Food and Agriculture
Organization of the
United Nations

Forest Resources Assessment Working Paper **185/e**

TESTING FIELD METHODS FOR ASSESSING THE FOREST PROTECTIVE FUNCTION FOR SOIL AND WATER

FEBRUARY, 2015

Forest Resources Assessment Working Paper 185/e

Testing field methods for assessing the forest protective function for soil and water

A thematic study to assess the scientific accuracy and cost efficiency of different field methods for gathering data to promote forest management for protection of soil and water, aimed at identifying a method to recommend to developing countries

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FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
Rome, 2015

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Foreword

Forests have a significant role in soil and water protection. They protect soil from degradation and erosion and enhance water purity by acting as a filter. Increasing losses of life and property due to sediment-related disasters in developing countries underline the need to manage forest for the protection of soil and water. Such management involves addressing water supply, water quality, drainage, storm-water runoff, water rights, land degradation, erosion and the overall planning and use of watersheds. Forest management decisions made now will affect forests many decades into the future. Thus, it is important for managers to plan now for future disaster resilience and water security. Sustainable forest management is an important component in strategic planning for water security and sediment- and water-related disaster resilience, which is one of the prime objectives of FAO.

Reliable data on the soil and water protective function of forest will support forest managers in articulating specific goals and objectives for soil and water management functions of forest and incorporating them in management plans and practices for disaster resilience and water security. These data will also support awareness raising on the important protective functions of forest, especially soil and water protection.

To identify the most scientifically valid and least expensive method for collecting data on the soil and water protective function of forest in developing countries, FAO carried out a comparative study of four methods: visual forest floor cover assessment; forest canopy and floor cover assessment; line-point transect forest cover assessment; and forest floor cover biomass assessment. In collaboration with partner organizations in three pilot countries – Mexico, Nepal and Viet Nam – the methods were field tested during the summer of 2014. An international workshop with the pilot country counterparts in October 2014 then evaluated the methods for the accuracy of the forest cover and erosion data obtained, time required, costs of gathering data and ease of use in the field. The results of the study are presented here.

Following discussion among the country counterparts, the method ranked best of the four, the line-point transect method, was improved to include collection of information on soil erosion in addition to forest cover. The resultant "line-point transect forest cover and erosion assessment" method is recommended as the best method for use by developing countries to collect data indicative of the soil and water protective function of forest.

This report will be of interest to forest inventory practitioners and researchers interested in evaluating forest protective function. It is an important step towards collecting consistent and comparable data and improving capacity for reporting to national inventories and national and global forest resource assessments. These data will support evidence-based decision- and policy-making for sustainable forest management as well as awareness raising on the important protective functions of forest. The study is complementary to the Global Forest Resources Assessment 2015 (FRA 2015), which sets out an approach for using evidence of forest resource change in national forest programmes to support sustainable forest management. Countries are invited to adapt the method, as necessary, to fit national and subnational circumstances.

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Acknowledgements

FAO is grateful to the Government of Japan for launching the project "Improved Information to Promote Forest Management for Protection of Soil and Water" in the framework of the Global Forest Resources Assessment 2015 and for providing not only financial support but also the Japanese knowledge, expertise and experience. FAO would like to thank Ichiro Nagame and Koji Hattori, Forest Agency of Japan; Makiko Uemoto, Ministry of Agriculture, Forestry and Fisheries (MAFF) of Japan; and Mr Omori from the Embassy of Japan in Rome.

FAO also would like to thank colleagues from National Forestry Commission (CONAFOR) of Mexico, especially Jacinto Samuel García Carreón, and Jésus David Gomez and Moises Matìas Ramos from Chapingo University. Thanks also go to our colleagues from the Department of Soil Conservation and Watershed Management (DSCWM), Nepal and to Sony Baral from the International Union for Conservation of Nature (IUCN). We would also like to thank our colleagues from the Forest Protection Department of the Ministry of Agriculture and Rural Development (FPD, MARD) of Viet Nam and the Viet Nam Academy of Forest Science.

Finally, we would like to thank all the FRA team members and other FAO colleagues in Forestry and in other departments who contributed to the design and implementation of project activities, especially Monica Garzuglia, Thomas Hofer, Örjan Jonsson, Marisalee Palermo, Leticia Piña and Shigemi Teppei.

Abbreviations and acronyms

C	centre point of a sampling plot
E	east
FCP	forest floor cover percentage
FRA	Global Forest Resources Assessment
GDAL	Geospatial Data Abstraction Library
GPS	geographic positioning system
GRS	Geographic Resource Solutions
N	north
NDVI	normalized difference vegetation index
OFGT	Open Foris Geospatial Toolkit
OS	operating system
PVC	polyvinyl chloride
QGIS	Quantum Geographic Information Systems
S	south
UNFF	United Nations Forum on Forests
USB	Universal Serial Bus
VHR	very high resolution
W	west

1. Introduction

The protective function of forest is one of the seven thematic elements of sustainable forest management identified by the United Nations Forum on Forests (UNFF). Soil and water protection is one of the most significant contributions of forest (FAO, 2008; Neary, Ice and Jackson, 2009). Trees, forest litter and undergrowth maintain high-quality water through reduction of erosion and filtering of pollutants. By limiting runoff and ensuring that flows are predominantly subsurface, they help moderate peak flows and prolong base flows. Conversely, removal of trees leads to increased risk of flooding and drought.

The Global Forest Resources Assessment 2010 (FRA 2010) (FAO, 2010) found that 330 million hectares of forest are designated for protective functions, including soil and water conservation, avalanche control, sand dune stabilization, desertification control and coastal protection. The area of forest designated for protection increased by 59 million hectares (an 8 percent increase) between 1990 and 2010, primarily owing to large-scale plantation in China. Regional differences in the area of forest with a protective function were notable and were partly attributed to differences in reporting and in defining criteria for evaluating this function (FAO, 2010). More specifically, not all countries have a category in their national statistics for forests with soil and water protective function as a primary use. FRA 2010 highlighted a need to harmonize and clarify the criteria for reporting in this category.

To improve data collection and reporting to FRA and national inventories, with the ultimate aim of better evidence-based decision- and policy-making, FAO developed the project "Improved Information to Promote Forest Management for Protection of Soil and Water". Implemented with the support and cooperation of the Forest Agency of Japan, the project sought to identify an easy, low-cost data collection method for use by developing countries in assessing the soil and water protective function of forests. This method would provide the basis for guidance to developing countries on planning and conducting measurements in forest areas intended for soil and water resource protection.

In seeking to establish methods to assess the soil and water protective function, the question is not only how to collect the information, but which information to collect. In the past, most methodology focused on measuring canopy cover (e.g. Robards *et al*., 2000). Recognizing the role of understorey vegetation and forest floor cover in soil and water protection, Suchar and Crookston (2010) studied the understorey cover and biomass indices as potential indicators of the soil and water protective function of forest. There were no known studies, however, on the measurement of understorey vegetation for the assessment of the soil and water protective function of forests.

Methods for evaluating forest for its soil and water protective function were discussed during a January 2014 workshop in Rome. Four methods, all potentially feasible for implementation in developing countries, were identified for comparison in the field:

- visual forest floor cover assessment;
- forest canopy and floor cover assessment;
- line-point transect forest cover assessment;
- forest floor cover biomass assessment.

In collaboration with partner organizations in three pilot countries – Mexico, Nepal and Viet Nam – the methods were field tested during the summer of 2014. Participating countries were asked to provide feedback on the time invested and the cost inputs for data collection.

An international workshop with the pilot country counterparts in October 2014 then evaluated the methods for the accuracy of the forest cover and erosion data obtained, time required, costs of gathering data and ease of use in the field.

The line-point transect method was ranked the best of the four. However, the collaborators concluded that this method would be more accurate if it included information on soil erosion in addition to vegetation cover, and the method was modified accordingly. The resultant "line-point transect forest cover and erosion assessment method" is presented in Chapter 9 as the best method for gathering data that can serve as a proxy indicator for the soil and water protective function of forest.

2. Field test approach

The study compared four methods for gathering data relevant to soil and water protective function (Table 1):

- visual forest floor cover assessment;
- forest canopy and floor cover assessment;
- line-point transect forest cover assessment;
- forest floor cover biomass assessment.

Each method was tested on multiple sites in three countries – Mexico, Nepal and Viet Nam.

