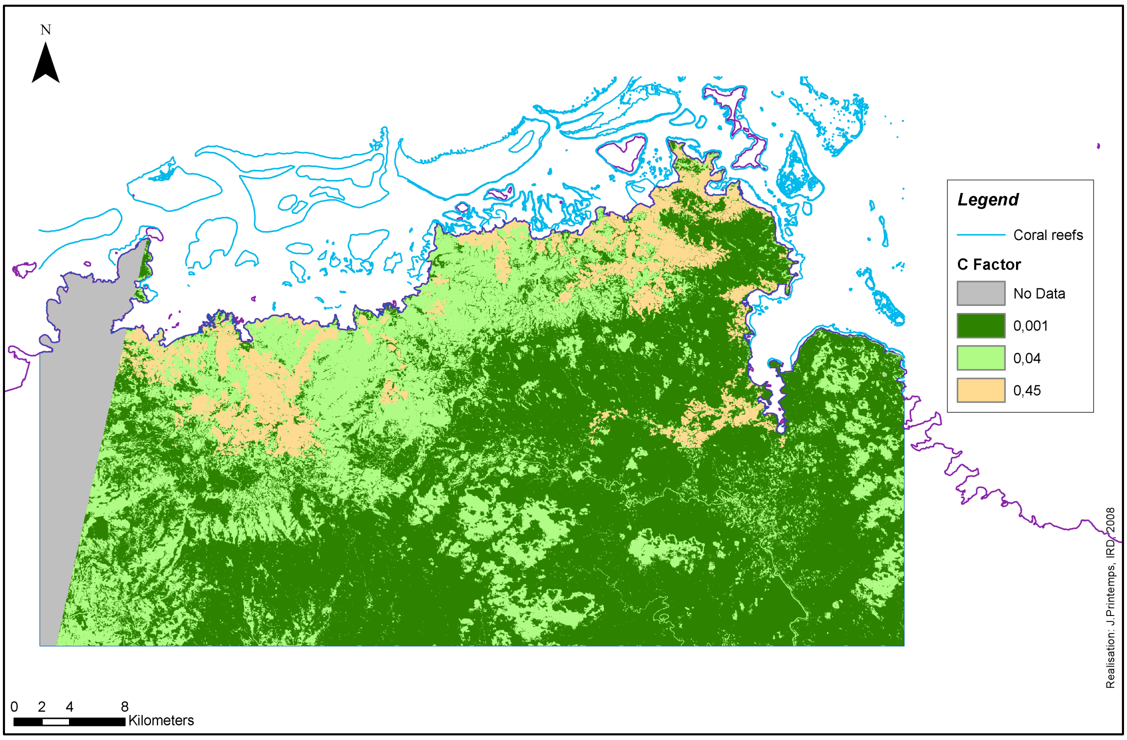

Figure 14: C Factor in the Study Area

3.6. SOIL CONSERVATION PRACTICE FACTOR P

The crops curves level, in alternating strips or terracing, reforestation on benches, mounding and ridge are the most effective practices of soil conservation. The P values are between 0 and 1, this value being given to land on which no practices cited is used.

Because of a lack of information on practices conservation tillage, we choose to adopt P = 1 over the study area. For this reason, it is considered invalid as anti-erosion and this factor will not impact the final product.

The results of the calculation of losses in soil will be slightly overvalued in relation to reality.

3.7. POTENTIAL SOIL LOSS MAP

We analyzed each factor of the model, we can know integrate these results and quantify soil loss. The overlay of the data is based on a combination in a mesh model (the size of pixels is 25m x 25m). This means that each layer of information is represented by a raster, whose value of each grid is equal to a level of sensitivity to erosion for the parameter in question. This level of sensitivity is represented by a previously defined value and is different for each parameter. All these rasters constitute a multivariate space.

Overlay is done by multiplication of values for the four factors: R, K, LS, C in the *Raster Calculator* under *ArcGIS*.

The result of this multiplication is a raster giving the amount of potentially soil loss in t/ha/yr over the study area (Figure 15). For purposes of clarity of the map, the values obtained were grouped into four classes and the distribution of the classes is shown by figure 16.

