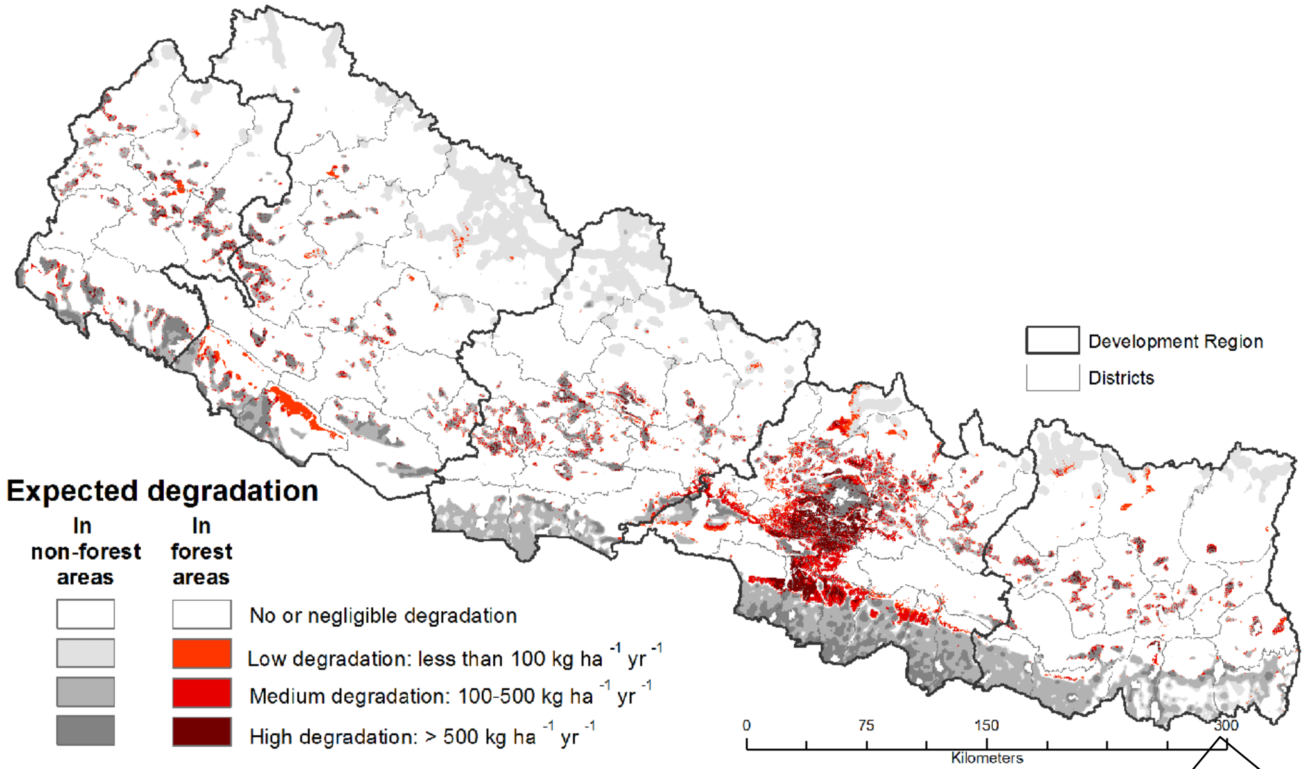
UN-REDD Programme Targeted Support (UNJP/GLO/386/UNJ) - Nepal

Data analysis for estimating emissions from forest degradation due to fuelwood harvesting in the context of Nepal's Forest Reference Level (FRL) construction



Update and upgrade of WISDOM* Nepal

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*** Woodfuel Integrated Supply/Demand Overview Mapping**

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Acronyms and abbreviations

ad	Air-dry (9 % moisture content, wet basis, according to FRA Nepal)
AGB	Aboveground Biomass
CBS	Central Bureau of Statistics
DEB	DendroEnergy Biomass (woody aboveground biomass less stump and twigs)
DFRS	Department of Forest Research and Survey
DM	Dry Matter, 0% moisture content, equivalent to oven-dry (od)
DTM	Digital Terrain Model
ESA	European Space Agency
FAO	Food and Agriculture Organization of the United Nations
FD	Forestry Department
fNRB	fraction of Non Renewable Biomass (i.e. non sustainable fraction)
FRA	Forest Resources Assessment
FRL	Forest Reference Level
Fw	Fuelwood
GACC	Global Alliance for Clean Cookstoves
GDB	Geodatabase
GIS	Geographic Information System
HH	Household
ICIMOD	International Centre for Integrated Mountain Development
kt	kilo tons ('000 metric tons)
LC	Land Cover
LCC	Land Cover Change
MAI	Mean Annual Increment
MFSC	Ministry of Forests and Soil Conservation
MODIS	Moderate-resolution Imaging Spectroradiometer
MPFS	Master Pland of the Forestry Sector
MRV	Measurement, Reporting and Verification of the UN-REDD Proghramme
NFI	National Forest Inventory
NLSS	Nepal Living Standars Survey
od	Oven-dry, at 0% moisture content
PPS	Probability Proportional to Size
REDD+	Reduced Emissions from Deforestation and forest Degradation
RWEDP	Regional Wood Energy Development Programme (FAO Project)
SIEF	Sustainable Increment Exploitation Factor
t	Metric ton (1000 kg)
ton	Metric ton (1000 kg)
TC	Tree Cover
VCF	Vegetation Continuous Field
VDC	Village Development Committee
WCMC-IUCN	World Conservation Monitoring Centre - International Union for the Conservation of Nature
WECS	Water and Energy Commission Secretariat
WHRC	Woods Hole Research Centre
WISDOM	Woodfuel Integrated Supply/Demand Overview Mapping

EXECUTIVE SUMMARY

Scope of this study is to support the national technical team of Nepal on Forest Reference Levels (FRLs) with estimates of forest degradation due to excessive woodfuel harvesting to be integrated in the construction of Nepal's Forest Reference Level (FRL) for REDD+.

In the absence of consistent multi-date observations of forest biomass stock for Nepal from which degradation rates could be measured , the degradation due to unsustainable woodfuel harvesting was estimated applying the Woodfuels Integrated Supply/Demand Overview Mapping (WISDOM) methodology.

It must be emphasized that there are no consistent multi-date observations of forest biomass stock for Nepal from which degradation rates could be estimated. The WISDOM approach is here use in substitution of a direct measurement method as it allows the estimation of the risk of forest degradation, rather than observing it, and thus it represents an indirect method for the estimation of forest degradation. No doubt, the direct observation and measurement of forest degradation is of paramount importance for the accurate accounting of forest-related carbon fluxes and efforts for the development of sound methodologies must continue.

Numerous studies affirm that woodfuel demand and supply patterns are very site specific and the impact of woodfuel extraction cannot be estimated by simply comparing national or sub-national statistics of fuelwood consumption and supply potential (Leach et al. 1988; RWEDP, 1997; Mahapatra and Mitchell, 1999; Drigo et al 2002; Arnold et al., 2003)[1]. Accordingly, in this study we assume that degradation depends on the spatial relation between fuelwood consumption and supply sources and on the harvesting of distant resources induced by the demand that is not locally satisfied. WISDOM was specifically developed to analyze this spatial relation and, through Woodshed analysis, to model woodfuel harvesting on a gradient of demand pressure and accessibility of resources. The flowchart in Figure (i) provides an overview of the phases of analysis.

Summary of demand and supply potential

The annual demand for fuelwood in 2010-2011 in all sectors of use is approximately 11.1 million tons (air-dry), which may be subdivided into 10.18 million tons of conventional wood made of stemwood and branches and 0.9 million tons of "marginal" fuelwood made of twigs and small branches from pruning of farm trees and shrubs.

Overall, the sustainable, accessible and potentially available supply of dendroenergy biomass (DEB) of Nepal is significantly greater than the demand. Excluding the industrial roundwood production, the annual accessible supply potential is over 17.2 million air dry tons (range 15.3 to 18.9), which is of 6.2 million tons greater than the demand. But this apparent surplus is purely theoretical since demand and supply potential are not evenly distributed.

National supply/demand balance and need for the analysis of harvesting sustainability

In good part of the Country the rural demand for fuelwood seems to be satisfied by the resources accessible within the typical harvesting horizon of 3 km or within 10-15 km for the larger settlements. However, this is not the case for the Mid Mount and Siwaliks of Central and Western Development Regions and in the densely populated Terai where the high concentration of the consumption creates a strong commercial fuelwood demand which poses a high pressure on the accessible resources with consequent risk of degradation.

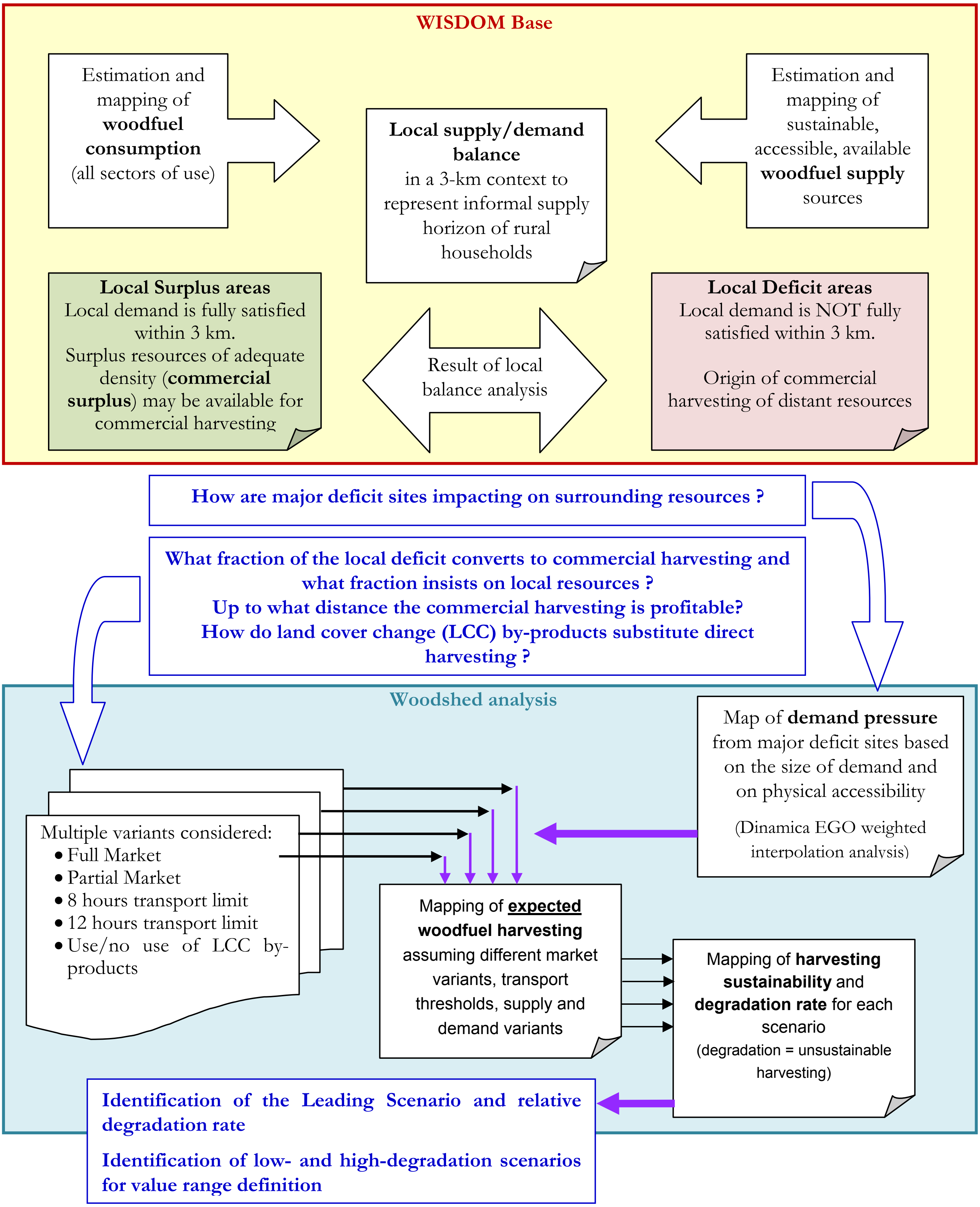
Such pressure on current wood resources and the consequent risk of degradation was estimated through woodshed analysis, taking a range of assumptions concerning (i) the fraction of demand of local deficit areas (i.e. all cities and many densely populated rural areas) that gives origin to commercial harvesting and the fraction that insists on scarce local resources; (ii) the transport time threshold that makes distant harvesting unprofitable, and (iii) concerning the role of land cover change (LCC) by-products used as fuel (see flowchart in next page).

As sensitivity analysis, alternative commercial harvesting assumptions, demand variants (total and conventional) and three supply variants (Minimum, Medium and Maximum) were considered. This provided a sense of how each assumption affects the final results and produced a range of values substituting the conventional statistically based confidence interval that was precluded by the large number and heterogeneity of input data.

[1] See also numerous case studies of WISDOM applications by FAO and others at www.wisdomprojects.net

FIGURE (i)

Overview of the phases of analysis



Leading Scenario

A thorough review of the scenarios considered, and the relative patterns and rate of degradation, allowed the identification of the most probable Leading Scenario, while low and high degradation scenarios were picked to represent the range of values.

The Leading Scenario is the one resulting from the application of the following variants/assumptions:

- Medium Supply (relative to the mean values of FRA sample plots)
- Conventional Demand (i.e. 95% of total demand, excluding the use of marginal fuelwood made by twigs and pruning material in rural Terai)
- Partial Market (whereby the full urban deficit but only ½ of the rural deficit originates commercial harvesting, while the remaining ½ induce overexploitation of local resources.
- 8 hours transport time threshold (maximum 8 hours from the nearest major deficit site)
- Midpoint between full use and no use of land cover change by-products

The results of the Leading Scenario are summarized in Table (i) by Development Region and by Physiographic zone. Results are presented for all land cover classes, including Forests, Other Wooded Lands and Other Lands, as well as for the Forest-Remaining-Forest (FRF) area, representing the area under forest cover for the whole reporting period 2000-2010. Results are presented as air-dry weight (basis of analysis) as well as dry matter (DM).

TABLE (i)

Summary of expected degradation induced by excessive fuelwood harvesting according to the Leading Scenario

	Total Nepal					Within Forest-Remaining-Forest (FRF)				
	Total area	Total direct harvesting after use of LCCbp		Total degradation from unsustainable direct harvesting after use of LCCbp		FRF area	Direct harvesting in FRF after use of LCCbp		Forest degradation from unsustainable direct harvesting in FRF after use of LCCbp	
Physigraphic Zone[2]	'000 ha	kt ad yr^{-1}	**kt DM yr^{-1}**	kt ad yr^{-1}	**kt DM yr^{-1}**	'000 ha	kt ad yr^{-1}	**kt DM yr^{-1}**	kt ad yr^{-1}	**kt DM yr^{-1}**
High Himalaya	3,538	30	27	10	9	162	5	4	0.3	0.3
High Mountains	3,012	1,265	1,151	59	54	1,803	597	543	11.2	10.2
Mid Mountains	4,309	5,085	4,628	417	379	2,213	2,412	2,195	153.3	139.5
Siwaliks	1,898	1,503	1,368	120	109	1,342	954	868	30.8	28.0
Terai	2,020	2,153	1,959	501	456	398	486	442	39.1	35.6
Development Region										
Far Western	1,979	1,374	1,250	131	119	1,004	658	598	16.9	15.4
Mid Western	4,251	1,881	1,711	158	144	1,494	824	750	16.6	15.1
Western	2,946	2,014	1,833	152	139	957	807	734	22.4	20.4
Central	2,747	2,760	2,512	522	475	1,280	1,281	1,166	162.3	147.7
Eastern	2,855	2,006	1,826	144	131	1,183	883	804	16.4	14.9
Total Nepal	**14,778**	10,036	**9,133**	**1,107**	**1,008**	5,918	4,453	**4,053**	**234.6**	**213.5**

[2] To be noted that two different nomenclatures are applied in Nepal referring to the same 5 physiographic zones.

	Applied in this report	Alternative names
1	High Himalaya	HighMount
2	High Mountains	MidMount
3	Mid Mountains	Hills
4	Siwaliks	Siwaliks
5	Terai	Terai

The **expected annual degradation** rate due to excessive fuelwood harvesting **over all land cover classes**, including Forests, Other Wooded Lands and Other Lands, according to the Leading Scenario is estimated to be 1,107 thousand tons air-dry (1,008 thousand tons DM).

Under the same Leading Scenario, the **expected annual degradation of the Forest-remaining-Forest (FRF)**, i.e. the area that remained under forest cover for the whole reporting period 2000-2010, is 235 thousand tons air-dry (214 thousand tons DM).

The geographic distribution of the expected degradation is best represented by the map of the degradation risk shown in Figure (ii), based on the quantity of woody biomass unsustainably harvested according to the Leading Scenario.

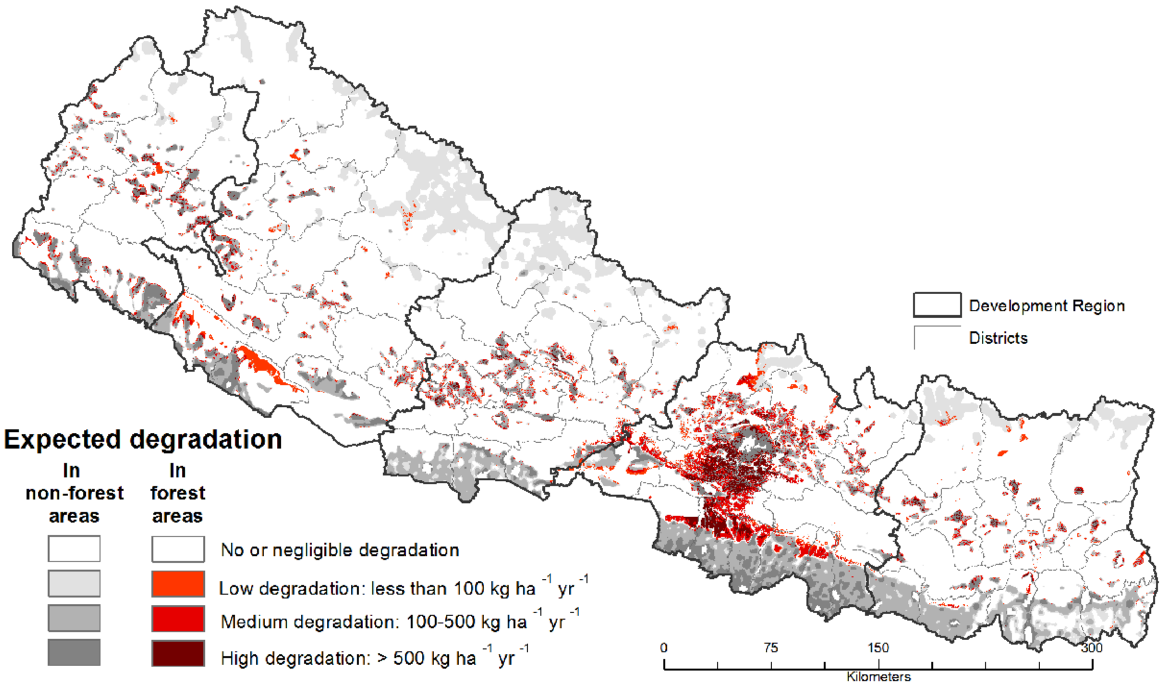
At country level, degradation of biomass stock is expected to take place over 25.7% of the entire territory, of which 10.4% may be classified of Low degradation, 10.4% Moderate degradation and 4.9% High degradation[3].

With reference to FRF, the degradation is expected to take place over 11.5% of the area, of which 3.5% may be classified of Low degradation, 5.2% Moderate degradation and 2.7% High degradation.

By Physiographic Zones degradation is expected primarily in the Terai (with 58.2% of the area under Moderate to High degradation) and Mid Mountains (with 16.6% of the area under Moderate to High degradation) followed by Siwalics (13.8% under Moderate to High degradation).

FIGURE (ii)

Ranking of risk of degradation due to unsustainable fuelwood harvesting



By Development Regions, the degradation is expected primarily in the Central Region, bearing ½ of the total degradation and with 35% of the land under Moderate to High risk.

In order to test the sensitivity of the model, a fairly large number of scenarios (28) were computed applying alternative data variants and assumptions. This was useful as it supported the identification of the Leading

[3] Ranking of degradation intensity: Classified as Low for degradation per hectare and per year below 100 ad kg; Moderate with degradation between 100 and 500 ad kg ha^{-1} yr^{-1} ; High with degradation above 500 ad kg ha^{-1} yr^{-1} .

Scenario, revealed how each data variant and assumption affected the final result and represented the range of possible degradation estimates, as a sort of confidence interval. The variants and assumptions leading to the highest and lowest degradation estimates are listed below.

Variants and assumptions leading to high degradation	Variants and assumptions leading to low degradation
Minimum Supply	Maximum Supply
Total Demand	Conventional Demand
Partial Market	Full Market
8 hours transport	12 hours transport
No use of LCC by-products	Full use of LCC by-products

Lowest estimates: According to the scenario based on most favorable variants and assumptions, the lowest degradation estimate for the whole Country is **59 thousand tons ad** (54 thousand tons DM, corresponding to the emission of 93 kt CO2e/year.). When referred to the Forest-Remaining-Forest only, the lowest estimated degradation is **51.1 thousand tons ad** (46.5 thousand tons DM, corresponding to the emission of 80,135 t CO2e/year).

Highest estimates: According to the scenario based on least favorable variants and assumptions, the highest degradation estimate for the whole Country is **2.24 million tons ad** (2,040 kt DM, corresponding to 3,516 kt CO2e/year). When referred to the Forest-Remaining-Forest only, the highest estimated degradation is **785 thousand tons ad** (714 kt DM, corresponding to the emission of 1,230 kt CO2e/year).

Role and contributions of WISDOM analysis

A key contribution that the WISDOM analysis can make to the direct assessment of forest degradation is in providing stratification of forests and other landscapes according the risk of degradation, as in Figure (ii). Since the measurement of changes in biomass stock requires very costly surveys based on very high resolution data and intensive field sampling, the use of robust stratification criteria will make the sampling design more efficient and less expensive.

Remaining in the REDD+ context, this study contributes by revealing the cause-effect mechanisms behind degradation processes. Beyond estimating deforestation and degradation we need to identify remedial actions and to this end WISDOM provides essential quantitative and spatial elements linking cause (demand for fuelwood) and effect (rates of degradation) that are fundamental to the formulation of focused forestry and energy policies and to the design of strategic and operational planning.

From a Sustainable Forest Management perspective, this analysis can support the definition of locally tailored management objectives, such as productive or protective functions, quantitative production targets to meet local and commercial demand through new plantations and/or improved management practices.

Similarly, in the agro-forestry context, this analysis can support the formulation and implementation of field programmes oriented to increase woody biomass production for energy self-sufficiency in rural areas where scarcity is most serious and where the systematic use of farm residues for energy impacts nutrients cycles and soil fertility.

1. INTRODUCTION

In Nepal, fuelwood represents 96 % of the total wood annually harvested from forest, other wooded lands and farmlands (FAOstat, for year 2010) and it produces over 80% of all energy consumed in all sectors (UN Energy statistics, for year 2012). These facts place fuelwood at the very core of the man-forest relation in Nepal. It is also evident that its role on the pressure exerted on forests and on woody biomass resources in general is of paramount importance.

Nepal has abundant woody biomass resources in its forests, woodlands and farmlands, whose annual sustainable growth potential exceeds the demand for fuelwood of the Country but demand and supply potential are unevenly distributed and so is the pressure on the resources, resulting in excessive harvesting in certain areas while other areas remain untapped. While sustainable harvesting with adequate rotation periods does not permanently reduce the biomass stock and does not diminish the productive potential of the forests, unsustainable harvesting, i.e. excessive and repeated wood extractions, are cause of forest degradation with loss of biomass stock and diminished regrowth capacity. As such, over time, sustainable harvesting does not result in net emissions since removals after harvesting (represented by forest re-growth) compensate for emissions caused at the time of harvesting, but when harvesting exceeds re-growth capacity it causes forest degradation associated with net emissions.

In order to identify the areas where fuelwood extraction may be higher than the sustainable productivity, and thus cause of forest degradation, it is necessary to analyze the spatial distribution of fuelwood demand and of the supply sources, which is the scope of the Woodfuel Integrated Supply/Demand Overview Mapping (WISDOM) methodology. WISDOM, which has been implemented in many countries and in various planning contexts, is here applied to provide quantitative and spatial-explicit estimates of the risk of forest degradation due to the current demand for fuelwood.

1.1 SCOPE OF THE UPDATE AND UPGRADE OF WISDOM NEPAL

Scope of the consultancy is to support the national technical team of Nepal on Forest Reference Levels (FRLs) for REDD+ with data analysis for estimating emissions from forest degradation in the context of Nepal's Forest Reference Level (FRL) construction, as described in the attached ToR.

The analysis follows the Woodfuels Integrated Supply/Demand Overview Mapping (WISDOM) methodology and, specifically, updates and upgrades the analysis WISDOM Nepal, conducted by the consultant in 2013 for the estimation and spatial distribution of the risk of forest degradation induced by excessive fuelwood extractions in Nepal, as contribution to the development of an MRV System.

It should be emphasized that degradation cannot be estimated by simply deducting fuelwood consumption from the sustainable supply potential. In fact, degradation depends on the spatial relation between fuelwood consumption and supply sources and on the harvesting induced by the demand that is not locally satisfied, harvesting that could take place at considerable distance from consumption sites. WISDOM was specifically developed to analyze this spatial relation and, through Woodshed analysis, to model woodfuel harvesting on a gradient of demand pressure and accessibility of resources.

The update of the WISDOM analysis is done in order to respond to the need for the estimation of forest degradation for the forthcoming REDD+ national reporting and in view of the availability of new and highly relevant cartographic and statistical information.

1.2 MAIN FEATURE OF THE WISDOM METHOD

The methodological approach is based on the following three fundamental characteristics of wood energy systems:

Geographical specificity. The patterns of woodfuel production and consumption, and their associated social, economic and environmental impacts, are site specific (Mahapatra and Mitchell, 1999; FAO/RWEDP, 1997;

FAO, 2003d).

Heterogeneity of woodfuel supply sources. Forests are not the sole sources of woody biomass used for energy. Other natural landscapes, such as shrublands, as well as other land uses –farmlands, orchards and agricultural plantations, agroforestry, tree lines, hedges, trees outside forest, etc. – contribute substantially in terms of fuelwood and, to a lesser extent, of raw material for charcoal production.

User adaptability. Demand and supply patterns influence each other and tend to adapt to varying supply patterns and resource availability. This means that quantitative estimations of the impacts that a given demand pattern has on the environment are very uncertain, and should be avoided (Leach and Mearns, 1988; Arnold et al., 2003).

In order to cope with the various dimensions of wood energy, the Wood Energy Programme of the FAO Forest Products Service has developed and implemented the **Woodfuel Integrated Supply/Demand Overview Mapping (WISDOM) methodology**, a spatially-explicit planning tool for highlighting and determining woodfuel priority areas or woodfuel hot spots (FAO, 2003). WISDOM is the fruit of collaboration between FAO's Wood Energy Programme and the Institute of Ecology of the National University of Mexico. At national level, the WISDOM approach has been implemented in Mexico (FAO, 2005), Slovenia (FAO, 2004a), Senegal (FAO, 2004b), Castilla y Leon (Spain), Italy, Croatia, Central Africa Republic, Mozambique, Argentina, Rwanda, Peru, Chad, Sudan and it's currently being implemented in Nepal. At subregional level, WISDOM was implemented over the eastern and central Africa countries covered by the Africover Programme (FAO, 2005g) and over the countries of South East Asia (FAO, 2007).

Recently, WISDOM has been applied in the Project "Geospatial Analysis and Modeling of Non-Renewable Biomass: WISDOM and beyond" carried out by Yale University and Mexico University UNAM for the Global Alliance for Clean Cookstoves (GACC). Scope of the GACC project was to estimate and map the non-renewable fraction of the woody biomass used for energy at sub-national level on all tropical countries.

WISDOM is meant to create a spatially-explicit knowledge base on supply and demand of woody (and non-woody) biomass for energy and thus to serve as a planning tool for highlighting and determining **priority areas** of intervention and to **focus planning options**. The result of the wall-to-wall supply/demand balance analysis is then used as starting point for the delineation of the necessary supply areas for existing or hypothetical commercial consumption sites.

WISDOM features:

- **Geo-referenced data bases.** A core feature of the approach is the spatial base on which the data is framed. The analysis and presentation of results for all modules is done with the help of a Geographic Information System (GIS).
- **Minimum administrative and spatial units of analysis.** The spatial resolution is defined at the beginning of the study, on the basis of the desired level of detail (national study, regional study) and as constrained by the main parameters or proxy variables that will be used to "spatialize" the information. In most cases the basis for the definition of the administrative level of analysis is provided by the existing demographic data (i.e. census units), which represents the most detailed sub-national structure of a country. The spatial level of analysis (i.e. the size of the pixel in GIS raster data) is usually determined by the mapping detail of the available land use/land cover data.
- **Modular and open structure**. WISDOM consists of modules on demand, supply, integration and woodshed analysis. Each module requires different competencies and data sources and its contents is determined by the data available or, to a limited extent, by the data purposively collected to fill critical data gaps. Once the common spatial base of reporting is defined, each module is developed in total autonomy using existing information and analytical tools and is directed to the collection, harmonization, cross-referencing and geo-referencing of relevant existing information for the area of study.
- **Adaptable framework**. As mentioned previously, the information of relevance to wood energy comes from multiple sources, ranging from census data to local pilot studies or surveys, to projected estimates with unknown sources, and is often fragmented and poorly documented. Proxy variables may be used to "spatialize" discontinuous values. In synthesis, WISDOM tries to make all existing knowledge work for a better understanding of biomass consumption and supply patterns.

- **Comprehensive coverage of woody and non-woody biomass resources and demand from different users**. The analytical framework includes of all sources of biomass potentially available for energy (i.e. fuelwood and charcoal, crop residues, industrial residues, etc.) and all users categories (rural and urban residential; industrial; commercial and public).

The WISDOM methodology may be divided into two sequential stages of analysis:

1 - **WISDOM Base**. This stage includes the analysis over the entire territory of the study area.

2 - **Woodshed[4] analysis**. This second stage of the analysis uses the result of the WISDOM Base to delineate the harvesting zones of major consumption sites that depend primarily on commercial. supply systems. Depending on the scale and objectives of analysis, the selected sites could be all major deficit areas (those that depend on commercial supply chains) or specific urban centers, rural villages and existing/planned biomass plants.

The specific steps of analysis are summarized below while a graphic overview is shown in Figure 1.

WISDOM Base

The application of the standard WISDOM analysis producing supply and demand balance mapping at the local level involves the following main steps (FAO, 2003b).

1. Definition of the minimum administrative *spatial* unit of analysis.
2. Development of the *demand* module.
3. Development of the *supply* module.
4. Development of the *integration* module.
5. Selection of the *priority* areas or woodfuel "hot spots" under different scenarios.

Woodshed analysis

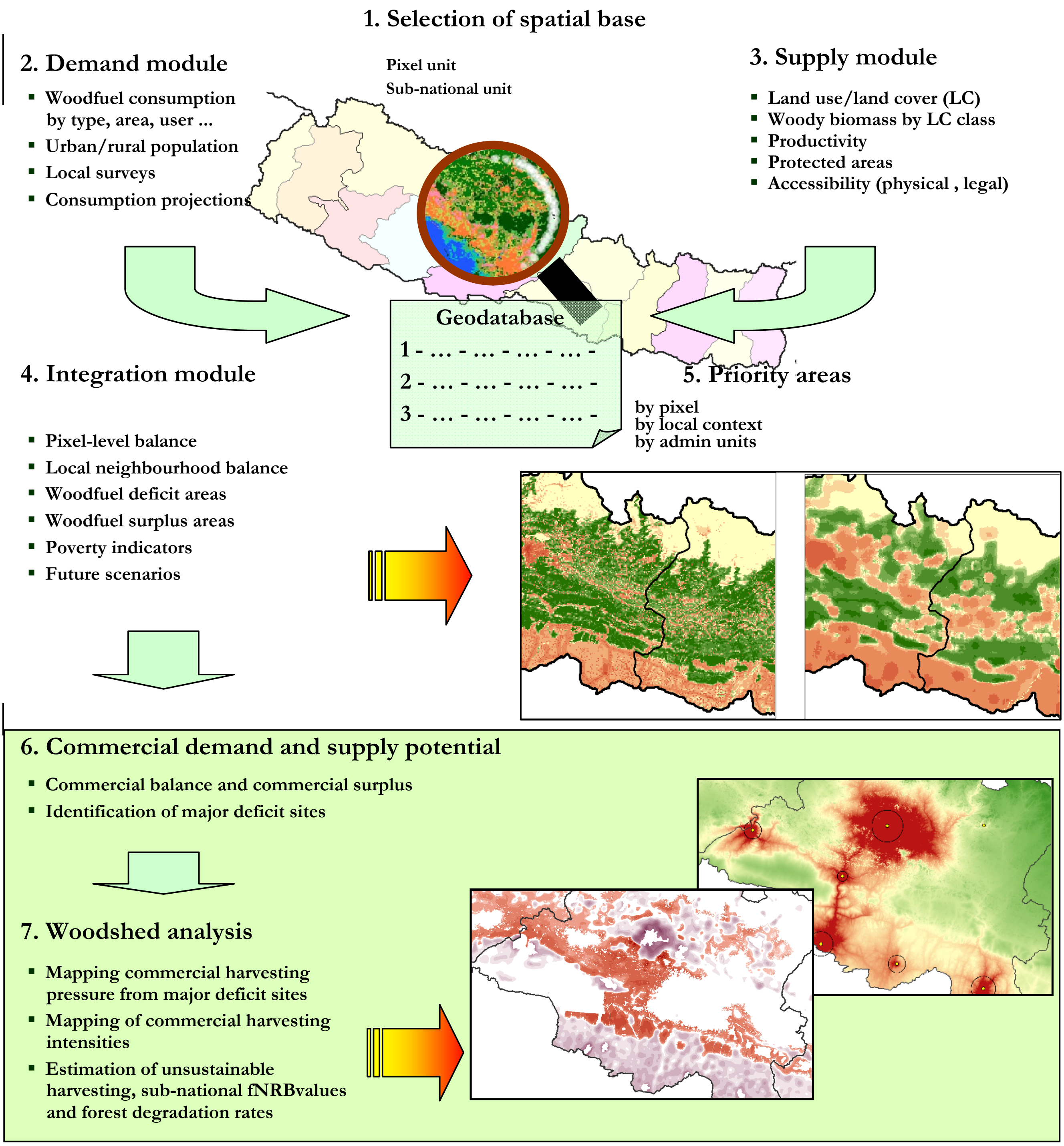
The analysis for the delineation of woodsheds, i.e. supply zones of specific consumption sites requires additional analytical steps that may be summarized as follows.

6. Mapping of potential "commercial" woodfuel supplies suitable for urban, peri-urban and rural markets.
7. Definition of woodsheds, or woodfuel harvesting areas, based on the level of commercial and non-commercial demand, woodfuels production potentials and physical/economic accessibility parameters. Estimation of harvesting sustainability, of woodfuel-related fNRB values at subnational level and of woodfuel induce forest degradation rates.

[4] The term "woodshed" is a neologism inspired by the familiar geographic concept of *water*shed. It is used to indicate the portion of the territory necessary to supply on a sustainable basis the woody biomass needed by a specific consumption site (existing or hypothetical).

FIGURE 1

WISDOM analytical steps. WISDOM Base (steps 1 to 5) and Woodshed analysis (steps 6, 7)



2. WISDOM ANALYSIS

The following Sections describe the steps of analysis undertaken during the development of WISDOM Nepal, following the procedure of analysis summarized in the previous Section.

The work implied the creation of a large amount of digital maps but only the most relevant ones are discussed and shown in this report. The details such as filename and development process of all the thematic maps used and produced during the WISDOM analysis are reported in Annex 6.

2.1 SELECTION OF SPATIAL BASE AND REFERENCE YEAR OF ANALYSIS

2.1.1 Scale and projection

Mapping details:

Projection: Preferred/common projection for Nepal : Modified UTM Central zone 84D (Datum Everest 1830) (single projection for whole country). Cell size of raster layers: 100 meters (1-ha cells)

Administrative units used for population mapping:

Census results are provided down to VDC level (3,986 units), which are used to map population distribution.

Most published census results related to the saturation of fuelwood in the residential sector (fraction of households using fuelwood) are at District level (75 units). Other sources refer to broader strata that represent aggregations of Districts and rural/urban contexts (ex: CBS NLSS 2010 study).

2.1.2 Reference year of WISDOM analysis

The reference years of the WISDOM analysis is usually determined by the reference years of the selected land cover data. The Land Cover map used as reference was prepared by using RapidEye MSS satellite imagery (Level 1b, 48 scenes) acquired in February–April 2010/11). Concerning the Demand Module, the year of the last demographic census is 2011. The temporal reference of the WISDOM analysis is therefore **2010-2011**.

In practice this study estimates the annual degradation rate of the final date of the FRL reporting period 2000-2010, which is not optimal since FRL should report on the degradation occurring over the whole period. In this respects the two following aspects should be considered:

1 - If the estimation of forest degradation was done measuring the loss of biomass stock between two points in time (just like is done for forest area change) the presence of two reference datasets, i.e. stock in 2000 and stock in 2010, would represent a fundamental requirement for the estimation process. Unfortunately, we are not (yet) able to observe the biomass stock with the precision needed to perceive the small changes due to degradation. WISDOM is an indirect method that produces estimates of annual unsustainable woodfuel harvesting and thus, estimates of expected annual degradation rates. We do not observe change of stock over time, we estimate the probable degradation comparing woodfuel harvesting and sustainable growth potential (MAI). In practice, we estimate the (expected) annual degradation rate using data of one year only, which cannot be done by observing forest stock in one year only. For the FRL this is not optimal, but this is simply due to the fact that the available forest cover map is dated 2010.