The term "site" refers here to the general location for the field test. Each site was defined as an area of approximately 2 500 ha. Each collaborating organization selected sites based on the following attributes. Sites should:

- be forest designated for soil and water protection;
- be covered under national forest inventory, with adequate descriptive data available including soil type, vegetation type, dominant species list and general forest structure;
- be easily accessible by those conducting the field test, e.g. close to a road and to the offices of field staff;
- have an array of understorey densities, ideally ranging from sparse to dense forest floor cover;

TABLE 1

Summary of methods (see Chapters 4 to 7 for details)

Method	Key elements	Variables	Equipment/supplies required
1. Visual forest floor cover assessment	Visual judgment and photographs for verification	Floor cover (%) Boulders and rocks (%) Erosion evidence	Clinometer Measuring pole Digital camera Measuring tape
2. Forest canopy and floor cover assessment	High resolution satellite images, canopy structure from the ground Forest floor pictures	Canopy (%) Canopy development class Species composition Point sampling of volume Forest floor cover (%)	High resolution satellite images Sampling for volume Prism or angle gauge Forest floor digital photographs OpenForis software (provided by FAO)
3. Line-point transect forest cover assessment	GRS Densitometer™	Overstorey and understorey forest cover	GRS Densitometer™
4. Forest floor cover biomass assessment	Quadrat sampling	Forest cover (%) Litter, dead material, debris Biomass	Frame for measuring Weighing scales Bags GRS Densitometer™ Tripod

- be covered by existing high resolution satellite imagery (either freely available or purchasable by FAO); thus areas generally covered by cloud cover were avoided. However, it should be noted that remote sensing images are not sufficient for the assessment of ground cover.

Within the sites, 20 m × 20 m plots were established for the measurements. All four methods were tested on each plot. Data were collected on 50 plots each in Nepal and Viet Nam and 150 plots in Mexico.

The methods were assessed on the basis of two main criteria: reliability and cost.

- Reliability was measured through a statistical analysis comparing the consistency of results using the different methods.
- Cost was calculated to include time spent by personnel (organized by general staff category) and other direct costs (e.g. materials, travel, training).

For ease of comparison and evaluation, it was important to ensure that all participating countries used the same formats for their data. To this end, project participants were asked to record precisely the time that field survey work started and ended each day and the number of people involved. In addition, they were asked to record the exact amount of time taken for lunch breaks, rest and commuting. It was also important to keep track of other direct costs such as petrol.

3. Preparation

SITE DESCRIPTION

The first step in carrying out the field survey was to describe the general information about the environment and forests of the survey sites. This information is necessary in order to analyse the state of forests for soil and water protective functions. General information on landform, parent material, climate and vegetation was recorded on the form in Annex 1. In addition, comprehensive data obtained from the national forest inventory could also be used to provide explanatory variables for evaluating soil and water protective functions if available. The participating countries were encouraged to compare general information from this project with existing national forest inventory data.

Landform

Since landform affects erosion rates, participants were asked to record altitude, slope inclination and direction in the field. Altitude was measured in metres using a GPS receiver. To establish slope inclination and slope direction, the downward water flow was measured with a clinometer and used as a reference point.

Parent material

Parent material affects soil characteristics including erodibility (the susceptibility of soil to erosion). Participants were invited to refer to published data such as geological maps. Where such geological data could not be obtained, a soil type from the site could be substituted. If a soil map had not been created for the area, soil types from the Harmonized World Soil Database (FAO, n.d.) were used.

Climate

Climatic conditions are the driving forces of soil erosion. Wind erosion is a critical factor in dry countries and water erosion is severe in humid countries. Air temperature also affects the decomposition of organic material on the forest floor, which is useful for soil aggregation. Annual precipitation, monthly average precipitation and mean annual temperature were recorded either from local weather station data or a global climate dataset.

Vegetation

Forest type and canopy and floor cover are key factors affecting soil and water. Of the natural factors affecting soil and water resource management, e.g. soil type, slope and climate, only vegetation can be manipulated. Thus, data on vegetation type and forest conditions are indispensable for managing forest for protective functions, and should be collected in an unbiased manner. The following information was recorded:

- biome: identified through reference to a local vegetation map or the world vegetation map (http://en.wikipedia.org/wiki/File:Vegetation.png);
- leaf type: broad leaf or needle leaf, and deciduous, evergreen or mixed;
- management: human-made/plantation or natural forest;
- basal area: measured using an angle gauge, with at least three replications.

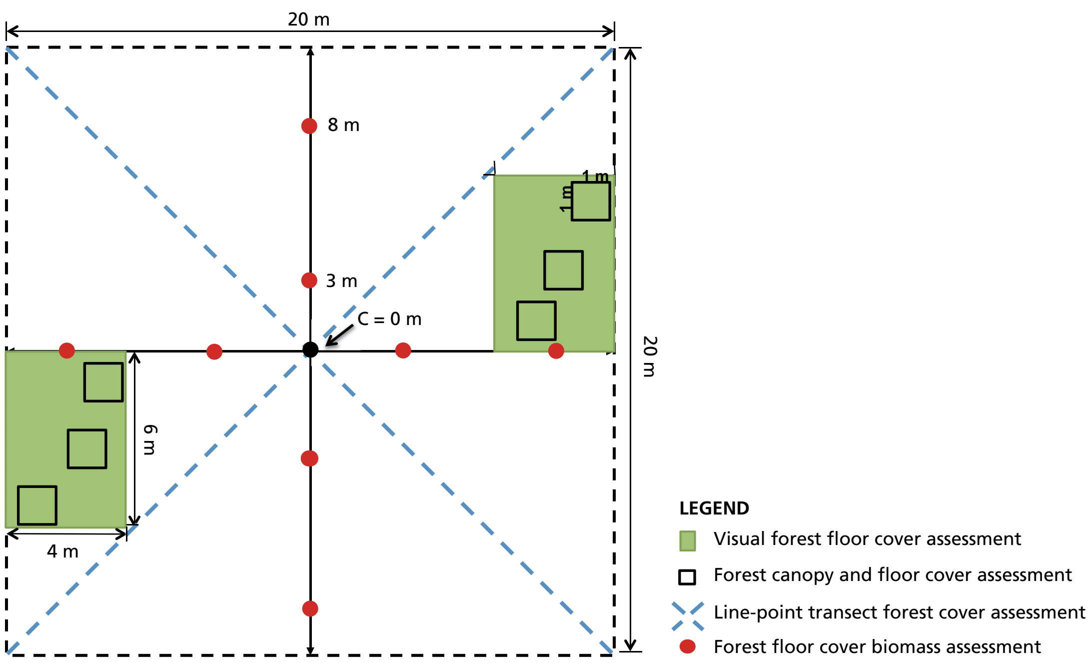
SET-UP OF SURVEY PLOTS

Plots were established measuring 20 m × 20 m, and the time taken to establish each plot was recorded.

For each plot, the centre point (C) (Figure 1) was determined with the aid of a hand-held GPS receiver or camera with GPS receiver, and the longitude and latitude were recorded.

FIGURE 1

Layout of 20 m × 20 m plot showing sampling for all four methods



4. Method 1: Visual forest floor cover assessment

This method assessed forest floor cover since it is an important factor in the protection of soil and water and is also an indicator of soil stability with regard to the presence or absence of evidence of soil erosion. This method was modified from the survey manual of the national forest monitoring system in Japan (Forest Agency of Japan, 2011).

SETTING UP SUBPLOTS

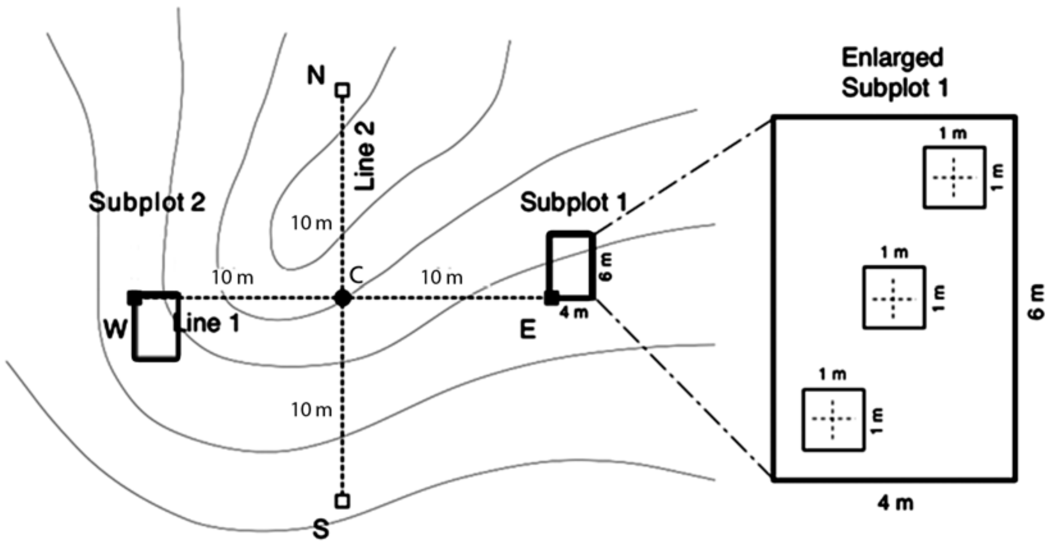
Two orthogonal lines were established to ensure a constant sampling area on all survey plots 10 m east and west and 10 m north and south from the centre (C) (Figure 2). Table 2 was used for any slope distance corrections.