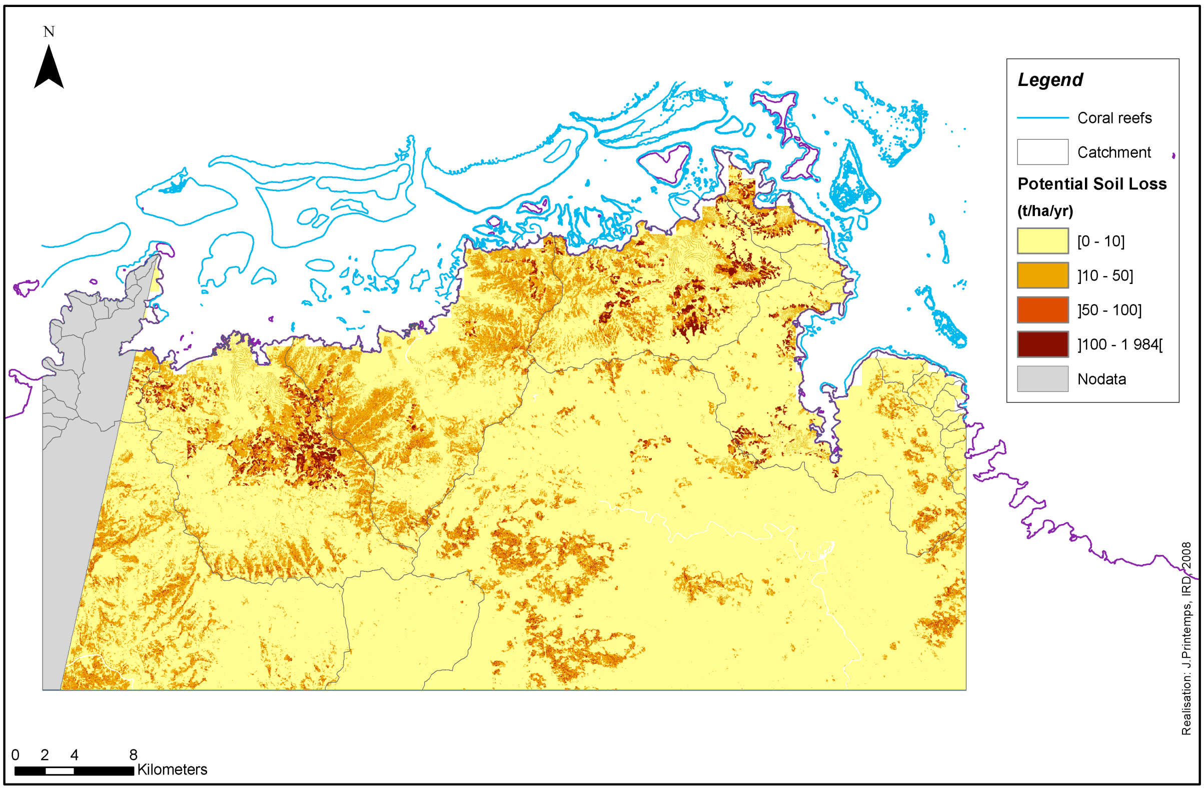

Figure 15: Potential Soil Loss Map in the Study Area

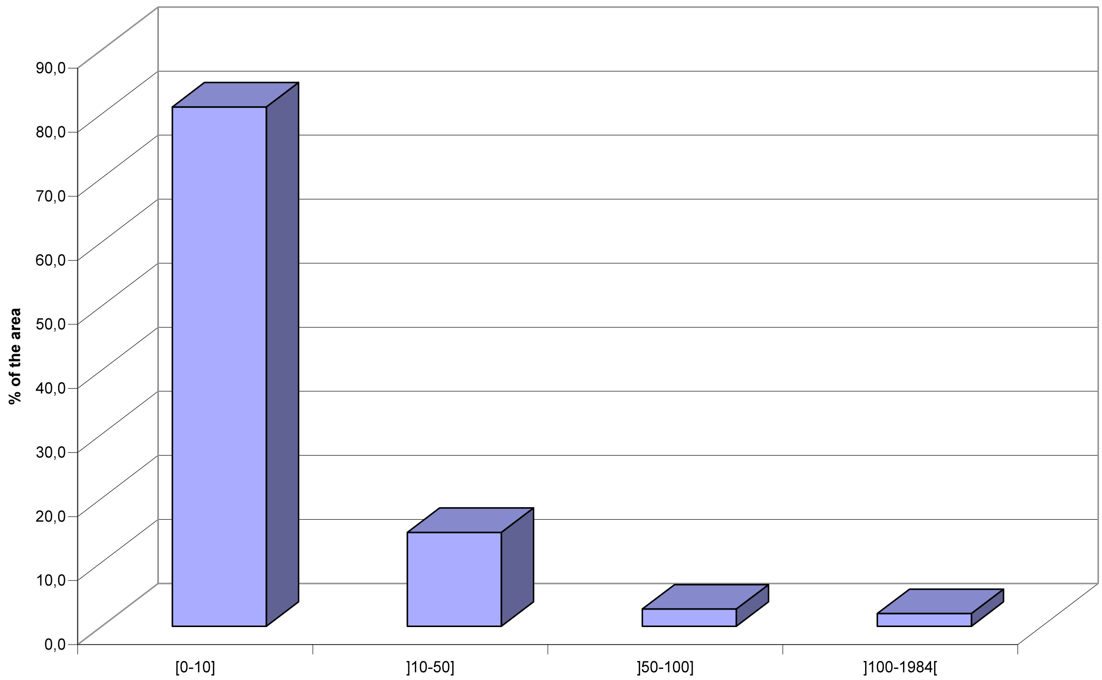

Figure 16: Distribution of soil loss classes

4. RESULTS AND DISCUSSION

4.1. ANALYSING THE POTENTIAL SOIL LOSS MAP

The implementation of the Wischmeier and Smith formula, taking into account the numerical values of the five factors, gives the potential soil loss for each pixel. The values of the potential erosion on the study area range between 0 and 1 984 t/ha/yr and help to highlight the areas most prone to erosion.