2 – One alternative solution to represent the whole period would be repeating the analysis for year 2000. This could be done by using forest cover data for 2000 and estimating woodfuel demand for the same year (using 1991-2001 censuses and adjusting sectoral estimates). Unfortunately the forest map of year 2000 was not available for this analysis, nor were available forest change rates covering the period 2000-2010 that could be used to estimate the forest areas in 2000 and to map the supply potential in 2000, at least tentatively. The degradation rate for year 2000 can be estimated in a subsequent analysis, once the forest resources for that reference year are known.

However, in order to contribute as consistently as possible to FRL reporting, the mask of the "forest remaining forest" for the period 2000-2010, as soon as it will be available, will be used to produce statistics on the expected annual degradation rates within such area for the leading scenario.

2.2 DEMAND MODULE

The goal of the Demand Module is to estimate the current consumption of woody biomass for energy in the various sectors (residential, commercial, industrial and public) and to represent as accurately as possible its spatial distribution. The main thematic layers and processing steps of the Demand Module are presented in the flowchart in Figure 2 and described in the following Sections.

2.2.1 Reference data

Household sector

The references that were used for the estimation of the current consumption of woodfuels in the residential sectors include the following:

(i) Census 2011 results at District level on the fraction of households using fuelwood as primary cooking fuel in rural and urban areas.

(ii) CBS NLSS 2010 , providing saturation and fuelwood consumption values for rural and urban areas based on 28670 households interviewed divided into 14 strata, as shown in Annex 1.

(iii) Estimates of the quantities consumed by fuelwood users (MPFS 1988, CBS's National Living Standard Survey 2010-2011, and other studies (Fox 1984, Rijal 2002). Annex 1 provides a summary of the per capita consumption values produced by various sources and of the values applied in the present study.

Saturation values and per capita consumption values derived from the references listed above are presented in Annex 1. The total consumption in the household sector , estimated by applying saturation and consumption values to the rural and urban population, is **9,885 kt ad[5], or 8,996 kt DM** (including conventional and marginal fuelwood).

Other uses of woody biomass at household level include cremations and the use of construction material.

Cremations

The cremation of the dead is a common practice among Hindus, with significant consumption of fuelwood. There are no statistics available about the fuelwood consumed in cremations ceremonies and therefore the estimation made in this study was based on district-wise census data on Hindus populations above 15 years (minimum age for the specific rituals of the cremation) and death rates (CBS, Census 2011), and assuming that approximately 600 kg of fuelwood is necessary for the complete cremation (World Food Programme estimate). Based on these assumptions, the total annual use of fuelwood for cremations is estimated at **53 kt ad or 48 kt DM**.

Construction material

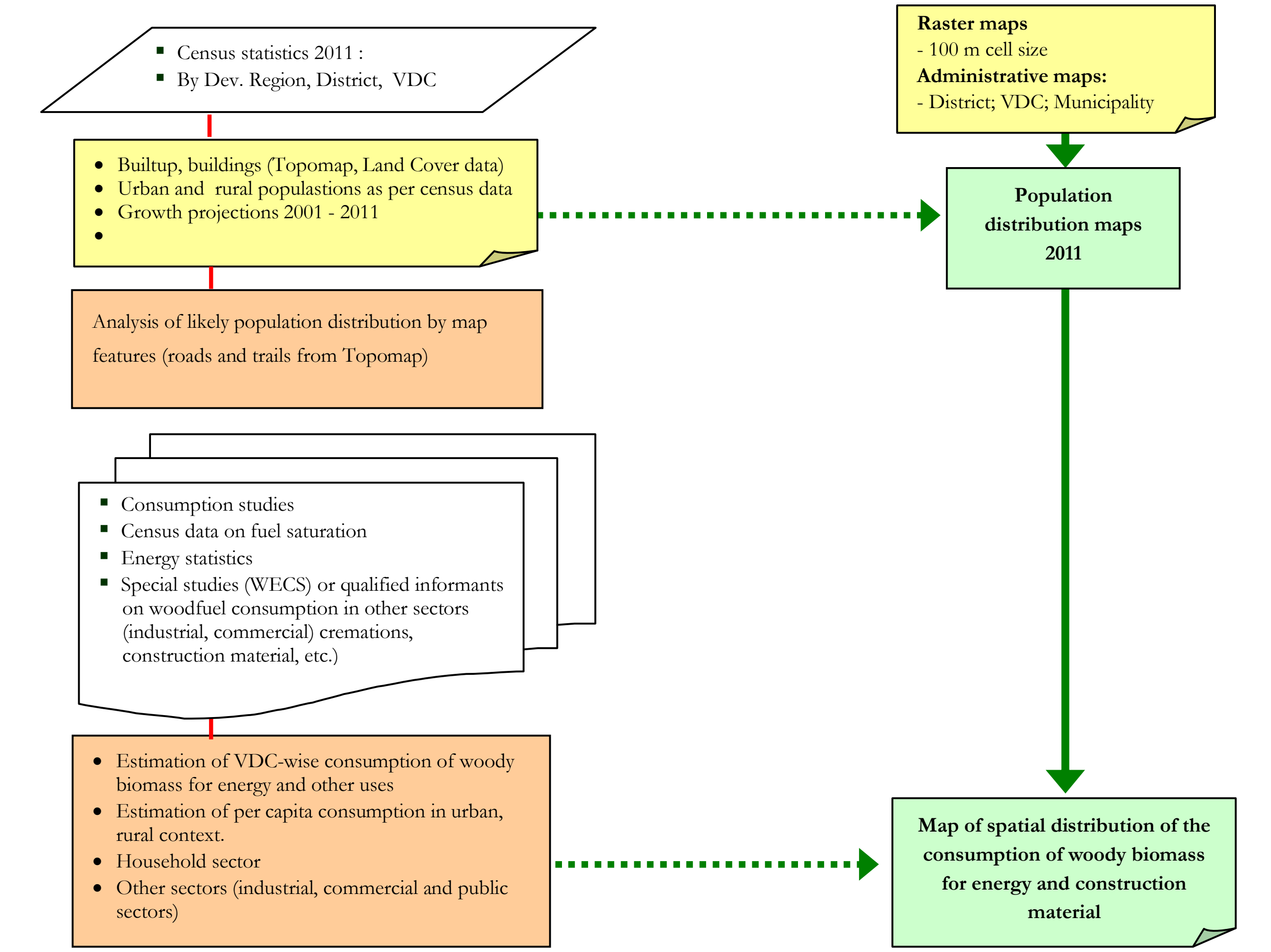
The construction material for rural houses, fences, stables, poles, etc. represents a sector of demand for woody biomass that is not accounted for in industrial wood demand statistics. The demand for construction material is mainly rural and is close to fuelwood demand, in terms of proveniences and production/marketing chains. For this, in order to account at least indicatively for this sector of woody biomass consumption, the demand for construction material is added to the rural demand for woodfuels by assigning an estimated per capita consumption. The consumption of construction material for fences, stables, rural houses construction and maintenance ranges between 5 and 20 kg (oven dry) per capita and per year, according to few available references encountered during WISDOM analyses in Rwanda (Drigo et al. 2013) , Mozambique (Drigo et al. 2008) and Sudan (Drigo 2012). In this study, in the absence of specific data, a tentative mid-range per capita value of 12.2 kg (air dry) per year was adopted, and applied to rural population, while 1/3 of such rate (4.1 kg, air dry) was

[5] Throughout this study the woody biomass values refer to air-dry matter (ad) since all references relative to fuelwood consumption as well as to biomass stock report air-dry biomass values (without specifying the moisture content). Dry Matter (DM) values (also called oven-dry [od] values) were derived by deducting the moisture content. FRA Nepal produced inventory results as air-dry values but provided a conversion factor of 0.91 (i.e. 9 % moisture, wet basis) for the conversion into oven-dry values (DFRS 2015), which was used to produce dry matter values.

applied to urban population. By applying these values to the rural and urban population, the amount of woody biomass used as constriction material at national level is estimated at **285 kt ad or 259 kt DM**.

FIGURE 2

Demand Module. Flowchart of main analytical phases. Input data: cartographic (yellow); statistical (white); estimated variables (orange); thematic map outputs (green).



Other sectors of consumption

For the estimation of the consumption of fuelwood in commercial and industrial sectors reference is made to the amounts estimated by WECS, by development regions and by Eco Belts (Terai, Hills and Mountains). The total consumption in the **industrial sector** is estimated at **423 kt ad or 385 kt DM**, while that of the **commercial sector** is estimated at **428 kt ad or 390 kt DM** (WECS 2013). Assuming that these consumptions are concentrated primarily in major agglomerations, they were tentatively located in municipalities and urban settlements.

2.2.2 Mapping fuelwood consumption

Once the sectors of consumption are defined and quantified, the subsequent step is to distribute such consumption over the territory with the best possible approximation.

From a spatial distribution perspective, two major types of consumption patterns may be distinguished: diffuse patterns, typical of the residential consumption, and other more localized sites, typical of industrial and commercial consumption sites, or even specific locations, such as biomass power plants and large tea factories. The first type is directly related to the distribution of the rural and urban population while for the second type the consumption is associated to special areas (i.e. urban areas only) or to specific locations such as towns or sub-urban areas or through geographic coordinates of known locations. Between these two extremes there are some types of consumptions, such as small industries, commercial and public users that are not ubiquitous but whose exact locations are not known. In these cases the distribution may be based on spatial proxies (elements of known spatial distribution) that are directly or indirectly correlated to the type of consumption considered.

In case of Nepal, the household sector dominates woodfuel consumption, and mapping human population is the prerequisite to mapping the relative consumption. But other consumption sectors, such as commercial (tea sellers, bakeries, restaurants, etc.) and industrial (brick making, blacksmithing etc.), are also more or less strongly related to population concentrations. For this, in absence of more precise data on the distribution of commercial and industrial users, urban population mapping was used as spatial proxy for the mapping of the consumption in these sectors.

Urban and rural population mapping.

Statistical and cartographic information relative to the distribution of the population at the level of Administrative Unit from Census 2011 obtained from the Central Bureau of Statistics (CBS). Figure 3 shows the main cartographic layers used to map the distribution of the population.

Location of Rural population:

The mapping of rural population (as defined by 2011 census) was done respecting the values reported at admin unit level (VDC). Within such units, the spatial distribution of the population was based on additional cartographic elements or spatial proxies such as built up areas and point settlement data. Roads and main trails were also used to locate probable sparse roadside settlements. Within a given unit, these features were used as spatial proxies of population presence to distribute census population where it's more probable to be found.

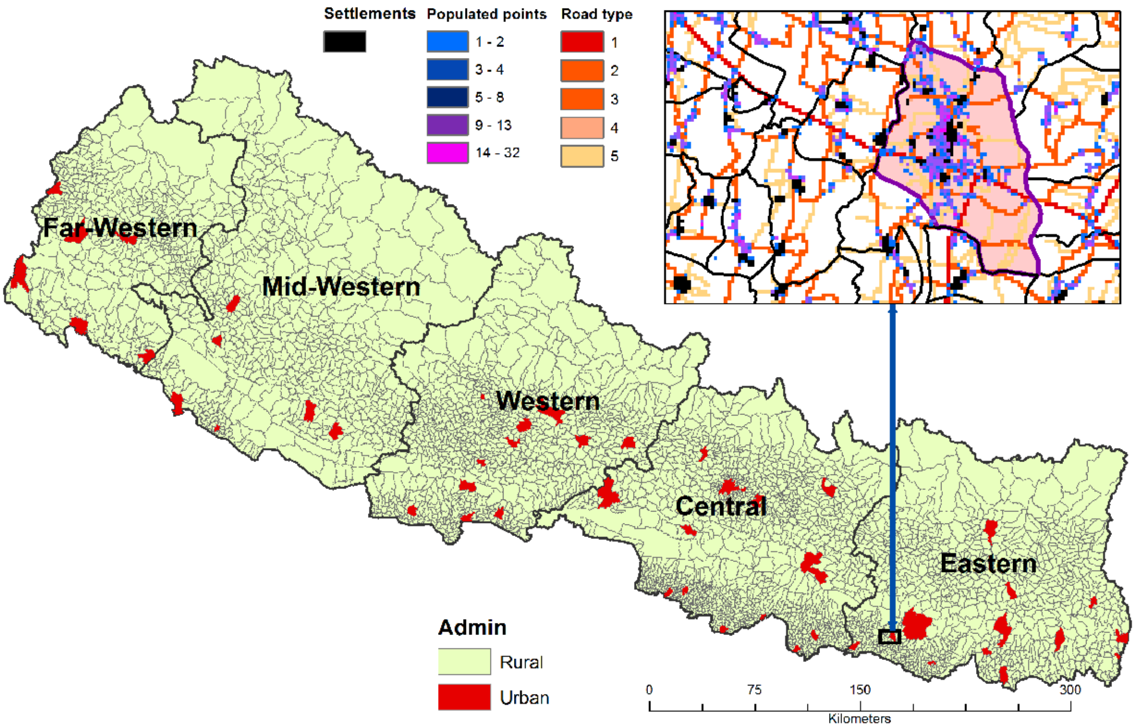
Location of Urban population:

The mapping of urban population (as defined by 2011 census) was done respecting the definitions (i.e. Municipalities) and values reported by the census. Within urban admin units, the spatial distribution of the population was based on cartographic elements or spatial proxies, such as urban boundaries.

Figure 10 in Results Section shows the resulting human population distribution map.

FIGURE 3

VDC and Municipalities of Census 2011 and spatial features used as proxies for distribution of rural and urban population



within VDCs and Municipalities

2.2.3 Rural fuelwood users' adaptability

Fuelwood itself can be made of stem wood or branch wood, which are the more **"conventional" fuelwood** assortments, or made of twigs, smaller branches and shrub wood (Figure 4), which we may call **"marginal" fuelwood** assortments usually excluded from forest inventories and thus not accounted for among the conventional supply sources.

The fuelwood consumption by rural households is based on available survey data that do not distinguish between conventional and marginal fuelwood and it may be misleading to consider that the entire consumption is made of conventional fuelwood. The latter may be true for the regions sufficiently rich of wood resources but it may overestimate the real wood consumption in wood-poor areas, where conventional fuelwood is replaced by marginal fuelwood. In rural areas where wood resources are particularly scarce, like in the Terai, the most likely effect of shortage of "conventional" fuelwood is that rural households use of a higher proportion of twigs and small branches from annual pruning in the mix of fuels used to satisfy basic households needs. Twigs and small branches that are harvested annually are woody and thus they are usually classified as "fuelwood" in consumption surveys but they are not accounted for by conventional forest inventories and are not considered in the estimation of the productivity of natural forests, shrublands and plantations (based on MAI) that includes stem and branch wood available at end rotation (and thinning cycles, if applied).

Hence, in one of the demand variants considered for supply/demand balance analysis, the consumption of such marginal wood products was deducted from the total demand and excluded from the balance analysis against conventional fuelwood productivity.

Unfortunately there is no data on the quantity of marginal wood products used as fuel in rural households. In order to quantify, at least tentatively, the impact of wood scarcity on consumption regimes, in one of the demand variants considered the consumption of fuelwood in rural Terai was reviewed assuming that up to 50% of the fuelwood gap (i.e. the difference between the demand and the supply locally available) may be satisfied by "marginal" fuelwood, rather than by conventional fuelwood from the felling of trees and shrubs. This was based on a preliminary supply/demand balance comparing the supply potential of conventional fuelwood and the entire fuelwood consumption on a local context of 6km, which allowed to calculate what percent of the demand may be fulfilled by local resources.

FIGURE 4

Conventional fuelwood and marginal fuelwood composed by twigs and small branches.

The 50% limit in the substitution of conventional fuelwood by marginal wood products was arbitrarily selected and is only tentative. Other thresholds could be applied but the best approach would be to survey the situation in the field. The reduction of the demand for conventional fuelwood was applied only on rural areas, which depend primarily on local and mostly informal supply, and is concentrated only in Terai. The urban demand for conventional fuelwood was not modified since the supply in this case is formal and market-based.

The exclusion of marginal non-commercial wood products from the supply/demand balance of conventional woody biomass is probably more realistic but the fraction of these products in the rural fuel consumption is here only tentatively estimated This particular component of rural households' consumption should be studied in greater detail as it plays an important role in the overall supply/demand balance as well as in the soil nutrients cycles.

What is the impact of the harvesting of marginal fuelwood on the rural environment? This is largely unknown. It seems, however, that the impact of the use of these marginal wood products and farm residues is more consistent on the soil fertility than on the forest resources and woody biomass stock as it is normally intended. The main impact is probably on the reduced re-integration of twigs, leaves and residues' nutrients into the soil of forests, plantations and agricultural fields. This is likely to produce a progressive loss of soil fertility, with consequent reduction of crop productivity and an increased level of vulnerability and worsened living conditions. The nexus between rural subsistence energy and soil fertility in Nepal certainly deserves a dedicated analysis.

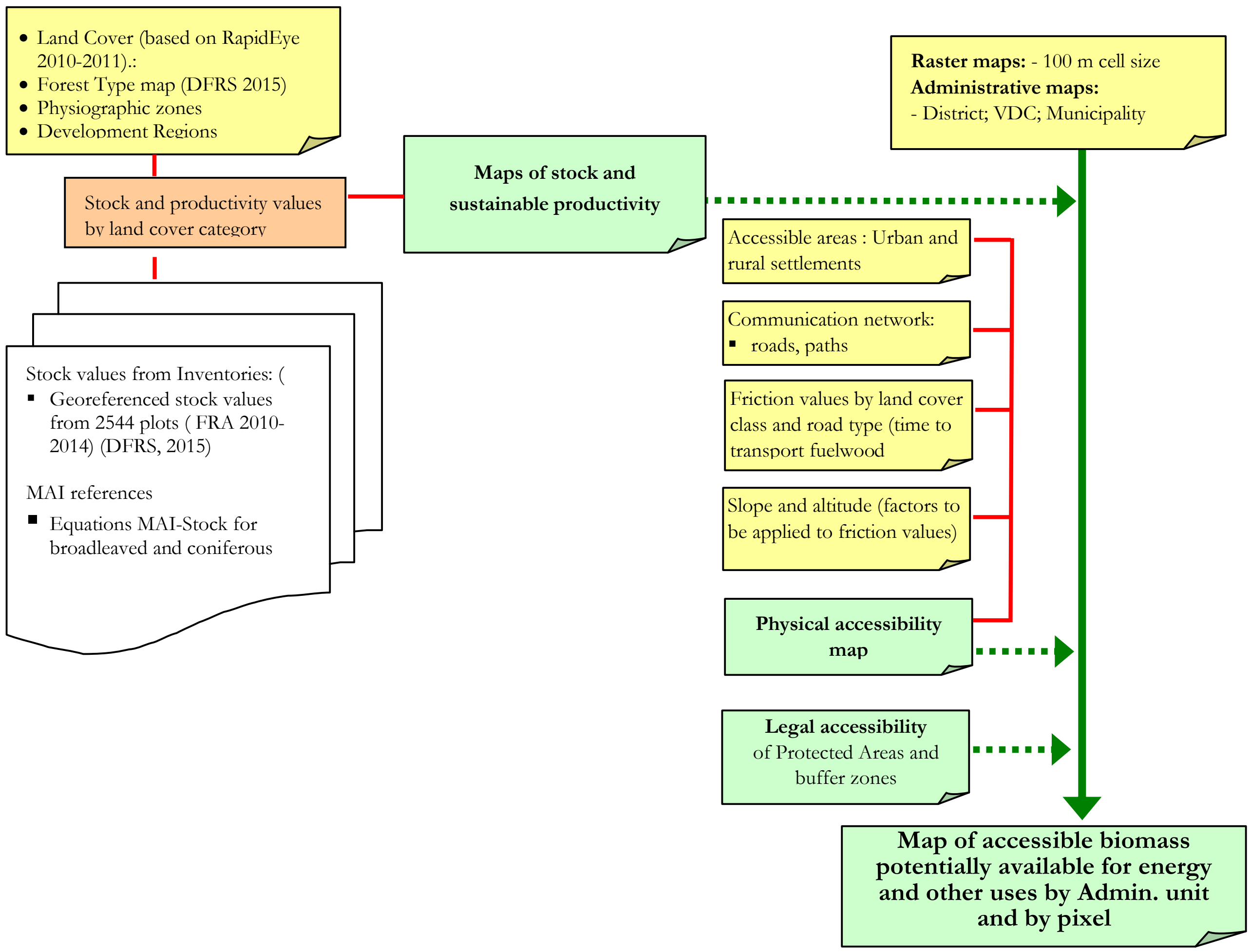
2.3 SUPPLY MODULE

Scope of the WISDOM Supply Module is to produce a spatial representation of natural and man-made sources of woody biomass, their stocking and production potential. The Supply Module analysis includes woody biomass entirely, comprising the components that may serve as fuelwood as well as other non-energy uses such as industrial roundwood and construction material.

The estimation and mapping of the fuelwood supply potential has been revised entirely and it is now based on Land Cover and Forest Type mapping and on georeferenced values of aboveground biomass from 2544 field plots produced by the Forest Resource Assessment (FRA) Nepal Project (2010–2014) executed by the Department of Forest Research and Survey (DFRS, 2015), under the Ministry of Forests and Soil Conservation (MFSC). The flowchart in Figure 5 shows the source data and the main analytical steps of the Supply Module.

FIGURE 5

Flowchart of the main analytical elements of the Supply Module. Input data: cartographic (yellow); statistical (white); estimated variables (orange); thematic map outputs (green).



2.3.1 Cartographic layers

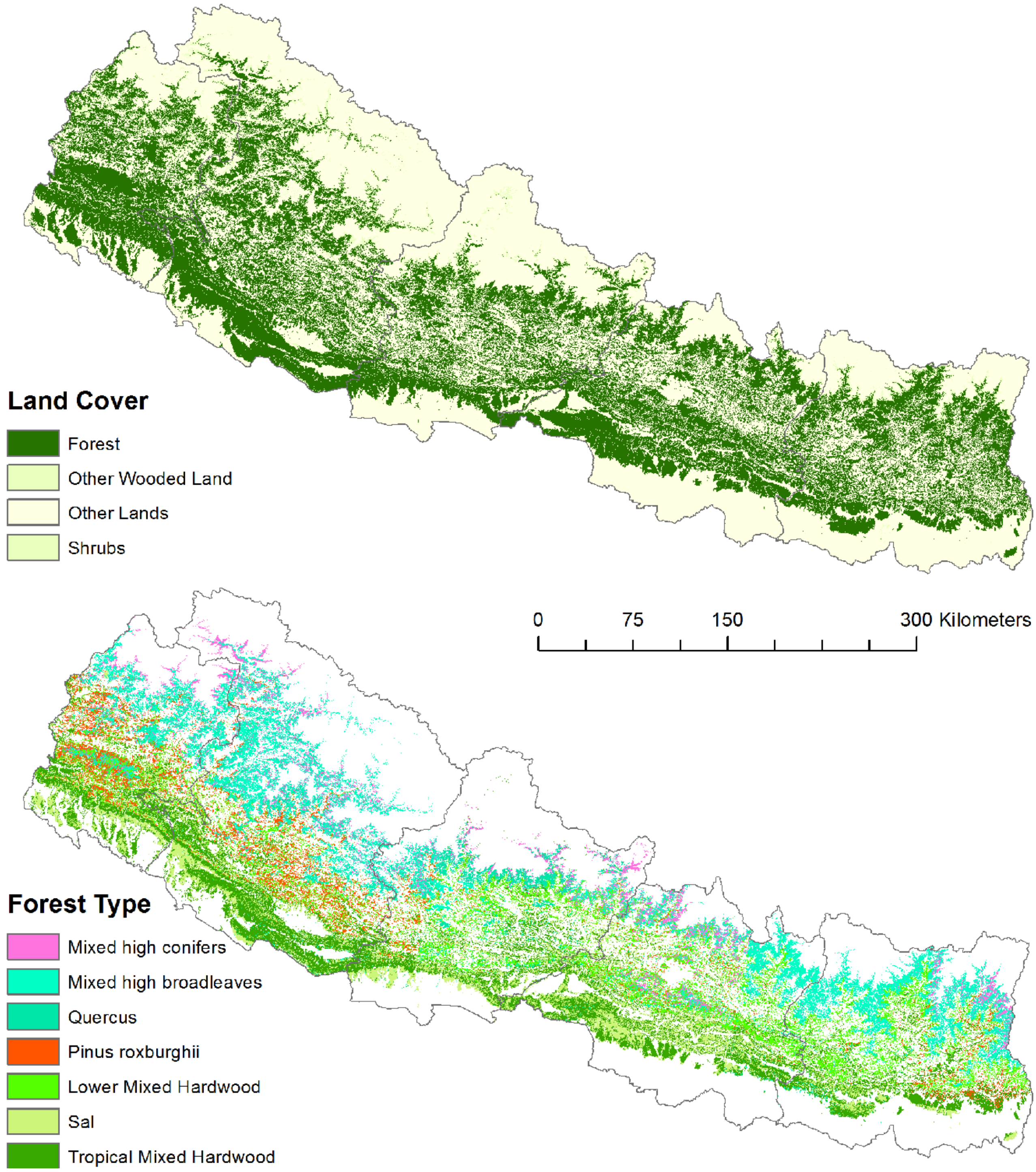
As mentioned above, the Land Cover and Forest Type mapping produced by DFRS as part of the Forest Resource Assessment (FRA) Nepal Project (DFRS 2015) was used as basis for the development of the Supply Module.

The Land Cover map, provided by DFRS, was in vector format. As part of data processing, and in order to obtain a coherent and complete raster map of land cover, the geometry of the original vector file was repaired, re-projected, and few evident data gaps (mainly in High Himalaya zone) were filled in using ICIMOD 2010 Land Cover data.

The Map of Forest Types was resampled to 100m and re-projected. The map was also edited to match exactly the land cover class "Forest". Subsequently, in order to guarantee that each class be represented by a meaningful number of field plots, the original 15 forest types were aggregated into 7 Forest Type Groups, as reported in Annex 2, Table A2.1. Figure 6 shows the raster versions of the reference maps of Land Cover and Forest Groups.

FIGURE 6

Raster versions (1-ha cell) of the map of Land Cover derived from the vector map produced by FRA Nepal and of the of Forest Types derived from the 30m r map produced by DFRS (DFRS 2015)..



2.3.2 Stock and productivity

Woody biomass stock

The estimation of woody biomass stock was based on 2544 geo-referenced sampling units from the National Forest Inventory (NFI) 2010-2014.

For the WISDOM analysis, the key parameter to be assessed is the **dendroenergy biomass (DEB)**, which is intended as the fraction of the aboveground biomass (AGB) that is suitable as fuelwood. DEB includes the total aboveground biomass, less foliage and stump. Since SU data from NFI included total AGB as well as its stem, branches and foliage components, all measured as air-dry (ad) biomass. DEB values for each SU was calculated by deducting the stump (estimated as 3.9% of AGB) and deducting the foliage from the total AGB, as follows:

$$DEB\ (ad\ t\ ha^{-1}) = [AGB\ (ad\ t\ ha^{-1})]*(1-0.039)\ -\ Foliage\ (ad\ t\ ha^{-1})] \quad (1)$$

With the purpose of spatially distributing DEB stock as precisely as possible, the 2544 SUs were post-stratified according to Land Cover class, Forest Type Group, Physiographic Zone and Development Regions, and in view of having an adequate number of SUs per stratum, as described in detail in Annex 2 (tables A2.2 to A2.4).

26 strata were identified for which mean DEB values and 95% confidence intervals were calculated (Table A2.5, Annex 2). One additional Non-Forest stratum (stratum 0) was created, with DEB = 0, to represent the unproductive lands in high mountain zones (Physiographic classes 1 and 2). In absence of other references, the unproductive area of mountain zones was derived from WISDOM Nepal 2013 data, which was based on ICIMOD 2010 and FAO/ESA Globcover 2009.

Strata means and confidence intervals were used to define Minimum, Medium and Maximum DEB stock values for the 26 strata (see Table A2.6, Annex 2)[6].

In order to achieve a more discrete distribution of DEB stock than the mapping of simple strata means, MODIS Vegetation Continuous Field (VCF) data[7] for year 2010 (DiMiceli et al, 2011) was used as spatial proxy for the modulation of DEB stock within strata. VCF data provides estimates of vegetation density in 2010, expressed as percentage of tree cover within 250m pixels, which is considered a suitable indicator of stock variability within the strata.

From VCF data, the mean tree cover percent of each stratum was calculated. The average DEB stock was then allocated to the average tree cover percent and the final pixel-level DEB stock value was calculated as follows:

$$DEB_{i,j} = \overline{DEB}_j \left(\frac{TC\%_i}{\overline{TC\%}_j} \right) \quad (2)$$

Where

$DEB_{i,j}$ is the stock of DEB of pixel *i* in stratum *j*, $\overline{DEB}_j$ is the average stock of DEB in stratum *j*,

$TC\%_i$ is the percentage of tree cover in pixel *i*, $\overline{TC\%}_j$ and is the average percentage of tree cover in stratum *j*.

This simple process considerably enhances the spatial distribution of the biomass stock (and improves it if the spatial proxy is reliable) while the mean stock value per strata of the resulting map matches exactly the average stock values per strata used as input.

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[6] To be noted that assigning DEB stock values to non-forest classes remains difficult and uncertain, since the field plots were distributed primarily to assess forest resources. The number of plot falling in Other Lands (OL) classes, although fairly numerous (975) are not necessarily representative of this large land cover class.

[7] Source for this dataset is the Global Land Cover Facility, www.landcover.org.

Productivity

As usual, the sustainable productivity of natural formations is a far less known parameter than the stock due to the scarcity of permanent sample plots, which are the only reliable sources of data for the estimation of the Mean Annual Increment (MAI). In order to fill this critical data gap, the MAI was estimated by applying simple equations relating stock and MAI values as percent of stock for coniferous formations (178 obs.) and for broadleaved formations (86 obs.) from a set of international field observations relative to tropical and sub-tropical ecological zones, as shown in Figure 7.

MAI_DEB_percent (Coniferous forest formations)= ([de_biom_t_ha]^-0.5069)*22.683 [based on tropical and sub-tropical stock-MAI values for broadleaved formations] (3)

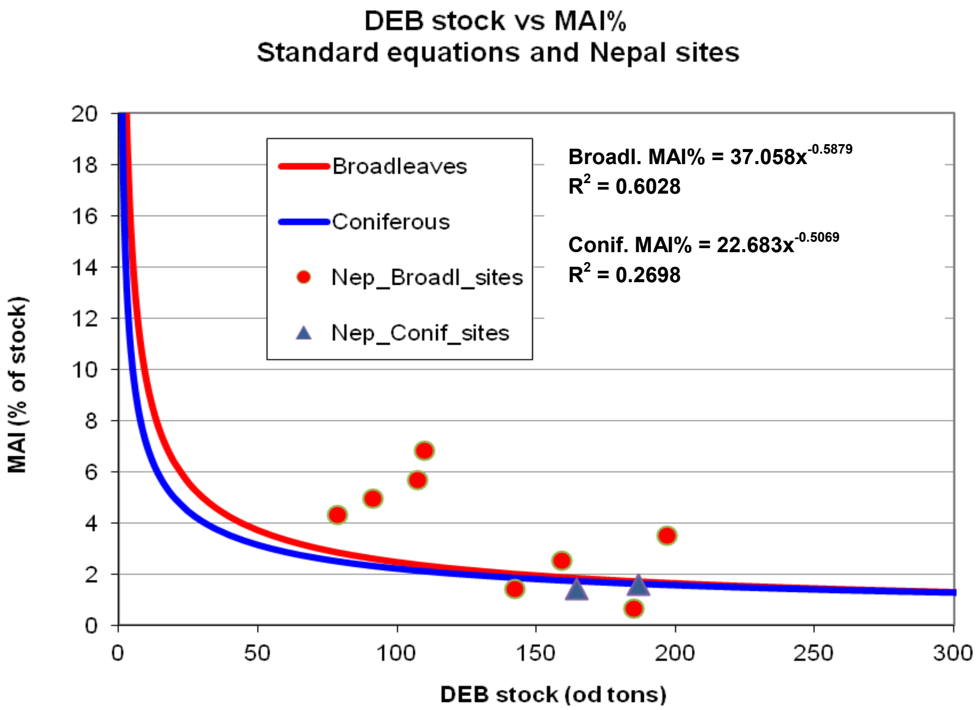
MAI_DEB_percent (All other formations)= ([de_biom_t_ha]^-0.5879)*37.058 [based on tropical and sub-tropical stock-MAI values for broadleaved formations] (4)

As a means to validate the standard equations in Nepal context, MAI estimates produced by recent studies of forest productivity in Nepal were reviewed. Observations for 11 sites were identified and the results from these sites are shown in the graph in Figure 7. They are too few to draw clear conclusions, however, it appears that they tend to agree with equation results for stands with higher stock, while the four sites with lower stock show MAI % values significantly higher than equations values. These records are too few to support an adjustment of the equation, considering also that 6 out of 11 records are based on biomass increments observed over 2-years only, a period definitely too short for the estimation of the MAI.

A conclusion that may be drown from these observations is that the equations are not overestimating the MAI and that the estimated productivity is somewhat conservative.

FIGURE 7

Stock vs MAI relations from standard equations of for natural broadleaves and coniferous formations and from Nepal observation sites.



The maps representing the spatial distribution of Minimum, Medium and Maximum DEB MAI were obtained through the application of the equations to the pixel values of the maps of Minimum, Medium and Maximum DEB stock.

2.3.3 Accessibility

In this assessment the accessibility has two components. One component is legal accessibility, which is based on the legal rights of wood harvesters to extract wood from a particular area. The second component is physical accessibility, which is based on the ability of wood harvesters to reach a given location. This may be determined by the distance between human settlements and woodfuel resources, but is mediated by infrastructure characteristics such as the existence of footpaths, roads, as well as factors like topographical gradients and other obstacles. We explore details of each component below.

2.3.3.1 Legal accessibility

The legal accessibility to woody biomass resources is determined on the basis of protection status and categories. Legal restrictions may range from total access interdiction to harvesting limitations of varying degrees. In most cases fuelwood harvesting if permitted to local communities for their own use while commercial fuelwood and charcoal production are forbidden. In case of Nepal, several categories of Protected Areas, covering a total area of 3,439,988 hectares, with a varying range of access rights to local communities for fuelwood harvesting, while commercial fuelwood production is thoroughly forbidden. The right of access is not precisely defined but discussion with qualified informants allowed to define a percent access value for each protection category, as discussed in detailed in Annex 4.

2.3.3.2 Physical accessibility

The estimation of the physical accessibility of biomass resources is based on a **fuelwood transport time map** covering Nepal following and adapting the procedure described by Nelson (2008) for the global Travel Time map to the nearest city of 50,000, or more people in year 2000 and by Drigo (2013, GACC Project, in progress). The main differences with previous studies include a redefinition of target locations and friction data based on detailed national data (DTM 30m, land cover and road, trail, paths network data) and the adaptation of friction factors to estimate the transport of fuelwood including going and returning with fuelwood load.

This map is the result of an accessibility model that considers target locations (in this case accessible features and populated places) and cost, or friction surface, based on several national datasets that represent roads, terrain features (slope, altitude) and land cover.

The subsequent fundamental step for the scope of this study is to convert transport time values (minutes to/from the nearest accessible feature) into accessibility factor to be applied to DEB supply sources. This is done under the assumption that the higher the transport time to the nearest populated place or communication infrastructure, the lower the percentage of accessible resources.

In the absence of specific reference data, it was here assumed that wood resources (for energy use) that are more than 10 hours of transport time from the nearest accessible feature (10 hrs collection time as per CBS-NLSS2010) may be considered as totally inaccessible and that the accessible fraction of DEB resources decreases progressively with the increase of travel time.

In this study the physical accessibility is used in two separate phases of analysis:

1. In the Supply Module, the <u>off-road</u> accessibility of woody biomass resources is used to estimate the fraction of the total MAI that is accessible to rural users and to commercial woodfuel producers.
2. In the woodshed analysis, accessibility is based on each Nepal's major consumption sites such as urban centers and densely populated rural areas. In addition to the off-road accessibility, this analysis also includes distances along roads and rivers to reach the selected consumption sites.

Details of the travel time map development process, data sources and results are provided in Annex 5.

2.3.4 Accessible and available MAI

2.3.4.1 Physical and legally accessible MAI

The estimation and mapping of accessible productivity is done by applying the legal and physical access limitations, in form of percent accessible maps, to the map of DEB MAI.

2.3.4.2 Available MAI

Not all accessible MAI can be assumed available for fuelwood production or as construction material. The main competing use is the industrial roundwood that feeds wood processing industries such as furniture making, wood panels production, electrical poles, building post, etc.

However, the reference values for the annual production of industrial roundwood production varies considerably:

FAOstat (same value for 1998 to 2012)	1,260,000 m^3
FAO FRA Country Report (2003-2007) (based on Nepal Forestry stats):	152,000 m^3
Nepal Forestry statistics of District-wise timber sale (year2010-11)	161,173 m^3
Nepal Foresters' Association for REDD Nepal, 2012	**3,183,370 m^3**

FAOstat values appear based on old estimates and cannot be taken as a solid reference. FAO FRA Country report and Nepal Forestry statistics of timber sales appear far too low to represent the entire timber production of Nepal and it's likely that these values capture only the recorded fraction of the actual production from Government Managed Forests.

The estimation produced by the Nepal Foresters' Association for REDD in 2012 is much higher than all other sources but seems to be the most comprehensive and reliable one, and was taken as reference for this study.

Rural construction material is assumed to be included in the total amount of industrial roundwood estimated in the 2012 REDD report and, in order to avoid double counting[8], it was deducted from the total.

The available fuelwood supply potential was then estimated by deducting the remaining amount of industrial roundwood, i.e. 1,997.5 kt ad (1,818 kt DM), from the accessible DEB MAI of Terai, Hills and Mountain Districts, as indicated by the 2012 REDD report. The details of the industrial roundwood production are presented in Annex 3.

In the absence of data on the specific location of industrial roundwood production sites, the deduction was spatially distributed on all accessible woody biomass resources, as indicated in the 2012 REDD report..