The number of rills or gullies and any other traces of erosion such as soil pillars were immediately checked along these two lines, before any other data collection activities could destroy the traces of erosion. Photographs were taken of any observed erosion.

For visual assessment of floor cover, two 4 m × 6 m subplots were set up at 6 m east and west from C (Figure 2) using a compass and a measuring tape (Figure 3). The subplots could be located at 6 m north and south from the centre if east and west sites were not feasible for the intended survey.

FIGURE 2

Plot and subplot layout for Method 1 on a contour map



FOREST FLOOR COVER PERCENTAGE (FCP) AND EVIDENCE OF EROSION

Visual assessment was used to estimate the forest floor cover (percentage of forest floor area), the percentage of vegetative cover (understorey up to 80 cm tall) and the percentage of boulder, rock and litter cover. The data were recorded on the form in Annex 2.

TABLE 2
Conversion of slope distances for line and subplot measurements

Inclination (°)	Distance (m)			
	4.0	6.0	10.0	20.0
0–5	4.0	6.0	10.0	20.0
5–10	4.0	6.1	10.1	20.2
11–15	4.1	6.1	10.2	20.5
15–20	4.2	6.3	10.5	21.0
21–25	4.3	6.5	10.8	21.6
26–30	4.5	6.8	11.3	22.5
31–35	4.7	7.1	11.9	23.7
36–40	5.0	7.6	12.6	25.2
>40	Stop survey for your safety			

FIGURE 3
Subplot establishment in Method 1

R. KHANAL, IUCN NEPAL

5. Method 2: Forest canopy and floor cover assessment

Two types of data were compared in this method: very high resolution (VHR) satellite images and ground data. The method compared two variables from both data sources: canopy cover and forest floor cover. FAO trained country personnel in processing of the imagery.

SATELLITE IMAGERY

The method used VHR imagery from two satellites, QuickBird and WorldView. The products covered all sites and had the following characteristics: 0.5 m spatial resolution, 25 km^2 square zones centred on the sites, 0 percent cloud cover and four spectral bands (blue, green, red and infrared). Canopy cover was derived from this imagery.

Image processing utilities from the Open Foris Geospatial Toolkit (OFGT) library were used to extract information from the satellite imagery. FAO's Open Foris Initiative develops, shares and supports software tools and methods for multipurpose forest assessment, monitoring and reporting. The tools are free and open source and are available at www.openforis.org.

The working environment for the image processing tools is a Linux-based operating system (OS). During the training sessions, participants used live USB sticks (i.e. bootable flash drives) equipped with Xubuntu 14.04 and customized with specific tools from the Geospatial Data Abstraction Library (GDAL), OFGT, the R Project for Statistical Computing, and Quantum Geographic Information Systems (QGIS). A specific description of this OS environment can be found on the OFGT wiki.

Unsupervised classification of VHR satellite imagery

Unsupervised classification is an iterative process that classifies an image based on natural groupings of the spectral properties of the pixels, without the user specifying how to classify any portion of the image. Similar pixels are assigned to the same clusters. The user usually specifies basic information such as which spectral bands or combinations of bands to use and how many clusters finally to produce. Clusters must then be manually related to classes of interest (here land cover classes).

Here the aim of the process was to classify an image (e.g. Figure 4) into at least four classes: canopy, non-canopy, shadows, other.

The following steps were used to detect canopy cover from VHR imagery. These steps were embedded in the Perl script given in Annex 3.

Step 1: Image preparation

- Calculate ratios between bands that are used to enhance detection of features.
- Input image (four bands) consists of blue, green, red and infrared.
- Output image (five bands) consists of red, infrared, normalized difference vegetation index (NDVI), green/red and texture.
- Ratio calculation and band stacking are performed with oft-calc and oft-stack.
- Texture is calculated from the glcm R package.

FIGURE 4

Close up of QuickBird imagery, featuring road, bare soil, tree crown and tree crown shadows

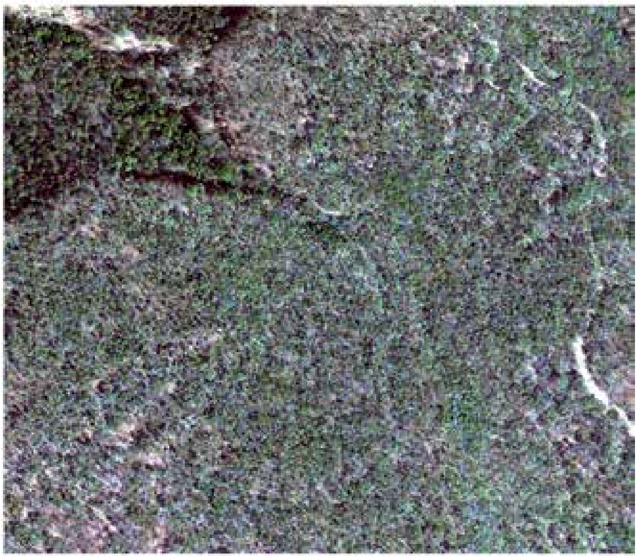


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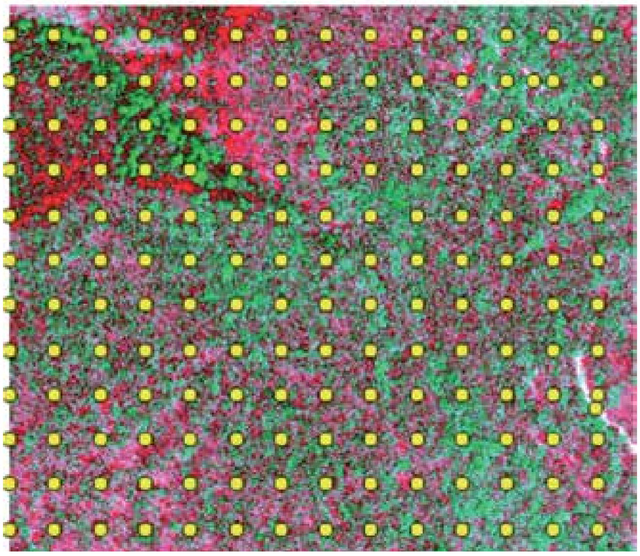
FIGURE 5

Systematic grid of points over the image



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Note: Special features can be added manually (see two points on the road)

Step 2: Grid generation

Generate a grid of points over the image for which to extract spectral features (oft-gengrid.bash). The spacing depends on the size of the data. By default, 15 × 15 = 225 points can be taken over the image. If obvious features are missed by the sampling, special points can be added manually (see road in Figure 5).

The spectral properties for the points generated over the imagery are extracted with oft-extr.

Step 3: Perform unsupervised classification

This is done with oft-kmeans and the results are sieved with gdal_sieve.py to eliminate individual pixels (Figure 6). The only parameter for the classification is the number of expected clusters which was set to 20.

Step 4: Assign a class for each cluster and calculate results

Each cluster must be visually assigned to a specific class. For each classification of a given image, the clusters will correspond to different classes: In general the lower clusters will correspond to dark classes (shadows, water) and the higher clusters to bright classes (bare ground, canopy), but this will change from one image to another and must be checked visually. An example of the correspondence between cluster and class is given in Table 3.

The final histogram is calculated with oft-his. With the pixel size known, it is possible to derive the area of each class, and the results are produced as a simple table. For the example in Table 3, for a total of 43.6 ha the classification showed 21.9 ha of tree canopy, 21.6 ha of bare soil and 556 m² of road.