The average of the values obtained on the area is 7.77 t/ha/yr, corresponding to 0.51mm of soil loss for 1m² in one year. 81% of pixels in the study area have a potential erosion rate of less than 10 t/ha/yr and correspond mainly to the areas covered by dense vegetation (forest).
Only 2% of the area have a potential soil loss superior to 100 t/ha/yr and correspond mainly to areas where cultures and steep slopes are associated.

These results are compatible with other estimations in the literature all over the world. For example, we can find:

- 200 to 400 t/ha/yr in Tahiti (Servant, 1974),
- 0 to 40 t/ha/yr in Italia (van Der Knijff and al., 2000),
- 55.35 t/ha/yr in Morocco (Sadiki and al., 2004)

They are also compatible with estimations and studies led in Fiji Islands, for example:

- Morrison, in 1981, found soil loss rate around 36.7 t/ha/yr under sugar cane near Nadi,
- Liedke, in 1984, found soil loss rate between 16.6 and 80 t/ha/yr near Lautoka,
- Nelson, in 1987, found soil loss rate between 10 and 170 t/ha/yr on Rewa and Ba watersheds.

We can notice that they are under results found in New Caledonia which range from 0 to 11 500 t/ha/yr (Printemps, 2007). But it is also important to remind that Hudson, in 1971, suggested that the soil loss tolerance level for tropical soils is 13.5 t/ha/yr. 16% of our study area have a potential soil loss rate superior to 13.5 t/ha/yr. That's proving that it is necessary to underline priority zones which have a high erosion risk but let to tell that erosion in this area isn't a major problem.

These results can give some directions for future coastal management. Indeed, the culture areas on slopes are the main zones impacted by erosion. Guidelines for cultivating sugar canes on these conditions should be given as it has been already done in Agroforestry handbooks produced by MAFF in collaboration with GTZ (Ratukalou et al., 1999).

4.2. ADVANTAGES OF WORKING WITH GIS

The integration of the model in a GIS has many advantages, especially those related to the large number of results on the factors involved in erosion.

This integration allows:

- a rational management of a multitude of qualitative and quantitative data on the various factors of erosion. This leads to the conclusion that the decisive factors of erosion on the zone are the vegetation cover and the slopes and at a lesser degree the erodibility of soils and the rainfall. So interventions should be focused on the land cover management in the fight against erosion;
- the elimination of the complexity and interdependence of the parameters of erosion by crossing the layers information on the thematic maps of each factor calculated independently of others;
- the introduction of the concept of dynamism through continuous updating of data into the GIS;
- the implementation of a synthetic map representing the distribution of the potential sensitivity of soil to erosion over the study area. We obtain a combination of factors involved in the process erosive for each pixel of 25m x 25m.

4.3. LIMITS AND PERSPECTIVES

We have obtained a spatialisation and a quantification of potential soil loss on our study area. These results come from modelling and need to be validating by a field phase. To have a better calibration of the factors, field data are essential. For instance, the setting up of weather stations, sediment traps, measurements in the rivers could help for having a more precise model, particularly in terms of quantity.

Besides, GIS is a booming technique, which needs to be developed. All the data used are not in the same resolution and some needs to be update. For example, we used the World Climate Data for the rainfalls which is 1 km resolution and we have a land cover map derived from a satellite image with a resolution of 2.5 m. These differences affect the final results which must be taken as orders of magnitude and not as real values. Indeed, on the scale of a pixel and under the average, the results appear to be correct but on the scale of a watershed, results seem too high compared to the reality, highlighting the model's limits.

But, beyond digital data, the characterization of areas which there is a risk of erosion demonstrates the usefulness of the model as a tool of management and soil conservation. Indeed, the relative comparison among sectors of the study area is more important than the absolute soil loss in any cell.

Therefore, the spatialisation and quantification of potential erosion on North of Viti Levu constitute tools for the Integrated Watersheds and Coastal Management. On the one hand, the spatialisation can target areas of priority development; on the other hand, quantifying the potential erosion is a first step for quantifying the terrigenous contribution in the lagoon. Starting from the map of potential erosion, it is possible to sum the results by pixel on an entire watershed or region to have an idea of the quantities of land that can reach the lagoon.