[8] For the scope of this analysis the annual demand for rural construction material, which was estimated to be 285,000 ad tons added to woodfuel demand (see Section 2.2.1).

2.4 INTEGRATION MODULE

The scope of the Integration Module is to combine the parameters developed in the demand and supply modules by discrete land units (pixels-level and sub-national unit-level) in order to discriminate areas of potential deficit and surplus according to estimated consumption levels and sustainable production potentials.

The first and most important result of the integration module is the balance between the accessible and available potential productivity and the total consumption of woody biomass for energy generation and other uses.

In order to describe the various planning dimensions of wood energy, the supply/demand balance analysis will be carried out at the following three levels:

(i) Cell-level balance, which is the basis of all other balance analyses,

(ii) balance in a local context, few km around consumption sites, representing the informal self-supply horizon of rural and peri-urban households and,

(iii) balance based on the "commercial" fraction of the local surplus (resulting from the previous level) considered as source of commercial woodfuel production systems serving distant consumption sites.

2.4.1 Pixel-level balance

The supply/demand balance at the level of individual map pixel (or cell) is calculated by deducting the pixel-level consumption from the pixel-level available productivity. The calculation of the supply/demand balance by individual 1-hectare cell has an useful accounting function but it represents a somewhat virtual balance since individual pixels are usually either a production or a consumption site. An example of pixel-level balance is shown in Figure 8. (left-side map).

2.4.2 Local neighborhood balance

In order to achieve a realistic perception of the supply/demand balance it is necessary to combine the consumption and the supply potential within an area related to the real supply zone. In the case of rural and peri-urban households, the distance that household's members are prepared to go to fetch fuelwood, on foot or by local transport means are good parameters to estimate the actual supply area. This should be estimated in terms of time needed to reach the resources and to transport them to the village but the underlying spatial modeling would be too complex and the harvesting horizon is here simplified to a radius of 3 km around each pixel.

An example of the balance analysis in a local context is shown in Figure 8 (middle map). Comparing the local balance to the pixel-level balance it is interesting to see how the local context tends to render more visible the deficit areas, giving a more realistic perception of deficit and surplus zones

2.4.3 "Commercial" balance and "commercial" surplus

The analysis of the "commercial" balance is based on the consideration that the management and commercial exploitation of sparse resources may be uneconomical. In a local supply/demand context dominated by direct fuelwood collection all wood resources may be considered suitable for local (rural) consumers, but when the demand and supply areas are far apart and the supply system is market driven, then only the wood resources that are economically viable to exploit are likely to be utilized.

For woodfuels markets such as those of urban centers, the supply potential consists of the "commercial" fraction of surplus resources resulting from local balance. The "commercial" surplus is estimated by first accounting for the supply that is utilized for local demand, which includes all available DEB production potential, and second, estimating the quantity of remaining DEB that is suitable for commercial utilization, which is limited to the legally accessible resources that justify transport and management costs. To assess the commercial surplus some basic quantitative thresholds related to stock and productivity were defined as follows:

- One threshold concerned the minimum stocking required for profitable fuelwood production, which is here preliminarily set to 14.6 tons / ha, air dry[9].

[9] There is no reference to the minimum stock for profitable fuelwood production in Nepal. The value here proposed was derived from a

- The second threshold concerned the rotation period determined by the estimated annual surplus of the local supply/demand balance: only the areas with surplus levels that guarantee rotation periods lower than 30 years were considered eligible. To reach such condition the available surplus MAI must exceed 0.5 ad t/ha/year.

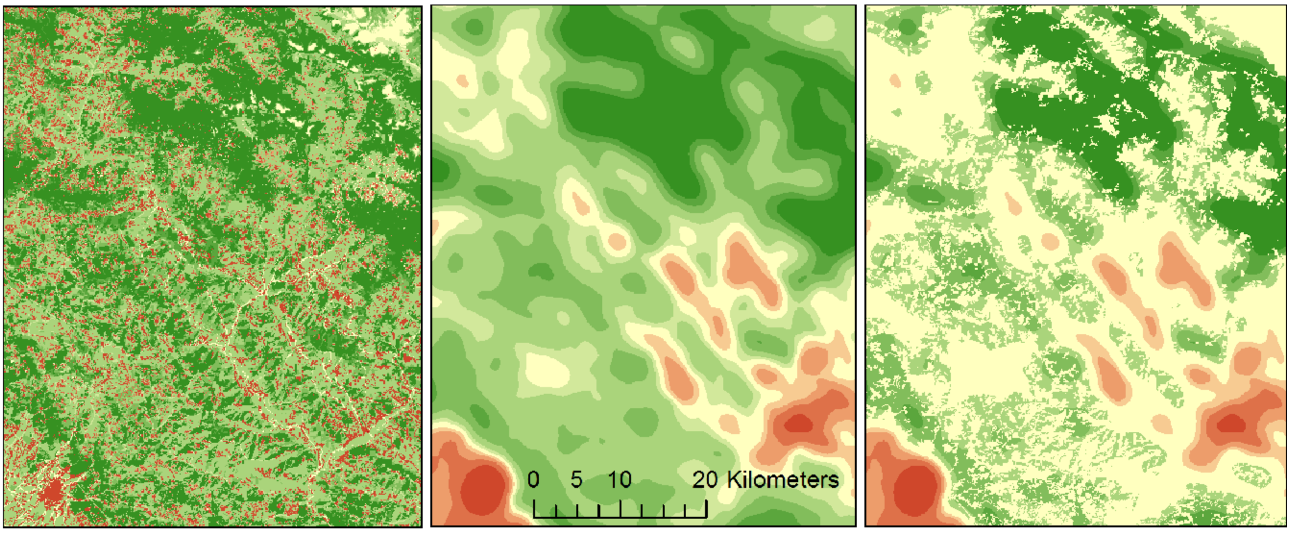
Consequently, only the accessible areas with a stock above 14.6 ad t/ha and a surplus above 0.5 odt/ha/year were considered as potential commercial sources. In addition, ALL Protected areas are excluded from commercial exploitation, including Buffer Zones in which local communities are entitled to exploitation of own use. An example of commercial balance analysis is shown in Figure 8 (right hand map).

At the local level of analysis it is important to verify the economic viability of the various situations with local operators and managers and to define the "economically viable" minimum surplus values that apply locally. .

The commercial balance analysis remains theoretical since it implies that the economically viable resources are rationally managed, such that the potentially sustainable increment is exploited entirely, without depleting the forest capital. The commercial balance is therefore useful for defining the theoretical limits of sustainable forest management but is unlikely to represent existing processes. Current exploitation is often unregulated, leading to overexploitation in some areas and under-exploitation in others.

FIGURE 8

Example of balance calculated at pixel-level, on a 3-km local context and commercial balance excluding non-commercial surplus resources. Example located over Rolpa, Pyuthan and Rolpa Districts, MWDR.



Pixel-level balance **Local balance within 3km context** **Commercial balance**

study on charcoal production in Mozambique (Mancini et al, 2007). In this study, the DEB stock threshold was set at 15 t / ha air-dry considering that below such level the cost of kiln preparation would be unprofitable.

2.5 WOODSHED ANALYSIS

Once the development of the WISDOM Base is complete, the subsequent step is to understand how conditions of local deficit, i.e. demand for woodfuel that cannot be met by local resources, translate into commercial harvesting and how such harvesting impacts on the available resources.

Keeping into account the woodfuel demand that cannot be satisfied by local resources (deficit areas in local balance maps) as well as the resources available and their accessibility from the main demand sites, it is possible to outline the supply zones where harvesting will likely concentrate.. These zones are termed "woodsheds" in analogy with the familiar geographical concept of watersheds (Drigo e Salbitano, 2008).

We may distinguish two types of woodsheds:

1. The **minimum sustainable woodshed** that represent what the supply zone should be for the sustainable supply of the needed DEB. The minimum sustainable woodshed is defined as the minimum area around the consumption sites in which the cumulative woodfuels balance between the local deficit and the (commercial) surplus is non-negative. This is a theoretical area, not the current harvesting area, and is meant to define the target area for sustainable forest management planning.
2. The **current** (or probable) **commercial woodshed**, or actual commercial harvesting area of a given consumption site, which is determined by the level of demand exceeding local resources, the available commercial surplus and its economic accessibility based on transport time considerations. The commercial woodshed is not based on sustainability considerations and may include unsustainable harvesting when the limits of economic accessibility induce excessive harvesting. The analysis of the commercial woodshed is particularly relevant for this study because it produces quantitative and spatial-explicit estimates of probable degradation processes due to excessive harvesting.

Figure 9 provides an overview of the steps of woodshed analysis, which are described in detail in the following sections.

2.5.1 Mapping commercial demand pressure

The first part of the analysis, leading to the map of the commercial demand pressure exerted by major deficit sites contributes to the analysis of the **minimum sustainable woodshed** as well as to that of the **current** (or probable) **commercial woodshed**.

The commercial demand pressure is here assumed to depend on the combined effect of (i) the woodfuel demand exerted by the local deficit sites and (ii) physical accessibility features.

In order to combine efficiently these two components, the analysis is carried out through weighted interpolation using Dinamica EGO processing environment. The model applied considers:

- as staring points of analysis, the location of deficit peaks (Categorical Map) with the associated local deficit values. These points represent the major deficit sites and are determined by the cumulative deficit values within a predefined horizon (in this case 20 km)[10]
- as weighting factor of interpolation, the friction map created for the analysis of accessibility, reporting the travel time needed to cross the cells, in minutes per meter.

The model creates an interpolation map for each individual point using the deficit value associated to the point as staring value and the friction map as weighting factor. These maps are then added together to form the cumulative "pressure" map determined by the intensity and location of the major deficit areas. Examples of the progressive interpolation are shown in Figure 10, while the final result is shown in Figure 20 in Results Section. By means of this combined cost factor, the cities with higher demand "produce" wider woodshed buffers while the cities with lower demand "produce" narrower buffers, well representing the territory under urban influence/pressure.

[10] The horizon for the cumulative deficit is designed so that the cumulative deficit of even large consumption areas, such as a large city or a cluster of nearby villages, can be summed to a single "peak" point. For this analysis, 26 major deficit points were identified.

FIGURE 9

Flowchart showing the main element of woodshed analysis.

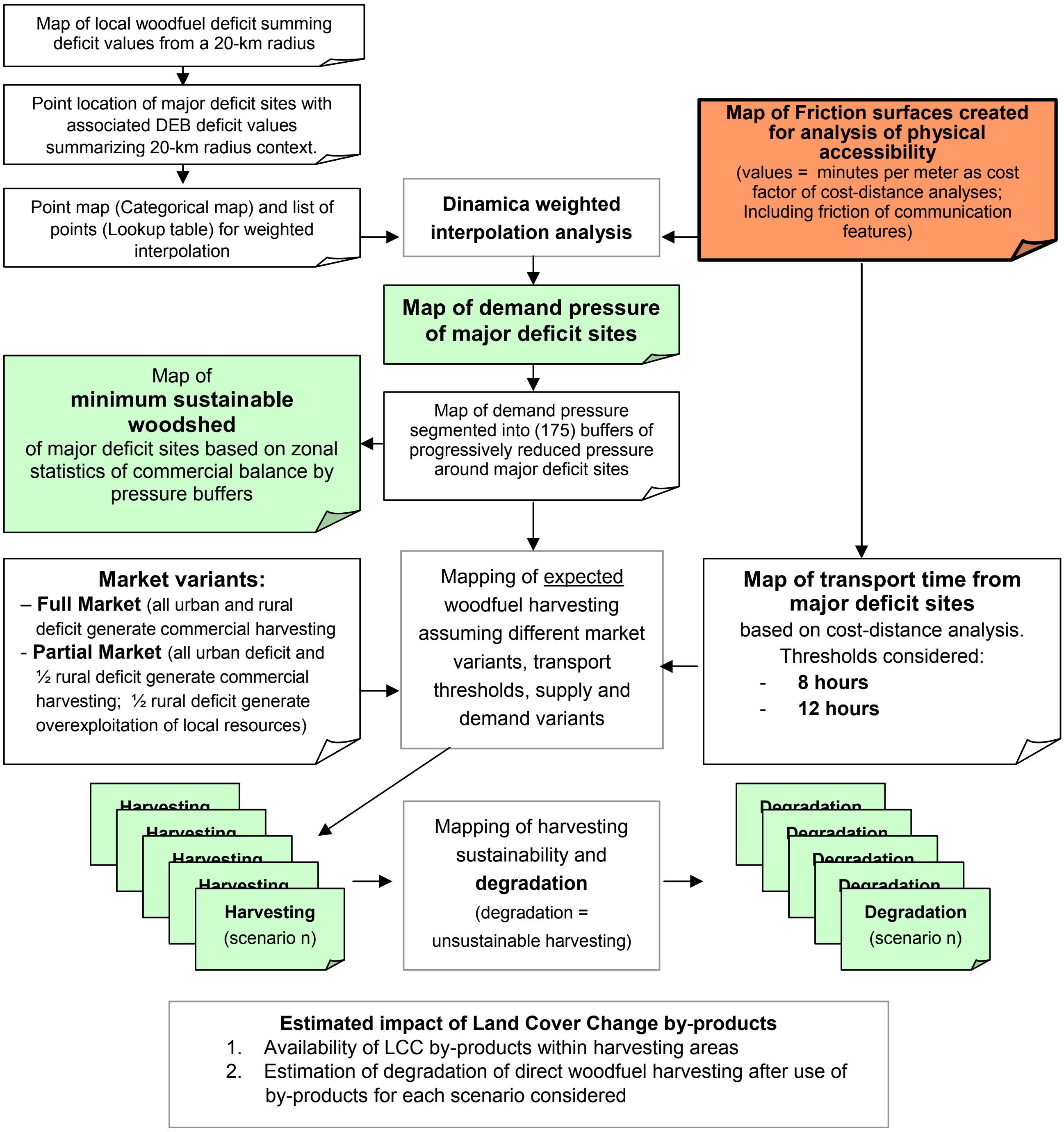
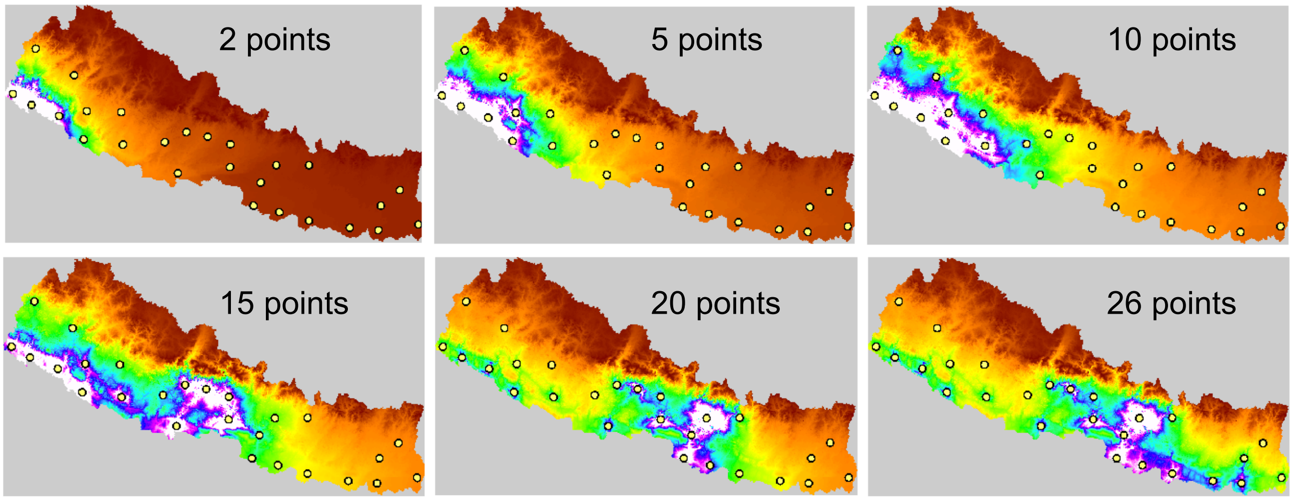


FIGURE 10

Examples of the progressive analysis combining demand pressure and physical accessibility for 26 major deficit sites.



2.5.2 Delineation of the minimum sustainable woodshed

Once the country-cumulative weighted interpolation map is produced, the procedure for the delineation of the **minimum sustainable woodshed** of the selected deficit sites is to calculate the supply/demand balance of each buffer (applying zonal statistics to the commercial balance) and to progressively expand the area buffer by buffer until the cumulative value of the commercial balance reaches a positive value, indicating that within such territory the supply potential (i.e. the commercial surplus) matches the demand. The minimum sustainable woodsheds for Medium Supply and Total / Conventional Demand variants, resulting from this analysis, are shown in Figure 21

To be noted, however, that the analysis of the minimum sustainable woodshed tells what should be the harvesting area in order to guarantee the sustainable supply of the needed woody biomass, assuming the rational and sustainable resources management system. This analysis doesn't tell what the actual harvesting area is, which is the scope of the next section, but it provides a revealing vision of the territory under urban influence and a clear target for forest management and sustainable wood energy planning.

2.5.3 Commercial woodsheds and estimation of harvesting intensity

The definition of the actual commercial woodshed and the estimation of harvesting intensity depend on several factors other than the distribution of resources and accessibility. Some factors influence the extent of the commercial harvesting area, other factors influence the response to local deficit conditions and the creation of commercial supply systems, while other factors influence the intensity of commercial harvesting, such as the availability of deforestation by-products and overall resource management practices, as discussed in the following sections.

2.5.3.1 Delineation of commercial harvesting area - Transport time threshold

We assume that the area of the commercial woodfuel harvesting depends primarily on economic considerations related to transport costs and market prices. We assume that beyond a certain transport time the cost of fuelwood at market place would be too high and the exploitation of those distant resources would be uneconomic. The transport cost of distant wood resources may become too high and the actual harvesting is likely to be concentrated on wood resources that are closer to market areas.

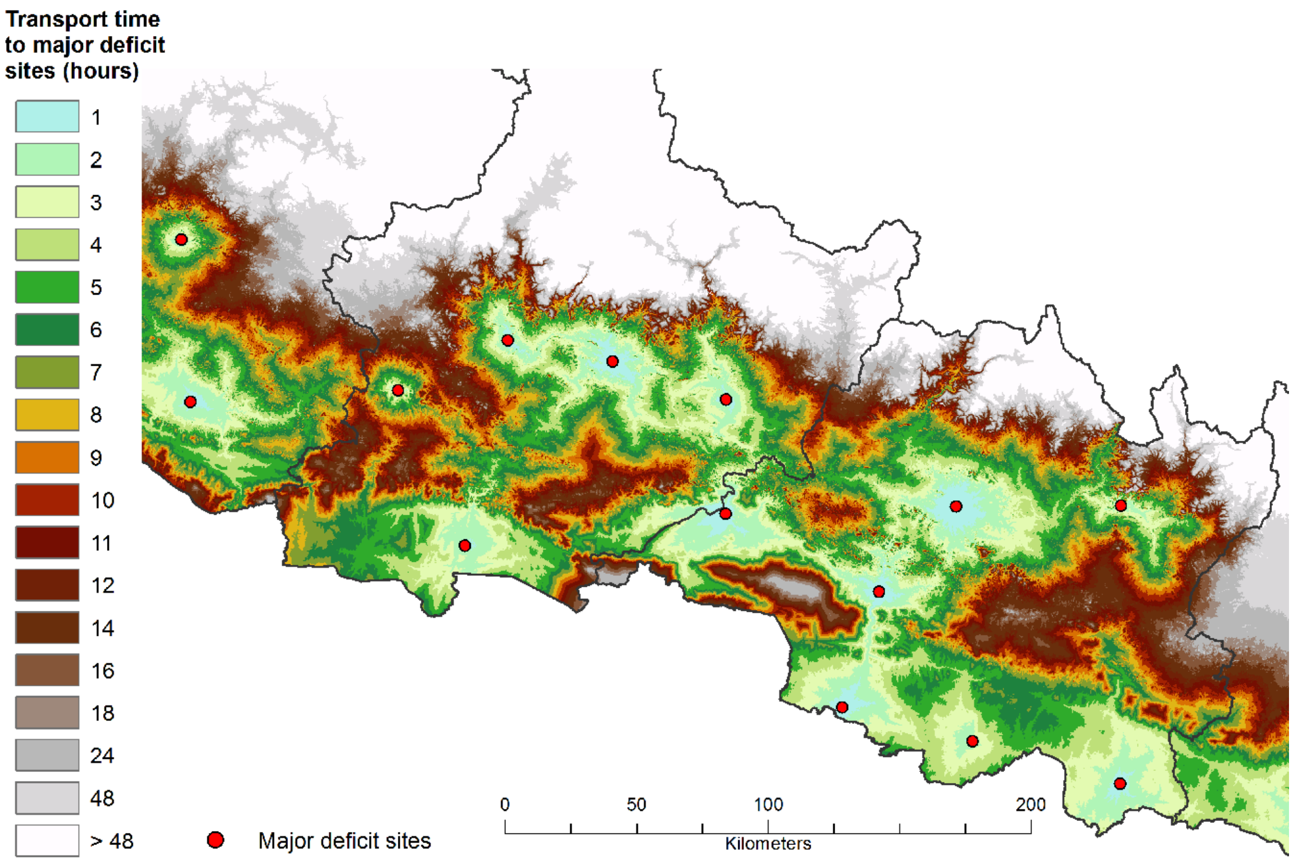
By conducting cost-distance analysis on the same major deficit points used for woodshed analysis using transport time as cost factor (see Annex 5 for a description of physical accessibility model), we can segment the resources according to transport time and thus we can apply threshold values as limit of actual supply zones in consideration of transport costs. Figure 11 shows the results of the transport time analysis.

We don't know with precision what such transport time threshold would be, although there seems to be a fair agreement that a truckload of fuelwood should not occupy a truck for more than one day.

In this analysis, in absence of clear evidence, we adopted two variants: 8-hours and 12-hours travel time thresholds (i.e. from market site to harvesting place and then loaded from harvesting place to roadside and to market), which represent approximately one “normal” and one “long” day of transport. These thresholds is not based on direct observations but only through "expert opinions" and needs to be verified in the field These thresholds were selected also with the scope of testing the impact of transport time component on the results of the study.

FIGURE 11

Transport time to the major deficit sites. Example showing Central and Western Development Regions.



2.5.3.2 From local deficit to commercial harvesting - Market variants

What fraction of the local deficit converts to commercial harvesting?

The demand for woodfuels in urban areas always create a local deficit; thus, it is safe to assume that they depend entirely on the commercial supply of fuelwood and charcoal. The situation in rural areas is less straightforward because the supply is primarily local and informal. Rural areas that are densely populated or that simply lack adequate accessible wood resources also experience deficit conditions, but these may induce different responses. For example, people may respond by:

(i) shifting towards non-conventional fuelwood assortments (annual pruning, twigs, etc.) and crop residues,
(ii) excessive harvesting of the limited resources locally available, or
(iii) depending on commercial supply.

Shifting to marginal wood assortments is already considered in demand scenario B, the two remaining responses to rural deficit are used as basis for alternative commercial harvesting scenarios:

1. **“Full Market”** scenario: All conditions of local deficit, including urban and rural areas, give origin to commercial harvesting of distant resources. Under the “Full Market” scenario, we assume that demand in rural deficit sites, like urban sites, is met by commercial harvesting rather than overexploitation of local rural resources. This assumption shifts pressure toward accessible forest resources and other distant areas with

surplus biomass and reduces the pressure on local resources.

2. **"Partial Market"** scenario: In this scenario, we assume that all deficit in urban areas gives rise to commercial harvesting (just like FM scenario), while only part of the rural deficit originates commercial harvesting of distant resources, and part gives origin to overexploitation of local resources. Lacking specific data, we assume that these two sources contribute equally to filling in for local rural deficit so that half of the deficit is met by overexploitation of local resources (with limits posed by available stock) and half is met by commercial harvesting. This assumption reduces commercial harvesting pressure in comparison to the Full Market scenario and increases the overexploitation of woody biomass in farmlands and woodlands close to sources of rural demand.

2.5.3.3 Accounting for Land Cover Change by-products

Though not directly linked to woodfuel demand, land cover change (LCC) processes impact woodfuel supplies. Deforestation releases large volumes of woody biomass, and afforestation augments renewable woodfuel supplies by adding to the existing growing stock. When deforestation occurs in regions accessible to woodfuel users or within the commercial harvesting area, the cleared woody biomass may be utilized as timber, woodfuel and construction material. Similarly, afforestation adds DEB equivalent to the mean annual increment (MAI) of the surrounding land class.

The quantity of woody biomass by-products annually available by physiographic zone and development regions, as result of deforestation and afforestation, was estimated on the basis of (i) the average bias-corrected areas of forest loss and gain per year derived from the Land Cover Change Assessment 2000-2010 produced by ICIMOD for the FRL submission and (ii) the average values of DEB stock and increment of the forests in the same areas. Details of the estimated woody biomass by-products by physiographic zone and development regions are presented in Annex 7.

However, the degree to which LCC by-products are actually used as woodfuel is unknown. To accommodate this uncertainty, we explore two additional scenarios.

- In the first scenario we assume LCC by-products are not used and that all demand originates woodfuel harvesting.
- In the second scenario, we assume that 70% of the DEB by-products are used as woodfuel and construction material while the rest are used as timber or left on site. To be noted that deforestation by-products are considered entirely non-renewable while those becoming available through afforestation are considered renewable. In any case, their availability within harvesting areas reduces direct wood harvesting.

Since the two scenarios here considered are the extremes of the actual range of possibilities, in the most probable scenario (Leading Scenario) an intermediate situation was chosen, whereby 35% of LCC by-products are assumed to be used for energy.

2.5.3.4 Scenarios considered

Combined with the Supply and Demand variants, the factors influencing the delineation of commercial woodsheds and harvesting intensity give origin to a wide range of scenarios, as presented in Table 1. While some of the assumptions considered are definitely more probable than others, forming what we may call the leading scenario, the range of results produced by other assumptions provide a measure of the "confidence interval" of leading estimates and, more important, provide a clear perception of how much the various aspects influence the results.

Conducting analyses with numerous individual combinations of data variants and assumptions (28 out of 48 possible combinations) based on preliminary data, allowed the identification of the most realistic combination that form the Leading Scenario, as well as the most favorable combination, leading to lowest degradation scenario, and the least favorable combination leading to highest degradation scenario. Table 1 shows the full range of data variants and assumptions considered, highlighting the combinations forming the Leading Scenario as well as then low- and high-degradation scenarios (discussed in Section 3.4, Results Chapter).

TABLE 1

Full range of combinations based on data variants and alternative assumptions made.

	Market variants->	FM - Full Market				PM - Partial Market			
	Transport thresholds->	12 hours		8 hours		12 hours		8 hours	
	Use of LCC by-products->	No use	Full Use	No use	Full Use	No use	Full Use	No use	Full Use
Supply var.↓	Demand variants ↓								
Minimum	A - Total demand	A_Mn_FM_12_N	A_Mn_FM_12_U	A_Mn_FM_8_N	A_Mn_FM_8_U	A_Mn_PM_12_N	A_Mn_PM_12_U	A_Mn_PM_8_N	A_Mn_PM_8_U
	B - Conventional demand	B_Mn_FM_12_N	B_Mn_FM_12_U	B_Mn_FM_8_N	B_Mn_FM_8_U	B_Mn_PM_12_N	B_Mn_PM_12_U	B_Mn_PM_8_N	B_Mn_PM_8_U
Medium	A - Total demand	A_Md_FM_12_N	A_Md_FM_12_U	A_Md_FM_8_N	A_Md_FM_8_U	A_Md_PM_12_N	A_Md_PM_12_U	A_Md_PM_8_N	A_Md_PM_8_U
	B - Conventional demand	B_Md_FM_12_N	B_Md_FM_12_U	B_Md_FM_8_N	B_Md_FM_8_U	B_Md_PM_12_N	B_Md_PM_12_U	B_Md_PM_8_N	B_Md_PM_8_U
Maximum	A - Total demand	A_Mx_FM_12_N	A_Mx_FM_12_U	A_Mx_FM_8_N	A_Mx_FM_8_U	A_Mx_PM_12_N	A_Mx_PM_12_U	A_Mx_PM_8_N	A_Mx_PM_8_U
	B - Conventional demand	B_Mx_FM_12_N	B_Mx_FM_12_U	B_Mx_FM_8_N	B_Mx_FM_8_U	B_Mx_PM_12_N	B_Mx_PM_12_U	B_Mx_PM_8_N	B_Mx_PM_8_U

Notes:

The combinations computed using preliminary data for sensitivity analysis are in black, while those in grey were not computed.

Yellow shading identifies the most likely combination forming the Leading Scenario (calculated as intermediate between No Use and Full Use of LCC by-products) . Red shading identifies the least favorable combination, leading to highest degradation scenario, while green shading identifies the most favorable combination leading to lowest degradation scenario.

2.5.4 Harvesting sustainability and degradation rates

2.5.4.1 Spatial distribution of commercial harvesting

Harvesting intensity within the commercial harvesting areas defined through the commercial woodshed analysis is not evenly distributed; thus, we assume that the expected amount of harvesting in any given pixel depends on the commercial demand pressure (**Errore. L'origine riferimento non è stata trovata.**) and on the commercial surplus available, as per the Equation 5:

$$Har_i = w\_s_i * (\sum c\_d / (\sum w\_s) \qquad \text{[eq. 5]}$$

where:

Har_i = commercial harvesting in pixel $_i$

w_s_i = weighted surplus = commercial surplus in pixel $_i$ * pressure level in pixel $_i$)

$\sum c\_d$ = Total commercial deficit within woodshed

$\sum w\_s$ = Total w_s within woodshed

With this algorithm, commercial harvesting is proportional to demand pressure and commercial surplus.

2.5.4.2 Estimating harvesting sustainability and degradation rates

The sustainability of woodfuel harvesting is estimated for any given area by subtracting the harvesting from the sustainable supply potential, which is the available commercial surplus of DEB MAI. When harvesting is smaller than the sustainable supply, then that harvesting is sustainable; when the harvesting is greater than the sustainable supply, the quantity exceeding the supply represents the unsustainable component of harvesting.

In this analysis we define degradation as the quantity of woody biomass harvested in excess of the sustainable supply potential. Hence, the quantity of estimated unsustainable harvesting, measured in ad t per hectare or aggregated by reporting unit, corresponds to the quantity of degradation induced by excessive woodfuel harvesting.

Resource management factor

However, if, when estimating the sustainability of commercial harvesting we consider the commercial surplus entirely, we implicitly assume that the resources are optimally exploited, maximizing the renewable capacity of supply sources. We consider this the minimum unsustainable harvesting resulting from optimal management, but this is not a realistic estimation of the actual exploitation practices.

We can approximate the expected unsustainable harvesting by applying a reduction factor representing sub-optimal resource management. Lacking reliable parameters describing actual exploitation practices, we refer to the "Sustainable Increment Exploitation Factor" (SIEF) defined in the pan-tropical WISDOM analysis (ref. Bailis et al. 2015, Drigo et al 2014), where statistics on the fraction of forest resources under management plans and forest plantation statistics (ref FAOstat 2010) were used as indicators of the national management status. SIEF ranges between 0 and 1, where 1 represents optimal management (optimal rotation) and 0 represents worst-case exploitation (stock depletion without rotations). In the process of analysis, the SIEF is applied to the available commercial surplus to reduce the sustainable increment used by harvesting and consequently increase the unsustainable harvesting fraction that impact on the stock.

In that study, the SIEF applied to commercial harvesting in Nepal, was 0.8, which is a relatively high value, indicating a somewhat rational resource management status. In this study, in the absence of other information about "management parameters", we apply the same value of SIEF to estimate the expected unsustainable fraction of commercial harvesting.

2.5.5 Worked out example of analysis

All maps generated in this study and all analytical steps leading to their creation are described in Annex 6.

In addition, as illustration of the procedure of analysis, we present in Table 2, for one selected scenario, the sequence of analytical steps leading to the mapping and quantitative estimation of the probable degradation rate. The scenario chosen is the one based on Conventional Demand (B), Medium Supply variant (Md), Partial Market (PM), 8-hours transport threshold (8): **B_Md_PM_8, which was finally chosen as the Leading Scenario**.

The estimation of the impact of LCC by-products on the direct harvesting and degradation rate is done at the end of the process. This facilitate the integration of different deforestation rates in the analysis.

TABLE 2

Procedure of analysis for scenario B_Md_PM_8 [Conventional Demand (B), Medium Supply variant (Md), Partial Market (PM), 8-hours transport threshold (8)]. Sequence of analytical steps leading to the mapping and quantitative estimation of the probable degradation rate according to the scenario chosen.