FIGURE 6

Close-up of the automatically classified image

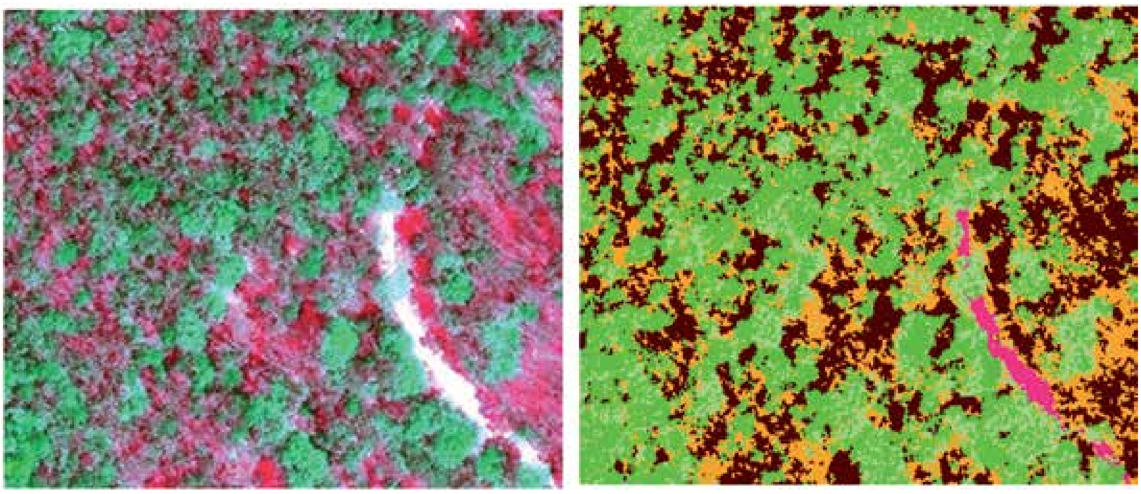

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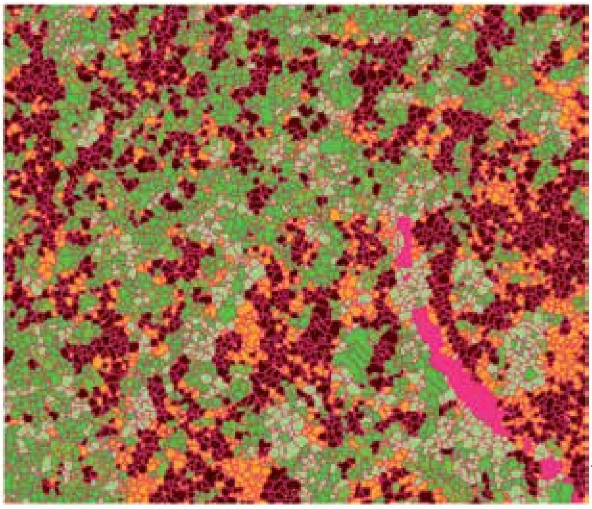
TABLE 3

Example of correspondence between cluster and class, with the associated histogram values

Cluster	1	2	3	4	5	6	7	8	9	10
Class	Shadow				Canopy		Shadow		Canopy	
Pixel (#)	100	55 462	132 861	160 389	42 986	79 457	101 163	126 413	118 217	67 149
Area (m²)	87 203				30 611		56 894		46 342	
Cluster	11	12	13	14	15	16	17	18	19	20
Class	Soil			Canopy			Soil	Canopy		Road
Pixel (#)	66 053	20 447	64 358	73 992	115 198	149 494	138 668	183 356	47 714	2 223
Area (m²)	37 715			84 671			34 667	57 768		556

Note: This correspondence is specific to the classification and must be checked visually.

FIGURE 7
Segments assigned with cluster values



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Step 5 (optional): Generate segments and produce an output vector layer
In addition it is possible to segment the imagery based on its relevant spectral properties (oft-seg) (Figure 7). The dimensionless parameter "threshold" will depend on the scene. For the example, a threshold of 10 was chosen. Zonal statistics could then be used to assign the majority cluster (oft-segmode) and calculate areas for each segment.

GROUND DATA

The ground photographs were obtained during field trips using a digital camera. A 1 m × 1 m pre-prepared polyvinyl chloride (PVC) frame was placed to mark out each subplot, two subplots per plot as shown in Figure 1 (page 6). The photographs were taken from directly above each frame, as vertically downwards as possible to avoid distortion. These photographs were later cropped to match the PVC frame and analysed digitally to determine the floor cover (FCP).

Three photographs per subplot were taken and referenced during the field campaigns. For 50 plots, this represented a database of 3 × 2 × 50 = 300 ground pictures to analyse, each with a unique ID to link with the field measurements. Personnel were advised not to take more numerous photographs because selecting and cropping them would have been difficult and time consuming later.

The software SamplePoint® (Booth, Cox and Berryman, 2006) was used to analyse the ground pictures. SamplePoint® provides a single-pixel sample point and the ability to view and identify the pixel context. It allows rapid measurements from image data with accuracy comparable to the most accurate field methods for ground-cover measurements. Expert use of the program requires minimal training. This tool is free and can be downloaded at www.samplepoint.org.

Point based assessment of floor cover from ground pictures

The following steps were used to build a database of images, feed it into SamplePoint® and assess the forest floor cover.

Step 1: Crop the images to match the frame

Images can be cropped using Windows Paint (Figure 8). Cropping to match the frame ensures comparability between field expert assessment and image analysis.

Step 2: Feed the database into SamplePoint®

Two parameters have to be set into SamplePoint® before the interpretation begins:

- the definition of the classes: soil, litter, plant, rocks, frame, erosion, other
- the spacing grid: 7 × 7 = 49 points

Step 3: Interpret points and generate results

The interpreters visually assess each point, for all the images in the database (Figure 9). Results are presented in an Excel spreadsheet giving the percentage of cover for each class over the database.

FIGURE 8

Cropping the ground picture to the dimensions of the frame

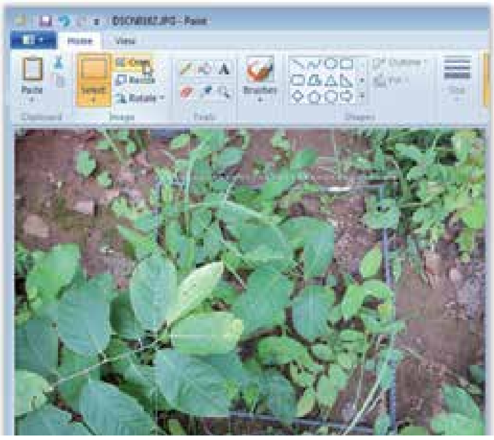

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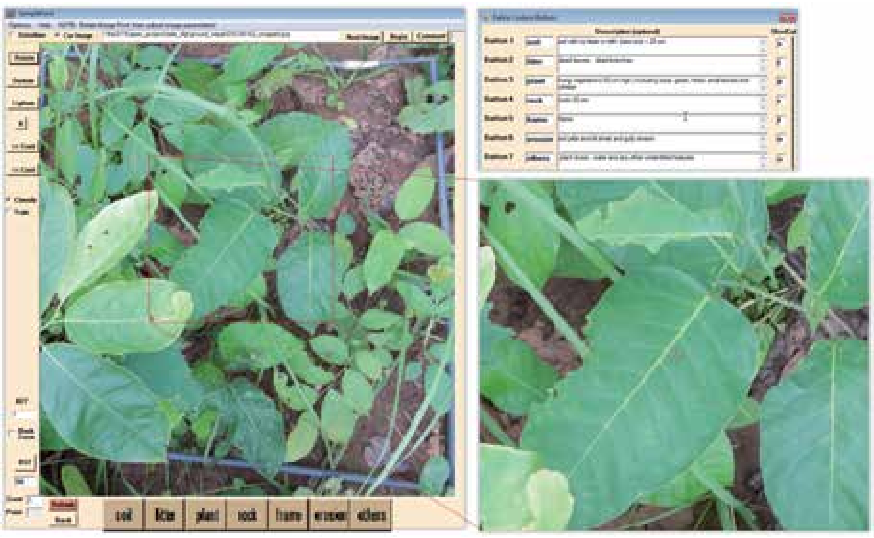
FIGURE 9

Overview of SamplePoint®



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6. Method 3: Line-point transect forest cover assessment

In line-point transect assessment the field technician tallies the vegetation or other landscape features at different points along a transect.

This method used a GRS Densitometer™, available from Geographic Resource Solutions (GRS), to measure crown cover. The GRS Densitometer™ uses a mirror to project a view of the sample location point in the canopy above to the person holding the instrument on the ground. The densitometer can be aligned to give an exact vertical line of sight into the canopy. Mounted inside the viewing tube are two levelling vials. The surveyor simply sights through the unit until the vial's bubbles are both level, then records the characteristics of the feature centred on the instrument's sighting dot (Figure 10).

The densitometer readings were taken by beginning at one corner of the plot and walking from one corner to the other, stopping every step as shown in Figure 11. The densitometer was used to determine whether the canopy reading was open sky or leaf/vegetation, and whether the ground reading was vegetation or other (e.g. bare soil, rocks, litter, moss). Along each diagonal line 30 readings were taken.