As the USLE model doesn't take into account area of deposition, we have developed an algorithm which analyse topography to find the areas of deposition (Figure 17). The soil loss map, combined to the map of areas of deposition/delivery, leads to the assessment of reel contributions in terms of terrigenous inputs in the hydrographic stream.

From this and with hydrologic models, we are working on sediment transfers to have a better comprehension of the sediment transport and try to know how much can go into the lagoon.

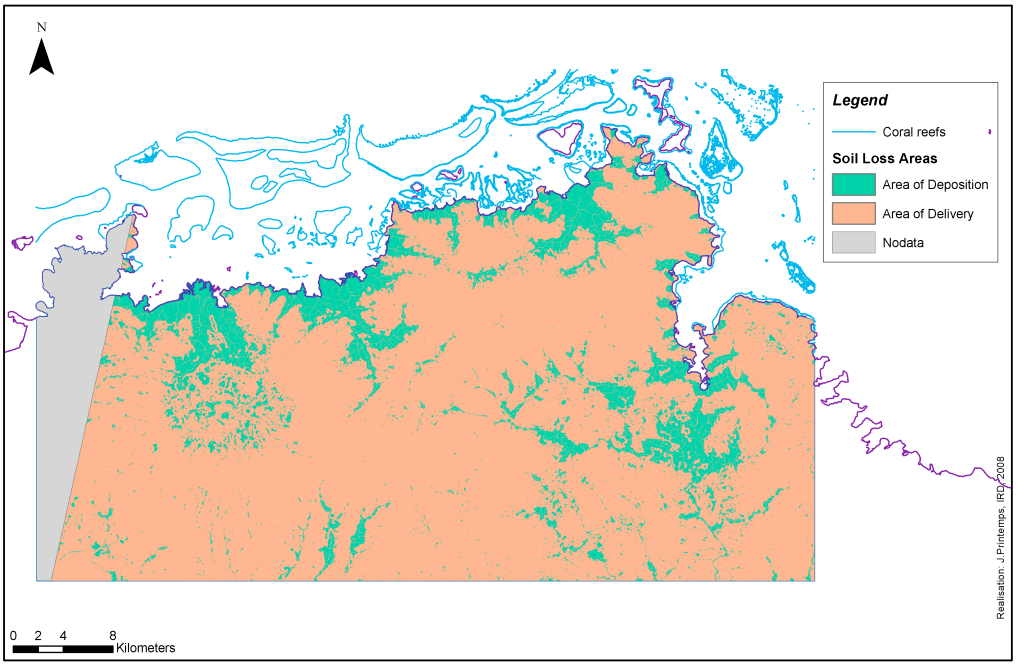

Figure 17: Areas of deposition and delivery on the study area

CONCLUSION

The implementation of the USLE model in Fiji can provide a better knowledge of the distribution of erosion hazard on the catchments of our study area. From the cross-cutting of four factors: the aggressiveness of rainfall, the soil erodibility, the slope length and steepness, the land cover and soil conservation practices, we were able to calculate and to map the potential soil loss with a resolution of 25m. Implemented in the North of Viti Levu, from Tavua to Rakiraki, this methodology has given potential soil loss rates between 0 and 1 984 t/ha/yr with an average of 7.77 t/ha/yr. These values correspond to low to medium erosion risk. The areas most impacted by erosion risk are those which are under soil cultivation (sugar cane) and on steep slopes.

The results allow us to establish an initial ranking of catchment areas most polluters in terms of terrigenous inputs production. Within an Integrated Coastal Zone Management, this study seems relevant. It identifies the catchment which risk areas should be classified as priority management to limit their impacts on the marine environment.

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, it is possible 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. From these studies, it would be possible to take some measures to reduce erosion on particular zones and to know if the best way is to plant trees, do contour-farming…

The USLE model is the first step towards a more precise estimation of terrigenous inputs spilled into the lagoon. To do that, several actions could be developed. Particularly, instrumentation of sites to dispose of field measurements on the terrestrial environment and on the marine environment could help to calibrate and validate the model. In the same time, it is necessary to work on taking better account of the dynamics of surface runoff with the use and implementation of hydrological transfer of sediments models. On the watershed scale, the final aim is to assess the sediment load to the marine environment from the values obtained for potential soil loss in order to protect coral reefs and marine zones.