Module and data layer (all relative to Conventional demand – Medium supply variant)	Summary value	Map name	Methodology	generating algorithm and maps used in the process
Supply module data				
DEB stock in adkg. - Mean value.	1,287,807 adkt	**stkadkg_md**	Dendroenergy biomass (DEB) stock is estimated using NFI sample plot data for 26 strata and mapped based on Land Cover, Forest Type maps (DFRS 2015) and using Tree Cover % as spatial proxy for distribution within strata.	Float("m_tc_stkmd" * "tc2010") m_tc_stkmd : calculated DEB for 1 % tree cover (see Annex 6) tc2010 : Tree cover percent derived from VCF data (DiMiceli et al, 2011)
MAI (adkg/ha/yr) - Medium stock variant	25,219 adkt	**mai_md**	The Mean Annual Increment (MAI) is estimated applying stock-MAI equations to the mao of stock. Separate equations are used for broadleaves and coniferous formations.	Con("stkadkg_md" > 0,Con("broad_conif" == 2, ((Power(("stkadkg_md" / 1000), -0.5069) * 22.683) * "stkadkg_md" / 100), ((Power(("stkadkg_md" / 1000), -0.5879) * 37.058) * "stkadkg_md" / 100)),0) broad_conif : map of forest area separating broadleaves and coniferous formations (see Annex 6)
Physically accessible MAI – Medium variant	20,891 adkt	**phacmai_md**	The physical accessibility of resources from the nearest accessible feature (road, track or settlement) is based on several factors (slope, altitude, friction of land cover types) and cost-distance algorithm. The accessibility, originally estimated in transport time is then converted to percent accessible.	Int("mai_md" * "ph_acc01" / 100 + 0.5) ph_acc01 : map of physical accessibility expressed as % (see Annex 6)
Physically and legally accessible MAI for <u>local consumption</u>	19,252 adkt	**acmai_md**	The physically accessible resources are further reduce on account of access restrictions applied in protected areas.	Int("phacmai_md" * "legac_loc_2" / 100 + 0.5) legac_loc_2 : map of legal accessibility expressed as % (see Annex 6)
Availabe (and accessible) MAI – Medium variant (-REDD2012 timber)	**17,244 adkt**	**av2mai_md**	The timber production (based on REDD 2012 report) is deducted from the accessible resources in order to obtain the "available" resources. Deduction is done on all wood resources as indicated in the report.	Int("acmai_md" * "av_factor" / 1000 + 0.5)
Demand Module data				

Module and data layer (all relative to Conventional demand – Medium supply variant)	Summary value	Map name	Methodology	generating algorithm and maps used in the process
"Conventional" Fuelwood consumption Medium variant (ad kg per pixel) -	10,176 adkt	**cons_rev2_md**	This Includes HH, industrial and commercial sectors, cremation wood and construction material. Revised for rural Terai in consideration of probable use of "marginal" fuelwood (twigs and annual pruning of farm trees and shrubs) to fill 1/2 of the gap estimated within a 6km horizon.	Con("rural_msk" == 0, "cons_adkg_3",Con("pc2rfulf6k_md" > 80, "cons_adkg_3", "cons_adkg_3" - "cons_adkg_3" * (100 - "pc2rfulf6k_md") / 200)) rural_msk : mask of rural areas cons_adkg_3 : Total consumption (including conventional and marginal fuelwood) pc2rfulf6k_md : % of demand fulfilled by resources available within 6 km (see Annex 6)
Integration Module data				
Cell-level balance	+7,068 adkt	**bal22_md**	Simple supply/demand balance calculated pixel-by-pixel as supply potential <minus> revised consumption(excluding marginal woody biomass used in rural Terai)	"av2mai_md" - "cons_rev2_md"
Local balance assuming a harvesting horizon of 3km	+7,065 adkt	**l_bal22_md**	Supply/demand balance calculated on a 3km harvesting context	focalmean(bal22_md; 20 + 10; circle; mean) and clipped on mutm_msk mutm_msk : mask of Nepal (value 1) used to “clip” data (see Annex 6)
Commercial balance	+5,429 adkt	**combal2_md**	The commercial balance reports the deficit values of the local balance but only the surplus values that may be considered suitable for commercial fuelwood harvesting, as discussed in Section 2.4.3 above.	Model (combal_md): 1: Combal_tmp1 = Con("l_bal22_md" < 500, Con("l_bal22_md" >=0,0, "l_bal22_md"), "l_bal22_md") 2: Combal_tmp2 = Con("Combal_tmp1">0, Con("stkadkg_md" > 14660, "Combal_tmp1",0), "Combal_tmp1") 3: combal2_md = Con("Combal_tmp2">0, Con("legac_com" == 0,0,"Combal_tmp2"),"Combal_tmp2")
Commercial demand pressure from major deficit sites				
Local deficit	-2,830 adkt	**l_def22_md**	Map of local deficit areas	Con("l_bal22_md" <= 0,"l_bal22_md",0)
Sum of deficit within a 20 km radius	n.a.	**def2md_20km**	Map showing for each pixel the sum of the deficit values within a radius of 20 km. Map created in order to locate the major deficit sites.	FocalSUM ("l_def2_md", circle, 200) Note: This step and the following three leading to the pressure map were based on preliminary balance results. This analysis was not re-runned after the last data revision

Module and data layer (all relative to Conventional demand – Medium supply variant)	Summary value	Map name	Methodology	generating algorithm and maps used in the process
				because their change on the pressure distribution was considered irrelevant.
Peak deficit locations	n.a.	**pnts_defsum20km_md.shp**	Point map with cumulative deficit estimated on a 20 km radius. 26 major deficit sites are identified.	Create point map placing points on peak deficit locations (based on 20km deficit map) Assign deficit value to the points from def2mn_20km, def2md_20km, def2mx_20km and define PointID code
Weighted cost distance map representing the pressure of the commercial demand onto the landscape	n.a.	**wcd_def2_md**	Interpolation map for each individual point using the deficit value associated to the point as staring value and the friction map as weighting factor. The 26 maps are then added up to form the cumulative "pressure" map determined by the intensity and location of the major deficit areas	Dinamica EGO program **wcd_def2_prec2_m**d**.egoml** cross_m_m.tif : Friction map in .tiff format pnt_id.tif : raster map of deficit points with points ID id_def2_md.csv : Lookup Tables with points ID (fieldname: key) and deficit values (fieldname: value; positive)
Weight to be used to distribute pressure on surplus resources	n.a.	**wcd_d2_md_c2**	Segmentation of wcd_def2_md into 175 classes reflecting the weighted cost distance values (weighted on wcd values)	Reclass of wcd_def2_md by ACSII file : recl_wcd_value_w_cat_02.txt
Travel time from major deficit sites				
Transport time from major deficit sites	n.a.	**time_wcd2_pnt** (minutes) **wcd2_hours** (hours)	Map showing transport time (going and back) from/to the nearest deficit site considering along-road and off-road transport components.	Cost distance (deficit points; cross_m_m)
Commercial woodsheds and estimation of harvesting intensity				
Rural and minor urban deficit generating unsustainable local harvesting	- 962 adkt	**lh_22md_8h**	According to the Partial Market scenario, 1/2 of the local rural deficit (within the 8hr zone) remains on site as unsustainable local harvesting (up to a maximum of 30% of the local stock), while the rest of the deficit generates commercial harvesting. Outside the 8hr zone, the deficit remains entirely on site as unsustainable harvesting	Con("l_bal22_md" < 0,Con("wcd2_hours" <= 8,Con("rural_msk" == 1,Con(- "l_bal22_md" / 2 <= ("stk_md_3km" * 0.3),"l_bal22_md" / 2,-("stk_md_3km" * 0.3)),0),"l_bal22_md"),0) rural_msk : Mask of rural areas stk_md_3km : Mean stock on a 3 km radius
Commercial deficit	- 1,868.adkt	**c_def22_md_8h**	Commercial deficit including total urban deficit and the fraction of the rural deficit within 8 hours (transport time) from major deficit sites that is not harvested locally	Con("wcd2_hours" <= 8,Con("combal2_md" < 0,"combal2_md" - "lh_22md_8h",0),0)
Weighted surplus value (surplus * pressure level)	189539000000	**wcsur22_md_8h**	Creation of the weighted surplus value (surplus * pressure level) within the woodshed zone of 8-hours around major deficit points for the distribution of the commercial deficit as harvesting	Con("wcd2_hours" <= 8, Con("combal2_md" > 0,"combal2_md" * "wcd_d2_md_c2",0),0)
Commercial harvesting by	- 1,868 adkt	**ch22_md_8hpm**	Commercial harvesting by pixel : tot deficit (sum	

Module and data layer (all relative to Conventional demand – Medium supply variant)	Summary value	Map name	Methodology	generating algorithm and maps used in the process
pixel			c_def22_md_8h) 1868250000 / total weighted surplus (sum wcsur22_md_8h) 189539000000 = 0.00985681 (multiplier of wcsur22_md_8h)	"wcsur22_md_8h" * 0.00985681
Total harvesting	10,181 ad kt	**h_22md8h**	Total harvesting, including: • sustainable local harvesting (sus_l_h_r2md) • Rural and minor urban deficit generating unsustainable local harvesting (lh_22md_8h) • Commercial harvesting (ch22_md_8hpm)	"sus_l_h_r2md" + "ch22_md_8hpm" - "lh_22md_8h"
Commercial harvesting sustainability	n.a.	**chs22md8h80pm**	Commercial harvesting sustainability assuming a SIEF of 0.8	Con("ch22_md_8hpm" > 0,"combal2_md" * 0.8 - "ch22_md_8hpm",0)
Non-Renewable commercial harvesting	-177 ad kt	**nrch22md8h80p**	Non-Renewable commercial harvesting within 8 hrs from major deficit sites assuming a SIEF of 0.8 This map includes only the unsustainable fraction of commercial fuelwood harvesting	Con("chs22md8h80pm"<0, "chs22md8h80pm",0)
Unsustainable harvesting and Degradation rate – All land cover classes – No use of LCC by-products				
TOTAL Non-renewable harvesting (no use of LCC by-products)	**1,140 kt ad or 1,038 kt DM**	**tnrh22md8h80p**	TOTAL Non-renewable harvesting merging unsustainable local harvesting (lh_22md_8h) and unsustainable commercial harvesting (nrch2md8h80p). NO USEW of LCC by-products is here assumed. This value refer to all DEB resources, including Forests, Other Wooded Lands and Other Lands	"nrch22md8h80p" + "lh_22md_8h" (both negatives)
Ranking by degradation risk		**b2mdpm8h_rank**		Con("tnrh22md8h80p" < 0,Con("tnrh22md8h80p" < -100,Con("tnrh22md8h80p" < - 500,3,2),1),0)
Degradation risk ranking by Dev Region, Physiographic zone		**dprnk_b2md8pm**		"d_reg_physio" * 100 + "b2mdpm8h_rank" **dprnk_b2md8pm.xls**
Degradation risk ranking in FRF by Dev Region, Physiographic zone		**rnkfrf_b2md8p**		"dprnk_b2md8pm" * "frf_msk"
Unsustainable harvesting and Degradation rate – All land cover classes – Intermediate Use of LCC by-products (Leading Scenario)				
TOTAL Non-renewable harvesting (Intermediate use of LCC by-products)	**1,107 kt ad or 1,008 kt DM**	**tnrh22md8h_r1**	TOTAL degradation from Non-renewable direct harvesting after use of FRL LCCbp.	Procedure of analysis: 1. Estimation of available LCC byproducts by sub-region (see Annex 7). 2. Estimation and mapping of reduced direct harvesting, deducting the amount replaced by LCC by-products: reduced local harvesting and commercial harvesting.

Module and data layer (all relative to Conventional demand – Medium supply variant)	**Summary value**	**Map name**	**Methodology**	**generating algorithm and maps used in the process**
				3. Mapping of the unsustainable fraction of reduced direct harvesting
Unsustainable harvesting and Degradation rate – Limited to Forest-Remaining-Forest (FRF) – Intermediate Use of LCC by-products (Leading Scenario)				
TOTAL Non-renewable Forest harvesting (Intermediate use of LCC by-products)	**235 kt ad or 214 kt DM**	**tnrh22md8h_r1** (masked for FRF area)	Forest degradation from unsustainable direct harvesting within Forest-Remaining-Forest (FRF) after use of FRL LCCbp	Estimation and mapping of the unsustainable fraction of direct harvesting taking place within forest-remaining-forest (FRF) areas. This is obtained through masking of map **tnrh22md8h_r1** for FRF (assigning 0 value to all non-FRF map areas.

3 RESULTS

3.1 Demand Module results

The map of 2011 population distribution, essential ingredient in the development of the Demand Module, is shown in Figure 12. The map representing the total consumption of fuelwood[11] in all sectors is shown in Figure 13.

Table 3a provides fuelwood consumption statistics by sub-regions intersecting Development Regions and Physiographic Zones. Table 3b summarizes fuelwood consumption by Physiographic zone and by Development Regions, as air-dry (ad) as well as dry-matter (DM) units. In consideration of its relevance in the analysis of supply/demand balance, distinction is made, at least tentatively, between "conventional" fuelwood made of stemwood and branches and "marginal" fuelwood, made of twigs and annual pruning of farm trees and shrubs.

TABLE 3a

Fuelwood consumption by sub-regions intersecting Development Regions and Physiographic Zones. Distinction is made between conventional fuelwood and marginal fuelwood.

Develop-ment Region	Physiographic Zone	**Rural consumption (conventional + marginal)**	**Urban consumption (conventional)**	**Total consumption (conventional + marginal)**	**Conventional consumption (excluding marginal)** Minimum supply variant	Medium supply variant	Maximum supply variant
		kt ad	kt ad	kt ad	kt ad	kt ad	kt ad
Far Western	HighHimal	3	0	**3**	2	**2**	2
	HighMount	264	0	**264**	260	**263**	263
	Mid Mount	539	39	**578**	574	**577**	578
	Siwaliks	53	1	**54**	54	**54**	54
	Terai	436	70	**507**	422	**437**	448
Mid Western	HighHimal	13	0	**13**	10	**10**	10
	HighMount	455	0	**455**	454	**455**	455
	Mid Mount	708	56	**764**	757	**762**	764
	Siwaliks	275	35	**309**	288	**293**	296
	Terai	345	41	**386**	301	**314**	323
Western	HighHimal	14	0	**14**	12	**12**	12
	HighMount	167	0	**167**	165	**166**	167
	Mid Mount	1,104	184	**1,287**	1259	**1270**	1275
	Siwaliks	104	46	**150**	149	**149**	150
	Terai	339	57	**397**	323	**344**	359
Central	HighHimal	2	0	**2**	2	**2**	2
	HighMount	168	2	**170**	170	**170**	170
	Mid Mount	1,384	293	**1,678**	1432	**1448**	1459
	Siwaliks	299	157	**457**	441	**445**	448
	Terai	1,043	211	**1,254**	891	**931**	960
Eastern	HighHimal	5	0	**5**	4	**4**	4
	HighMount	178	0	**178**	178	**178**	178
	Mid Mount	870	59	**930**	928	**929**	930
	Siwaliks	136	77	**213**	212	**212**	213
	Terai	657	184	**841**	708	**750**	775
Nepal		**9,562**	**1,513**	**11,075**	9995	**10176**	10294

Note: Since the consumption of conventional fuelwood in rural areas is influenced by the availability of woody biomass, three variants are presented, with reference to Minimum, Medium and Maximum supply potentials.

[11] The consumption in the residential sector is inclusive of construction material for fences, house repairs etc.

TABLE 3b

Summary of total and conventional fuelwood consumption by Physiographic zone and by Development Region.

	Total consumption (conventional + marginal)		Conventional consumption (excluding marginal)	
Physiographic Zone	kt ad yr^{-1}	kt DM yr^{-1}	kt ad yr^{-1}	kt DM yr^{-1}
High Himalaya	36	32	29	27
High Mountains	1,235	1,124	1,232	1,121
Mid Mountains	5,237	4,766	4,986	4,537
Siwaliks	1,183	1,076	1,154	1,050
Terai	3,385	3,080	2,776	2,526
Development Region				
Far Western	1,405	1,278	1,333	1,213
Mid Western	1,927	1,754	1,834	1,669
Western	2,015	1,834	1,941	1,766
Central	3,561	3,240	2,995	2,726
Eastern	2,167	1,972	2,074	1,887
Total Nepal	**11,075**	**10,079**	**10,176**	**9,260**

3.2 Supply Module results

Maps of DEB stock per hectare (and per pixel) is shown in Figure 14. Maps of per hectare values of total MAI, and physically & legally accessible MAI are shown in Figure 15 and Figure 16. Finally, Figure 17 shows the same map, but only with biomass that is potentially available for energy use after accounting for industrial uses of roundwood like timber and pulp production. All maps shown refer to the Medium variant.

Table 4a provides the summary of the same items by Development Region and Physiographic zones including Minimum, Medium and Maximum variants.

Comparing the supply potential, best represented by the Available DEB MAI, to woodfuel consumption shown in Tables 3a and 3b we can see that at national level the supply exceeds the demand for all variants considered. For Medium supply and Total consumption variants the national surplus is 8 million tons (range 6.7 to 10.1), which represents a factor supply/demand of 1.7 (range 1.6 to 1.9). From this it appears that Nepal is self-sufficient by a large margin, however, there is a great variability on the geographic distribution of the demand and supply, which creates areas of deficit that are better revealed by balance analyses discussed below.

TABLE 4a

Dendroenergy biomass (DEB) stock, Mean Annual Increment (DEB MAI), legally and physically accessible DEB MAI and DEB MAI available for energy uses, according to Minimum, Medium and Maximum variants. Values presented by sub-regions intersecting Development Region and Physiographic zones.

		DEB stock			**DEB MAI**		
		Minimum variant	**Medium variant**	Maximum variant	Minimum variant	**Medium variant**	Maximum variant
			kt ad			kt ad yr^{-1}	
Far Western	HighHimal	4,687	**6,763**	8,840	109	**132**	150
	HighMount	71,093	**93,693**	116,288	1,180	**1,347**	1,487
	Mid Mount	47,552	**63,641**	79,727	1,247	**1,403**	1,536
	Siwaliks	27,449	**30,978**	34,506	544	**577**	607
	Terai	21,515	**26,216**	30,913	515	**585**	642
Mid Western	HighHimal	13,677	**20,791**	27,905	297	**368**	424
	HighMount	159,024	**205,615**	252,195	2,656	**2,998**	3,288
	Mid Mount	43,173	**56,589**	70,004	1,342	**1,495**	1,628
	Siwaliks	52,436	**57,593**	62,752	1,195	**1,255**	1,309
	Terai	14,812	**17,964**	21,113	352	**400**	439
Western	HighHimal	11,885	**16,788**	21,690	256	**304**	343
	HighMount	82,062	**107,625**	133,180	1,296	**1,462**	1,603
	Mid Mount	54,548	**68,712**	82,882	1,714	**1,872**	2,012
	Siwaliks	27,178	**30,154**	33,131	566	**598**	627
	Terai	7,569	**9,862**	12,153	293	**355**	401
Central	HighHimal	4,969	**6,987**	9,004	112	**131**	147
	HighMount	53,101	**67,270**	81,440	952	**1,055**	1,144
	Mid Mount	48,727	**61,854**	74,989	1,592	**1,745**	1,879
	Siwaliks	78,078	**86,176**	94,278	1,504	**1,590**	1,666
	Terai	16,342	**20,459**	24,571	566	**675**	759
Eastern	HighHimal	8,523	**12,901**	17,280	188	**229**	261
	HighMount	83,357	**107,951**	132,550	1,426	**1,600**	1,747
	Mid Mount	52,474	**67,684**	82,904	1,645	**1,804**	1,943
	Siwaliks	23,180	**25,842**	28,506	527	**561**	591
	Terai	13,266	**17,699**	22,126	549	**678**	775
Nepal		**1,020,676**	**1,287,807**	**1,554,925**	**22,625**	**25,219**	**27,408**

/Continue

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		Legally and physically accessible DEB MAI			Available DEB MAI		
		Minimum variant	**Medium variant**	Maximum variant	Minimum variant	**Medium variant**	Maximum variant
			kt ad			kt ad yr^{-1}	
Far Western	HighHimal	9	**10**	11	8	**10**	11
	HighMount	624	**720**	799	591	**686**	764
	Mid Mount	1,219	**1,370**	1,500	1,088	**1,237**	1,365
	Siwaliks	518	**550**	578	434	**471**	502
	Terai	444	**506**	556	367	**428**	477
Mid Western	HighHimal	38	**47**	54	36	**45**	52
	HighMount	1,522	**1,721**	1,889	1,398	**1,595**	1,762
	Mid Mount	1,335	**1,487**	1,619	1,177	**1,329**	1,459
	Siwaliks	868	**915**	957	739	**794**	839
	Terai	234	**272**	301	193	**230**	258
Western	HighHimal	36	**43**	48	33	**40**	45
	HighMount	779	**877**	961	692	**788**	870
	Mid Mount	1,695	**1,851**	1,989	1,499	**1,658**	1,796
	Siwaliks	521	**551**	577	441	**476**	505
	Terai	293	**354**	401	242	**299**	344
Central	HighHimal	7	**8**	9	7	**8**	9
	HighMount	471	**524**	570	440	**493**	539
	Mid Mount	1,549	**1,697**	1,827	1,383	**1,533**	1,663
	Siwaliks	1,000	**1,064**	1,120	863	**933**	992
	Terai	535	**641**	723	442	**543**	621
Eastern	HighHimal	21	**25**	28	20	**24**	27
	HighMount	906	**1,015**	1,108	848	**957**	1,050
	Mid Mount	1,632	**1,789**	1,927	1,461	**1,620**	1,758
	Siwaliks	514	**548**	577	446	**483**	513
	Terai	540	**666**	761	447	**565**	654
Nepal		**17,312**	**19,252**	**20,892**	15,295	**17,244**	18,876

TABLE 4b

Summary of DEB stock, Mean Annual Increment (DEB MAI), physically and legally accessible DEB MAI and DEB MAI available for energy uses by Physiographic zone and by Development Region - Medium variant. Values presented as air-dry (ad) and dry-matter (DM) units

	DEB stock		Total DEB MAI		Accessible DEB MAI		Available DEB MAI	
Physiogr. Zone	kt ad yr^{-1}	kt DM yr^{-1}	kt ad yr^{-1}	kt DM yr^{-1}	kt ad yr^{-1}	kt DM yr^{-1}	kt ad yr^{-1}	kt DM yr^{-1}
High Himalaya	64,230	58,449	1,164	1,059	134	121	126	115
High Mountains	582,154	529,760	8,462	7,701	4,858	4,421	4,519	4,112
Mid Mountains	318,479	289,816	8,318	7,569	8,194	7,457	7,377	6,713
Siwaliks	230,744	209,977	4,582	4,170	3,628	3,301	3,157	2,872
Terai	92,199	83,901	2,693	2,451	2,439	2,219	2,065	1,879
Develop. Region								
Far Western	221,291	201,375	4,044	3,680	3,156	2,872	2,832	2,577
Mid Western	358,552	326,282	6,517	5,930	4,442	4,042	3,992	3,633
Western	233,140	212,158	4,591	4,178	3,676	3,345	3,262	2,968
Central	242,746	220,899	5,196	4,729	3,935	3,581	3,511	3,195
Eastern	232,077	211,190	4,871	4,432	4,043	3,679	3,648	3,320
Total Nepal	**1,287,807**	**1,171,904**	**25,219**	**22,949**	**19,252**	**17,519**	**17,244**	**15,692**

3.3 Integration Module results

As explained in Section 2.4, the **pixel-level balance** is simply the difference between the supply potential and the demand, pixel-by-pixel, while the **local balance** is calculated by averaging the pixel-level balance of the surrounding 3 km. The local balance produces a "smoothing" effect and the balance statistics by sub-national units vary slightly compared to pixel-level balance, remaining anyway equal at the national level.

The map of **pixel-level** supply/demand balance is shown in Figure 18, while the map of the **local balance** estimated within local harvesting context of 3 km is shown in Figure 19 (both relative to the Leading Scenario).

The third balance map, shown in Figure 20, represents the "commercial" balance which shows the deficit areas entirely (red areas) but only the local surplus (green areas) considered suitable to commercial fuelwood production. The commercial balance is the most important ingredient of woodshed analysis as it shows the amount and distribution of local deficit and the resources potentially available to commercial harvesting.

Table 5 presents the commercial supply/demand balance according to the three scenarios considered by Development Region and Physiographic zones.

TABLE 5

Commercial supply/demand balance by Development Region and Physiographic zone according to Minimum, Medium (Leading) and Maximum degradation scenarios.

	Scenario->	**High degradation sc.**	**Medium degradation (Leading Scenario)**	**Low degradation sc.**
	Demand variants ->	**Total demand**	**Conventional demand**	**Conventional demand**
	Supply variants ->	Minimum variant	**Medium variant**	Maximum variant
		kt ad yr^{-1}	kt ad yr^{-1}	kt ad yr^{-1}
Far Western	HighHimal	1	**3**	4
	HighMount	254	**345**	416
	Mid Mount	450	**599**	728
	Siwaliks	356	**400**	434
	Terai	-172	**-45**	-9
Mid Western	HighHimal	2	**10**	15
	HighMount	757	**960**	1,121
	Mid Mount	331	**492**	628
	Siwaliks	323	**396**	441
	Terai	-211	**-108**	-92
Western	HighHimal	-1	**2**	3
	HighMount	387	**467**	532
	Mid Mount	140	**323**	462
	Siwaliks	259	**303**	335
	Terai	-170	**-62**	-35
Central	HighHimal	0	**0**	1
	HighMount	134	**171**	202
	Mid Mount	-358	**24**	150
	Siwaliks	263	**357**	421
	Terai	-846	**-423**	-377
Eastern	HighHimal	3	**6**	8
	HighMount	505	**592**	666
	Mid Mount	413	**584**	739
	Siwaliks	191	**236**	273
	Terai	-400	**-204**	-154
Grand total Nepal		**2,611**	**5,429**	**6,910**

In a large part of the country, the rural demand for fuelwood seems to be satisfied by the resources accessible within the typical harvesting horizon of 3km or within 10-15km for the larger settlements. However, this is not the case for the densely populated Terai, and in large areas in the Mid Mountains and Siwaliks of the Central and Western Development Regions, as shown in Figure 13. In these areas, the high concentration of the consumption that cannot be locally satisfied creates a strong commercial fuelwood demand, which poses a high pressure on the accessible resources with consequent risk of degradation. With reference to the conventional demand, 7.4 million tons ad or 6.7 million tons DM (72%) is met from local resources, while 2.8 million tons ad or 2.6 million tons DM (28%) is NOT met from local resources - representing the local deficit - as summarized by physiographic zone and by development region in Table 6.

TABLE 6

Fuelwood demand satisfied by local resources (within a 3-km context) and demand that is NOT satisfied by local resources (local deficit) by Physiographic zones. The values refer to the Conventional fuelwood demand (medium supply variant), excluding marginal fuelwood.

	Conventional fuelwood consumption		**Conventional consumption locally satisfied**		**Conventional consumption NOT satisfied by local resources (Local deficit)**	
Physiographic Zone	kt ad yr^{-1}	kt DM yr^{-1}	kt ad yr^{-1}	kt DM yr^{-1}	kt ad yr^{-1}	kt DM yr^{-1}
High Himalaya	29	27	21	19	8	8
High Mountains	1,232	1,121	1,166	1,061	66	60
Mid Mountains	4,986	4,537	3,988	3,629	998	908
Siwaliks	1,154	1,050	776	706	377	344
Terai	2,776	2,526	1,399	1,273	1,377	1,253
Development Region						
Far Western	1,333	1,213	1,071	974	262	238
Mid Western	1,834	1,669	1,472	1,339	362	329
Western	1,941	1,766	1,501	1,366	440	400
Central	2,995	2,726	1,679	1,528	1,316	1,198
Eastern	2,074	1,887	1,627	1,480	447	406
Nepal	**10,176**	**9,260**	**7,350**	**6,688**	2,827	**2,572**

FIGURE 12

Map of 2011 Population distribution

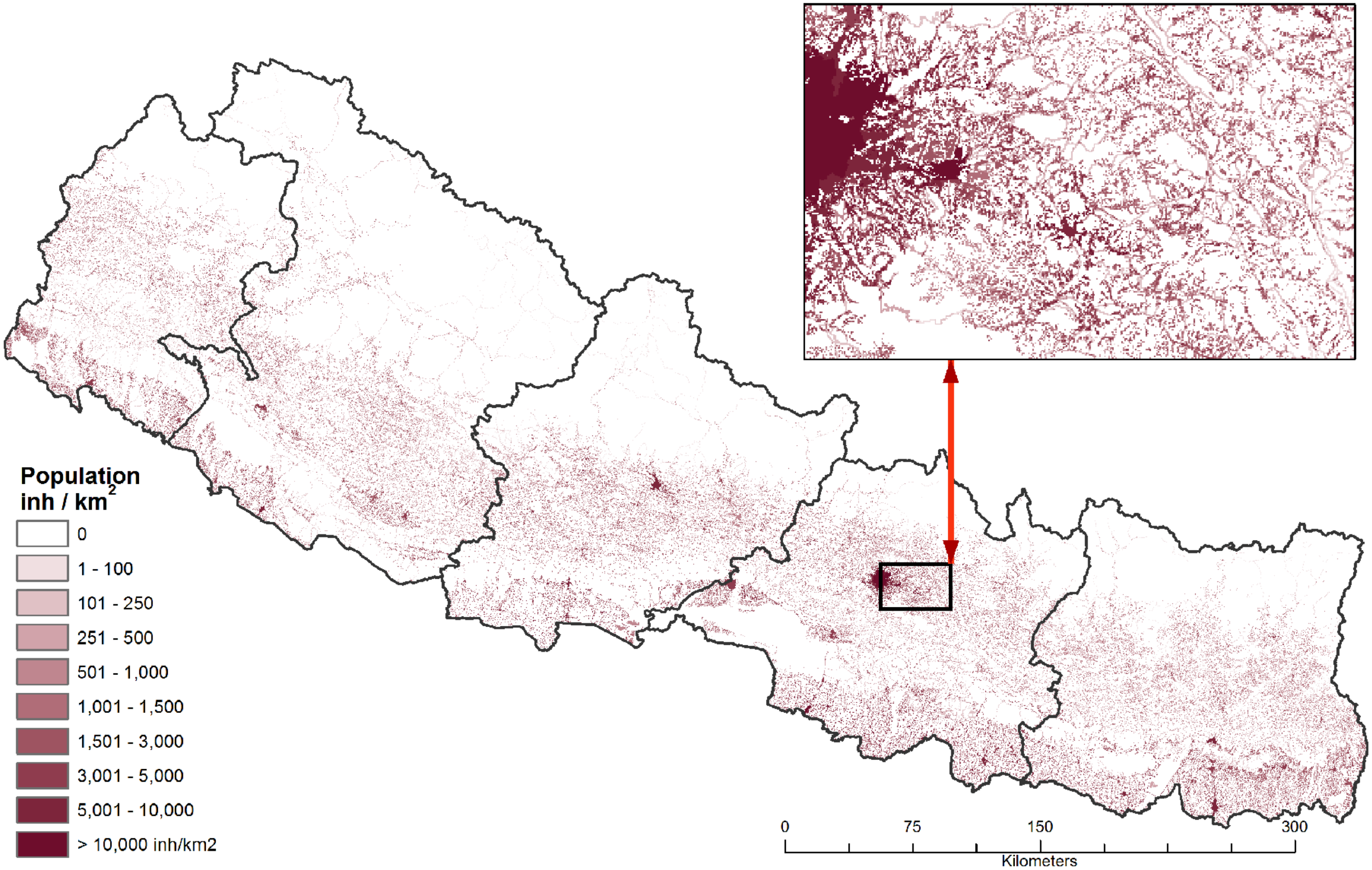


FIGURE 13

Map of "conventional" fuelwood consumption (all sectors).

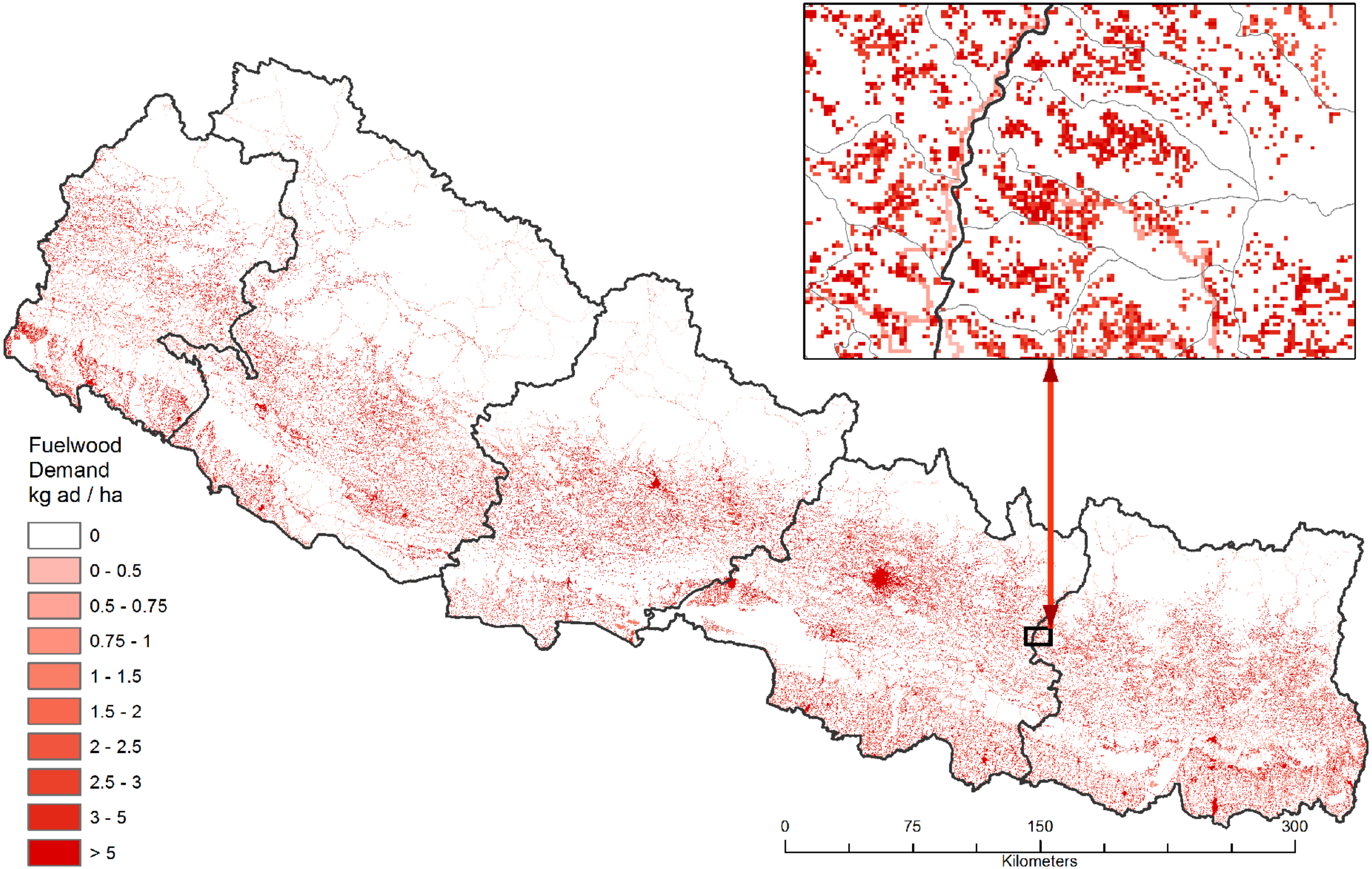


FIGURE 14

Map of dendroenergy biomass (DEB) distribution- Medium variant.

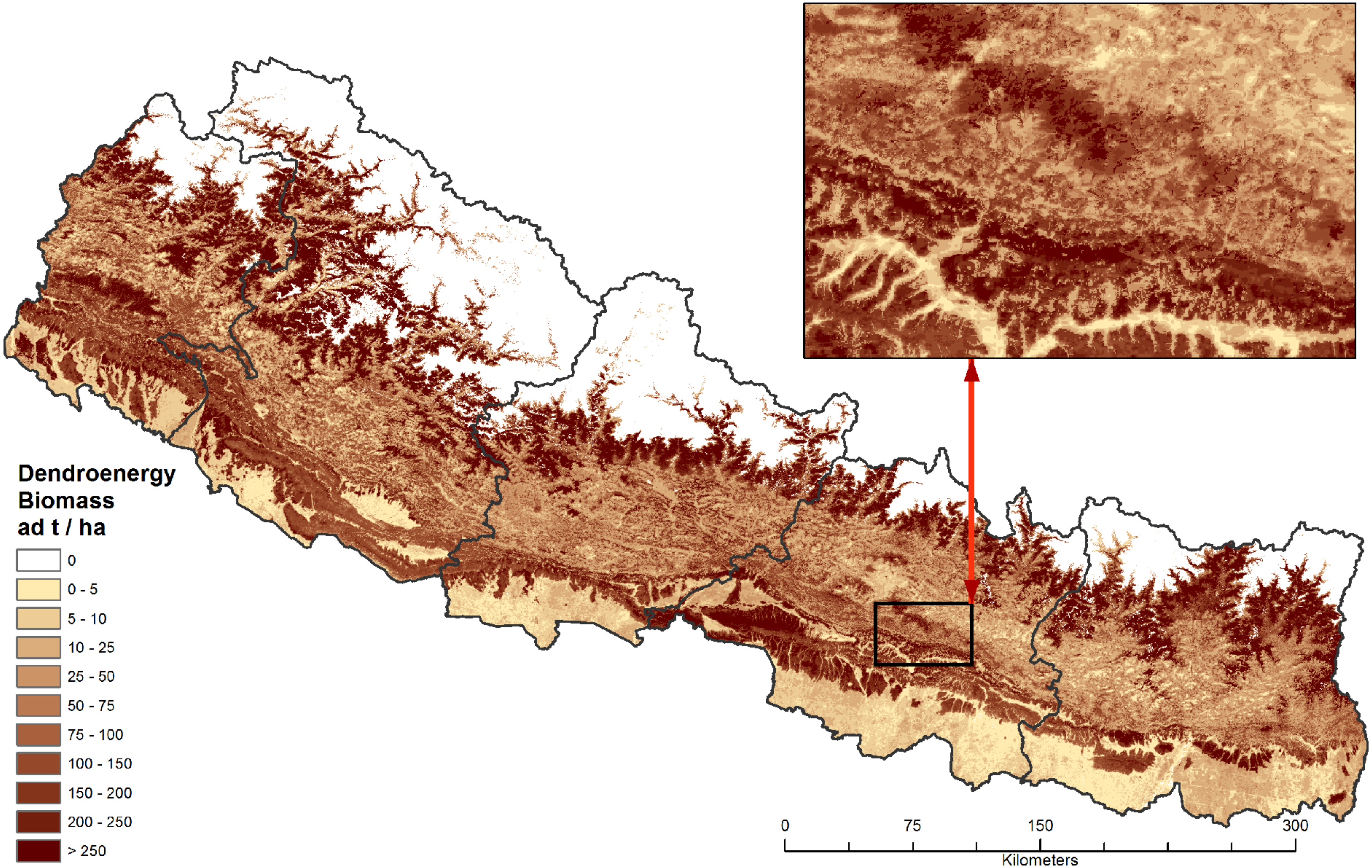


FIGURE 15

Map of total mean annual increment of dendroenergy biomass (DEB MAI) – Medium variant.