FIGURE 10

Point sampling using the GRS Densitometer™

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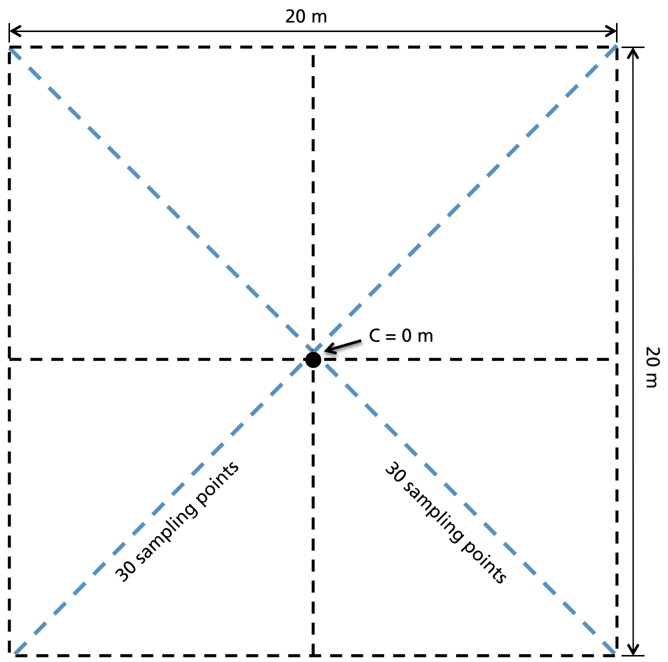
FIGURE 11

Densitometer canopy and ground cover sampling along diagonal lines



To prevent data error, it was important to adjust the densitometer to a horizontal position for each and every reading. A team of two readers and one recorder was recommended for swift data collection. The readers were instructed to announce the readings in a moderate and clear voice so the recorder could transcribe the reading in the data entry form shown in Annex 4. After recording the data for both transects, the data entry form was checked to make sure all readings were entered as completely as possible.

7. Method 4: Forest floor cover biomass assessment

In this forest floor cover measurement approach, herbaceous vegetation up to 80 cm tall was cut at the base and weighed. Vegetation was measured in small areas referred to as "clip plots". The average weight of herbaceous vegetation within the land use area was then extrapolated based on the average biomass found within the areas sampled.

PREPARATION

The first step was to create clip plot frames which could be made of various materials and could be circular or rectangular in shape. A 50 cm × 50 cm square clip plot frame made of PVC pipe was recommended.

A hanging field scale was calibrated at the base camp prior to field sampling.

FIELD MEASUREMENTS

In each 20 m × 20 m plot, eight clip plots were distributed along the two transecting 20 m lines as shown in Figure 12, at 3 m and 8 m from the centre. The clip plots were created by dropping the clip plot frame from a position parallel to the ground (Figure 13). All the herbaceous vegetation inside the area of the clip plot was clipped and weighed. If there was no herbaceous vegetation within the clip plot area, the herbaceous biomass was recorded as zero.

FIGURE 12

Layout of clip plots for forest floor biomass assessment

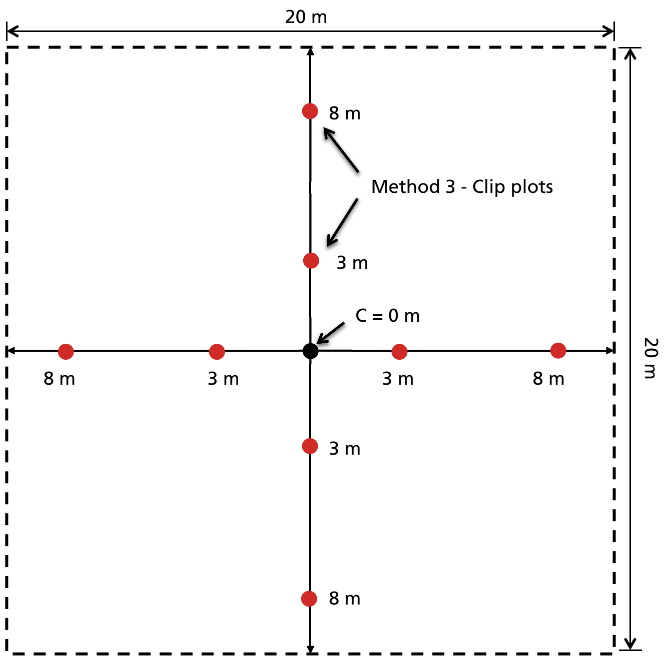


FIGURE 13
Example of a clip plot

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The herbaceous vegetation removed from each clip plot was placed in a subsample bag and weighed. The weight of an empty subsample bag was subtracted to obtain the weight of the vegetation only.

Then the subsamples from all clip plots were combined, and 100 to 300 g of this material was placed in a sample bag for further analysis. This composite sample was weighed and recorded (again, with the weight of the sample bag subtracted) and the sample bag was labelled with the plot identification number and weight.

The composite samples were taken to the laboratory and dried until a constant weight was reached (i.e. the dry weight). The ratio of wet weight to dry weight was calculated for these samples. This ratio was then used to estimate the total dry weight of non-woody vegetation found within the clip plots.

The same steps were repeated for the litter layer. Litter was defined as all dead organic surface material on top of the mineral soil. It includes some still-recognizable material (dead leaves, twigs, dead grasses and small branches) and some unidentifiable decomposed fragments of organic material. Dead wood with a diameter of less than 10 cm was included in the litter layer. The form in Annex 5 was used to record the data.

8. Ranking the methods

The statistical reliability of floor cover measurements and the cost (including time) were compared to identify the best method for data collection.

RELIABILITY

Analysis of variance (ANOVA), analysing the differences in group means among the forest floor cover data for all plots in all three countries, was carried out for the first three methods. Since Method 4 measured biomass only, it could not be compared with the other methods in this respect. The analysis revealed that Methods 1 to 3 were significantly different in the consistency of the data collected, as indicated by the three different connecting letters A, B and C. The forest floor cover data collected by Method 3 was the most consistent; the data sampled at various points deviated less from the mean than those collected using the other two methods, especially Method 1 (Table 4).

DATA COLLECTION COSTS

Information on time spent in all data collection activities was invaluable in ascertaining which of the method(s) was most cost effective and worthy of scientific application for future studies. The data sheet in Annex 6 was used to record the summary of time spent on all methods. The results (Figure 14 and Table 5) show not only that the different methods took different amounts of time, but also that the time varied among the countries. In all three countries Method 4, forest floor cover biomass assessment, required the most time and Method 3, line-point transect forest cover assessment, required the least time.

Figure 15 shows the main costs involved in collecting data for each method and travelling to the field. The running costs were highest for Method 4, forest floor cover biomass assessment, and lowest for Method 3, line-point transect forest cover assessment. The costs of travel to the field were higher than the running costs. FAO provided some of the equipment and materials, and some was already available in the countries (see Annex 7).

COMPARISON OF THE METHODS

The advantages and disadvantages of each method were compared during an international workshop attended by the pilot countries (Table 6). The participants noted that Method 3, line-point transect forest cover assessment, was the easiest to perform in the field whereas Method 4, Forest floor cover biomass assessment, was tedious. They also mentioned that Method 1, Visual forest floor cover assessment, needed experienced personnel to judge the percent cover because the method is not mechanical.

TABLE 4

Analysis of variance (ANOVA) for forest floor cover in all three pilot countries ($\alpha = 0.05$)

Method	Count	Mean	Variance	Connecting letter
Visual floor cover assessment	255	81.80	417.80	C
Forest canopy and floor cover assessment	255	89.02	245.06	B
Line-point transect forest cover assessment	255	91.97	154.27	A

Note: Levels not connected by the same letter are significantly different.