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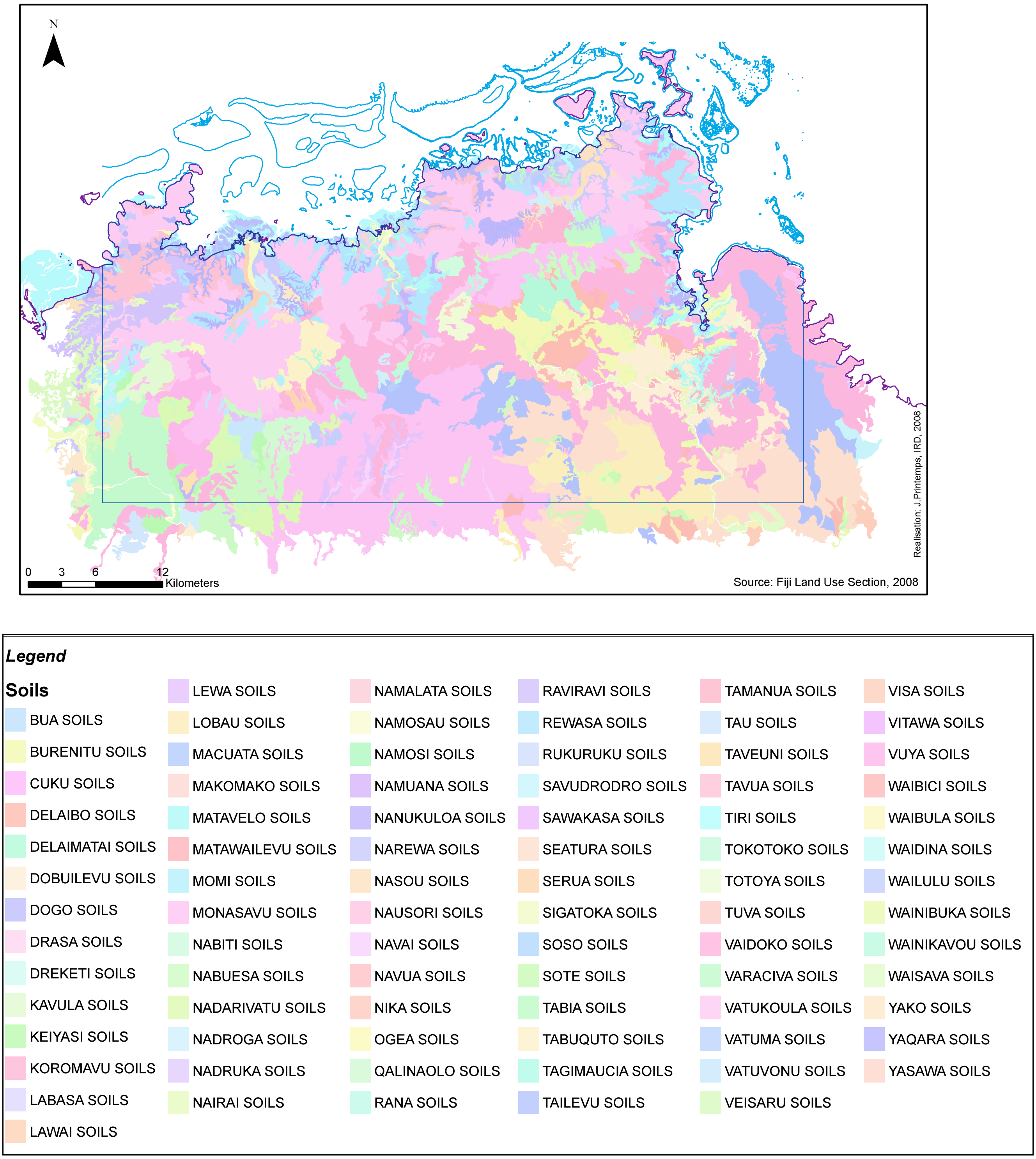
- all other partners, in New Caledonia and in Fiji.

ANNEX 1: Soil Map



ANNEX 2: Soil Classification and Texture

Soil Name	Set	Soil Taxonomy[4]	FAO[5]	Twyford and Wright[6]	Texture
BUA SOILS	Raviravi	Typic kanhaplustalf, very fine, ferruginous, isohyperthermic	Eutric Planosol	Ferruginous latosol with a strong dry season	Silty clay loam
BURENITU SOILS	Delaimatai	Typic haplustalf, fine, ferruginous, isohyperthermic	Eutric Nitosol	Humic latosol with a moderate dry season	Clay
CUKU SOILS	Vitawa	Typic ustropept, fine-silty, mixed, isohyperthermic	Eutric Cambisol	Steepland soil related or associated with red yellow podzolic soils with a strong dry season	Silty clay
DELAIBO SOILS		Typic eutropept, coarse-loamy, mixed, isohyperthermic	Eutric Cambisol	Steepland soil related to or associated with nigrescent soils with a weak dry season	Clay
DELAIMATAI SOILS		Typic kanhaplustalf, clayey, ferruginous, isohyperthermic	Dystric Nitosol	Humic latosol with a strong dry season	Clay
DOBUILEVU SOILS		Typic hapludoll, fine-loamy, smectitic, isohyperthermic	Haplic Phaeozem	Nigrescent soil with a weak to moderate dry season	Clay
DOGO SOILS		Typic sulfaquent, loamy over clayey, mixed, isohyperthermic	Thionic fluvisol	Saline soil of the marine marsh	Sandy clay loam
DRASA SOILS		Ultic haplustalf, fine, ferruginous, isohyperthermic	Eutric Nitosol	Humic latosol with a strong dry season	Clay
DREKETI SOILS	Dogo	Sulfic tropaquept, clayey, mixed, isohyperthermic	Thionic fluvisol	Saline soil of the marine marsh	Silty clay
KAVULA SOILS		Ustic dystropept, fine, kaolinitic, isohyperthermic	Dystric Cambisol	Steepland soil related to or associated with humic latosols with a strong dry season	Clay loam
KEIYASI SOILS		Typic haplustalf, fine, smectitic, isohyperthermic	Haplic Kastanozem	Nigrescent soil with a strong dry season	Silty clay loam
KOROMAVU SOILS	Vanuavou	Lithic urtorthent, loamy-skeletal, mixed, isohyperthermic	Eutric Regosol	Steepland soil related to or associated with nigrescent soils with a strong dry season	Silt loam
LABASA SOILS	Soso	Aeric topaquept, clayey over sandy, mixed, isohyperthermic	Dystric Gleysol	Saline soil of the marine marsh	Silty clay
LAWAI SOILS		Fluventic ustropept, loamy, mixed, isohyperthermic	Eutric Fluvisol	Recent soil from alluvium with a moderate to strong dry season	Silt loam