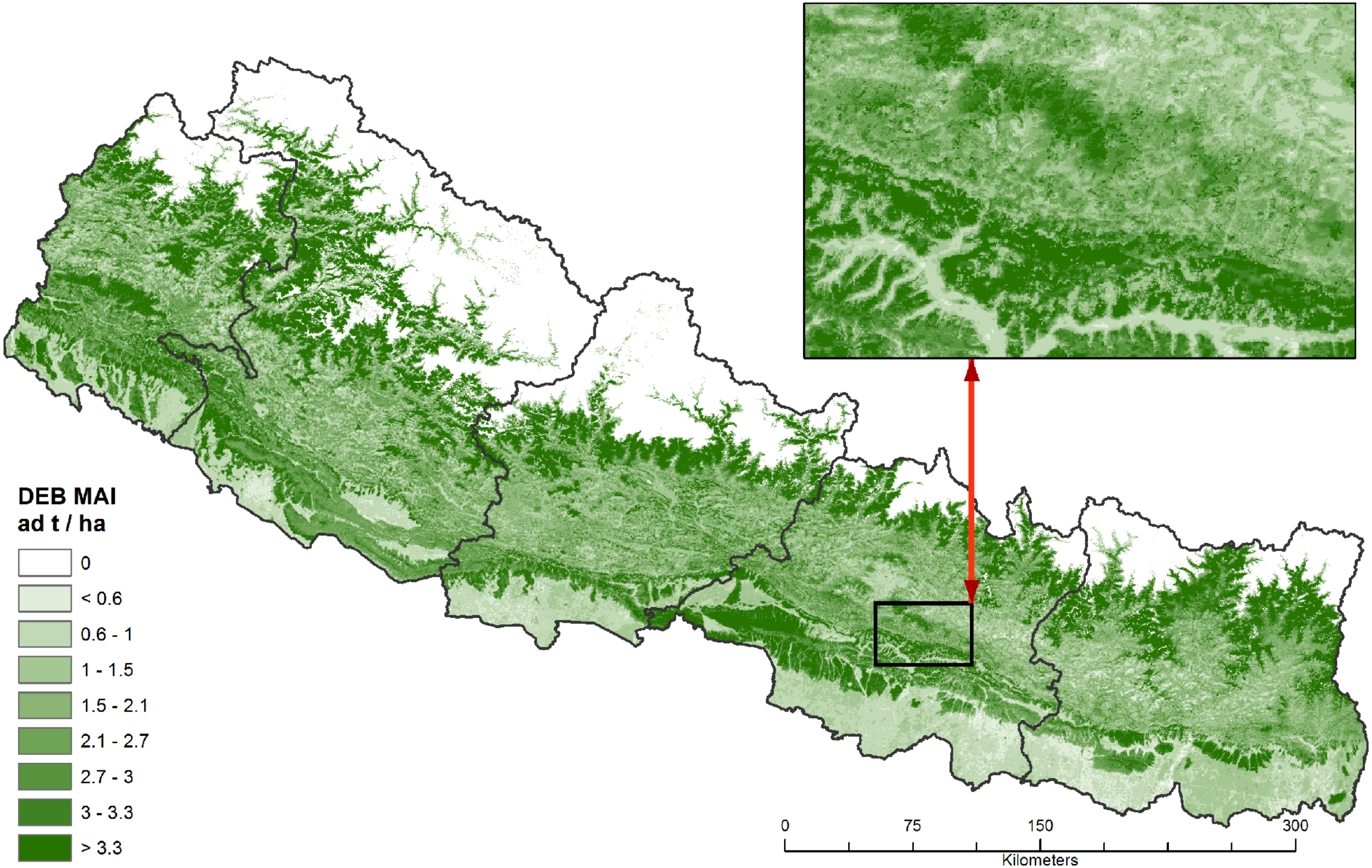


FIGURE 16

Map of physically and legally accessible DEB MAI – Medium variant

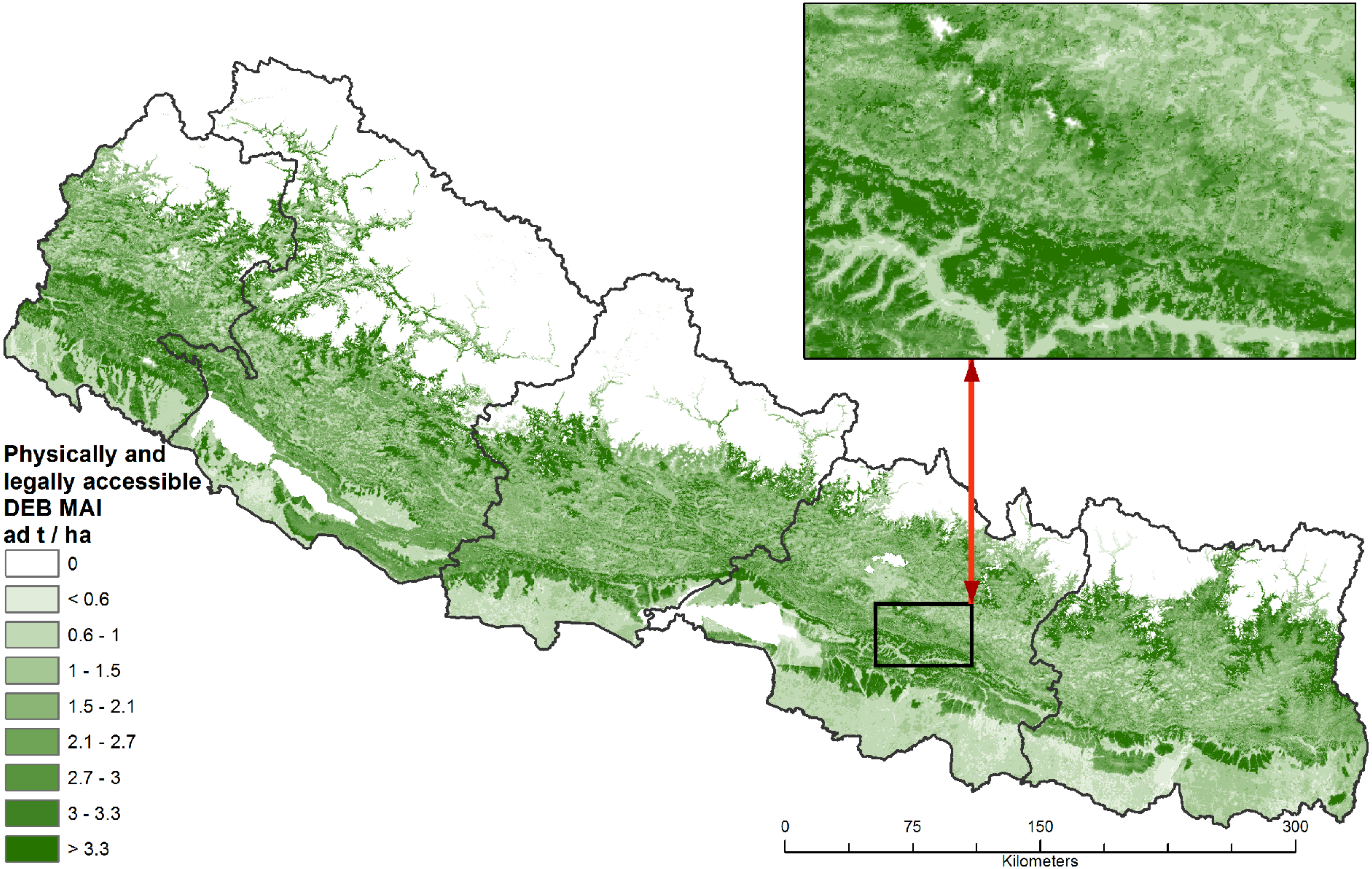


FIGURE 17

Map of the fraction of the physically and legally accessible DEB MAI that is potentially available for energy use – Medium variant

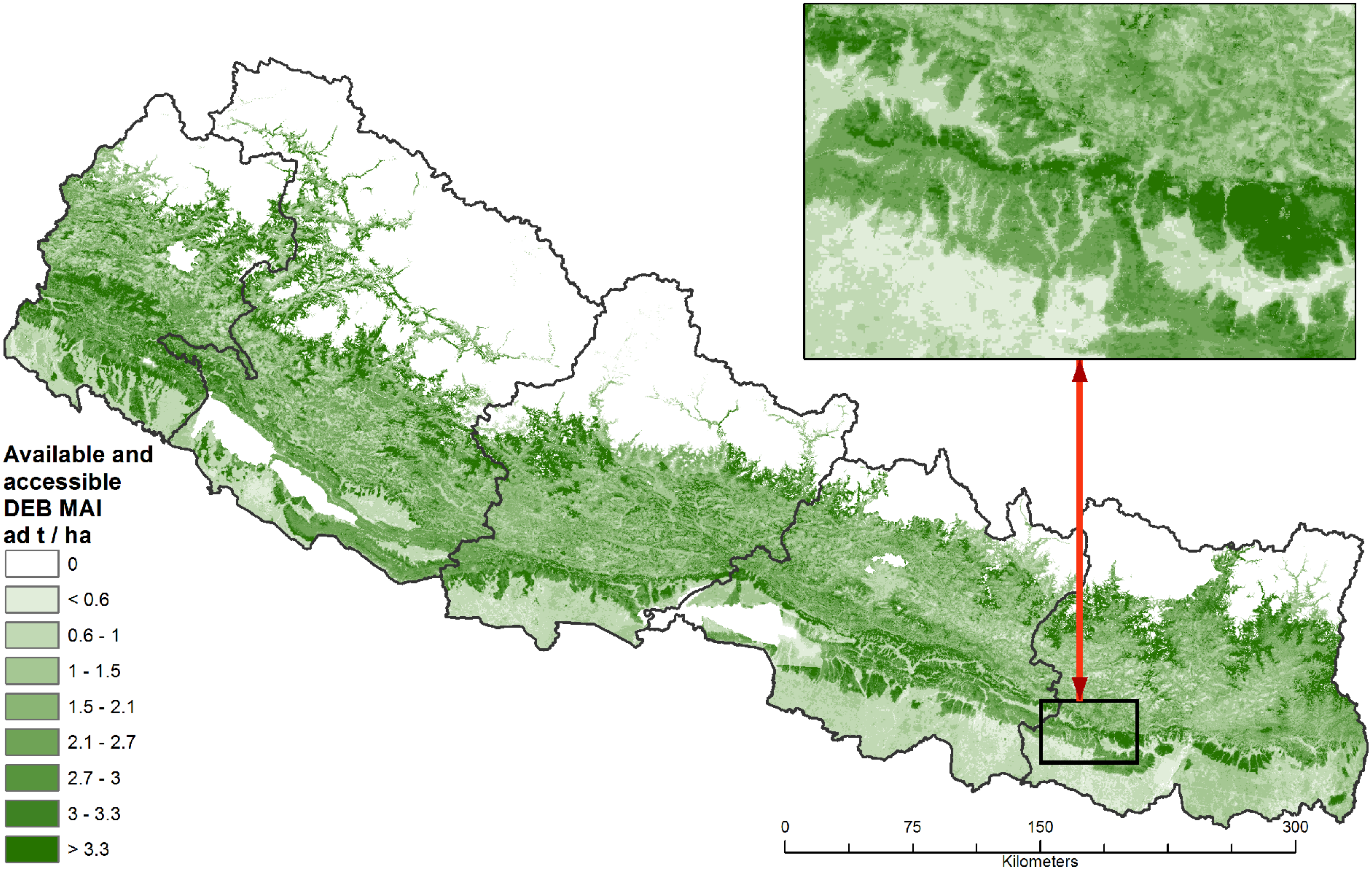


FIGURE 18

Map of pixel-level supply/demand balance – Medium supply and Conventional demand variants.

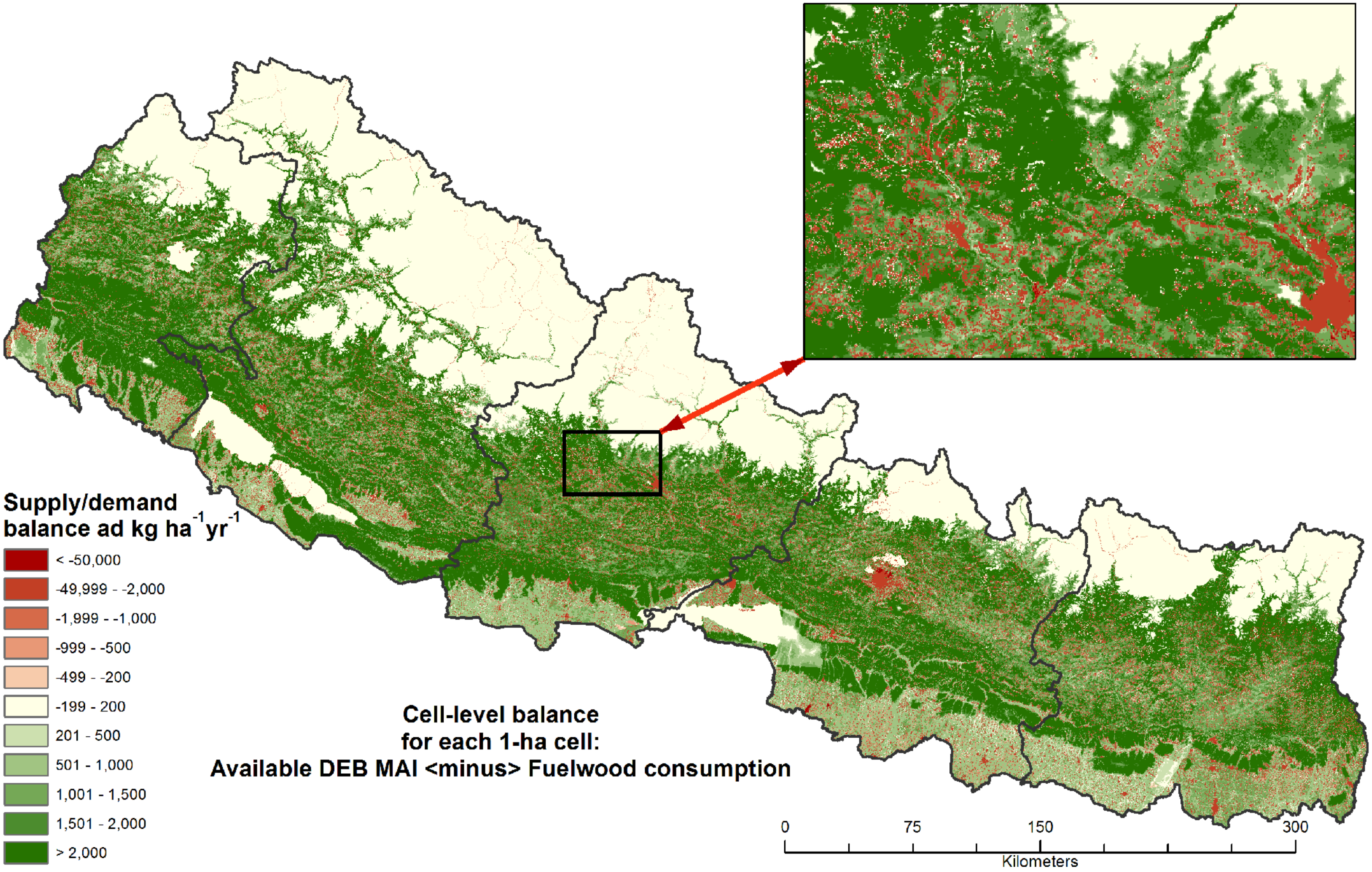


FIGURE 19

Map of Local Balance estimated within local harvesting context of 3 km. Medium supply and Conventional demand variants.

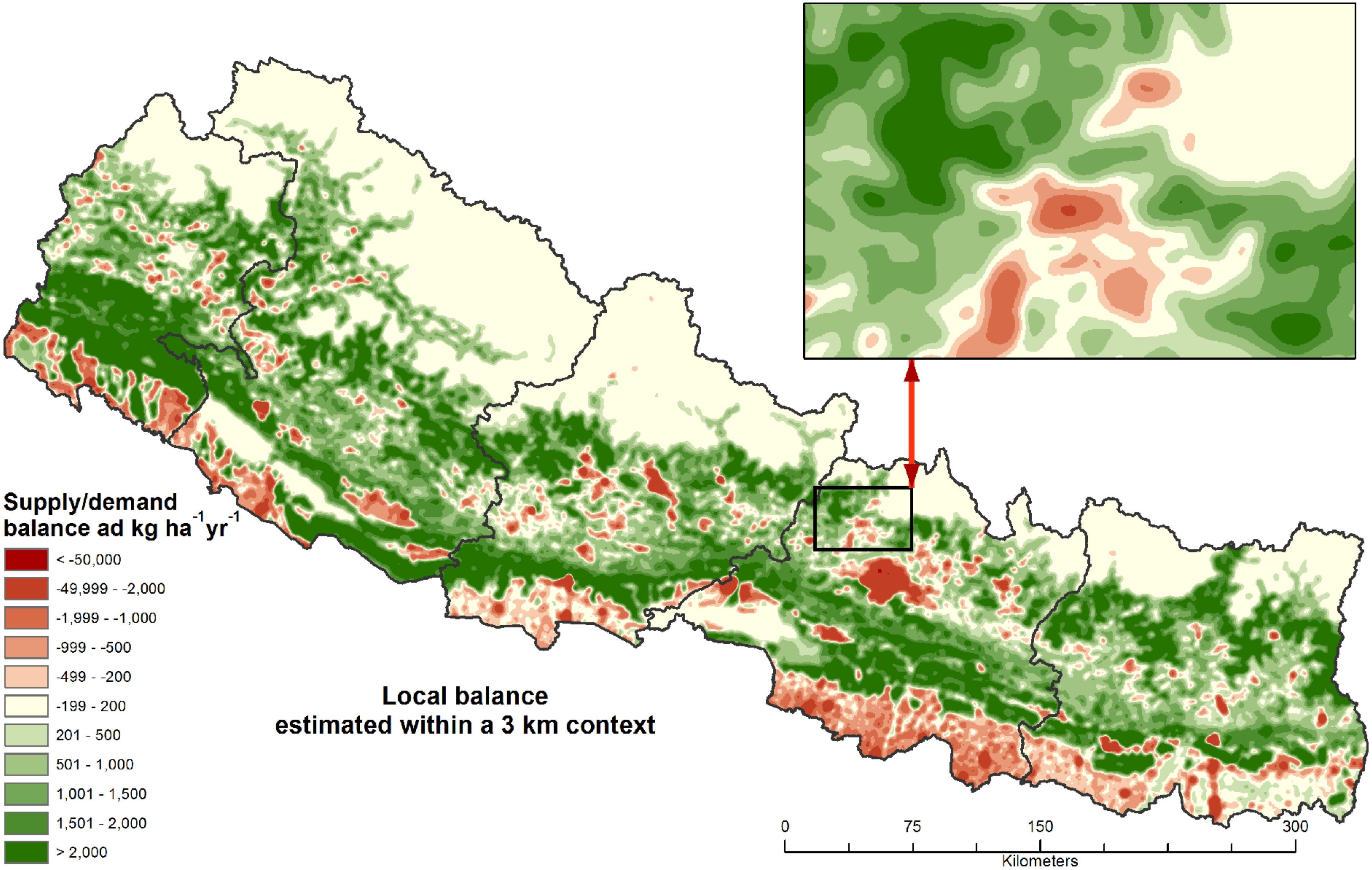
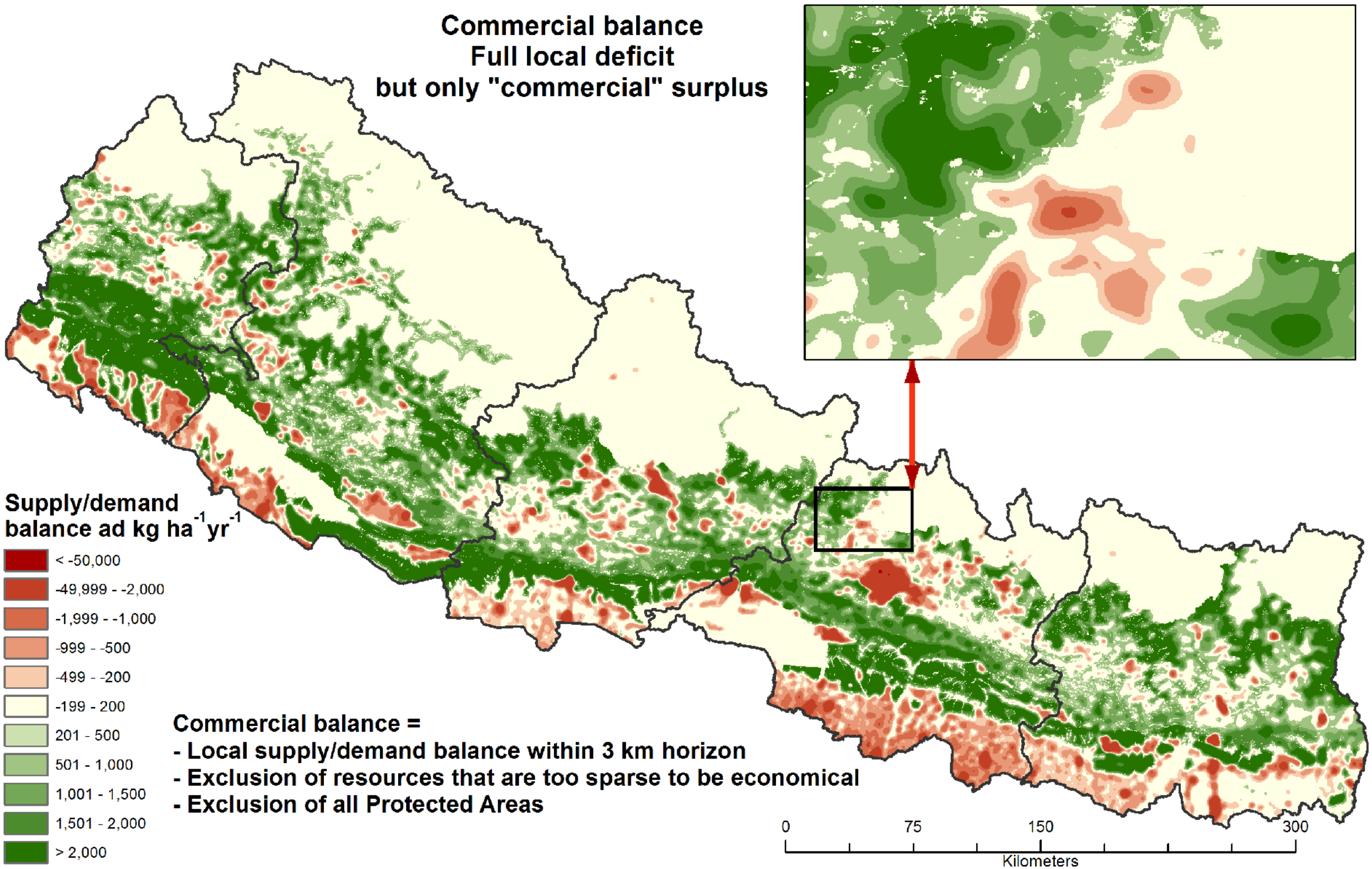


FIGURE 20

Map of commercial balance . Medium supply and Conventional demand variants.



3.4 Woodshed analysis and expected forest degradation

The map in Figure 21 shows the expected commercial harvesting pressure determined by the combined effect of the demand for fuelwood exerted by 26 major deficit sites and the physical accessibility of surplus resources.

Sustainable woodsheds

Figure 22 shows the theoretical **minimum sustainable woodsheds** of the 26 major deficit sites according to scenarios Total Demand – Medium Supply (A_Md) and Conventional Demand – Medium Supply (B_Md). The minimum sustainable woodsheds represent the smallest accessible areas wherein the sustainable supply potential matches the demand and that may be totally self-sufficient if managed with sustainable forest management criteria. These woodsheds are theoretical since they do not represent actual harvesting areas, but they indicate the territory where sustainable wood energy planning should become a primary target of forest and landscape management programmes.

Probable woodsheds and expected degradation rates

Taking a concrete perspective, we believe that current fuelwood harvesting practices are not guided primarily by principles of sustainable resource management. Demand pressure and economic accessibility of resources strongly influence harvesting intensities. In this study we considered several factors that may influence the intensity and distribution of the commercial harvesting that is necessary to fill the local deficit estimated through the analysis of local balance (see Section 2.5.3).

Table 7 presents the full combination of the variants and assumptions considered, giving origin to as much as 48 different scenarios and provides national-level degradation results for the three scenarios that have been processed on final data. The upper part of Table 7 (Part 1) presents the total estimated degradation for all land cover classes, including Forest, Other Wooded Lands and Other Lands, while the lower part of the table (Part 2) presents the degradation of forest-remaining-forest, i.e. the area that remained under forest cover for the whole reporting period 2000-2010 (ICIMOD 2016).

The model sensitivity analysis, based on preliminary degradation estimates for 28 scenarios, allowed to understand how much the various aspects considered do influence the results, to identify the most probable combination of factors (Leading Scenario) and to provide some sort of "confidence interval" around such Scenario. This process allowed to identify the three main reference scenarios: the Leading Scenario presenting the most probable conditions, the Low Degradation Scenario and the High Degradation Scenario, as discussed below.

All variants considered do influence the final estimates but what appears most influential on the quantity and the geographic distribution of the degradation is the market response to local deficit, represented by the "Full Market" and "Partial Market" variants. With the FM variant, which assumes that all local deficit originates commercial harvesting, the degradation is located exclusively on forests and other wooded land, leaving the rural areas and sparse vegetation formations totally unaffected. On the contrary, the PM variant assumes that only half of the deficit in rural areas originates commercial harvesting while the other half comes from overharvesting of local resources.

Leading Scenario

The thorough review of the various scenarios considered and the impact of variants and assumptions vis-à-vis the results obtained, pointed the FRL Team to identify the most probable scenario, that we may call the Leading Scenario. This is the scenario Md B PM 8h, shown in Figures 24 to 26, characterized by the following variants and assumptions:

- Medium Supply (relative to the mean values of FRA sample plots)
- Conventional Demand (i.e. 95% of total demand, excluding the use of marginal fuelwood made by twigs and pruning material in rural Terai)
- Partial Market (whereby the full urban deficit and half rural deficit originate commercial harvesting, while the remaining half induces overexploitation of local resources).
- 8 hours transport time threshold (maximum 8 hours from the nearest major deficit site).
- Midpoint between full use and no use of land cover change by-products.

TABLE 7

Degradation expressed as ad kt of unsustainable harvesting according to data variants and alternative assumptions made.

1 - Degradation of all land cover classes (including Forests, OWL and OL)

	Market variants->	**FM - Full Market**				**PM - Partial Market**			
	Transport thresholds->	**12 hours**		**8 hours**		**12 hours**		**8 hours**	
	Use of LCC by-products->	**No use**	**Full Use**	**No use**	**Full Use**	**No use**	**Full Use**	**No use**	**Full Use**
Supply var. ↓	Demand variants ↓	Annual degradation due to unsustainable harvesting (ad kt)							
Minimum	**A - Total demand**							-2,239	-1,912
	B - Conventional demand								
Medium	**A - Total demand**								
	B - Conventional demand							**-1,140**	**-796**
Maximum	**A - Total demand**								
	B - Conventional demand	-112	-59						

2 - Degradation of Forest-remaining-Forest (area under forest cover for the period 2000-2010)

	Market variants->	**FM - Full Market**				**PM - Partial Market**			
	Transport thresholds->	**12 hours**		**8 hours**		**12 hours**		**8 hours**	
	Use of LCC by-products->	**No use**	**Full Use**	**No use**	**Full Use**	**No use**	**Full Use**	**No use**	**Full Use**
Supply var. ↓	Demand variants ↓	Annual degradation due to unsustainable harvesting (ad kt)							
Minimum	**A - Total demand**							-785	-656
	B - Conventional demand								
Medium	**A - Total demand**								
	B - Conventional demand							**-246**	**-189**
Maximum	**A - Total demand**								
	B - Conventional demand	-84	-51						

Tables 8a and 8b present the expected degradation relative to the Leading Scenario for the whole territory of Nepal as well as for the Forest-Remaining-Forest area. Table 8a presents the expected degradation by sub-regions intersecting Development Regions and Physiographic Zones, expressed as air dry tons as well as dry matter. Table 8b summarizes the expected degradation by Physiographic Zone and by Development Region, expressed as thousand tons (ad and DM). Table 8c presents the adjusted values of harvesting and degradation relative to the bias-corrected FRF area of 6,302,245 ha presented in FRL Nepal reporting. The "bias-corrected" harvesting and degradation values were obtained by applying a fixed factor of 1.065 (bias-corrected FRF / mapped FRF) to the values relative to the mapped FRF area..

As evident from these tables, the larger fraction of unsustainable harvesting is expected to take place outside forest areas, in Other wooded Lands and Other Land.

The degradation is estimated as woody biomass unsustainably harvested. Converted to carbon and then to CO_2 applying relevant factors, these values can be used to estimate the net GHG emissions relative to the degradation induced by excessive woodfuel extraction. It should be once more emphasized that these are <u>indirect</u> estimates representing the risk of degradation and not direct measurements of observed biomass loss. As such, these values can be used as reference only in the absence of direct observations of forest degradation

Another important aspect is the area that is under risk of degradation. Table 9 shows the area of the whole Country and that of the FRF that is annually degraded by categories of risk based on the quantity of DEB unsustainably harvested according to the Leading Scenario. With estimated degradation per hectare and per year below 100 ad kg the risk is classified as Low; with a degradation between 100 and 500 ad kg the risk class is classified as Moderate and with values above 500 ad kg the risk is classified as High. The distribution of the degradation risk categories according to the Leading Scenario is shown in Figure 26.

TABLE 8a

Expected degradation induced by excessive fuelwood harvesting by sub-regions intersecting Development Regions and Physiographic Zones according to the Leading Scenario

		Total Nepal				Within Forest-remaining-forest (FRF)			
		Total area	Total Direct harvesting after use of LCCbp	Total degradation from unsustainable direct harvesting after use of LCCbp		FRF area	Direct harvesting in FRF after use of LCCbp	Forest degradation from unsustainable direct harvesting after use of LCCbp	
		Area ('000 ha)	t ad yr-1	t ad yr-1	**t DM yr-1**	Area ('000 ha)	t ad yr-1	t ad yr-1	**t DM yr-1**
Far Western	HighHimal	314	2,409	738	**672**	10	251	5	**5**
	HighMount	471	262,585	20,034	**18,231**	277	113,940	3,395	**3,089**
	Mid Mount	662	600,647	40,649	**36,990**	406	289,073	8,957	**8,151**
	Siwaliks	211	142,800	331	**301**	183	120,824	32	**29**
	Terai	321	365,636	68,834	**62,639**	128	133,550	4,557	**4,147**
Mid Western	HighHimal	1515	10,356	3,681	**3,350**	42	1,201	19	**18**
	HighMount	1159	446,393	26,821	**24,407**	591	176,905	3,479	**3,166**
	Mid Mount	790	826,835	29,797	**27,115**	393	382,606	7,349	**6,687**
	Siwaliks	550	363,493	38,463	**35,001**	383	201,066	2,529	**2,301**
	Terai	237	233,631	59,609	**54,244**	85	62,668	3,253	**2,960**
Western	HighHimal	967	11,607	3,255	**2,962**	40	1,925	25	**23**
	HighMount	482	190,873	4,036	**3,673**	297	92,620	612	**557**
	Mid Mount	956	1,333,700	79,099	**71,980**	414	551,630	19,889	**18,099**
	Siwaliks	241	195,366	12,498	**11,373**	166	123,602	1,475	**1,342**
	Terai	300	282,790	53,573	**48,752**	40	36,983	381	**347**
Central	HighHimal	249	1,798	477	**435**	23	412	80	**73**
	HighMount	373	188,822	7,706	**7,012**	246	101,945	3,352	**3,050**
	Mid Mount	935	1,353,020	232,407	**211,490**	485	685,306	104,318	**94,929**
	Siwaliks	636	526,372	57,020	**51,888**	435	323,841	24,340	**22,150**
	Terai	555	690,414	224,341	**204,150**	92	169,777	30,193	**27,476**
Eastern	HighHimal	494	3,425	1,696	**1,543**	47	760	160	**146**
	HighMount	528	175,882	838	**763**	391	111,687	368	**335**
	Mid Mount	967	971,189	35,074	**31,918**	515	503,078	12,769	**11,620**
	Siwaliks	260	275,215	11,558	**10,518**	176	184,419	2,384	**2,170**
	Terai	607	580,695	94,869	**86,331**	54	83,240	717	**652**
Total Nepal		**14,778**	**10,035,952**	**1,107,406**	**1,007,740**	**5,918**	**4,453,309**	234,638	**213,520**

TABLE 8b

Summary of direct fuelwood harvesting and expected degradation by Physiographic zone and by Development Region according to the Leading Scenario. Values are presented as '000 tons air-dry (ad) as well as dry matter (DM).

	Total Nepal					Within Forest-Remaining-Forest (FRF)				
	Total area	Total direct harvesting after use of LCCbp		Total degradation from unsustainable direct harvesting after use of LCCbp		FRF area	Direct harvesting in FRF after use of LCCbp		Forest degradation from unsustainable direct harvesting in FRF after use of LCCbp	
Physigraphic Zone	'000 ha	kt ad yr^{-1}	**kt DM yr^{-1}**	kt ad yr^{-1}	**kt DM yr^{-1}**	'000 ha	kt ad yr^{-1}	**kt DM yr^{-1}**	kt ad yr^{-1}	**kt DM yr^{-1}**
High Himalaya	3,538	30	27	10	9	162	5	4	0.3	0.3
High Mountains	3,012	1,265	1,151	59	54	1,803	597	543	11.2	10.2
Mid Mountains	4,309	5,085	4,628	417	379	2,213	2,412	2,195	153.3	139.5
Siwaliks	1,898	1,503	1,368	120	109	1,342	954	868	30.8	28.0
Terai	2,020	2,153	1,959	501	456	398	486	442	39.1	35.6
Development Region										
Far Western	1,979	1,374	1,250	131	119	1,004	658	598	16.9	15.4
Mid Western	4,251	1,881	1,711	158	144	1,494	824	750	16.6	15.1
Western	2,946	2,014	1,833	152	139	957	807	734	22.4	20.4
Central	2,747	2,760	2,512	522	475	1,280	1,281	1,166	162.3	147.7
Eastern	2,855	2,006	1,826	144	131	1,183	883	804	16.4	14.9
Total Nepal	**14,778**	10,036	**9,133**	**1,107**	**1,008**	5,918	4,453	**4,053**	**234.6**	**213.5**

TABLE 8c

Adjusted values of direct fuelwood harvesting and expected degradation relative to "bias-corrected" FRF area by Physiographic zone according to the Leading Scenario. These are the values presented in FRL Nepal submission paper relative to the bias-corrected area of forest-remaining-forest after application of correction factor 1.065 . Values are '000 tons dry matter (DM).

	Within bias-corrected Forest-Remaining-Forest (bcFRF) area		
Physiographic Zone	bcFRF area	Direct harvesting in bcFRF after use of LCC-bp	Forest degradation from unsustainable direct harvesting in bcFRF after use of LCC-bp
	'000 ha	kt DM yr^{-1}	
High Himalaya	**173**	**4**	**0.3**
High Mountains	**1,919**	**579**	**11**
Mid Mountains	**2,357**	**2,337**	**149**
Siwaliks	**1,429**	**924**	**30**
Terai	**424**	**471**	**38**
Total Nepal	**6,302**	**4,315**	**227**

TABLE 9

Risk of degradation induced by excessive fuelwood harvesting by Development Region and Physiographic zone according to the Leading Scenario

		Total Nepal				Within Forest-remaining-forest			
		Risk of annual degradation				Risk of annual degradation			
		No or negligible	Low <100 kg ha^{-1} yr^{-1}	Moderate 100-500 kg ha^{-1} yr^{-1}	High >500 kg ha^{-1} yr^{-1}	No or negligible	Low <100 kg ha^{-1} yr^{-1}	Moderate 100-500 kg ha^{-1} yr^{-1}	High >500 kg ha^{-1} yr^{-1}
		'000 hectares				'000 hectares			
Far Western	HighHimal	262.6	50.4	0.5		9.4	0.9		
	HighMount	425.7	11.4	18.3	15.4	264.2	5.7	4.6	2.5
	Mid Mount	559.4	21.3	54.1	27.4	380.9	5.8	13.3	6.0
	Siwaliks	209.5	0.5	1.0	0.1	182.5	0.1	0.1	
	Terai	174.3	14.0	62.9	69.6	111.7	4.4	8.5	3.4
Mid Western	HighHimal	1086.2	429.1			38.7	3.0		
	HighMount	1094.3	25.9	18.7	19.7	576.9	7.9	3.6	2.6
	Mid Mount	686.6	31.2	54.5	17.2	366.0	9.6	13.8	3.6
	Siwaliks	447.4	32.6	40.8	29.4	352.3	25.9	3.4	1.5
	Terai	96.5	21.3	74.1	45.5	63.4	12.4	8.2	1.3
Western	HighHimal	708.3	254.4	4.1	0.6	39.0	1.3	0.1	
	HighMount	471.7	3.9	3.8	2.4	294.8	0.9	1.0	0.4
	Mid Mount	725.0	68.9	119.1	42.6	350.5	22.1	31.3	10.0
	Siwaliks	208.5	7.9	16.6	8.1	157.6	3.5	3.8	0.7
	Terai	90.8	45.4	145.2	18.9	38.7	0.3	0.6	0.2
Central	HighHimal	198.2	50.5	0.0		20.2	2.6	0.0	
	HighMount	326.6	24.1	18.2	3.8	222.6	12.6	9.3	1.4
	Mid Mount	530.0	84.3	185.9	134.5	290.0	37.3	85.6	71.8
	Siwaliks	451.5	41.1	102.0	41.2	341.2	23.2	52.1	18.5
	Terai	56.7	24.4	288.0	186.3	19.0	4.7	40.8	27.1
Eastern	HighHimal	338.0	153.9	1.7		40.9	5.6	0.5	
	HighMount	521.5	4.2	1.4	0.6	387.3	3.3	0.6	0.2
	Mid Mount	853.2	33.5	60.0	20.4	474.2	12.5	21.1	7.6
	Siwaliks	228.3	8.2	14.9	8.5	168.0	2.6	3.6	1.4
	Terai	222.3	98.4	249.4	36.4	50.2	1.8	1.4	0.3
	HighHimal	2,593	938	6	1	148	13	1	0
	HighMount	2,840	70	61	42	1,746	30	19	7
	Mid Mount	3,354	239	474	242	1,862	87	165	99
	Siwaliks	1,545	90	175	87	1,202	55	63	22
	Terai	641	203	820	357	283	24	60	32
Far Western		1,632	98	137	112	949	17	27	12
Mid Western		3,411	540	188	112	1,397	59	29	9
Western		2,204	381	289	73	881	28	37	11
Central		1,563	224	594	366	893	81	188	119
Eastern		2,163	298	327	66	1,121	26	27	10
Grand total Nepal		**10,973**	**1,541**	**1,535**	**729**	**5,240**	**210**	**307**	**160**

Overall, 25.7 % of the national territory is under some level of risk of degradation, of which10.4 % is Low, 10.4% is Moderate and 4.9 % is High. When looking exclusively to FRF area, the area under risk of degradation is 11.5%, of which 3.5 % is Low, 5.2 % is Medium and 2.7 is High.

By Physiographic Zones degradation is expected primarily in the Terai (with 58.2% of the area under Moderate to High degradation) and Mid Mountains (with 16.6% of the area under Moderate to High degradation) followed by Siwalics (13.8% under Moderate to High degradation).

Range of degradation estimates

As shown in Table 6 above, each scenario produced different degradation estimates. Besides the understanding of how each assumption and data variant affected the results and helped to identify the Leading Scenario, these scenario indicate the range of possible degradation estimates.

The variants and assumptions leading to the highest and lowest degradation estimates are listed below.

Variants and assumptions leading to High degradation	Variants and assumptions leading to Low degradation
Minimum Supply	Maximum Supply
Total Demand	Conventional Demand
Partial Market for total land	Full Market for total land
(Full Market for FRF)	(Partial Market for FRF)
8 hours transport	12 hours transport
No use of LCC by-products	USE of LCC by-products

Lowest estimates. According to the scenario based on **most favorable variants and assumptions**, the lowest degradation estimate for the whole Country is **59 thousand tons ad** (54 thousand tons DM). When referred to the Forest-Remaining-Forest only, the lowest estimated degradation is **51.1 thousand tons ad** (46.5 thousand tons DM).

Highest estimates. According to the scenario based on **least favorable variants and assumptions**, the highest degradation estimate for the whole Country is **2.24 million tons ad** (2.04 million tons DM). When referred to the Forest-Remaining-Forest only, the highest estimated degradation is **785 thousand tons ad** (714 thousand tons DM).