FIGURE 14

Data collection time for each method

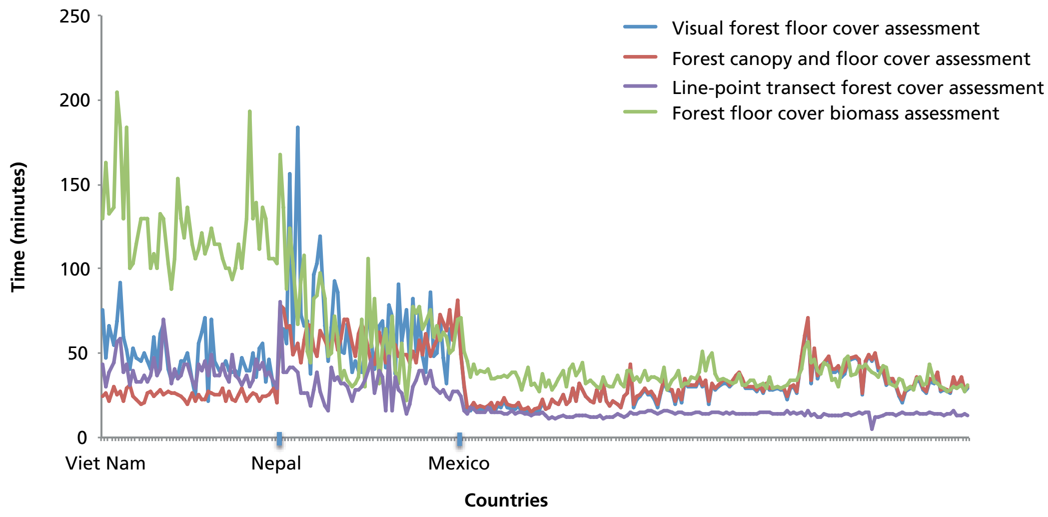


TABLE 5

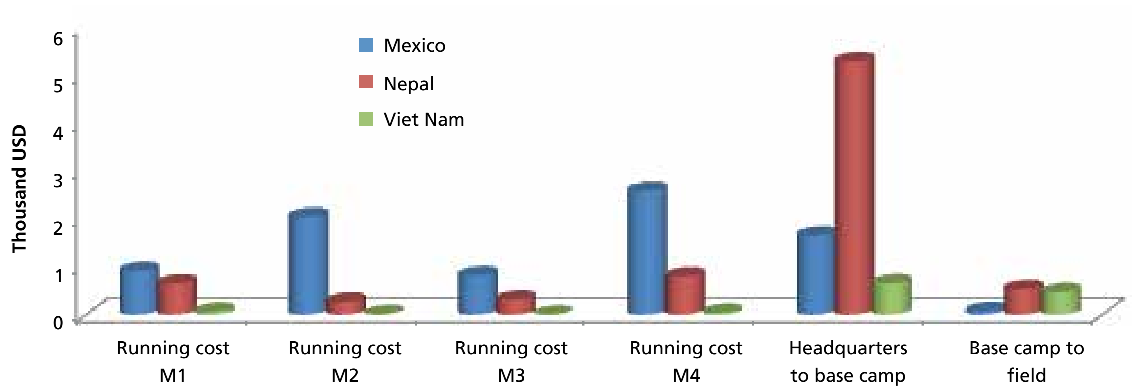
Analysis of variance (ANOVA) for data collection time among all four methods (α = 0.05)

Method	Count	Average	Variance	Connecting letter
Visual floor cover assessment	255	40.36	485.09	A
Forest canopy and floor cover assessment	255	34.64	219.81	B
Line-point transect forest cover assessment	255	22.88	156.10	D
Forest floor cover biomass assessment	255	59.95	1 489.85	C

Note: Levels not connected by the same letter are significantly different.

FIGURE 15

Partial expenses incurred during the project



Notes: M1 = visual forest floor cover assessment; M2 = forest canopy and floor cover assessment; M3 = line-point transect forest cover assessment; M4 = forest floor cover biomass assessment

Based on the above results and the discussion during the workshop, it was concluded that Method 3, the line-point transect method, was the best among the four methods tested in the field. However, this method was also seen to have the limitation of not capturing erosion evidence. The method was therefore modified to include erosion. The resultant “line-point transect forest cover and erosion assessment” method is presented in Chapter 9 as the recommended method for gathering data that can serve as a proxy indicator for the soil and water protective function of forest.

TABLE 6

Workshop discussion: advantages and disadvantages of the four methods

Advantages	Disadvantages	Improvements
Method 1: Visual forest floor cover assessment		
Easy to realize in the field, relatively quick Is the only method tested that includes early observation of erosion signs Low cost	Not really precise, very subjective evaluation, not very quantifiable Training and expertise required Field frame preparation can be difficult because of vegetation (but can be adjusted to the vegetation situation, as the recommended frame was only a proposal) Reference needed for understanding the percentages and the signs Needs more preparation than other methods	Provide reference, e.g. photographs Add one more assessment item about human disturbance Measure by transects
Method 2: Forest canopy and floor cover assessment		
Picture analysis is easy Very good method for forest cover, accessible to anybody with a good camera It is good to put down a frame before taking an image, as it gives a reference for the surface	Canopy analysis through satellite pictures can be difficult as very high resolution images are needed Distortion problem on slopes without equipment to keep the camera higher off the ground Satellite images are expensive and image analysis requires training	The measurement of the two variables (forest cover and canopy) should be separated Equipment is needed to make sure that the camera is 2 m from the ground, to be adjusted according to the inclination Improvements needed on how to take the pictures Subplot frame size should be larger in order to have better statistics and less error Can be improved with measurement of erosion
Method 3: Line-point transect forest cover assessment		
Easy and quick Precise and accurate Better confidence in the data collected, as they come from 60 measurements, which means better statistical results	For shrub conditions (thick and thorny) the other methods are quicker Densitometers need to be imported	Making a densitometer could be less expensive than buying one, although the one provided by FAO was not so expensive (approximately USD130) and very handy Can be improved with measurement of erosion
Method 4: Forest floor cover biomass assessment		
Different variables collected than in the other methods: biomass gives additional information about the vegetation cover	Very expensive; very long time required to process the biomass and get the information Difficult to have the laboratory equipment Variables measured are different than in other methods and thus cannot be compared The relation among biomass (herbaceous and litter) and forest cover and canopy cover is not so clear (it is just a separate variable)	Adjust for those countries that have no equipment to dry the biomass by focusing on live biomass and measuring the dry weight for only one subplot It is important to consider the best time for biomass estimation, according to the condition of the vegetation Biomass can be dried in a microwave oven for four cycles of 5 minutes each; this is not as scientifically correct as the long time in the oven, but is very practical Can be improved with measurement of erosion

9. Recommended method: Line-point transect forest cover and erosion assessment

This method uses a GRS Densitometer™, available from Geographic Resource Solutions (www.grsgis.com). The instrument uses a mirror to project a view of the sample location point in the canopy above to the person holding the instrument on the ground. The densitometer can be aligned to give an exact vertical line of sight up into the canopy or down to the ground. Mounted inside the viewing tube are two levelling vials. The surveyor simply sights through the unit until the vial's bubbles are both level, then records the characteristics of the feature centred on the instrument's sighting dot.

The data collection is best done by a team of three people, two persons taking the densitometer reading and the third recording the data.

Steps

1. Establish 20 m x 20 m plots (see Figure 16) with two east-west and north-south imaginary orthogonal lines to ensure a uniform unbiased sampling.
2. Use the densitometer to determine the crown and floor cover of the forest, as follows. Adjust the densitometer to a horizontal position. Walk from one end of the imaginary east-west line to the other, stopping to take a canopy reading (sky or leaf/vegetation) and a ground cover reading (vegetation, roots, forest litter, stones/rocks, dead wood and bare soil) at every step. Repeat for the north-south line. Take 30 readings along each line.

FIGURE 16

Quadrat with imaginary east-west and north-south lines along which 30 densitometer measurements each should be made

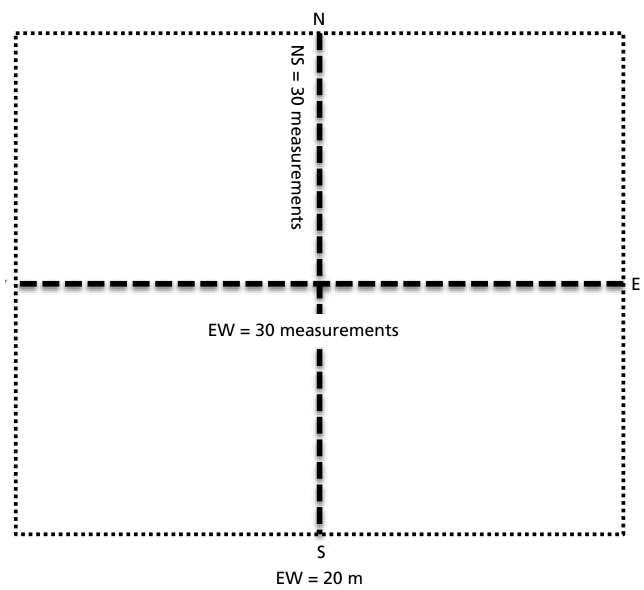


FIGURE 17

Example of erosion evidence: a high concentration of soil pillars, observed during the field study in Nepal

S. BARAL, IUCN NEPAL

3. The reader should announce the readings in a moderate voice, so as to allow the recorder to hear and transcribe the reading correctly. The recorder should make sure to fill in all the spaces in the data entry sheet (Form 2). To prevent data error, it is important to adjust the densitometer to a horizontal position for each and every reading.
4. While recording the canopy and ground cover, also record the presence of soil pillars as erosion evidence (Figure 17). Record the number of rills and gullies present along the lines and their width and depth. Also record the general slope of the sampling site.