[4] Soil Taxonomy Classification System (Leslie and Seru, 1998)
[5] Food and Agriculture Organisation Classification (FAO, 1974)
[6] Twyford and Wright Classification System (1965)

Soil Name	***Set***	***Soil Taxonomy***	***FAO***	***Twyford and Wright***	***Texture***
LEWA SOILS		Oxic dystropept, fine, kaolinitic, isothermic	Dystric Cambisol	Upland ferruginous latosol with a weak dry season	Clay loam
LOBAU SOILS	Visa	Typic dystropept, fine, ferruginous, isohyperthermic	Dystric Cambisol	Steepland soil related to or associated with humic latosols with no dry season	Silty clay
MACUATA SOILS		Typic ustorthert, fine-loamy, kaolinitic, isohyperthermic	Dystric Cambisol	Ferruginous latosol with a strong dry season	Clay loam
MAKOMAKO SOILS		Typic haplustult, clayey, kaolinitic, isohyperthermic	Orthic Acrisol	Humic latosol with a strong dry season	Clay
MATAVELO SOILS					Clay
MATAWAILEVU SOILS	Dobuilevu	Typic argiudoll, very fine, kaolinitic, isohyperthermic	Orthic Luvisol	Nigrescent soil with a weak to moderate dry season	Clay loam
MOMI SOILS		Typic ustropept, fine, smectitic, isohyperthermic	Eutric Cambisol	Nigrescent soil with a strong dry season	Clay
MONASAVU SOILS		Oxic humitropept, fine, kaolinitic, isothermic	Humic Cambisol	Upland steepland soil related to or associated with humic latosol with no dry season	Clay loam
NABITI SOILS	Raviravi	Ustic dystropept, very fine, mixed, isohyperthermic	Dystric Cambisol	Ferruginous latosol with a strong dry season	Silty clay loam
NABUESA SOILS	Waibici	Oxic humitropept, fine, kaolinitic, isothermic	Humic Cambisol	Upland humic latosol with no dry season	Clay loam
NADARIVATU SOILS		Typic dystropept, fine-silty, kaolinitic, isothermic	Dystric Cambisol	Upland steepland soil related to or associated with humic latosol with a weak to moderate dry season	Clay loam
NADROGA SOILS	Vanuavou	Udertic haplustoll, fine, mixed, isohyperthermic	Haplic Kastanozem	Nigrescent soil with a strong dry season	Clay loam
NADRUKA SOILS		Cumulic haplaquoll, very-fine, kaolinitic, isohyperthermic	Mollic Gleysol	Gley soil related to latosols with a moderate to strong dry season	Clay
NAIRAI SOILS	Lakeba	Typic kandiustult, clayey, kaolinitic, isohyperthermic	Orthic Acrisol	Steepland soil related to or associated with ferruginous latosols with a moderate and strong dry season	Clay loam
NAMALATA SOILS		Udic haplustoll, fine, mixed, isohyperthermic	Hyplic Kastanozem	Humic latosol with a moderate to strong dry season	Clay
NAMOSAU SOILS		Typic acrustox, clayey, gibbsitic, isohyperthermic	Acric Ferralsol	Ferruginous latosol with a strong dry season	Silty clay loam
NAMOSI SOILS	Sote	Typic humitropept, fine, kaolinitic, isohyperthermic	Humic Cambisol	Humiclatosol with a weak or no dry season	Clay loam