FIGURE 21

Map of harvesting pressure determined by the fuelwood demand of major deficit sites and physical accessibility. Medium supply and Conventional demand variants

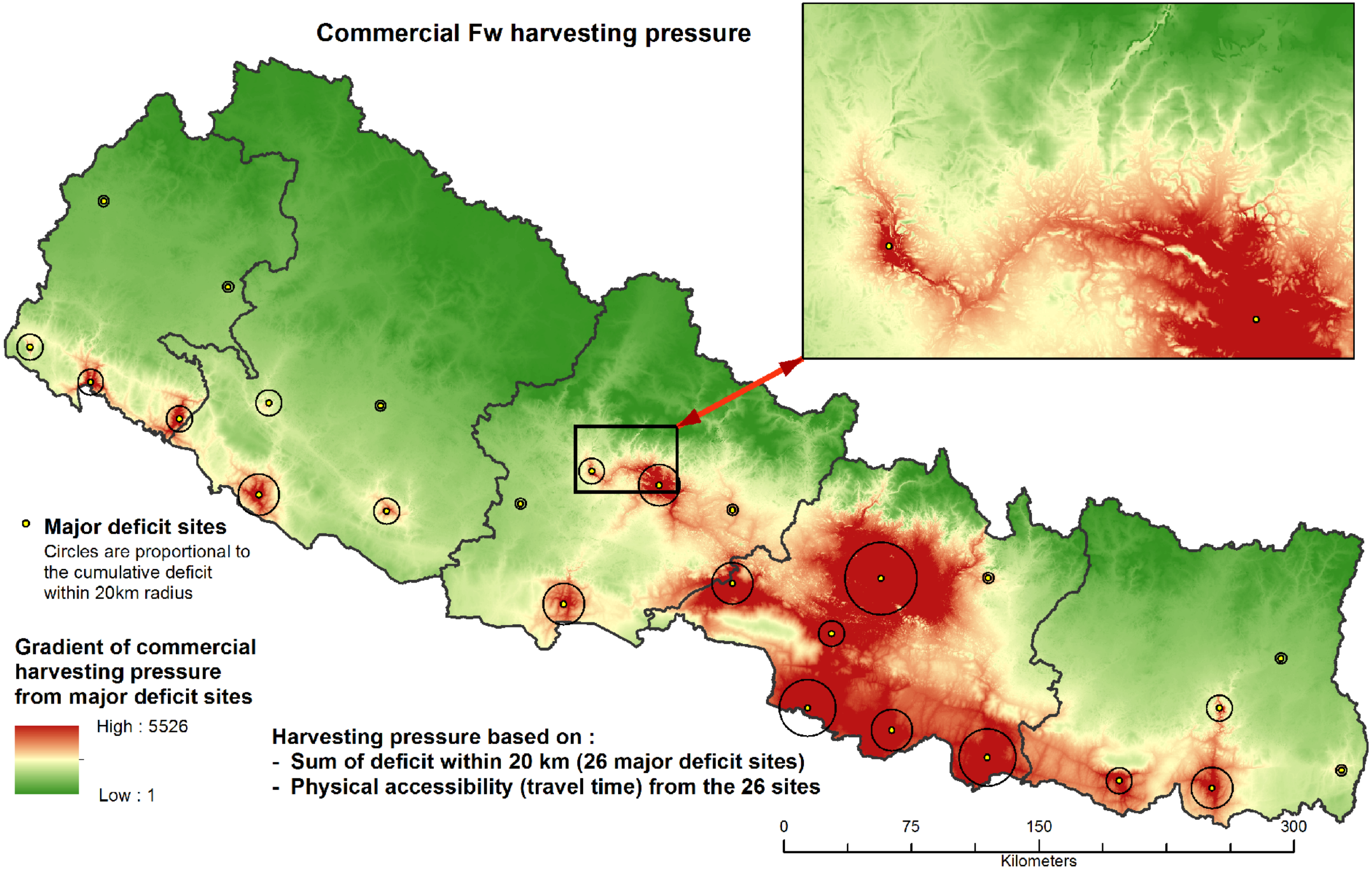


FIGURE 22

Map of minimum sustainable commercial woodsheds according to scenarios Total Demand – Medium Supply (A_Md) and Conventional Demand – Medium Supply (B_Md).

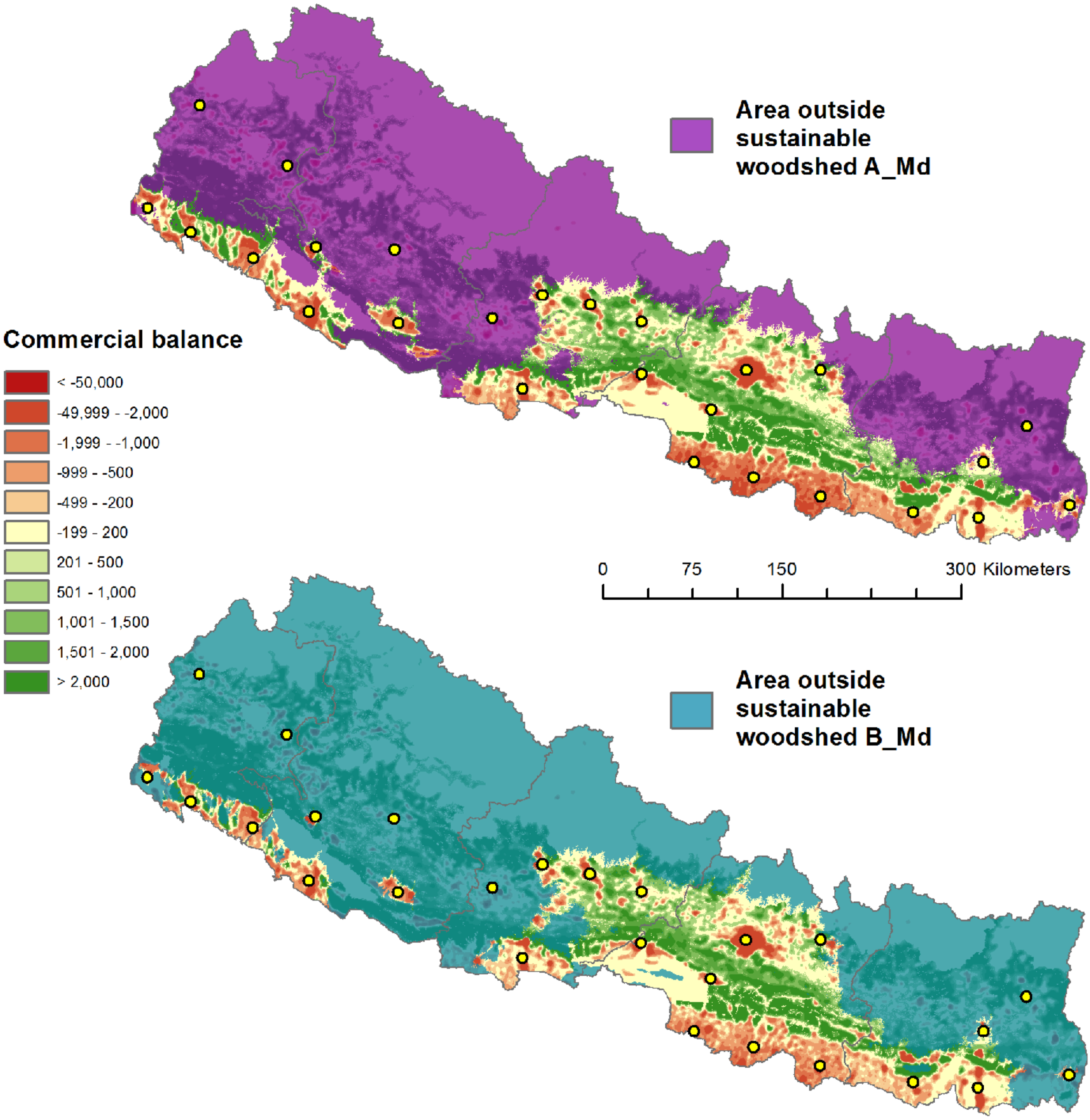


FIGURE 23

Limits of commercial harvesting areas used for scenarios building: transport time threshold of 8 hours and 12 hours.

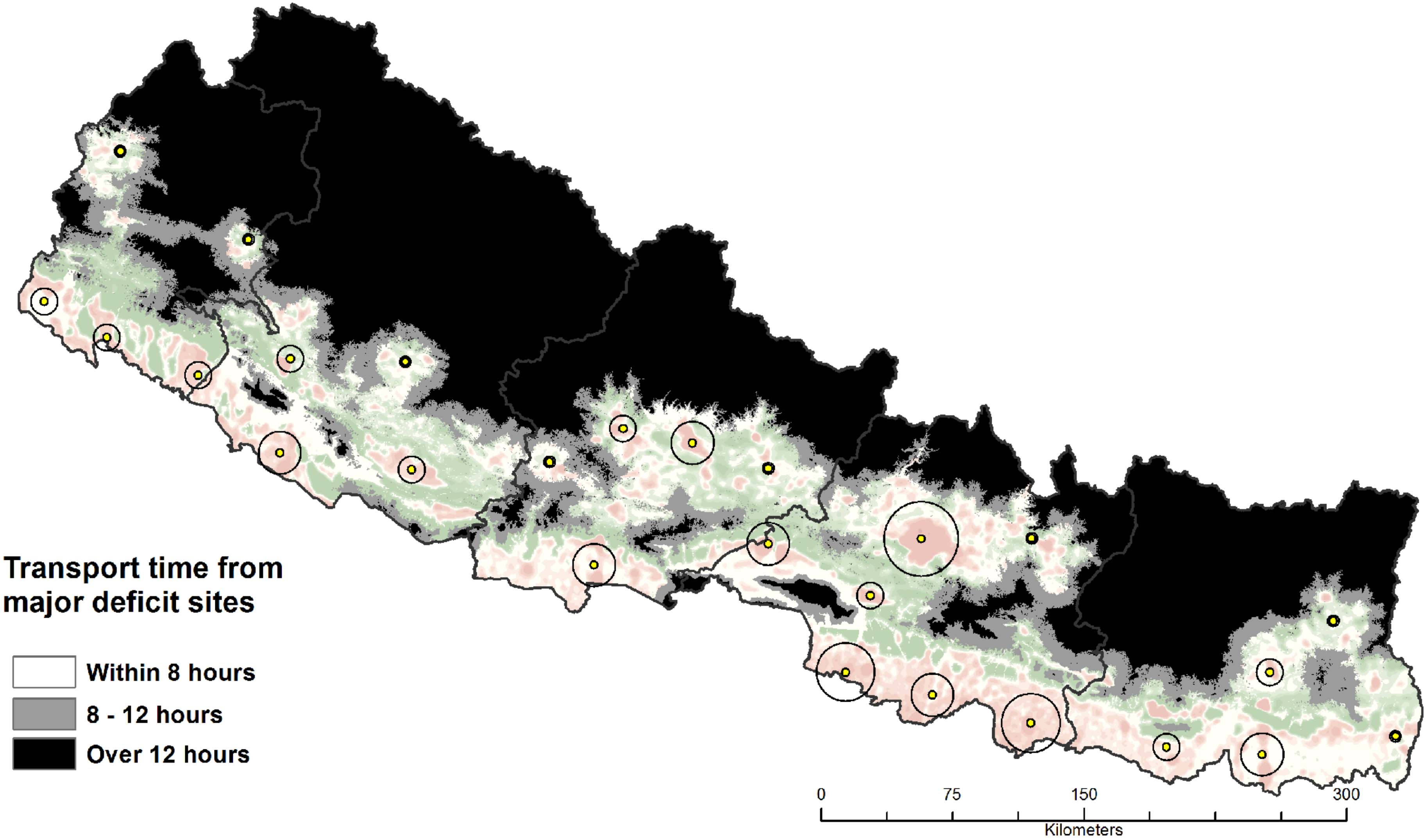


FIGURE 24

Map of harvesting intensity according to Partial Market scenario, whereby only half of rural deficit gives origin to commercial harvesting, the rest impacting local resources as overharvesting. Scenario depicted: Conventional demand, Medim supply, Partial Market, 8 hours (B Md PM 8h) . Identified as the Leading Scenario.

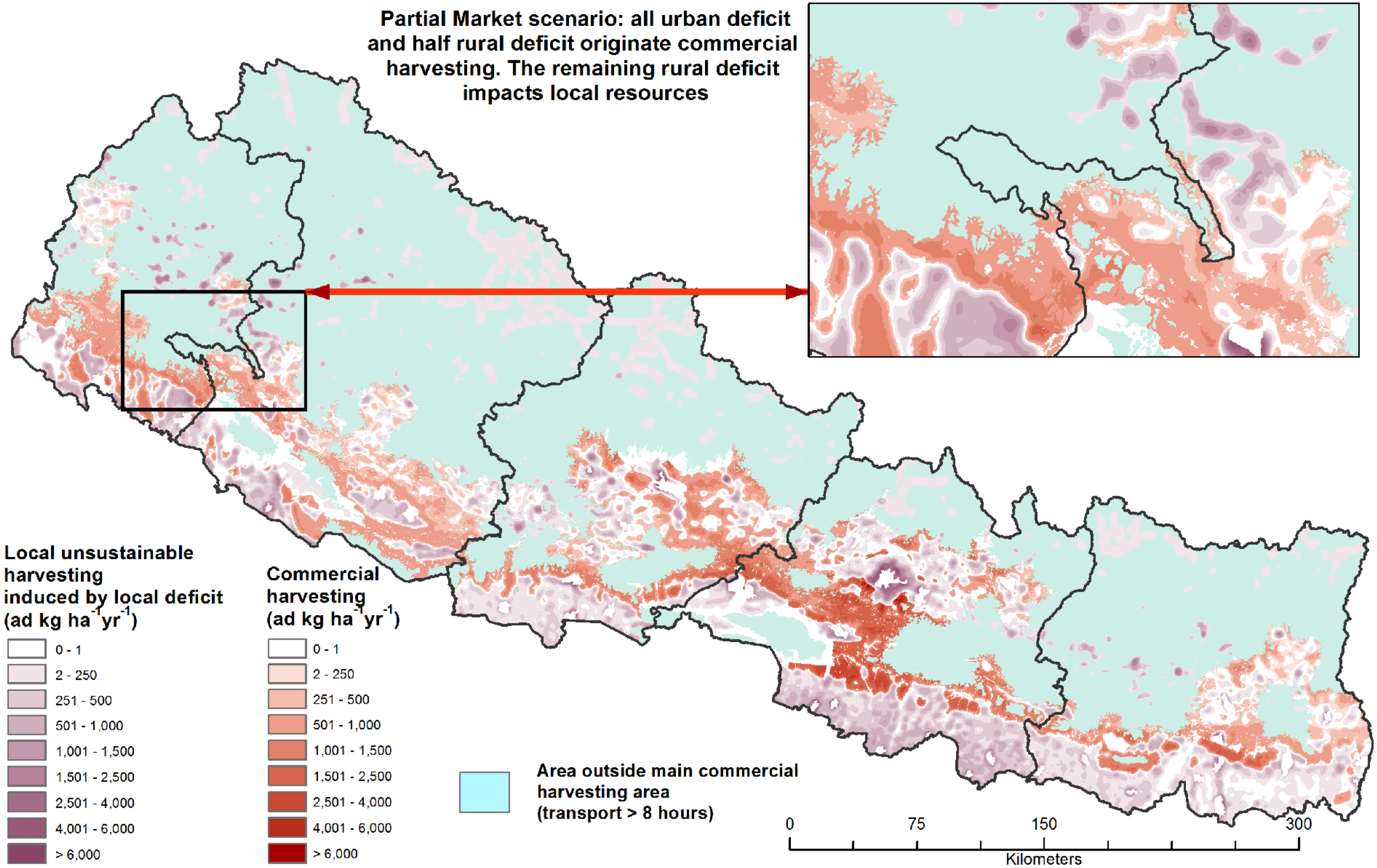


FIGURE 25

Map of the total unsustainable harvesting (including commercial and local) according to Partial Market scenario. Scenario depicted: Conventional demand, Medium supply, Partial Market, 8 hours (B Md PM 8h). Identified as the Leading Scenario.

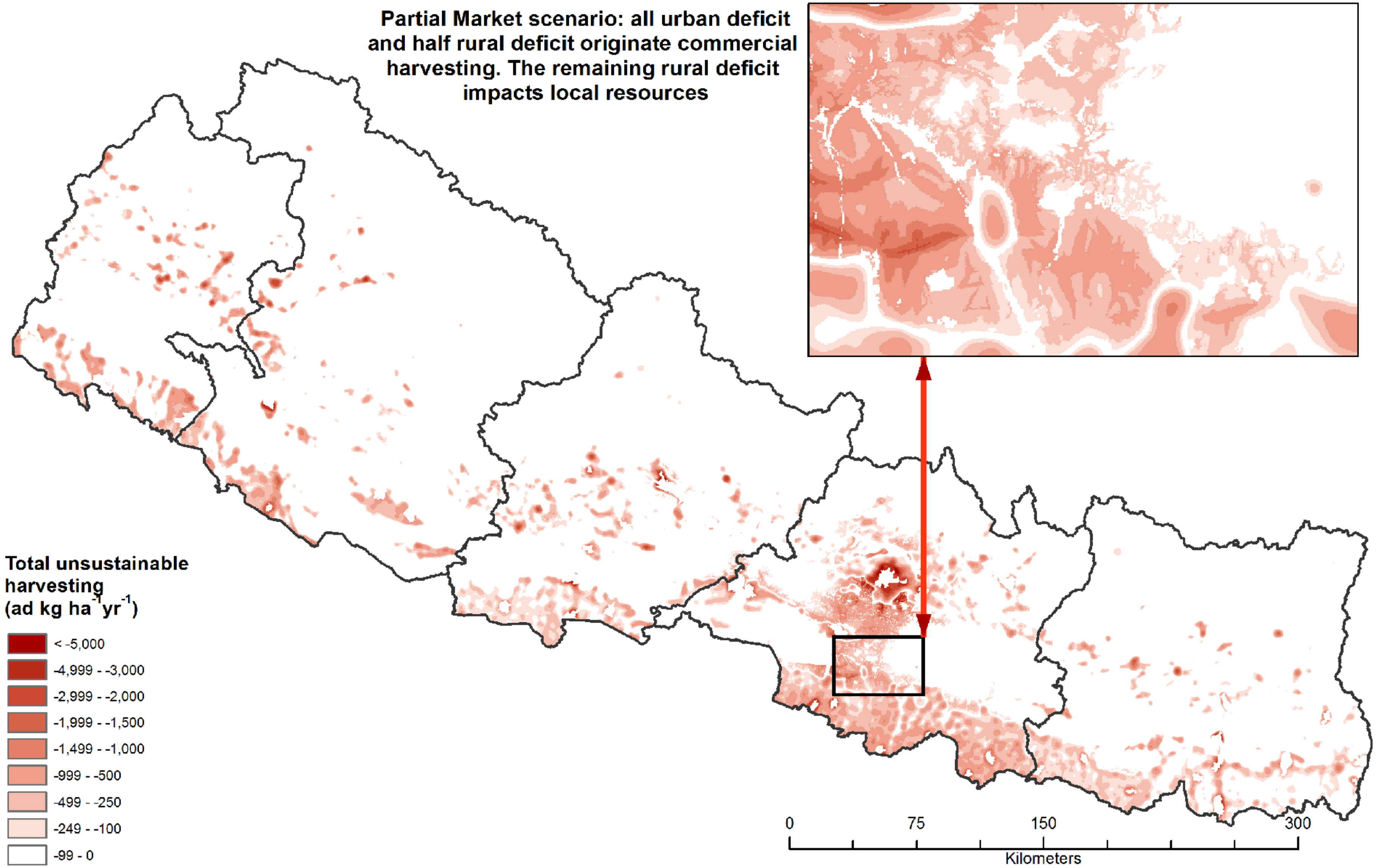
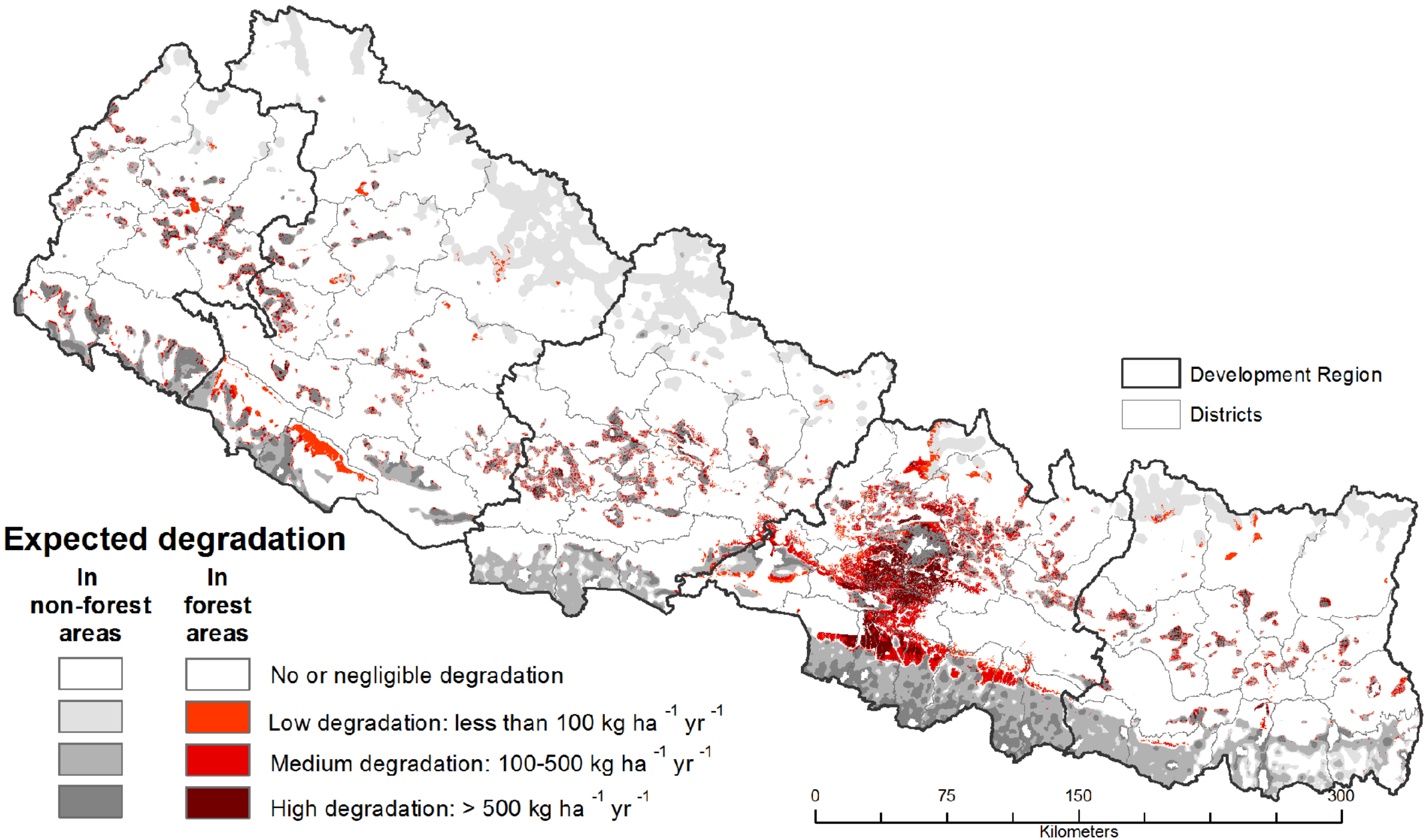


FIGURE 26

Leading Scenario (B Md PM 8h) – Ranking of risk of degradation due to unsustainable fuelwood harvesting.



CONCLUSIONS AND RECOMMENDATIONS

Estimated degradation rate

- Overall, the accessible sustainable supply potential of Nepal is greater than the demand for woody biomass for energy and for other uses. Excluding the industrial roundwood production, the annual accessible supply potential is over 17.2 million air dry tons (range 15.3 to 18.9), while the annual demand for conventional fuelwood is approximately 10.5 million tons, with a theoretical surplus of 6.8 million tons (range 5 to 8.3).
- In good part of the Country the rural demand for fuelwood seems to be satisfied by the resources accessible within the typical harvesting horizon of 3 km or within 10-15 km for the larger settlements. However, this is not the case for the Mid Mount and Siwaliks of Central and Western Development Regions and in the densely populated Terai where the high concentration of the consumption creates a strong commercial fuelwood demand which poses a high pressure on the accessible resources with consequent risk of degradation.
- The **total expected annual degradation all land cover classes**, including Forests, Other Wooded Lands and Other Lands, according to the Leading Scenario is estimated to be 1,107 thousand tons air-dry (1,008 kt DM). Expressed as percent of the accessible DEB stock, this values correspond to 0.14%. The annual degradation rates resulting from all scenarios considered range between 0.01 and 0.35 %, which indicates that at national level the annual degradation rate is rather moderate, no matter what assumptions are made.
- Under the same Leading Scenario, the **expected annual degradation of the Forest-remaining-Forest**, i.e. the area under forest cover for the whole reporting period 2000-2010, is **235 thousand tons air-dry (214 kt DM).**
- At country level, degradation of biomass stock is expected to take place over 25.7% of the entire territory, of which 10.4% may be classified of Low degradation, 10.4% Moderate degradation and 4.9% High degradation, based on the quantity of biomass loss expected.
- With reference to the Forest-Remaining-Forest, the degradation is expected to take place over 11.5% of the FRF area, of which 3.5% may be classified as Low degradation, 5.2% Moderate degradation and 2.7% High degradation.
- The geographic distribution of the expected degradation by physiographic zones, according to the Leading Scenario, is primarily in the Terai (58% of the area under Moderate to High risk of degradation) and Mid Mount (17% Moderate to High risk) followed by Siwalics (14% Moderate to High risk).
- The geographic distribution of the expected degradation by Development Region, according to the Leading Scenario, is primarily in the Central Region, bearing 47% of the total expected degradation and with 35% of the land under Moderate to High risk..
- From a quantitative perspective, the Mid Mount zone of the Central Region shows the largest expected degradation: 232 thousand tons ad (211 kt DM) in all land categories (21% of total degradation) and 104 thousand tons ad (95 kt DM) in the Forest-Remaining-Forest (44% of FRF degradation). In relation to the impact on the existing stock, the area under highest risk is the Terai zone of the Central Development region, where the annual DEB loss is 1.3 % of accessible stock.

Role and contributions of WISDOM analysis

- It should be emphasized that through this analysis we estimated the risk of degradation, spatialized and quantitative, but still the risk and not the actual degradation, that remains to be assessed in the field and through multi-temporal high-resolution remote sensing techniques. The WISDOM analysis represents an indirect estimation of the degradation induced by excessive woodfuel harvesting.
- The direct observation and measurement of forest degradation is far more challenging, and expensive,

than the assessment of deforestation both in terms of field measurements and resolution of remote sensing data. A key contribution that the WISDOM analysis can make to the direct assessment of forest degradation is in the stratification of forests and other landscapes according the risk of degradation (see Figure 27). Since the measurement of changes in biomass stock requires very costly surveys based on very high resolution data and intensive field sampling, the use of robust stratification criteria will make the sampling design more efficient and less expensive. Such stratification will allow to distribute the observations where the phenomenon is more likely to happen, for instance through a statistically efficient PPS approach, and thus reduce the costs of the assessment.

- Besides providing an indirect estimation of woodfuel-induced degradation, the WISDOM methodology supports the definition of priority areas of intervention for forestry and energy planning, which is the main reason of its development. The results of this analysis, in fact, can be used in several forestry and energy contexts.
- Remaining in the REDD+ context, for instance, this study contributes by revealing the cause-effect mechanisms behind degradation processes. Beyond measuring deforestation and degradation we need to identify remedial actions and to this end WISDOM provides essential quantitative and spatial elements linking cause (demand for fuelwood) and effect (rates of degradation) that are fundamental to the formulation of focused forestry and energy policies and to the design of strategic and operational planning.
- From a Sustainable Forest Management perspective, this analysis can support the formulation of locally tailored management objectives, such as productive or protective functions, quantitative production targets to meet local and commercial demand through new plantations and/or improved management practices.
- In the agro-forestry context, this analysis can support the formulation and implementation of field programmes oriented to increase woody biomass production for energy self-sufficiency in rural areas where scarcity is most serious and where the systematic use of farm residues for energy impacts nutrients cycles and soil fertility.

Main conclusions on WISDOM development

The development of WISDOM Nepal implied several assumptions and some tentative value attributions to fill in for information gaps, as discussed in the previous sections. In order to test the sensitivity of the model to such assumptions alternative values were considered and a fairly large number of scenarios (28) were computed.

This was useful as it supported the identification of the Leading Scenario and revealed how each data variant and assumption affected the final result. However, the assumptions remained assumptions and, in order to improve and consolidate the knowledge base they need validation and tentative estimates should be replaced by solid reference data. The most relevant information gaps to be filled in with priority include the following:

Data weakness on supply

- There is little data on sustainable productivity in forests and nothing at all on productivity in farmlands and shrublands. These are important sources of fuelwood that must be well understood in order to assess with accuracy the true impact on forest resources.
- The physical accessibility of wood resources is of paramount importance in a mountain country like Nepal. Updated road network data, including non-motorable trails foothpaths is essential for a correct estimation of accessible resources.

Data weakness on demand

- Fuelwood consumption surveys must adopt quantitative measurement techniques avoiding as much as possible people's estimates of consumption per month or per year. FAO produced useful practical guidelines on fuelwood consumption surveys (FAO, 2002) that offer interesting solutions. In particular, the "average day consumption" approach seems very effective as it allows to measure a day's consumption with good accuracy with only one visit.

- Consumption surveys must differentiate “conventional” fuelwood made of stem wood and branches from “marginal” fuelwood made of twigs and smaller branches that are not considered among forest products and that are often produced through annual or periodic pruning of farm trees and shrubs, hedges, etc..
- The coping strategies put in place by rural households in scarcity or absence of “conventional” fuelwood are little known. Annual or periodic pruning of farm trees, shrubs, hedges, etc. certainly produce more fuelwood than it is generally assumed
- The ignorance of fuelwood type, supply sources and their sustainable productivity often induce the overestimation of the impact of fuelwood on forest resources (and thus to bad policies)

Assumptions made in the analysis of commercial woodshed

- How the shortage of resources in rural areas revert to commercial harvesting of distant resources or to the overexploitation of local ones remains uncertain, although this has important consequences on degradation estimates. In order to cover this aspect, separate assumptions were made in this study (Full Market and Partial Market variants) that need to be verified in the field for fine tuning of WISDOM model.
- Similarly, assumptions were made concerning the efficiency, or rationality, of commercial fuelwood harvesting. A relatively high efficiency was assumed in this study (SIEF=0.8) based on previous studies but this was only tentative. Detailed knowledge on the official and customary management practices, on the areas under community management plans and un-managed public forests will allow to fine tune this parameter for a more accurate estimation and mapping of actual forest degradation.

REFERENCES

Arnold M., G. Köhlin, R. Persson, G. Shepherd, 2003. "Fuelwood Revisited : What Has Changed in the Last Decade ?" Occasional Paper No. 39. Center for International Forestry Research (CIFOR). Bogor Barat, Indonesia.

Bailis, Robert; Drigo, Rudi; Ghilardi, Adrian; and Masera, Omar 2015. The carbon footprint of traditional woodfuels. Nature Climate Change. doi:10.1038/nclimate2491

Central Bureau of Statistics, (CBS) Nepal. 2011. Nepal Living Standard Survey III -2010.

Central Bureau of Statistics, (CBS) Nepal. 2012. National Population and Housing Census 2011 (Village Development Committee/Municipality)

DFRS, 2015. State of Nepal's Forests. Forest Resource Assessment (FRA) Nepal, Department of Forest Research and Survey (DFRS). Kathmandu, Nepal.

DiMiceli, C.M., M.L. Carroll, R.A. Sohlberg, C. Huang, M.C. Hansen, and J.R.G. Townshend (2011), Annual Global Automated MODIS Vegetation Continuous Fields (MOD44B) at 250 m Spatial Resolution for Data Years Beginning Day 65, 2000 - 2010, Collection 5 Percent Tree Cover, University of Maryland, College Park, MD, USA.

Drigo R. 2012. WISDOM Sudan - Spatial analysis of woodfuel supply and demand in Sudan based on WISDOM methodology and new land cover mapping. Activity carried out in the framework of Sudan Institutional Capacity Programme: Food Security Information for Action (SIFSIA) FAO OSRO/SUD/620/MUL. FAO.

Drigo R. and F. Salbitano. FAO. 2008. WISDOM for Cities. Analysis of wood energy and urbanization aspects using WISDOM methodology. FAO Forestry Department Urban forestry – Wood energy. (in English and French).English version: http://www.fao.org/documents/advanced_s_result.asp?QueryString=wisdom+for+cities&search=Search

Drigo R., A. Munyehirwe, V. Nzabanita and A. Munyampundu. 2013 Final report - Update and upgrade of WISDOM Rwanda and Woodfuels value chain analysis as a basis for a Rwanda Supply Master Plan for fuelwood and charcoal. AGRICONSULTING S.p.A. , for the Department of Forestry and Nature Conservation (DFNC), Rwanda Natural Resources Authority (RNRA).

Drigo R., O.R. Masera and M.A. Trossero. 2002. Woodfuel Integrated Supply/Demand Overview Mapping – WISDOM: a geographical representation of woodfuel priority areas. Unasylva Vol. 53 2002/4, pp 36-40. FAO. (Available in English, Spanish and French) See: http://www.fao.org/docrep/005/y4450e/y4450e12.htm

Drigo R., R. Bailis, O. Masera, and A. Ghilardi. 2014. Pan-tropical analysis of woodfuel supply, demand and sustainability. Yale-UNAM NRB Project: Tier I : Final Report. Global Alliance for Clean Cookstoves (GACC) Project "Geospatial Analysis and Modeling of Non-Renewable Biomass: WISDOM and beyond"

FAO 2007. Wood-energy supply/demand scenarios in the context of poverty mapping. A WISDOM case study in Southeast Asia for the years 2000 and 2015. Prepared by R. Drigo for the Environment and Natural Resources Service (SDRN) and Forest Product Service (FOPP). Environment and Natural Resources Working Paper 27. ISBN 978-92-5-105710-0. http://www.fao.org/docrep/010/a1106e/a1106e00.htm

FAO. 2002. A guide for woodfuel surveys. Prepared by T. A. Chalico and E. M. Riegelhaupt. EC-FAO Partnership Programme (2000-2002) Sustainable Forest Management Programme. See: http://www.fao.org/docrep/005/Y3779E/Y3779E00.HTM

FAO. 2004. Unified Bioenergy Terminology – UBET. FAO Forestry Department, Wood Energy Programme.

FAO. 2010. Global Forest Resources Assessment 2010 - Country Report - Nepal. Forestry Department, FRA2010/144, Rome.

Hansen MC, Potapov PV, Moore R, Hancher M, Turubanova SA, et al. 2013. High-Resolution Global Maps of 21st-Century Forest Cover Change. *Science* 342: 850-53

ICIMOD. 2016. Map of forest-remaining-forest derived from the analysis of Landsat data of 2000 and 2010.

IUCN-WCMC. 2009. World Database of Protected Areas. Released by the International Union for the Conservation of Nature (IUCN) and by the World Conservation Monitoring Centre (WCMC).

Leach, M. & R. Mearns, 1988. “Beyond the Woodfuel Crisis: People, Land and Trees in Africa.” Earthscan Publications. London.

Mahapatra A.K. & C.P. Mitchell, 1999. “Biofuel consumption, deforestation, and farm level tree growing in rural India.” Biomass and Bioenergy 17:291-303.

Mancini M., E. Mattioli, M Morganti, P. Bruschi, M.A. Signorini. 2007. Conhecimento e exploracao de produtos florestais nao madereiros e carvao na zona de Muda, Provincia de Manica (mocambique). Projecto AIFM.

Masera O., R. Bailis, R. Drigo, A. Ghilardi and I. Ruiz-Mercado. 2015 . Environmental Burden of Traditional Bioenergy Use. Annual Review of Environment and Resources 11/2015; 40(1). DOI:10.1146/annurev-environ-102014-021318.

Master Plan for the Forestry Sector Project. 1988. Master Plan for the Forestry Sector of Nepal. [18 reports]. Ministry of Forests and Soil Conservation.

Nelson, A. (2008) Estimated travel time to the nearest city of 50,000, or more people in year 2000. Global Environment Monitoring Unit - Joint Research Centre of the European Commission, Ispra Italy. Available at http://bioval.jrc.ec.europa.eu/products/gam/index.htm

Nepal Energy Efficiency Programme (NEEP). 2013. Biomass Energy Strategy (BEST) for Nepal - Baseline Report.

Nepal Foresters’ Association. 2012. The Demand and Supply of Wood Products in Different Regions of Nepal. Report submitted to REDD Forestry Climate Change Cell, Babarmahal, Kathmandu. Prepared by Keshav Raj Kanel, Kumud Shrestha, Amulya Ratna Tuladhar, Mijan Raj Regmi.

R. Drigo, C. Cuambe, M. Lorenzini, A. Marzoli, J. Macuacua, C. Banze, P. Mugas, D.Cunhete. 2008. WISDOM Mozambique Final Report. Wood energy component of the Consolidation Phase of the Project “Integrated Assessment of Mozambican Forests”. AGRICONSULTING, for the Direcção Nacional de Terras e Florestas, Ministério de Agricultura, Moçambique. See : http://www.wisdomprojects.net/pdf?file=WISDOM_Mozambique_web_pub.pdf

R. Drigo, Gehendra Karki and Saroj K. Sharma. 2014. WISDOM Nepal and contribution to MRV. Consultancy report of Project "Development of a Measurement, Reporting and Verification (MRV) System for Emissions and Removals". Project implemented by Agriconsulting SpA.

Rijal H.B., H Yoshida. 2002. Investigation ad Evaluation o Firewood Consumption i Traditional Houses in Nepal. Dept. of Global Environment Eng., Faculty of Eng., Kyoto University.

RWEDP, 1997. “Regional study on wood energy today and tomorrow in Asia.” Regional Wood Energy Development Programme (RWEDP) in Asia GCP/RAS/154/NET. Field Document N 50. Food and Agriculture Organization of the United Nations / Kingdom of The Netherlands. Bangkok, Thailand.

RWEDP. 2001. References Nepal. Wood energy information analysis in Asia - Nepal. National Consultants: S.M. Amatya, D.L. Shrestha, D.K. Kharal and R.P. Ghimire, Water and Energy Commission Secretariat, Kathmandu. http://www.fao.org/docrep/006/ad353e/AD353e00.htm#TopOfPage

WECS (2010). Energy Sector Synopsis Report 2010. Water and Energy Commission Secretariat, Kathmandu, Nepal

WECS. 2013. National Survey of Energy Consumption and Supply Situation of Nepal. Draft Final Report Submitted to the Water and Energy Commission Secretariat by Narayan B Shrestha, Ph.D, Team Leader, NSoECS; Kathmandu. December, 2013.