10. Conclusions

This study tested four methods for collecting data on the soil and water protective function of forests. The study showed that the line-point transect forest cover assessment method was the most accurate, least expensive and most easily applied among the four methods tested. This method is scientifically accurate and records forest canopy and floor cover as a set. The instrument used in this method, the GRS Densitometer™, is small, light and easy to carry and comparatively cost efficient.

It is known that forest protects soil and water, but reporting on this function is not extensive and the mechanism of the protection is not clear. Therefore, it is desirable to identify the type or cover of forest that, along with other geophysical parameters, determines the protective function for soil and water. The discussions carried out in the context of this study concluded that comparing erosion evidence with vegetation parameters offers the most potential for understanding this function, and that a combination of vegetation cover, erosion evidence and slope could be used to derive a relationship. The vegetation cover and type and the slope parameters are different from site to site and biome to biome. Erosion evidence may be shaped by these parameters.

Therefore, after extensive discussion with the country coordinators of the field study, the authors of the study decided to modify the line-point transect forest cover assessment method to incorporate erosion evidence. The resulting line-point transect forest cover and erosion assessment method presented in this publication is therefore recommended for use in developing countries to enhance data collection and reporting on forest protective function for FRA and national inventories.

HOW THE DATA GATHERED USING THE RECOMMENDED METHOD CAN IMPROVE REPORTING ON THE PROTECTIVE FUNCTION OF FOREST FOR SOIL AND WATER

As the replication of sampling sites increases, it will be possible to answer the following questions with greater confidence.

- When does forest provide the protective function for soil and water?
- What forest indicator points out when forest management is necessary for the protection of soil and water?
- What is the critical topography for protection of soil and water?
- Can forest understorey cover be an indicator for the protection of soil and water? If yes, how? What percentage cover is critical under what topographic and hydrological conditions?
- What is/are the function(s) of the forest canopy for soil and water protection?
- What should be the critical level of forest canopy and ground cover for best management practices for soil and water protection?

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ANNEX 1

Collection form for general information on landform, climate and forest vegetation obtained from the field, weather bureau and forest inventories

Supervisor	
Date	
Landform (recorded or measured in the field)	
Altitude	
Slope (°)	
Slope direction	
Parent materials (from geo maps or database) or soil type (from soil map)	
Climate (from weather bureau)	
Annual precipitation (mm)	
Monthly average precipitation (mm)	
Mean annual temperature (°C)	
Mean monthly temperature (°C)	

Vegetation (from national forest inventory)	
Structure	
Composition	
Vegetation type	
Forest species	
Biome	
Vegetation (recorded or measured in the field)	
Leaf type	
Canopy cover	
Management type	
Basal area 1	
Basal area 2	
Basal area 3	
Average basal area	

ANNEX 2

Data collection sheet for Method 1: Visual forest floor cover assessment

<table>
<tr><td colspan="4"></td><td>Subplot 1</td><td>Subplot 2</td></tr>
<tr><td colspan="4">Date</td><td></td><td></td></tr>
<tr><td colspan="4">Surveyor</td><td></td><td></td></tr>
<tr><td colspan="4">ID No.</td><td></td><td></td></tr>
<tr><td colspan="6"></td></tr>
<tr><td rowspan="3" colspan="2">Site, plot</td><td>Site no.</td><td></td><td></td><td></td></tr>
<tr><td>Site name</td><td></td><td></td><td></td></tr>
<tr><td>Subplot position</td><td>[E, W, N or S]</td><td></td><td></td></tr>
<tr><td colspan="6"></td></tr>
<tr><td rowspan="9">Subplot</td><td rowspan="4">Coverage</td><td>Inclination (°)</td><td></td><td></td><td></td></tr>
<tr><td>FCP (%)</td><td>(litter or veg. <80 cm)</td><td></td><td></td></tr>
<tr><td>Understorey (%)</td><td>(only veg. <80 cm)</td><td></td><td></td></tr>
<tr><td>Boulder and rock (%)</td><td>(min. dia. >20 cm)</td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td rowspan="4">Erosion</td><td>Soil pillar</td><td>[1:Yes or 0:No]</td><td></td><td></td></tr>
<tr><td>Rill, subplot</td><td>[1:Yes or 0:No]</td><td></td><td></td></tr>
<tr><td>Gully, subplot</td><td>[1:Yes or 0:No]</td><td></td><td></td></tr>
<tr><td colspan="2">Number of photographs</td><td></td><td></td></tr>
<tr><td colspan="6"></td></tr>
<tr><td rowspan="3" colspan="2">Line</td><td>Line direction</td><td>(EW or NS)</td><td></td><td></td></tr>
<tr><td>Rill number, line</td><td></td><td></td><td></td></tr>
<tr><td>Gully number, line</td><td></td><td></td><td></td></tr>
<tr><td colspan="6"></td></tr>
<tr><td colspan="6">Time required to collect all data (from beginning to end per plot)</td></tr>
<tr><td colspan="6">Remarks</td></tr>
</table>

ANNEX 3

PERL script for unsupervised classification

```
################ Author :  Rémi d'Annunzio {mailto:remi.dannunzio@fao.org}
################ Last update :          30/07/2014
################ Description : The script takes a VHR imagery in input, prepares the imagery, performs an unsupervised classification and produces results

################  Define your path & set parameters
$rootdir = "/media/HD-PCU2/fra2015/japan_project/data_ofgt";
$resdir = "$rootdir/results";
$scriptdir = "$rootdir/scripts";

$nb_points=225;
$nb_clusters = 20;
$segment_size = 10;
$thresh_seg = 100;

if(@ARGV[0] eq ''){die("Usage : perl /my/path/classify_satellite.pl <input.tif>\n");}

##########################################################################################
########### Read imagery names and paths
$vhrimg = `basename @ARGV[0]`;
$image=`readlink -f @ARGV[0]`;
chomp($image);
chomp($vhrimg);

$imagedir = substr($image,0,-length($vhrimg));
$vhr = substr($vhrimg,0,length($vhrimg)-4);

print "$vhr\n";
print "$imagedir\n";

########### If necessary create a working directory
chdir $resdir;
mkdir "results_$vhr";
$workdir="$resdir/results_$vhr";
chdir $workdir || die "Failed to locate $workdir: $!";

##########################################################################################
########### Analyse imagery info
@info=`gdalinfo $imagedir/$vhr.tif`;
#print "@info\n";

#look for text "Pixel Size"
@pixline= grep /Pixel Size/,@info;
```

```
############change from array to vector
$pixline=@pixline[0];

############remove extra spaces
chomp($pixline);

############ replace expression "Pixel Size = (" by "" (nothing)
$pixline =~ s/Pixel Size = \(//;

############split by comma then take the left
($pix,$rest)=split(",",$pixline);
chomp($pix);

@sizeline= grep /Size is/,@info;
$sizeline=@sizeline[0];
chomp($sizeline);
$sizeline =~ s/Size is //;
($size_x,$size_y)=split(",",$sizeline);
chomp($size_x);
chomp($size_y);
$size=$size_x*$size_y;

print "Imagery consists of $size pixels of resolution $pix \n";
$spacing = $size_x * $pix / sqrt($nb_points);

print "spacing between points  = $spacing\n";
chdir "$workdir";
#die;
#=comment
open(MYFILE,">>$workdir/log_$vhr.txt");

###############################################################################
############ Create a log file
$time = localtime;
print  MYFILE "##############################\nNew session begins at $time \n";

###############################################################################
############ Generate a grid of point, extract information from the image
system "oft-gengrid.bash $imagedir/$vhr.tif $spacing $spacing grid.txt";
$time = localtime;
print  MYFILE "grid generated at $time \n";

###############################################################################
############ Calculate texture
system "Rscript $scriptdir/texture_glcm.R $imagedir/$vhr.tif $vhr\_texture.tif";

###############################################################################
############ Calculate NDVI
system "oft-calc $imagedir/$vhr.tif temp.tif <<aof \n 4 \n #3 \n #4 \n #4 #3 - #4 #3 + / 100 *
\n #2 #3 / 100 * \n aof";
```

```
##################################################################################
########### Stack imagery, compress, and remove temp files
system “oft-stack -o temp_text.tif temp.tif $vhr\_texture.tif”;
system “gdal_translate -co \”COMPRESS=LZW\” temp_text.tif $vhr\_5b.tif”;
system “rm temp*.tif”;
$time = localtime;
print  MYFILE “ratio calculated at $time \n”;

##################################################################################
########### Extract spectral signature
system “oft-extr -o extr.txt grid.txt $vhr\_5b.tif <<aof \n 2 \n 3 \n aof”;
$time = localtime;
print  MYFILE “point info extracted at $time \n”;

##################################################################################
########### Perform the classification
system “oft-kmeans -o $vhr\_km.tif -i $vhr\_5b.tif <<aof \n extr.txt \n $nb_clusters \n aof”;
system “gdal_sieve.py $vhr\_km.tif $vhr\_km\_sieved.tif”;
system “rm $vhr\_km.tif”;
system “oft-his -i $vhr\_km\_sieved.tif -o $vhr\_hist.txt <<aof \n $nb_clusters \n aof”;
$time = localtime;
print  MYFILE “classification done at $time \n”;

##################################################################################
########### Generate segments and burn classified results into segments
# parameters for segmentation are NO_DATA_VALUE=0, Min_seg_size=$segment_size,
Min_spec value = 0 and weighting=0

system “oft-seg -region -ttest -automax $vhr\_5b.tif temp.tif <<aof \n 0 \n $segment_size \n
0 \n 0 \n aof”;
$time = localtime;
print  MYFILE “segmentation done at $time \n”;
#system “oft-seg -region -th $thresh_seg $vhr\_5b.tif temp.tif <<aof \n 0 \n 0 \n aof”;

system “oft-segmode.bash temp.tif $vhr\_km\_sieved.tif $vhr\_segs.tif”;
system “gdal_polygonize.py -f \”ESRI Shapefile\” $vhr\_segs.tif $vhr\_segs.shp”;
system “oft-addattr.py $vhr\_segs.shp DN km_class $vhr\_segs.tif.txt”;
$time = localtime;
print  MYFILE “polygons generated at $time \n”;
close MYFILE;
```