Soil Name	Set	Soil Taxonomy	FAO	Twyford and Wright	Texture
NAMUANA SOILS	Sarowaqa	Typic dystropept, fine, kaolinitic, isohyperthermic	Dystric Cambisol	Steepland soil related to or associated with red yellow podzolic soils with a moderate dry season	Sandy clay
NANUKULOA SOILS		Typic ustropept, fine, mixed, isohyperthermic	Eutric Cambisol	Nigrescent soil with a moderate to strong dry season	Clay
NAREWA SOILS		Vertic haplaquoll, fine, smectitic, isohyperthermic	Eutric Gleysol	Gley soil associated with latosols with a strong dry season	Clay
NASOU SOILS	Drasa	Fluventic dystropept, fine, mixed, isohyperthermic	Dystric Cambisol	Humic latosol with a strong dry season	Clay loam
NAUSORI SOILS		Typic tropaquept, fine, kaolinitic, isohyperthermic	Eutric Gleysol	Gley soil with a very weak or no dry season	Clay loam
NAVAI SOILS		Fluventic hapludoll, fine, mixed, isothermic	Eutric Fluvisol	Recent upland soil from alluvium with a very weak or no dry season	Clay loam
NAVUA SOILS		Fluvaquentic eutropept, very-fine, kaolinitic, isohyperthermic	Eutric Cambisol	Gley soil with a very weak or no dry season	Silt loam
NIKA SOILS		Udic haplustert, fine, smectitic, isohyperthermic	Pellic Vertisol	Gley soil related to ingrescent soils with a strong dry season	Clay loam
OGEA SOILS		Typic eutrostox, clayey, ferruginous, isohyperthermic	Eutric Ferralsol	Latosolic soil with a moderate dry season	Sandy loam
QALINAOLO SOILS		Typic humitropept, fine, mixed, isothermic	Humic Cambisol	Upland humic latosol with no dry season	Clay loam
RANA SOILS		Typic troposaprist, euic, isohyperthermic	Eutric Histosol	Organic soil with a very weak or no dry season	Sandy loam
RAVIRAVI SOILS	Raviravi	Ustic dystropept, fine, kaolinitic, isohyperthermic	Dystric Cambisol	Ferruginous latosol with a strong dry season	Clay loam
REWASA SOILS	Nunukuloa	Udic haplustalf, fine, mixed, isohyperthermic	(Eutric) Luvisol	Nigrescent soil with a moderate dry season	Clay
RUKURUKU SOILS	Makomako	Ultic paleustalf, very fine, mixed, isohyperthermic	Eutric Nitosol	Humic latosol with a strong dry season	Clay loam
SAVUDRODRO SOILS		Typic humitropept, fine, kaolinitic, isohyperthermic	Humic Cambisol	Red yellow podzolic soil with a weak or no dry season	Sandy clay loam
SAWAKASA SOILS		Oxyaquic eutropept, fine, kaolinitic, isohyperthermic	Gleyic Cambisol	Gley soil related to latosols with a weak dry season	Clay loam

Soil Name	Set	Soil Taxonomy	FAO	Twyford and Wright	Texture
SEATURA SOILS	Visa	Oxic humitropept, fine, ferruginous, isohyperthermic	Humic Cambisol	Steepland soils related to or associated with humic latosols with no dry season	Clay loam
SERUA SOILS	Visa	Typic kanhaplohumult, clayey, ferruginous, isohyperthermic	Humic Acrisol	Steepland soil related to or associated with humic latosols with no dry season	Clay loam
SIGATOKA SOILS		Cumulic haplustoll, fine-silty, mixed, isohyperthermic	Eutric Fluvisol	Recent soil with a moderate to strong dry season	Clay loam
SOSO SOILS		Typic tropaquept, clayey, mixed, isohyperthermic	(Thionic) Gleysol	Saline soil of the marine marsh	Silty clay
SOTE SOILS		Typic humitropept, very fine, kaolinitic, isohyperthermic	Humic Cambisol	Humic latosol with a very weak or no dry season	Clay
TABIA SOILS	Drasa	Humic kandiustox, clayey, ferruginous, isohyperthermic	Humic Ferralsol	Humic latosol with a strong dry season	Clay
TABUQUTO SOILS		Typic kanhaplustult, clayey, kaolinitic, isohyperthermic	Humic Acrisol	Ferruginous latosol with a strong dry season	Loam
TAGIMAUCIA SOILS		Acrudoxic hapludand, medial, isothermic	Vitric Andosol	Upland latosolic soil with to dry season	Sandy clay loam
TAILEVU SOILS	Visa	Typic dystropept, fine, kaolinitic, isohyperthermic	Dystric Cambisol	Steepland soil related to or associated with humic latosols with a weak dry season	Silty clay loam
TAMANUA SOILS		Fluvaquentic eutropept, fine, kaolinitic, isohyperthermic	Eutric Fluvisol	Recent soil from alluvium with a very weak to no dry season	Silty clay loam
TAU SOILS		Lithic haplustoll, fine, smectitic, isohyperthermic	Haplic Kastanozem	Steepland soil related to and associated with nigrescent soils with a strong to moderate dry season	Clay loam
TAVEUNI SOILS		Hydric melanudand, hydrous, isohyperthermic	Humic Andosol	Latosolic soil with a weak dry season	Loam
TAVUA SOILS		Typic haplustalf, fine, smectitic, isohyperthermic	Eutric Nitosol	Nigrescent soil with a strong dry season	Clay loam
TIRI SOILS		Typic sulfaquept, clayey over fine loamy, mixed, isohyperthermic	Thionic Fluvisol	Saline soil of the marine marsh	Clay loam