ANNEXES

ANNEX 1: FUEL SATURATION AND PER CAPITA CONSUMPTION IN RESIDENTIAL SECTOR

CBS NLSS 2010 - Percent saturation cooking fuel

stratum	Firewood	Leaves/rubbish/straw/thatch	Dung	Bio-gas	Cylinder gas	Kerosene	Other	Total HH
Urban-Kathmandu Valley	**2.9**	0.7	0.0	0.0	92.8	3.2	0.4	3593
Urban-Terai	**46.4**	5.2	6.8	4.2	34.9	0.4	2.1	3240
Urban-Hill	**46.4**	0.2	0.4	8.0	43.7	0.5	0.9	2043
Rural-Terai-Far-Western	**92.3**	0.0	0.5	5.4	1.8	0.0	0.0	826
Rural-Terai-Mid-Western	**85.0**	0.0	0.9	7.3	5.7	0.0	1.0	1158
Rural-Terai-Western	**42.3**	4.1	38.5	4.6	9.1	0.3	1.2	1999
Rural-Terai-Central	**53.0**	13.1	28.4	3.0	2.1	0.1	0.4	2701
Rural-Terai-Eastern	**39.4**	7.9	40.5	5.1	6.5	0.0	0.6	2354
Rural-Hill-Far-Western	**99.1**	0.0	0.9	0.0	0.0	0.0	0.0	892
Rural-Hill-Mid-Western	**96.5**	0.0	0.2	0.9	2.5	0.0	0.0	1749
Rural-Hill-Western	**90.3**	0.2	0.5	4.6	4.0	0.0	0.4	2041
Rural-Hill-Central	**79.6**	0.9	0.1	1.7	16.8	0.2	0.7	2256
Rural-Hill-Eastern	**98.4**	0.4	0.4	0.5	0.3	0.0	0.0	1827
Mountain	**91.9**	0.0	0.4	0.4	6.6	0.4	0.3	1991
Total	**60.5**	**3.0**	**9.7**	**3.1**	**22.6**	**0.6**	**0.7**	**28670**

Per capita consumption in **rural areas** (ad kg / person / year)

	REGI_NAME	MPFS 1988	Fox (1984)	Source: Rijal (2002)	CBS_NLSS2010	average weighted on Fw users
Terai	Far-Western	479			546	514
	Mid-Western					
	Western	482		535		
	Central	474				
	Eastern	483				
Hills (or Mid Mount)	Far-Western	548	511		691	610
	Mid-Western					
	Western	743		348		
	Central	484		561		
	Eastern	829				
Mountains	Far-Western	548			707	781
	Mid-Western					
	Western	743				
	Central	484				
	Eastern	829		1130		

Per capita consumption in **urban areas** (ad kg / person / year)

<table>
<tr><th></th><th>REGI_NAME</th><th>MPFS
1988</th><th>Source: Rijal
(2002)</th><th>CBS_NLSS2010</th><th>based on rural HH less farming uses.
applied to users only</th></tr>
<tr><td rowspan="5">Terai</td><td>Far-Western</td><td rowspan="15">248
(applied to tot urban pop)</td><td rowspan="8"></td><td rowspan="15">162 Kathmandu

589 elsewhere</td><td rowspan="5">407</td></tr>
<tr><td>Mid-Western</td></tr>
<tr><td>Western</td></tr>
<tr><td>Central</td></tr>
<tr><td>Eastern</td></tr>
<tr><td rowspan="5">Hills (or Mid Mount)</td><td>Far-Western</td><td rowspan="5">483</td></tr>
<tr><td>Mid-Western</td></tr>
<tr><td>Western</td></tr>
<tr><td>Central</td><td>235</td></tr>
<tr><td>Eastern</td><td rowspan="6"></td></tr>
<tr><td rowspan="5">Mountains</td><td>Far-Western</td><td rowspan="5">619</td></tr>
<tr><td>Mid-Western</td></tr>
<tr><td>Western</td></tr>
<tr><td>Central</td></tr>
<tr><td>Eastern</td></tr>
</table>

ANNEX 2: SUPPLY MODULE – REFERENCE DATA, STOCK AND MAI VALUES

Table A2.1 Forest types from DFRS (Shiva, 2014) and grouping applied for this study

Forest Type code	pixel_ha	name_short	NAME	FT Group code	Forest Type Group
1	1,455,272	TMH	Tropical Mixed Hardwood	1	Tropical Mixed Hardwood
2	900,798	S	Sal	2	Sal
4	1,025,268	LMH	Lower Mixed Hardwood	3	Lower Mixed Hardwood
5	1,108,412	UMH	Upper Mixed Hardwood	6	Mixed high broadleaves
6	499,610	Pr	Pinus roxburghii	4	Pinus roxburghii
7	74,113	KS/SK	Acacia catechu & Dalbergia sisso	6	Mixed high broadleaves
8	213,502	Pw	Pinus wallichiana	7	Mixed high conifers
9	449,117	Q	Quercus	5	Quercus
10	5,982	Jw	Juglans wallichiana	6	Mixed high broadleaves
11	18,575	Td	Tsuga dumosa	7	Mixed high conifers
12	110,221	A	Abies spectabilis & Abies pindrow	7	Mixed high conifers
13	20,164	Ct	Cupressus torulosa	7	Mixed high conifers
15	27,228	Ce	Cedrus deodara	7	Mixed high conifers
16	41,190	Bu	Betula utilis	6	Mixed high broadleaves
17	20,673	Sp	Picea smithiana	7	Mixed high conifers

Table A2.2 Distribution of NFI Sampling Units by Forest Groups, OWL and OL, by Development Region and by Physiographic Zone

SU (number)			Physiographic zones			
Forest Group and Dev.Region	Terai	Siwaliks	Mid Mount	HighMount	HighHimal	Total
Mixed high conifers			**15**	**62**	**10**	**87**
Far Western				6		6
Mid Western				26	6	32
Western				14	4	18
Central			13	16		29
Eastern			2			2
Mixed high broadleaves	**1**	**6**	**36**	**170**	**3**	**216**
Far Western	1		9	40		50
Mid Western		3	3	42	1	49
Western		1	3	20		24
Central		1	8	38		47
Eastern		1	13	30	2	46
Quercus			**33**	**52**	**11**	**96**
Far Western			8	9		17
Mid Western			3	22	3	28
Western			14	8	8	30
Central			3	8		11
Eastern			5	5		10
Pinus roxburghii		**16**	**75**	**26**		**117**
Far Western		10	25	9		44
Mid Western			21	11		32
Western			11	3		14
Central			10	1		11
Eastern		6	8	2		16
Lower Mixed Hardwood		**16**	**162**	**45**		**223**
Far Western		11	30	3		44
Mid Western		3	26	1		30
Western		2	38	17		57
Central			31	14		45
Eastern			37	10		47
Tropical Mixed Hardwood	**82**	**276**	**75**	**4**		**437**
Far Western	31	34	5			70
Mid Western	10	94	19			123
Western	2	39	27	4		72
Central	30	80	8			118
Eastern	9	29	16			54
Sal	**81**	**159**	**73**	**8**		**321**
Far Western	18	21	9	8		56
Mid Western	20	32	14			66
Western	19	21	28			68
Central	13	63	16			92
Eastern	11	22	6			39
Sub Total	**164**	**473**	**469**	**367**	**24**	**1497**
OWL & Srubs	**7**	**11**	**21**	**25**	**8**	**72**
Far Western			1	8		9
Mid Western	2	6	4	6	5	23
Western	2		7	6	2	17
Central		1	4	2	1	8
Eastern	3	4	5	3		15
Non Forest	**167**	**219**	**389**	**170**	**30**	**975**
Far Western	33	15	38	23		109
Mid Western	22	62	71	56	10	221
Western	21	26	76	29	19	171
Central	41	77	113	21		252
Eastern	50	39	91	41	1	222
Grand Total	**338**	**703**	**879**	**562**	**62**	**2544**

Table A2.3 Mean Dendroenergy Biomass (DEB) ha^{-1} by Forest Groups, OWL and OL, by Development Region and by Physiographic Zone

Mean DEB ad t ha^{-1}			Physiographic zones			
Forest Group and Dev.Region	Terai	Siwaliks	Mid Mount	HighMount	HighHimal	Total
Mixed high conifers			**130.3**	**317.9**	**196.0**	**271.5**
Far Western				440.8		440.8
Mid Western				302.4	128.5	269.8
Western				258.8	297.2	267.3
Central			130.4	348.8		250.9
Eastern			130.1			130.1
Mixed high broadleaves	**17.1**	**62.3**	**279.6**	**266.9**	**262.4**	**262.1**
Far Western	17.1		387.1	349.4		349.6
Mid Western		100.0	123.4	241.0	627.1	233.0
Western		74.1	136.1	274.6		249.0
Central		0.0	173.0	199.3		190.5
Eastern		0.0	339.8	273.9	80.0	278.2
Quercus			**155.5**	**366.3**	**249.8**	**280.5**
Far Western			313.3	538.0		432.3
Mid Western			400.8	365.8	413.3	374.6
Western			58.0	429.8	188.5	192.0
Central			78.5	147.6		128.8
Eastern			74.8	307.5		191.2
Pinus roxburghii		**114.0**	**101.0**	**113.7**		**105.6**
Far Western		172.5	95.5	106.8		115.3
Mid Western			116.0	132.8		121.8
Western			92.4	91.6		92.2
Central			93.1	0.0		84.7
Eastern		16.6	100.8	129.8		72.8
Lower Mixed Hardwood		**145.3**	**97.9**	**116.6**		**105.1**
Far Western		157.1	168.6	29.7		156.3
Mid Western		139.3	95.8	172.8		102.7
Western		89.2	71.9	78.4		74.4
Central			79.2	191.7		114.2
Eastern			84.6	96.7		87.2
Tropical Mixed Hardwood	**164.7**	**148.1**	**82.3**	**79.4**		**139.3**
Far Western	145.3	205.6	18.6			165.5
Mid Western	129.6	124.3	105.9			121.9
Western	166.4	140.3	89.0	79.4		118.4
Central	186.0	175.4	47.7			169.4
Eastern	199.6	93.0	80.0			106.9
Sal	**209.3**	**196.6**	**142.4**	**48.7**		**183.8**
Far Western	276.8	224.2	100.4	48.7		196.1
Mid Western	215.6	185.1	139.9			184.8
Western	184.7	218.8	194.2			199.2
Central	183.5	190.4	94.6			172.8
Eastern	160.7	183.6	96.5			163.7
Total Forest means	**185.9**	**162.1**	**121.9**	**253.5**	**229.0**	**175.6**
OWL & Shrubs	**21.1**	**30.6**	**20.7**	**95.4**	**306.4**	**79.9**
Far Western			14.4	95.1		86.2
Mid Western	12.4	28.4	16.0	118.5	398.7	128.9
Western	21.2		10.8	111.8	179.6	67.5
Central		0.0	36.2	27.5	98.1	37.3
Eastern	26.7	41.6	27.2	62.4		38.0
Non Forest	**9.4**	**14.5**	**25.2**	**64.6**	**88.4**	**28.9**
Far Western	25.9	26.2	15.0	59.2		29.2
Mid Western	4.1	14.2	26.7	87.8	149.6	42.0
Western	10.5	28.0	31.7	39.3	55.2	32.4
Central	4.3	9.0	22.2	48.8		17.5
Eastern	4.4	12.5	26.7	62.0	106.4	26.0

Table A2.4 Aggregation of SUs based on the number of sampling units, mean DEB values, physiographic zones and Development Regions to form 26 main strata.

<table>
<tr><th></th><th colspan="5">Physiographic zones</th></tr>
<tr><th>Forest Group and Dev.Region</th><th>Terai</th><th>Siwaliks</th><th>Mid Mount</th><th>HighMount</th><th>HighHimal</th></tr>
<tr><td>Mixed high conifers</td><td colspan="5"></td></tr>
<tr><td>Far Western</td><td colspan="3" rowspan="5">1</td><td colspan="2" rowspan="5">2</td></tr>
<tr><td>Mid Western</td></tr>
<tr><td>Western</td></tr>
<tr><td>Central</td></tr>
<tr><td>Eastern</td></tr>
<tr><td>Mixed high broadleaves</td><td colspan="5"></td></tr>
<tr><td>Far Western</td><td colspan="3" rowspan="5">3</td><td colspan="2" rowspan="2">4</td></tr>
<tr><td>Mid Western</td></tr>
<tr><td>Western</td><td colspan="2" rowspan="3">5</td></tr>
<tr><td>Central</td></tr>
<tr><td>Eastern</td></tr>
<tr><td>Quercus</td><td colspan="5"></td></tr>
<tr><td>Far Western</td><td colspan="3" rowspan="5">6</td><td colspan="2" rowspan="5">7</td></tr>
<tr><td>Mid Western</td></tr>
<tr><td>Western</td></tr>
<tr><td>Central</td></tr>
<tr><td>Eastern</td></tr>
<tr><td>Pinus roxburghii</td><td colspan="5"></td></tr>
<tr><td>Far Western</td><td colspan="5" rowspan="2">8</td></tr>
<tr><td>Mid Western</td></tr>
<tr><td>Western</td><td colspan="5" rowspan="3">9</td></tr>
<tr><td>Central</td></tr>
<tr><td>Eastern</td></tr>
<tr><td>Lower Mixed Hardwood</td><td colspan="5"></td></tr>
<tr><td>Far Western</td><td colspan="2" rowspan="5">10</td><td rowspan="2">11</td><td colspan="2" rowspan="5">13</td></tr>
<tr><td>Mid Western</td></tr>
<tr><td>Western</td><td rowspan="3">12</td></tr>
<tr><td>Central</td></tr>
<tr><td>Eastern</td></tr>
<tr><td>Tropical Mixed Hardwood</td><td colspan="5"></td></tr>
<tr><td>Far Western</td><td rowspan="5">14</td><td rowspan="5">15</td><td colspan="3" rowspan="5">16</td></tr>
<tr><td>Mid Western</td></tr>
<tr><td>Western</td></tr>
<tr><td>Central</td></tr>
<tr><td>Eastern</td></tr>
<tr><td>Sal</td><td colspan="5"></td></tr>
<tr><td>Far Western</td><td rowspan="2">17</td><td rowspan="5">19</td><td colspan="3" rowspan="5">20</td></tr>
<tr><td>Mid Western</td></tr>
<tr><td>Western</td><td rowspan="3">18</td></tr>
<tr><td>Central</td></tr>
<tr><td>Eastern</td></tr>
<tr><td>OWL & Shrubs</td><td colspan="5"></td></tr>
<tr><td>Far Western</td><td colspan="3" rowspan="5">21</td><td colspan="2" rowspan="5">22</td></tr>
<tr><td>Mid Western</td></tr>
<tr><td>Western</td></tr>
<tr><td>Central</td></tr>
<tr><td>Eastern</td></tr>
<tr><td>Non Forest</td><td colspan="5"></td></tr>
<tr><td>Far Western</td><td rowspan="5">23</td><td rowspan="5">24</td><td rowspan="5">25</td><td colspan="2" rowspan="5">26</td></tr>
<tr><td>Mid Western</td></tr>
<tr><td>Western</td></tr>
<tr><td>Central</td></tr>
<tr><td>Eastern</td></tr>
</table>

Table A2.5 Strata definition (see also previous tables for strata definition), smpling statistics and mean DEB values by stratum.

stratum	Ha	Forest Group / Land Cover	Physiographic zone	Development Region	No of SU	SD deb_adtha	95% Confidence Interval (CI)	Mean DEB adtha
1	58,308	Mixed high conifers	Terai, Siwaliks, Mid Mount	All	15	75.8	38.4	**130.3**
2	352,055	Mixed high conifers	HighMount, HighHimal	All	72	302.2	69.8	**301.0**
3	243,047	Mixed high broadleaves	Terai, Siwaliks, Mid Mount	All	43	238.0	71.1	**243.2**
4	509,709	Mixed high broadleaves	HighMount, HighHimal	FW, MW	83	237.0	51.0	**297.9**
5	476,941	Mixed high broadleaves	HighMount, HighHimal	W, C, E	90	182.5	37.7	**238.2**
6	126,346	Quercus	Terai, Siwaliks, Mid Mount	All	33	177.0	60.4	**155.5**
7	322,771	Quercus	HighMount, HighHimal	All	63	287.4	71.0	**345.9**
8	359,140	Pinus roxburghii	All	FW, MW	76	107.2	24.1	**118.0**
9	140,470	Pinus roxburghii	All	W, C, E	41	83.8	25.7	**82.6**
10	51,903	Lower Mixed Hardwood	Terai, Siwaliks	All	16	78.7	38.6	**145.3**
11	213,467	Lower Mixed Hardwood	Mid Mount	FW, MW	56	159.4	41.8	**134.8**
12	591,018	Lower Mixed Hardwood	Mid Mount	W, C, E	106	64.2	12.2	**78.5**
13	168,880	Lower Mixed Hardwood	HighMount, HighHimal	All	45	95.6	27.9	**116.6**
14	209,552	Tropical Mixed Hardwood	Terai	All	82	92.2	20.0	**164.7**
15	823,401	Tropical Mixed Hardwood	Siwaliks	All	276	88.5	10.4	**148.1**
16	422,319	Tropical Mixed Hardwood	Mid Mount, HighMount, HighHimal	All	79	66.4	14.6	**82.1**
17	108,944	Sal	Terai	FW, MW	38	127.7	40.6	**244.6**
18	86,569	Sal	Terai	W, C, E	43	103.0	30.8	**178.2**
19	433,136	Sal	Siwaliks	All	159	102.7	16.0	**196.6**
20	272,149	Sal	Mid Mount, HighMount, HighHimal	All	81	109.3	23.8	**133.1**
21	93,114	OWL & Shrubs	Terai, Siwaliks, Mid Mount	All	39	28.3	8.9	**23.6**
22	551,493	OWL & Shrubs	HighMount, HighHimal	All	33	221.6	75.6	**146.5**
23	1,599,576	Non Forest (OL)	Terai	All	167	29.7	4.5	**9.4**
24	501,681	Non Forest (OL)	Siwaliks	All	219	38.4	5.1	**14.5**
25	1,992,956	Non Forest (OL)	Mid Mount	All	389	39.8	4.0	**25.2**
26	760,558	Non Forest (OL)	HighMount, HighHimal	All	200	130.8	18.1	**68.2**

Note: One additional stratum was created (stratum 0) to represent the unproductive areas of mountain zones, for which a DEB = 0 was assumed.

Table A2.6 Minimum, Medium and Maximum values of DEB stock and Mean Annual Increment (MAI) by stratum.

stratum	Forest Group / Land Cover	Physiographic zone	Development Region	Minimum DEB (mean – CI) adtha	Medium DEB (mean) adtha	Maximum DEB (mean + CI) adtha	Minimum DEB MAI adt/ha/yr	Medium DEB MAI adt/ha/yr	Maximum DEB MAI adt/ha/yr
1	Mixed high conifers	Terai, Siwaliks, Mid Mount	All	92.0	**130.3**	168.7	2.342	**2.704**	3.007
2	Mixed high conifers	HighMount, HighHimal	All	231.2	**301.0**	370.8	3.363	**3.749**	4.086
3	Mixed high broadleaves	Terai, Siwaliks, Mid Mount	All	172.0	**243.2**	314.3	2.957	**3.411**	3.791
4	Mixed high broadleaves	HighMount, HighHimal	FW, MW	246.9	**297.9**	348.9	3.456	**3.734**	3.985
5	Mixed high broadleaves	HighMount, HighHimal	W, C, E	200.5	**238.2**	276.0	3.198	**3.433**	3.648
6	Quercus	Terai, Siwaliks, Mid Mount	All	95.1	**155.5**	215.9	2.340	**2.866**	3.281
7	Quercus	HighMount, HighHimal	All	275.0	**345.9**	416.9	3.636	**3.997**	4.317
8	Pinus roxburghii	All	FW, MW	93.9	**118.0**	142.1	2.066	**2.313**	2.535
9	Pinus roxburghii	All	W, C, E	57.0	**82.6**	108.3	1.620	**1.945**	2.223
10	Lower Mixed Hardwood	Terai, Siwaliks	All	106.7	**145.3**	183.9	2.498	**2.836**	3.125
11	Lower Mixed Hardwood	Mid Mount	FW, MW	93.1	**134.8**	176.6	2.326	**2.710**	3.029
12	Lower Mixed Hardwood	Mid Mount	W, C, E	66.2	**78.5**	90.7	2.021	**2.167**	2.300
13	Lower Mixed Hardwood	HighMount, HighHimal	All	88.6	**116.6**	144.5	2.284	**2.557**	2.794
14	Tropical Mixed Hardwood	Terai	All	144.8	**164.7**	184.7	2.798	**2.952**	3.094
15	Tropical Mixed Hardwood	Siwaliks	All	137.7	**148.1**	158.5	2.760	**2.844**	2.925
16	Tropical Mixed Hardwood	Mid Mount, HighMount, HighHimal	All	67.5	**82.1**	96.8	2.043	**2.215**	2.370
17	Sal	Terai	FW, MW	204.0	**244.6**	285.2	3.268	**3.522**	3.752
18	Sal	Terai	W, C, E	147.4	**178.2**	209.0	2.823	**3.053**	3.260
19	Sal	Siwaliks	All	180.7	**196.6**	212.6	3.093	**3.203**	3.308
20	Sal	Mid Mount, HighMount, HighHimal	All	109.3	**133.1**	156.9	2.505	**2.716**	2.907
21	OWL & Shrubs	Terai, Siwaliks, Mid Mount	All	14.7	**23.6**	32.4	0.815	**1.029**	1.204
22	OWL & Shrubs	HighMount, HighHimal	All	70.9	**146.5**	222.1	1.687	**2.413**	2.962
23	Non Forest (OL)	Terai	All	4.8	**9.4**	13.9	0.670	**0.879**	1.033
24	Non Forest (OL)	Siwaliks	All	9.4	**14.5**	19.6	0.868	**1.036**	1.173
25	Non Forest (OL)	Mid Mount	All	21.3	**25.2**	29.2	1.247	**1.338**	1.421
26	Non Forest (OL)	HighMount, HighHimal	All	50.1	**68.2**	86.3	1.724	**1.958**	2.158

Note: The Medium DEB values are made by the sample means; Minimum and Maximum DEB values are made by subtracting and adding the 95% confidence intervals (CI) to the means. DEB MAI values are calculated by applying the stock-MAI equation (ref…..) to the DEB stock values of individual map pixels. The MAI values are the strata average of the resulting pixel values.

ANNEX 3: INDUSTRIAL ROUNDWOOD PRODUCTION

From:

Nepal Foresters' Association. 2012. The Demand and Supply of Wood Products in Different Regions of Nepal. Report submitted to REDD Forestry Climate Change Cell, Babarmahal, Kathmandu. Prepared by Keshav Raj Kanel, Kumud Shrestha, Amulya Ratna Tuladhar, Mijan Raj Regmi.

Estimate Supply of Timber in 2011 (in '000 tons ad)

Supply source	Mountain	Hills (or Mid Mountains)	Terai	Total
Agriculture	29.6	336.0	128.0	493.6
NCI-Non Cultivated Inclusions	72.5	83.9	7.7	164.1
Forests				
CF and CFM	53.6	512.4	380.9	946.8
Forests under PA				
Leasehold Forests	2.9	3.9		6.8
Government Managed Forests	0.8	357.9	306.8	665.5
Grassland		5.5	0.2	5.7
Other				
Total	159.3	1299.6	823.6	2,282.5

The annual demand for rural construction material, which was estimated to be 285,000 ad tons and was already added to woodfuel demand (see Section 2.2.1). Such material is assumed to be included in the total amount of industrial roundwood estimated in the 2012 REDD report and, in order to avoid double counting, it was deducted from the total. The available fuelwood supply potential was then estimated by deducting the remaining amount of industrial roundwood, i.e. 1,997.5 kt ad, from the accessible DEB MAI of Terai, Hills and Mountain Districts.

ANNEX 4: LEGAL ACCESSIBILITY OF BIOMASS RESOURCES

Preliminarily, we assume all woody biomass is legally accessible with the exception of resources found within protected areas, which face some restrictions.

In reality, National Parks and other conservation areas present various restrictions on the exploitation of forest resources. In order to account for these legal constraints, an accessibility factor was allocated to the protected areas on the basis of IUCN definitions of Protected Area Management Categories and on national experts' opinions on the access rates (percent accessible) of biomass resources to local communities and to commercial operators in each protection category. The Map of protected areas of Nepal (file Nat_parks_MRV_Db from MRV_Database) is more detailed and more complete than the dataset published by WCMC-IUCN and is therefore used as main reference.

The estimated accessibility for fuelwood harvesting for local and commercial use is shown in Table A4.1. The maps showing the corresponding areas are presented in Figure A4.1. All protected areas (including buffer zones) are 0% accessible for commercial production of fuelwood.

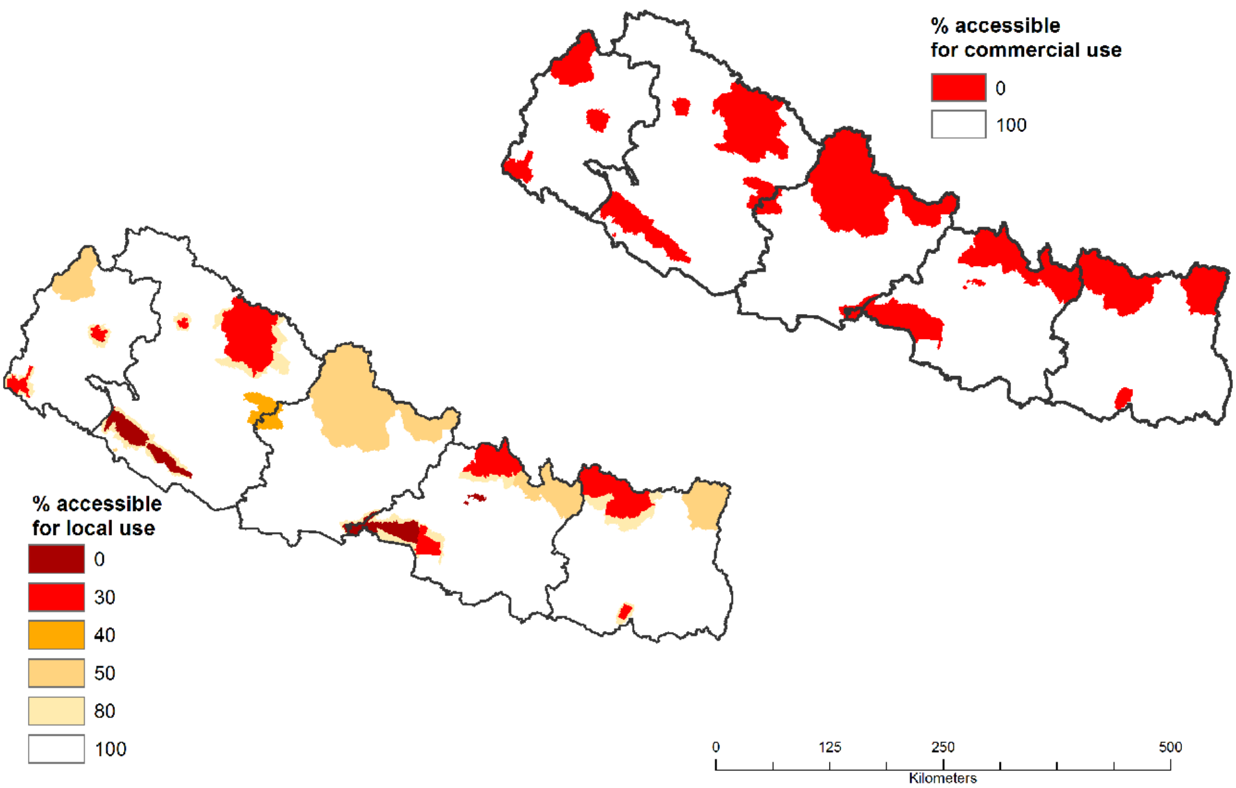
TABLE A4.1

Categories of Protected Areas of Nepal and their assumed accessibility for local and for commercial fuelwood production

Protected areas	Area (ha)	For Local Use:	For Commercial Use:
National Parks (Terai to Middle Mountains)	1,083,202	0 %	0 %
National Parks (High Mountains)		30 %	0 %
Wildlife Reserves	109,989	30 %	0 %
Hunting Reserves	119,247	40 %	0 %
Conservation Areas	1,551,873	50 %	0 %
Buffer zones of NP, WR and CAs	575,677	80 %	0 %

FIGURE A4.1

Distribution of protected areas and their assumed accessibility for local and for commercial fuelwood production



ANNEX 5: PHYSICAL ACCESSIBILITY OF BIOMASS RESOURCES

Off-road accessibility-Travel time to nearest access feature (city, populated area, motorable road, cart tract)

Assuming that the resources that are located along communication routes (motorable roads and cart tracts - there are no navigable rivers and railway is negligible-) or that are close to populated places (urban centres, villages and densely populated rural areas) have highest accessibility, it may be assumed that the accessibility of the resources located far from such features are inversely proportional to the time (or effort) necessary to reach them (considering here the time needed to go and return with fuelwood load).

In order to associate a parameter of physical accessibility to the legally-accessible woody biomass resources, a **fuelwood transport time map** is produced following and adapting the procedure described by Nelson[12] and by Drigo[13] . The specific features of the Nepal study include a redefinition of the target locations based on the most detailed available national maps (road, tracts, trail and footpaths; buildings and builtup areas), the use of 30m elevation model and of best available land cover data, and the adaptation of friction factors and slope factors to Nepali situation.

Target locations

The target locations are all accessible areas, including:

1. Populated places,:

    a. Urban areas. Map name **built_4mn** . The speed of 15 km/hr = 4 min/km assumed for urban transport assumed.

    b. Densely populated rural areas. Defined as rural areas with population density above 178 inh. $km^{2\ -1}$, as average of surrounding 3 cells (300 m radius). With such population density, the biomass resources that still exist are assumed to be totally accessible (unless protected by law) independently from the presence of a road network. The mask of the densely populated rural areas is **pop178_16mn**, derived from the map pop_f3mean. The value is 16 for the 16min/km assumed [double speed than for cultivated area in consideration of the expected high density of paths and roads])

2. Communication features:

    a. Road network (map: road4_mnts), composed by:
        i. Metalled motorable road
        ii. Secondary motorable road
        iii. Cart track
        iv. Main trail
    b. Railways (not relevant in Nepal)

The target locations (or source features of cost-distance analysis) is composed by the layers described above, merged into a single map.

Friction surface components

Land cover friction

The base friction values applied to land cover classes and communication features, intended as transport speed in

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[12] Nelson, A. (2008) Estimated travel time to the nearest city of 50,000, or more people in year 2000. Global Environment Monitoring Unit - Joint Research Centre of the European Commission, Ispra Italy. Available at http://bioval.jrc.ec.europa.eu/products/gam/index.htm

[13] Pan-tropical map of accessibility for the YALE-GACC Tier I analysis of woodfuels supply and demand (Drigo et al., 2014).

minutes per km assuming flat terrain and altitude below 2000 msl are reported in Table A5.

TABLE A5.1

Friction values (minutes / km return trip) applied to land cover classes and communication features, assuming flat terrain and altitude below 2000 msl

	NEW_LCOVER	Icimod LC_Class	**Going m/km**	**loaded factor**	**Return loaded**	**tot return trip min/km**
Land cover	Forest	- all classes -	30	1.5	45	**75**
	Other Wooded	- all classes -	20	1.5	30	**50**
	Other	River and lake	60	1	60	**120**
	Other	Snow/Glacier	30	2	60	**90**
	Other	Grassland	18	1.5	27	**45**
	Other	Agriculture	16	1.5	24	**40**
	Other	Bare Area	16	1.5	24	**40**
	Other	Builtup Area	4	1.5	6	**10**
	No data	River	60	1	60	**120**
	No data	- all other classes -	16	1.5	24	**40**
Target location layers	Builtup areas		4	1	4	**8**
	Densely populated rural areas		8	1	8	**16**
	Metalled motorable road		**2**	1	2	**4**
	Secondary motorable road		**4**	1	4	**8**
	Cart track		**6**	1	6	**12**
	Main trail		**10**	1	10	**20**
Other features	Footpath		**12**	1.33	16	**28**
	Railway		**4**	1	4	**8**

Elevation factor

A speed reduction factor is applied to higher elevation starting from elevations greater than 2000 msl, as done by Nelson. Since the original factor reported in Nelson's documentation appears too abrupt (the speed gradient at 2000 m elevation suddenly lowers to only 7% of the speed below 2000 m), the speed factor calculation was therefore revised as shown in Table A5.2 to provide a smoother speed reduction progression.

Map of the travel time increase induced by altitude (1 / speed factor)

elev_fact = `Con("aster100" > 2000,1 / (Power(0.132, 0.00048*"aster100") * 7),1)`

TABLE A5.2

Crossing time factors based on altitude

	Nelson's factor f=0.15^(0.0007*Elevation(m))	**Nepal case study** f=7*(0.132^(0.00048*Elevation(m)))	
Altitude	f	speed factor	crossing time factor (1/speed factor)
below 2000		1.000	1.00
2000	0.070	1.00	1.00
2100	0.061	0.91	1.10
2200	0.054	0.82	1.21
2500	0.036	0.62	1.62
2750	0.026	0.48	2.07
3000	0.019	0.38	2.64
3250	0.013	0.30	3.36
3500	0.010	0.23	4.29
4000	0.005	0.14	6.97
4500	0.003	0.09	11.34
5000	0.001	0.05	18.43
6000	0.000	0.02	48.71
7000	0.000	0.01	128.76
8000	0.000	0.00	340.33

Slope factor

The slope map was produced on the basis of the Digital Elevation Model of 30m spatial resolution (source: ASTER). The effect of slope on travel speed is estimated following Nelson's approach, which was based on van Wagtendonk and Benedict (1980)[14] and is computed as follows: **v = v0e-ks** , where:

v = off road foot based velocity over the sloping terrain,
v0 = the base speed of travel over flat terrain, 5km/hr in this case,
s = slope in gradient (metres per metre) and,
k = a factor which defines the effect of slope on travel speed

For the Nepali case study a base walking speed of 5km/hr and k = 2.0 were assumed (and constant for uphill and downhill travel). The velocities over the slope grid were computed and then converted into a friction factor by dividing the base speed by the slope speed. This was then used as a multiplier against foot-based travel components (map = **slope_fact**). The estimated effect of slope on off-road speed and on crossing time are shown in Table A5.3.

TABLE A5.3
Effect of slope on off-road speed and on crossing time

slope %	gradient meter per meter	crossing time factor	speed decrease factor
0	0	1.00	1.00
1	0.01	1.03	0.95
2	0.02	1.07	0.91
5	0.05	1.17	0.79
10	0.1	1.38	0.62
15	0.15	1.62	0.48
20	0.2	1.90	0.38
25	0.25	2.24	0.30
30	0.3	2.63	0.23
35	0.35	3.09	0.18
40	0.4	3.62	0.14
45	0.45	4.26	0.11
50	0.5	5.00	0.09
60	0.6	6.90	0.06
70	0.7	9.52	0.03
80	0.8	13.13	0.02
90	0.9	18.12	0.01
100	1	25.00	0.01
200	2	625.00	0.00

Cost-distance analysis

The cost feature is represented by the cell crossing friction (in minutes per km) resulting from the combination of the friction surface components described above, as follows:
cross_mkm (float) = " frict_all_mkm " * " slope_fact " * "elev_fact"

cross_mkm / 1000 = cros_m_m = (friction as minutes/meter)

Off-road travel time to nearest accessible feature resulting from cost-distance analysis (minutes):

Source: **target**; Cost: **cros_m_m** = **cd_min**

Results of travel time

The results of the analysis are presented in Figure A5.2 that shows the map of travel time to nearest accessible feature (hours of transport, return trip).

[14] van Wagtendonk, J. W. and Benedict, P. R. 1980. Travel time variation on backcountry trails. Journal of Leisure Research 12 (2): 99-106.