ANNEX 4

Data sheet for Method 3: Line-point transect forest cover assessment

Plot No.:	Transect No.:
Location:	Supervisor:
Topography:	Data recorder:
Vegetation type:	
Starting coordinates:	

Legend

Canopy reading: L (leaf); S (sky)

Ground reading: 0 (vegetation); 1 (roots); 2 (forest litter); 3 (stone/rock); 4 (dead wood); 5 (bare soil)

Point No.	Canopy reading	Ground reading		Point No.	Canopy reading	Ground reading		Point No.	Canopy reading	Ground reading
1				21				41		
2				22				42		
3				23				43		
4				24				44		
5				25				45		
6				26				46		
7				27				47		
8				28				48		
9				29				49		
10				30				50		
11				31				51		
12				32				52		
13				33				53		
14				34				54		
15				35				55		
16				36				56		
17				37				57		
18				38				58		
19				39				59		
20				40				60		
Time required (minutes):										
Remarks:										

Computation: Canopy reading = No. of sky/No. of transects × 100%

Ground reading = No. of vegetation/No. of transects × 100%

ANNEX 5

Data collection for Method 4: Forest floor cover biomass assessment

Date			
Site			
Plot No.			
Data recorder			
Field supervisor			
Herbaceous vegetation			
Clip plot	Field weight (g)	MC sample weight (g) (dried)	Remarks
1		Sample dried in the laboratory	
2			
3			
4			
5			
6			
7			
8			
Litter			
Clip plot	Field weight (g)	MC sample weight (g) (dried)	Remarks
1		Sample dried in the laboratory	
2			
3			
4			
5			
6			
7			
8			
Time required to collect samples			

ANNEX 6

Total time record form for each method (summary)

Date		
Site		
Field supervisor		
Time record (minutes)		
Operation		Time
Access by car		
Access by other transportation		
Access by foot		
Operation		Time
Method 1	Preparation in the field	
	Data or sample collection	
	Sample preparation	
	Sample analysis	
	Data input	
	Data analysis	
Method 2	Preparation in the field	
	Data or sample collection	
	Sample preparation	
	Sample analysis	
	Data input	
	Data analysis	
Method 3	Preparation in the field	
	Data or sample collection	
	Sample preparation	
	Sample analysis	
	Data input	
	Data analysis	
Method 4	Preparation in the field	
	Data or sample collection	
	Sample preparation	
	Sample analysis	
	Data input	
	Data analysis	

ANNEX 7
Equipment and materials

Equipment provided by FAO to each pilot country (one each):

- 2–5 kg hanging scale
- 300 g hanging scale
- Densitometer
- Digital camera with GPS

Equipment provided by the countries

- Drying oven
- Laboratory scale
- Calibration weights

Equipment that countries were asked to prepare in advance of the fieldwork

	No. of pieces
• Slant meter, angle meter, clinometer	1
• Measuring tape, 50 m	2
• Measuring tape, 30 m	1
• Marking iron pegs	8
• Square frame (1 × 1 m)	1
• Clip plot frame (50 × 50 cm)	1
• Clippers to remove vegetation	4
• Hand saw	1
• Durable plastic sheeting	10
• Cloth or paper sample bags	250
• Compass	1
• Hammer	1
• Red and white surveyor's pole	2
• Field notes and pencils, ballpoint pens	3

Other miscellaneous materials

- Raincoats (if the weather is bad)
- Petrol
- Stationery not included in the above list

Glossary

Adapted from Society of American Foresters, 1998; FAO, 2012; IPCC, 2003

Altitude
Height above mean sea level

Basal area
The area of a given unit of land occupied by the cross-section area of tree trunks and stems measured at breast height

Biome
A regional ecosystem with a distinct assemblage of vegetation, animals, microbes and physical environment often in a certain climate and soil

Boulder
A rock with grain size of usually no less than 30 cm diameter

Canopy cover
The percentage of the ground covered by a vertical projection of the outermost perimeter of the natural spread of the foliage of plants; cannot exceed 100 percent (also called crown closure or crown cover)

Clinometer
A surveying instrument for measuring angle of elevation or slope, or incline of a landform

Clip plot
Field plot used for the collection of biomass samples

Erosion
The wearing away of material from the earth's surface by natural processes such as weathering, dissolution, abrasion, corrosion and transportation

Floor cover
Vegetation or litter that covers the forest floor

Forest
Land spanning more than 0.5 ha with trees higher than 5 m and canopy cover of more than 10 percent, or trees able to reach these thresholds *in situ*; does not include land that is predominantly under agricultural or urban land use

Forest cover
Total cover of the forest area delineated by vertical projection

Gully
A dry channel of 30 cm or more in both width and depth, left behind as a consequence of severe overland flow during precipitation; note that gullies are not smoothed by farm tillage, whereas rills (which are less than 30 cm in width and depth) are

Herbaceous biomass
Biomass of living vegetation dominated by non-woody plants known as herbs

Image cropping
Removal of the outer parts of an image to focus on an area of interest

Image histogram
Number of pixels occupied by each given cluster/class in an image

Landform
A specific geomorphic feature on the surface of the earth; can range from plains, plateaus, and mountains to hills, valleys and alluvial fans

Litter
Dead plant residue covering the forest floor

Normalized difference vegetation index (NDVI)
A simple indicator that can be used to analyse remote sensing measurements and assess whether the target being observed contains live green vegetation

Overstorey forest cover
See Canopy cover/Crown cover

Parent material
The geologic material (mineral or organic) from which soil develops

Plot
An experimental unit, or a specific area in the forest established for the purpose of sampling

Quadrat
A square or rectangular plot of land marked off for the study of plants and animals

Remote sensing image
The use of aerial sensor technologies to detect and classify objects on Earth, both on the surface and in the atmosphere and oceans, by means of propagated electromagnetic radiation signals

Rill
A dry channel of less than 30 cm in width and depth, left as consequence of severe overland flow during precipitation; note that rills are smoothed by farm tillage, whereas gullies (which are more than 30 cm in width and depth) are not

Rock
A naturally occurring solid aggregate of one or more minerals

Satellite imagery
Images of the Earth collected by artificial satellite

Slope
Gradient or steepness of terrain

Soil pillar
Soil column capped by leaves, roots, pebbles, gravel or twigs, formed during overland flow scouring; used as an indicator of sheet erosion

Texture
A set of metrics calculated in image processing designed to quantify the spatial arrangement of colour or intensities in an image

Topography
Relief features or ground surface configuration of an area

Understorey
An underlying layer of vegetation, especially the plants that grow beneath a forest canopy

Understorey density
Density of vegetation in the understorey of a forest

Vegetation composition
Biodiversity of an ecological system, including the variety of genes, species, communities, and ecosystems

Vegetation structure
Physical arrangement of various physical and biological components of a forest

Vegetation type
Vegetation in an assemblage where there is a characteristic dominant species or species, or a common aspect of the assemblage

Prepared with the support of the **Ministry of Agriculture, Forestry and Fisheries of Japan**

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I4509E/1/04.15