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TOKOTOKO SOILS		Aeric tropaquept, very-fine, kaolinitic, isohyperthermic	Eutric Gleysol	Gley soil related to latosols with a very weak or no dry season	Silty clay loam
TOTOYA SOILS	Delaimatai	Udic haplustalf, fine, kaolinitic, isohyperthermic	Orthic Luvisol	Ferruginous latosol with a moderate to strong dry season	Clay
TUVA SOILS		Typic kanhaplustult, fine, ferruginous, isohyperthermic	Orthic Acrisol	Ferruginous latosol with a strong dry season	Silty clay loam
VAIDOKO SOILS	Vanuavou	Lithic hapludoll, fine, kaolinitic, isohyperthermic	Haplic Phaeozem	Steepland soils related to or associated with nigrescent soils with a moderate dry season	Clay
VARACIVA SOILS		Typic kanhaplustult, clayey, kaolinitic, isohyperthermic	Orthic Acrisol	Steepland soils related to or associated with ferruginous latosols with a strong dry season	Clay loam
VATUKOULA SOILS	Vanuavou	Udic rhodustalf, fine, mixed, isohyperthermic	Ferric Luvisol	Nigrescent soil with a strong dry season	Clay
VATUMA SOILS		Fluventic haplustoll, fine, mixed, isohyperthermic	Haplic Kastanozem	Recent soil from alluvium with a strong dry season	Clay loam
VATUVONU SOILS	Dakadaka	Lithic ustorthent, coarse-loamy, mixed, isohyperthermic	Eutric Regosol	Nigrescent soils with a strong dry season	Sandy clay loam
VEISARU SOILS	Veisaru	Typic tropaquept, fine, kaolinitic, isohyperthermic	Dystric Gleysol	Gley soil related to latosols with a moderate to strong dry season	Clay
VISA SOILS	Visa	Typic humitropept, fine, kaolinitic, isohyperthermic	Dystric Cambisol	Humic latosol with a very weak or no dry season	Clay
VITAWA SOILS	Vitawa	Typic haplustalf, fine, smectitic, isohyperthermic	Orthic Luvisol	Steepland soil associated with red yellow podzolic soils with a strong dry season	Clay loam
VUYA SOILS		Typic rhodustult, clayey, mixed, isohyperthermic	Dystric Nitosol	Humic latosol with a moderate to strong dry season	Clay
WAIBICI SOILS	Waibici	Oxic dystropept, fine, mixed, isothermic	Dystric Cambisol	Upland humic latosol with no dry season	Clay loam
WAIBULA SOILS	Wainibuka	Fluventic hapludoll, fine-loamy, mixed, isohyperthermic	Haplic Phaeozem	Recent soil from alluvium with a weak dry season	Sandy loam

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WAIDINA SOILS	Sote	Typic eutropept, fine, kaolinitic, isohyperthermic	Eutric Cambisol	Humic latosol with a very weak or no dry season	Silt loam
WAILULU SOILS	Wailulu	Oxic humitropept, fine, kaolinitic, isothermic	Humic Cambisol	Upland humic latosol with a weak dry season	Clay loam
WAINIBUKA SOILS		Fluventic hapludoll, fine, smectitic, isohyperthermic	Haplic Phaeozem	Recent soil from river alluvium with weak to moderate dry season	Clay
WAINIKAVOU SOILS		Epiaquic tropohumult, fine, kaolinitic, isohyperthermic	Humic Acrisol	Red yellow podzolic soil with a weak or no dry season	Silty clay loam
WAISAVA SOILS		Fluventic hapludoll, fine, smectitic, isohyperthermic	Haplic Phaeozem	Nigrescent soil with a weak to moderate dry season	Clay
YAKO SOILS	Moto	Entic haplustoll, fine, smectitic, isohyperthermic	Haplic Kastanozem	Nigrescent soil with a strong dry season	Clay
YAQARA SOILS	Tavua	Kanhaplic haplustalf, fine, kaolinitic, isohyperthermic	Eutric Nitosol	Nigrescent soil with a strong dry season	Silty clay loam
YASAWA SOILS		Typic ustipsamment, carbonitic, isohyperthermic	Arenosol	Recent soil from coastal sands with a strong dry season	Sandy