FIGURE A5.1

Friction and target features

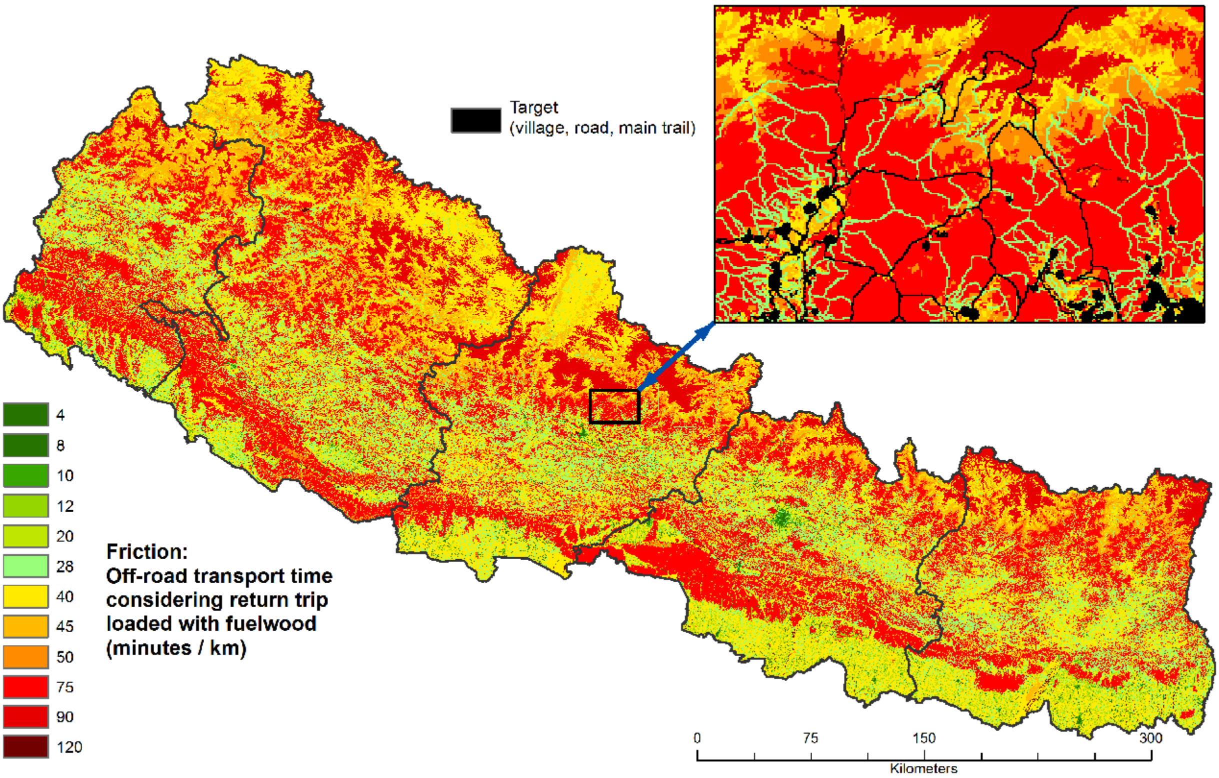
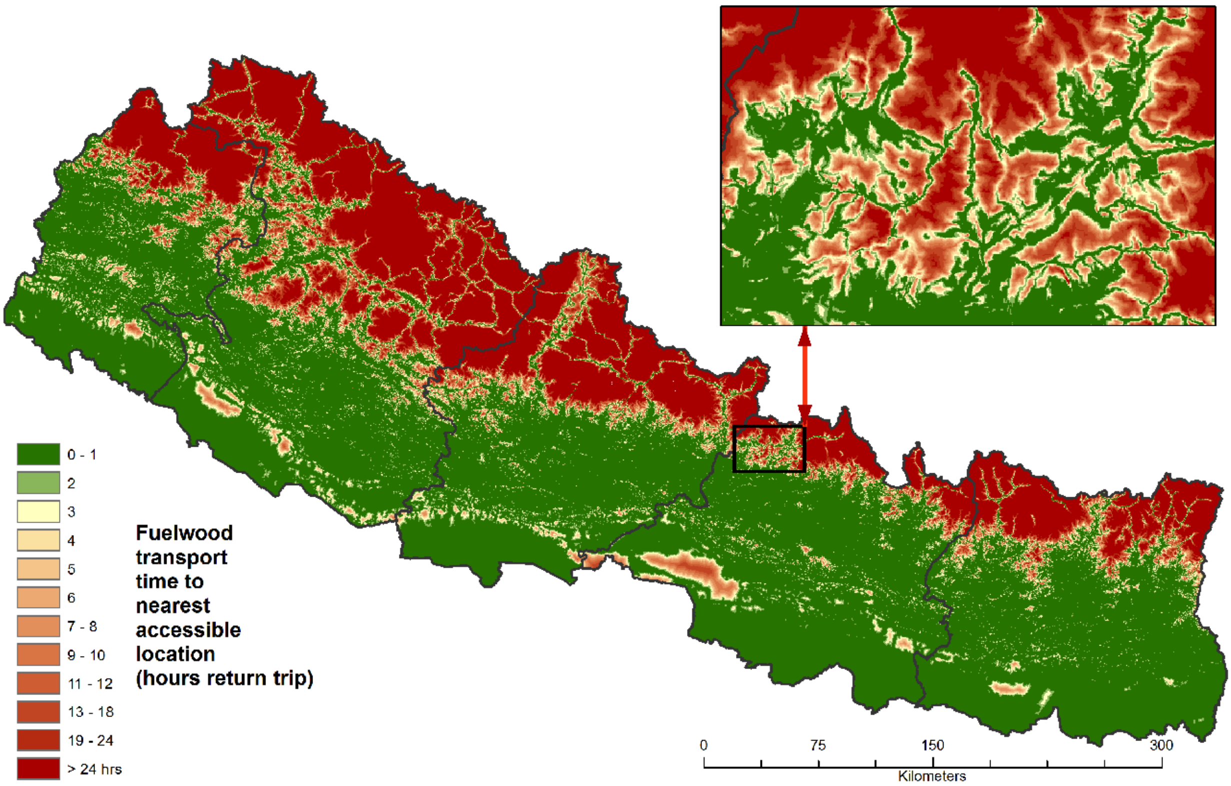


FIGURE A5.2

Fuelwood transport time map (hours from the nearest target feature)



Accessibility

The next fundamental step of analysis is to develop a map of accessibility based on the travel time map that help to assess what fraction of the existing (and legally accessible) DEB resources may be considered as truly accessible.

The conversion of travel time to percent of accessibility is based on the hypothesis that resources further than 10 hours off-road transport time to the nearest accessible feature are non accessible. Table A.5.4 presents the hypothesis of conversion of travel time into percent of accessibility applied, by which 84.1 % of all resources are physically accessible and 15.9 inaccessible.

TABLE A5.4

Hypotheses of accessibility factors to be applied to estimate DEB resources based on travel time (ref. cd_02_clip)

						Non-accessible MAI (%) :	**17.2**
						Accessible MAI (%) :	**82.8**
	Transport time from nearest target feature						accessible MAI
cd2_20	minutes	hours	work days	**MAI ktad**	access loss (%)	% accessible	k t ad
1	60	1	0.1	**15,788**	0	**100**	**15,788**
2	120	2	0.3	**2,037**	2	**98**	**1,996**
3	180	3	0.4	**1,173**	4	**94**	**1,102**
4	240	4	0.5	**788**	6	**88**	**693**
5	300	5	0.6	**599**	8	**80**	**479**
6	360	6	0.8	**482**	10	**70**	**338**
7	420	7	0.9	**402**	12	**58**	**233**
8	480	8	1.0	**344**	14	**44**	**151**
9	540	9	1.1	**301**	16	**28**	**84**
10	600	10	1.3	**259**	18	**10**	**26**
11	720	12	1.5	**422**	10	**0**	**-**
12	840	14	1.8	**341**	0	**0**	**-**
13	960	16	2.0	**275**	0	**0**	**-**
14	1,080	18	2.3	**229**	0	**0**	**-**
15	1,200	20	2.5	**196**	0	**0**	**-**
16	1,440	24	3.0	**318**	0	**0**	**-**
17	1,800	30	3.8	**348**	0	**0**	**-**
18	2,160	36	4.5	**242**	0	**0**	**-**
19	2,880	48	6.0	**296**	0	**0**	**-**
20	> 2,880	> 48	> 6	**380**	0	**0**	**-**
				25,219			**20,891**

ANNEX 6: NAMES AND DESCRIPTION OF MAIN MAPS

Raster maps of WISDOM analysis are projected at M UTM Central zone 84D with Datum Everest 1830 (single projection for whole country), with cell size/resolution of 100 m, unless otherwise specified.

Module/filename	Type	Description
		Cartographic base
Nepal_VDC_MUTM84	v	Map of VDC (and Municipalities) corresponding to Census 2011 admin structure
Districts_VDC	v	Districts derived from VDC map.
Dev_reg_VDC	v	Development regions derived from VDC map (most detailed).
physiography_MRV_Db	v	Physiographic zones of Nepal (from MRV_Database)
physio_dev_Marzoli	v	Dev regions (rough delineation !) and physiographic zones Map used by Marzoli
geo_region_MRV_Db	v	Broad grouping of Districts into Terai, Hill and Mountain. Used by CBS for HH survey stratifications (from MRV_Database)
physio	r	physiographic zones. Two nomenclatures are commonly applied for the physiographic zones, **Alternative nom.** / **Applied in this report** 1 HighMount / High Himalaya 2 MidMount / High Mountains 3 Hills / Mid Mountains 4 Siwaliks / Siwalikst 5 Terai / Terai
d_reg_physio	r	Combination of Development Region (first digit) and physiographic zone (last digit)
d_reg_phy_for		Combination of Development Region (first digit) and physiographic zone (last digit) WITHIN forest area (for lc_fra_00 =100) Con("lc_fra_00" == 100,"d_reg_physio",0)
d_r_phy_frf_i		**Combination of Development Region (first digit) and physiographic zone (last digit) WITHIN forest-remaining-forest according to ICIMOD forest maps 2000-2010.** **Used to produce degradation statistics for FRL reporting.** Note: forest class do not match DFRS land classes. Some ICIMOD FRF is outside DFRS forest and vice-versa **"d_reg_physio" * "FRFmsk_icimod"**
drphfrfi_reac		Reachable forest (FRF <100%slope) "d_r_phy_frf_i" * 10 + "slp_100pc"
drphfrfi_r_la		FRF with slope <100% outside protected areas (legally accessible for commercial harvesting) Con("legac_com" == 100,"drphfrfi_reac",0)
drp_frf_rla_7		FRF with slope <100% outside protected areas (legally accessible for commercial harvesting) by altitude classes "drphfrfi_r_la" * 100 + "aster_alt_7"
vdc_mutm	r	Map of VDC (and Municipalities). Map values correspond to the OBJECTID of map **Nepal_VDC_MUTM84.shp**
vdc_num	r	Map of VDC (and Municipalities). Map values correspond to the vdc_num field of map **Nepal_VDC_MUTM84.shp** For the relation with CBS admin codes see file **vdc_pop11_&_HH_demand.xls**
mutm_msk	**r**	**Mask of analysis based on vdc_mutm (value 1)**
mutm_msk0		0-mask
mutm_msk_exp1	r	Mask of analysis expanded of 1 cell. Used to clip rasters with larger cell size.
		Accessibility
		Physical accessibility
road_MRV_Db	v	Road network (from MRV_Database)
Road_2013	v	Detailed road network for the District of Sindhupalchowk. Example of currently updated road network produced by Road Dept.
		Slope
aster30_mutm	r30	DTM 30 m
slope30_100	r	Slope percent rise (100m res.) based on DTM 30 (aster30_mutm) Attention: small gaps on northern borders
aster100_rep		DTM 100m based on Aster30 (extended outside borders) Aster 30 m focalmean 3 rect. & resampled 100m & extended to allow slope mapping and data filling along borders

	Repaired for sink problems on Himalaya using Fill patch
aster_alt_7	Altitude stratified to 7 classes 1=0-500, 2=500-1000, 3=.. 1500, 4=..2000, 5=..2500, 6=..3000, 7= >3000
elev_fact2	**Elevation factor** Con("%aster100_rep%" > 2000,1 / (Power(0.132, 0.00048 * "%aster100_rep%") * 7),1)
slprep100_100	Slope percent rise (100m res.) based on DTM 100 slope_rd = slope (aster100_rep) with extended values beyond borders Clipping of slope_rd on mutm_msk
slp_100pc	reclass of slprep100_100 to 1 (<=100%) and 0 (>100%)
	Slope factor 5^(2 * ("slope100_100" / 100))
slope_fact2	= Power(5,2 * ("%slprep100_100%" / 100)) This operation introduces some NoData cells !!!
Trans_ln_ed ited v	Mosaic of 1996 topo maps transportation features. Original transportation categories "cleaned" for consistency and converted to 6 categories in "gridval" attribute. Priority for rasterization in "priority"
roads_topo (with map edges!! as footpaths) r roads_topo2	Roads and paths map from 1996 25k topo sheets (750 sheets !!) Raster of Trans_ln_edited on field "gridval" attribute. Priority for rasterization in "priority" Final transportation categories:

gridval	min/km	Description	
1	**2**	Metalled motorable road	
2	**4**	Secondary motorable road	
3	**6**	Cart track	These are mostly motorable now
4	**12**	Main trail	These are mostly motorable now
5	**12**	Footpath	
6	**4**	Railway	
7		Ropeway (not operational)	

	Target locations: **Urban areas and dense rural settlements**
built_8mn	Builtup area . 8 min/km assumed speed for return crossing
pop178_16mn	Dense rural areas (pop/km2 > 178). national avg density = 177.6. 16 min/km assumed speed for return crossing = "pop_f3mean" > 178
road4_mnts	(see table below)

code	min/km return trip
1	4
2	8
3	12
4	20

target	Mosaic of built_8mn; pop178_16mn; road4_mnts and clipped on on mutm_msk With min/km values
target0	Mosaic of built_8mn; pop178_16mn; road4_mnts and clipped on on mutm_msk With 0 value
	Friction
frict_min_km	Friction values calculated in **new_lc_icimod_traveltime_factors.xls** Friction values estimated by combination of new_lcover and gridcode and transferred to **nlc_gridcode** raster map through reclass using: recl_nlc_gridcode_frict_mkm.txt
frictminkmex	expanded to fill gaps
frict_minkm	Friction of land cover classes in minutes per km considering round trip (unloaded and loaded) map frictminkmex clipped on mutm_msk to fill in data gaps
fric_lc_slp	= frict_minkm * slope_fact2
road2_frict	Friction along road categories including footpaths.

	Assign friction values from file **new_lc_icimod_traveltime_factors.xls** through reclassify
road_frict_fl rd2_frict_fl	Create float version of roads friction = float(road2_frict)
fric_lcslp_rd	= mosaic (rd2_frict_fl ; fric_lc_slp) last
cross_mkm (float)	Float("fric_lcslp_rd " * "elev_fact2")
cross_m_m (float)	**Friction map showing crossing time as minutes per meter** **= cross_mkm / 1000**
	Cost distance
cd2_min_path	**cost distance (target0 ; cross_m_m)**
cd2_hr_i	Cost distance in hours (integer) = int(cd2_min_path / 60 + 0.5) This inserts NoData due to long numbers.
cd2_20	Segmentation of cd2_hr_i into 20 classes **(see file new_lc_icimod_traveltime_factors.xls)** NoData cells are reclassified to 20 (all in central himalaya region)
ph_acc01	Reclass of cd2_20 as in file **new_lc_icimod_traveltime_factors.xls**

Legal accessibility

Nat_parks_MRV_Db v	Map of protected areas of Nepal. Seems more detailed than WCMC-IUCN dataset. To be preferred to the latter for accessibility analysis. (from MRV_Database)
legac_loc_2 legac_com	Legacc **for local use** assumed 0% for Nat Parks and Wild Life Reserves (30% if located in High Mount and High Himalaya zones); 50% for Nature Conservation areas and Hunting Reserves and 100% for buffer zones. All protected areas (including buffer zones) are 0% accessible for commercial production of fuelwood (map expanded and clipped on mask to clean border areas) The legac maps are preliminary because the final delineation of buffer zones is still missing.!!

VALUE		legacc_com Million adt
1	FWDR	3.15
2	MWDR	5.00
3	WDR	2.97
4	CDR	3.93
5	EDR	3.49
		18.5

Demand Module

Population mapping

builtbuf50	Built up areas from topo map vector layer (built up only) expanded through buffer of 50m and rasterized to 100 m. 1 : builtup
	Revised procedure of pop mapping using builtup, buildings and trails
builtup1000	= builtbuf50 * 1000
Nepal_Builtup_points_in_84	Individual houses (points) from 1996 topo map mosaiced into single layer
buildings	Raster of Nepal_Builtup_points_in_84.shp (value: 1 to 32 : number of building points per pixel)
pz_builtup2	popzone "builtup" including topo data and Icimod settlements (value 1; 0)
pz_building2	popzone "buildings" (values 1 to 32)
pz_rd2 pz_rd2_farm	popzone "roads" (value 1) with addition of farmland for the VDC not covered by roads and building data
	See **vdc_pop11_&_demand_sector_2.xls**
mul_builtup2	recl_vdc_num_mul_pz_builtup2.txt
mul_building2	recl_vdc_num_mul_pz_building2.txt
mul_rd2_farm	recl_vdc_num_mul_pz_rd2_farm.txt
pop_builtup2	pop of builtup area (*100)

	= "mul_builtup2" * "pz_builtup2"
pop_building2	pop of building area (*100) = "mul_building2" * "pz_building2"
pop_rd2_farm	pop of roadside (and farm in gap areas) (*100) = "mul_rd2_farm" * "pz_rd2_farm"
pop2011x100	= "pop_rd2_farm" + "pop_building2" + "pop_builtup2"

Consumption mapping

pccons_adkg_3	Per capita fuelwood consumption (considering total population, i.e. users and non users) including HH, industrial and commercial sectors, cremation wood and construction material. See **vdc_pop11_&_demand_sector_2.xls** reclass(vdc_num; recl_vdc_num_pccons_adkg_3.txt)
cons_adkg_3	**fuelwood consumption (ad kg per pixel) including HH, industrial and commercial sectors, cremation wood and construction material.** **Int("pop2011x100" * "pccons_adkg_3" / 100 + 0.5)**

Revision of rural consumption in deficit areas

A distinction is made between the rural use of "conventional" fuelwood (solid wood pieces from stems and branches) and of "marginal" fuelwood (twigs produced through annual/ periodic pruning of trees and shrubs on farmlands). In rural areas where conventional fuelwood is not available (here considering an horizon of 6 km) the "marginal" fuelwood is assumed to replace conventional fuelwood (here considered to replace 50%).

rural_msk	Mask of rural areas (val 1) recl_vdc_num_rur_msk.txt
rural_cons	Rural consumption only = "cons_adkg_3" * "rural_msk"
rurcons_f60	For analysis of % fulfilled in rural areas focalmean (rural_cons, circle, 60, mean)
pc2rfulf6k_md	**Percent of rural consumption fulfilled within 6 km - Medium variant** **= Con("rurcons_f60" == 0, 0, Int("av2mai_md_f60" / "rurcons_f60" * 100 + 0.5))**
pc2rfulf6k_mn	**Percent of rural consumption fulfilled within 6 km - Minimum variant** **= Con("rurcons_f60" == 0, 0, Int("av2mai_mn_f60" / "rurcons_f60" * 100 + 0.5))**
pc2rfulf6k_mx	**Percent of rural consumption fulfilled within 6 km - Maximum variant** **= Con("rurcons_f60" == 0, 0, Int("av2mai_mx_f60" / "rurcons_f60" * 100 + 0.5))**
cons_rev2_mn	"Conventional" Fuelwood consumption (ad kg per pixel) - Minimum variant including HH, industrial and commercial sectors, cremation wood and construction material Revised for rural areas in consideration of probable use of "marginal" fuelwood (twigs and annual pruning of farm trees and shrubs) to fill 1/2 of the gap estimated within a 6km horizon. Con("rural_msk" == 0,"cons_adkg_3",Con("pc2rfulf6k_mn" > 80,"cons_adkg_3", "cons_adkg_3" - "cons_adkg_3" * (100 - "pc2rfulf6k_mn") / 200))
cons_rev2_md	**"Conventional" Fuelwood consumption (ad kg per pixel) - Medium variant** **including HH, industrial and commercial sectors, cremation wood and construction material Revised for rural areas in consideration of probable use of "marginal" fuelwood (twigs and annual pruning of farm trees and shrubs) to fill 1/2 of the gap estimated within a 6km horizon.** Con("rural_msk" == 0,"cons_adkg_3",Con("**pc2rfulf6k_md**" > 80,"cons_adkg_3", "cons_adkg_3" - "cons_adkg_3" * (100 - "**pc2rfulf6k_md**") / 200))
cons_rev2_mx	"Conventional" Fuelwood consumption (ad kg per pixel) - Minimum variant including HH, industrial and commercial sectors, cremation wood and construction material Revised for rural areas in consideration of probable use of "marginal" fuelwood (twigs and annual pruning of farm trees and shrubs) to fill 1/2 of the gap estimated within a 6km horizon. Con("rural_msk" == 0,"cons_adkg_3",Con("pc2rfulf6k_mx" > 80,"cons_adkg_3", "cons_adkg_3" - "cons_adkg_3" * (100 - "pc2rfulf6k_mx") / 200))
c_rev2_md_3km	Local Demand a harvesting horizon of 3km – Conventional demand – Medium variant = focalmean(cons_rev2_md; 20 + 10; circle; mean) and clipped on mutm_msk
sus_l_h_r2md	Sustainable local harvesting (harvesting that matches local supply potential "c_rev2_md_3km" + "l_def22_md"

Supply Module

Land Cover

FRA_Nepal_LC.gdb	Original file presented topology errors that prevented the conversion to raster and other GIS processing. The vector file was cleaned by repair geometry (same map name was kept)
fra_lc_wgs	The repaired file wgs84 vector map was rasterized on field “Class_Re” (0.0009, 0.0009 DD)
fra_lc_mutm95	Raster map fra_lc_wgs was projected to M UTM Central zone 84D with Datum Everest 1830 (cell size 95m)
fra_lc_mutm00	Raster fra_lc_mutm95 was resampled to 100m and snapped to mutm_msk. The resulting map presented few gata gaps (nodata) and slight differences along the borders due to projection (maximum gaps 1 cell thick)
fra_lc_clip	Data gaps and border inconsistencies were filled in through Model “expand_mosaic_clip”. The map presents several class inconsistencies due to bad edge matching between data tiles and other unknown problems met during the creation of the first vector dataset. These cannot be corrected at this stage. Major problematic portions to be replaced by mosaicing these areas with other land cover data !!
fra_lc	Portions of the ICIMOD map lc2010_mutm.tif were used to replace small areas that presented evident classification errors. The areas were reviewed in detail using google earth. The portions of lc2010_mutm.tif were reclassified to match fra_lc_clip classes and mosaiced over the problematic areas. The replaced portions covered two areas in High Himalaya for a total area of 344 km^2.
lc_fra	Final version of FRA Land Cover map (MUTM, 100m). Matching mutm_msk Values: 1 Forest 2 Other Wooded Land 3 Other Lands 4 Shrubs
lc_fra_00	Reclass of lc_fra, merging OWL and Shrubs that are not meaningfully distinguished Reclass: 1 Forest 100 2 Other Wooded Land 200 3 Other Lands 300 4 Shrubs 200
forest_msk	Forest mask derived from lc_fra (class 1 only)

forest_msk

Forest Type

final.tif	Map of forest types received by DFRS. Based on work of Shiva Khanal using Landsat data 2013-2014. Projection WGS_84_UTM_zone_44N. 30m resolution. Note: Forest types (ft) are defined for the “forest” class of the land cover dataset (above). However, the map presents data gaps within the lc forest class for 10% of the forest area, as well as forest types outside the forest class.
ft_wgs84	Projection of final.tif to GCS wgs 1984
ft_30m_mutm	Projection of ft_wgs84 to MUTM, keeping the original resolution
ft_100m_mutm	Resampling of ft_30m_mutm to 100m snapped to fra_lc (and all other WISDOM data layers).
forest_type	Reviewed version of ft_100m_mutm, exactly matching fra_for_msk area. The process of eliminating ft outside the forest (ref. fra_for_msk) and filling in data gaps based on existing neighboring ft values included numerous progressive focal-statistics, mosaicing and clipping processes (see Model builder “expand_mosaic_clip_ft”. The final version of the process being ft11_in_f_msk, then clipped on forest mask from lc_fra

VALUE	pixel_ha	name_short	NAME
1	1,455,272	TMH	Tropical Mixed Hardwood
2	900,798	S	Sal
4	1,025,268	LMH	Lower Mixed Hardwood
5	1,108,412	UMH	Upper Mixed Hardwood
6	499,610	Pr	Pinus roxburghii
7	74,113	KS/SK	Acacia catechu & Dalbergia sisso
8	213,502	Pw	Pinus wallichiana
9	449,117	Q	Quercus
10	5,982	Jw	Juglans wallichiana
11	18,575	Td	Tsuga dumosa
12	110,221	A	Abies spectabilis & Abies pindrow
13	20,164	Ct	Cupressus torulosa
15	27,228	Ce	Cedrus deodara
16	41,190	Bu	Betula utilis
17	20,673	Sp	Picea smithiana
	5,970,125		

ft_groups

Aggregations of forest types in order to have a meaningful number of field plots

VALUE	name_short	NAME	G_val	Group
1	TMH	Tropical Mixed Hardwood	1	Tropical Mixed Hardwood
2	S	Sal	2	Sal
4	LMH	Lower Mixed Hardwood	3	Lower Mixed Hardwood
5	UMH	Upper Mixed Hardwood	6	Mixed high broadleaves

6	Pr	Pinus roxburghii	4	Pinus roxburghii
7	KS/SK	Acacia catechu & Dalbergia sisso	6	Mixed high broadleaves
8	Pw	Pinus wallichiana	7	Mixed high conifers
9	Q	Quercus	5	Quercus
10	Jw	Juglans wallichiana	6	Mixed high broadleaves
11	Td	Tsuga dumosa	7	Mixed high conifers
12	A	Abies spectabilis & Abies pindrow	7	Mixed high conifers
13	Ct	Cupressus torulosa	7	Mixed high conifers
15	Ce	Cedrus deodara	7	Mixed high conifers
16	Bu	Betula utilis	6	Mixed high broadleaves
17	Sp	Picea smithiana	7	Mixed high conifers

fg_00	lc_fra_00 and ft_groups Con("ft_groups","lc_fra_00" + "ft_groups","lc_fra_00")
lc00_fg	Land cover with forest type groups. Mosaic fg_00 on lc_fra_00 The class Other land (300) is too big to be represented by OL samples. In mountain areas all unproductive areas must be removed from OL class.
lc_fg	Land cover with forest strata groups within forest area. Class 390 represents the unproductive part (i.e. 0 stock in WISDOM 2013 map debadkg) of Other land in Physiographic classes 1 and 2 (High and Medium Mountain)
lc_fg_dr_phys	Combination of land cover, forest types, development regions and physiographic zones "lc_fg" * 10000 + "d_reg_physio"

Georeferenced field plot data

all_pnts_mutm

Mutm version of the point maps of Forest, OWL and OL plots provided by DFRS. To be noted that these plots were defined as “forest”, “Other Wooded Land” or “Other Land” during field work, not from the land cover map, which was completed at a later stage.
Original map attributes associated to the points included:

S_N_forest	= sample plot number of Forest plots
S_N_owl	= sample plot number of OWL plots
S_N_oth_l	= sample plot number of OL plots (separate serial numbers)
UTM (easting; northing) and geographic (lon; lat in DD) coordinates	
stem_ha	= Number of trees >=5cm DBH
Stem_adt	= Stem biomass of trees >=5cm DBH (air-dry t /ha)
Bran_adtha	= Branch biomass of trees >=5cm DBH (air-dry t /ha)
Fol_adtha	= Foliage biomass of trees >=5cm DBH (air-dry t /ha)

Attributes of Forest plots previously provided by DFRS:

physiog	= Phisiographic zones
cc_pc	= Crown cover percent estimated from the field

Calculated attributes:
agb_adtha = aboveground biomass of trees >=5cm DBH (air-dry t /ha)
= [Stem_adt + Bran_adtha + Fol_adtha]
deb_adtha = Dendroenergy biomass (DEB) of trees >=5cm DBH (air-dry t /ha). Derived from total aboveground biomass <minus> foliage (given) and stump (assumed as 3.9% of agb)
= [agb_adt] *(1-0.039)- [Fol_adtha]
FRA_lc = Land cover class taken from fra_nepal_LC

physiog = Physiographic zone from

Forest Type values and FT groupings ere derived for each plot falling within FRA_lc “Forest” from ft maps.
Elaboration of DEB statistics by strata and definition of strata is done in file **all_pnts.xlsx**

The definition of meaningful strata was based on the combination of land cover, forest type groups, development regions and physiographic zones presenting an adequate number of field plots and significantly different DEB values.
26 strata were defined (plus stratum 0, unproductive).
For Strata definition, mean deb adtha and 95% confidence intervals see file **all_pnts.xlsx**

strat_26	Map of final strata for DEB mapping. 26 productive strata and stratum 0, unproductive areas. See file **stk_MAI_01.xlsx** for lc_fg_dr_phys details and reclassification. Reclass file: \WISDOM_Nepal_update_2016\gis\supply**recl_lc_fg_dr_phys_strat26.txt**
tc2010_230m	
tc2010_100m tc2010_100m0	class 200 (water bodies) converted to 0 Con("tc2010_100m" == 200,0,"tc2010_100m")
tc2010_100mf1	

tc2010_f1int	Int("tc2010_100mf1" + 0.5)
tc2010	"tc2010_f1int" * "mutm_msk"
m_tc_stkmn **m_tc_stkmd** m_tc_stkmx	Multipliers of tc2010 to obtain minimum, medium and maximum deb stock maps. Multiplier values are based on mean deb stock (in adkg) and mean tree cover for each stratum. See file all_pnts.xisx Multiplier reclass files: recl_strat_26_m_tc_stkmn.txt **recl_strat_26_m_tc_stkmd.txt** recl_strat_26_m_tc_stkmx.txt
stkadkg_mn	DEB stock in adkg. - Minimum strata values (mean minus 95% confidence interval) Float("m_tc_stkmn" * "tc2010")
stkadkg_md	**DEB stock in adkg. - Mean value** **Float("m_tc_stkmd" * "tc2010")**
stkadkg_mx	DEB stock in adkg. – Maximum strata values (mean plus 95% confidence interval) Float("m_tc_stkmx" * "tc2010")
stk_mn_3km	FocalMean(stkadkg_mn, circle, 20+10, mean)
stk_md_3km	**FocalMean(**stkadkg_md**, circle, 20+10, mean)**
stk_mx_3km	FocalMean(stkadkg_mx, circle, 20+10, mean)
	Maps of physically and legally accessible stock used to estimate degradation rates as % of (accessible) stock
ac_stk_mn	Accessible stock – Minimum variant ("stkadkg_mn" * "ph_acc01" * "legac_com") / 10000
ac_stk_md	**Accessible stock – Medium variant** **("stkadkg_md" * "ph_acc01" * "legac_com") / 10000**
ac_stk_mx	Accessible stock – Maximum variant ("stkadkg_mx" * "ph_acc01" * "legac_com") / 10000
	DEB MAI of ALL land cover classes in odkg/cell(ha)/year Equation for coniferous forests (forest type groups 4 and 7) **y =22.683 x^-0.5069** [y= DEB MAI as % of DEB stock ; x= DEB stock in t od / ha] equation for all other formations **y =37.058 x^-0.5879** [y= DEB MAI as % of DEB stock ; x= DEB stock in t od / ha]
mai_mn	MAI (adkg/ha/yr) - Minimum stock variant: Con("stkadkg_mn" > 0,Con("broad_conif" == 2,((Power(("stkadkg_mn" / 1000), -0.5069) * 22.683) * "stkadkg_mn" / 100),((Power(("stkadkg_mn" / 1000), -0.5879) * 37.058) * "stkadkg_mn" / 100)),0)
mai_md	**MAI (adkg/ha/yr)** - **Medium stock variant:** Con("stkadkg_md" > 0,Con("broad_conif" == 2,((Power(("stkadkg_md" / 1000), -0.5069) * 22.683) * "stkadkg_md" / 100),((Power(("stkadkg_md" / 1000), -0.5879) * 37.058) * "stkadkg_md" / 100)),0)
mai_mx	MAI (adkg/ha/yr) - Maximum stock variant: Con("stkadkg_mx" > 0,Con("broad_conif" == 2,((Power(("stkadkg_mx" / 1000), -0.5069) * 22.683) * "stkadkg_mx" / 100),((Power(("stkadkg_mx" / 1000), -0.5879) * 37.058) * "stkadkg_mx" / 100)),0)
phacmai_mn	Physically accessible MAI - Minimum variant Int("mai_mn" * "ph_acc01" / 100 + 0.5)
phacmai_md	**Physically accessible MAI – Medium variant**

	Int("mai_md" * "ph_acc01" / 100 + 0.5)
phacmai_mx	Physically accessible MAI - Maximum variant Int("mai_mx" * "ph_acc01" / 100 + 0.5)
acmai_mn	Physically and legally accessible MAI for local consumption - Minimum variant = Int("phacmai_mn" * "legac_loc" / 100 + 0.5)
acmai_md	**Physically and legally accessible MAI for local consumption – Medium variant** **= Int("phacmai_md" * "legac_loc" / 100 + 0.5)**
acmai_mx	Physically and legally accessible MAI for local consumption - Maximum variant = Int("phacmai_mx" * "legac_loc" / 100 + 0.5)
	Deduction of industrial roundwood production
	The timber production (based on REDD 2012 report) is deducted from the accessible resources in order to obtain the "available" resources. Deduction is done on all wood resources as indicated in the REDD 2012 report, applying rfeduction factors to the accessible MAI of Terai, Hills and Mountain Districts.
av2mai_mn	Availabe (and accessible) MAI - Minimum variant Int("acmai_mn" * "av_factor_mn" / 1000 + 0.5)
av2mai_md	**Availabe (and accessible) MAI** – Medium variant **Int("acmai_md" * "av_factor" / 1000 + 0.5)**
av2mai_mx	Availabe (and accessible) MAI - Maximum variant Int("acmai_mx" * "av_factor_mx" / 1000 + 0.5)
av2mai_md_f60	**For analysis of % fulfilled in rural areas - Medium variant** **focalmean (av2mai_md, circle, 60, mean)**
av2mai_mn_f60	For analysis of % fulfilled in rural areas - Medium variant focalmean (av2mai_mn, circle, 60, mean)
av2mai_mx_f60	For analysis of % fulfilled in rural areas - Medium variant focalmean (av2mai_mx, circle, 60, mean)
	Average stock and MAI of forest areas by dev regions and physio zones for the estimation of LCC by-products
stk_mn_for	= "stkadkg_mn" * "fra_for_msk" Mean stock of forest areas: zst_d_reg_physio_stk_mn_for.dbf
stk_md_for	**= stkadkg_md * fra_for_msk** **Mean stock of forest areas:** **zst_d_reg_physio_stk_md_for.dbf**
stk_mx_for	= "stkadkg_mx" * "fra_for_msk" Mean stock of forest areas: zst_d_reg_physio_stk_mx_for.dbf
mai_mn_forest	= mai_mn * fra_for_msk Mean MAI of forest areas: zst_d_reg_physio_mai_mn_forest.dbf
mai_md_forest	= mai_md * fra_for_msk Mean MAI of forest areas: zst_d_reg_physio_mai_md_forest.dbf
mai_mx_forest	= mai_mx * fra_for_msk Mean MAI of forest areas: zst_d_reg_physio_mai_mx_forest.dbf
h12h_msk	Mask of harvesting zone, combining woodshed 12h (wcd2_hours <= 12) and local harvesting areas (cons_adkg_3; focal 3km: cons_3_3km; cons_3_3kmmsk)

	Con("wcd2_12h_msk" + "cons_3_3kmmsk" == 0,0,1)
har_d_r_phys	Combination of d_reg_physio codes and harvesting region, used to extract Hansen LCC within the harvesting zones, that may be considered accessible to users "d_reg_physio" * "h12h_msk"
	Integration Module
	Cell-level balance
bal12_mn	Cell-level balance - Minimum variant = "avmai2_mn" - "cons_adkg_3"
bal22_md	**Cell-level balance considering revised demand (excluding marginal woody biomass used in rural Terai) - Medium variant** **= "avmai2_md" - "cons_rev_md"**
bal22_mx	Cell-level balance considering revised demand (excluding marginal woody biomass used in rural Terai) - Maximum variant = "avmai2_mx" - "cons_rev_mx"
	Local-level balance
	Assuming a harvesting horizon of 3 km
l_bal12_mn	Local balance assuming a harvesting horizon of 3km – Total demand – Minimum variant = focalmean(bal12_mn; 20 + 10; circle; mean) and clipped on mutm_msk
l_bal22_md	**Local balance assuming a harvesting horizon of 3km – Conventional demand – Medium variant** **= focalmean(bal22_md; 20 + 10; circle; mean) and clipped on mutm_msk**
l_bal22_mx	Local balance assuming a harvesting horizon of 3km – Conventional demand – Maximum variant = focalmean(bal22_mx; 20 + 10; circle; mean) and clipped on mutm_msk
	Commercial balance
	Commmercial balance – Total demand
combal12_mn	Model (combal1_mn) for Commmercial balance – Total demand – Minimum variant : 1: Combal_tmp1 = Con("l_bal12_mn" < 500, Con("l_bal12_mn" >=0,0, "l_bal12_mn"), "l_bal12_mn") 2: Combal_tmp2 = Con("Combal_tmp1">0, Con("stkadkg_mn" > 14660, "Combal_tmp1",0), "Combal_tmp1") 3: combal1_mn = Con("Combal_tmp2">0, Con("legac_com" == 0,0,"Combal_tmp2"),"Combal_tmp2")
	Commmercial balance – Conventional demand
combal2_md	**Model (combal_md) for Commmercial balance – Conventional demand – Medium variant** : 1: Combal_tmp1 = Con("l_bal22_md" < 500, Con("l_bal22_md" >=0,0, "l_bal22_md"), "l_bal22_md") 2: Combal_tmp2 = Con("Combal_tmp1">0, Con("stkadkg_md" > 14660, "Combal_tmp1",0), "Combal_tmp1") 3: combal_md = Con("Combal_tmp2">0, Con("legac_com" == 0,0,"Combal_tmp2"),"Combal_tmp2")
combal22_mx	Model for Commmercial balance – Conventional demand – Maximum variant : 1: Combal_tmp1 = Con("l_bal22_mx" < 500, Con("l_bal22_mx" >=0,0, "l_bal22_mx"), "l_bal22_mx") 2: Combal_tmp2 = Con("Combal_tmp1">0, Con("stkadkg_mx" > 14660, "Combal_tmp1",0), "Combal_tmp1") 3: combal_mx = Con("Combal_tmp2">0, Con("legac_com" == 0,0,"Combal_tmp2"),"Combal_tmp2")
	Woodshed analysis
	Local deficit and peak deficit locations
	Note: The analysis of peak deficit location and the following steps leading to the pressure map were based on preliminary balance results. This analysis was not re-run after the last data revision because their change on the pressure distribution was considered irrelevant.
l_def1_mn	**Local deficit - Total demand – Minimum Supply variant** = Con("l_bal1_mn" <= 0,"l_bal1_mn",0)

def1mn_20km	Major deficit areas SUMMARIZING the deficit within a 20 km radius - Conventional demand – Minimum variant =focalSUM ("l_def1_mn", circle, 200)
l_def2_md	**Local deficit - Conventional demand – Medium variant** **= Con("l_bal2_md" <= 0,"l_bal2_md",0)**
def2md_20km	**Major deficit areas SUMMARIZING the deficit within a 20 km radius - Conventional demand – Medium variant** **focalSUM ("l_def2_md", circle, 200)**
l_def2_mx	Local deficit - Conventional demand – Maximum variant = Con("l_bal2_mx" <= 0,"l_bal2_mx",0)
def2mx_20km	Major deficit areas SUMMARIZING the deficit within a 20 km radius - Conventional demand – Maximum variant =focalSUM ("l_def2_mx", circle, 200)
pnts_def1sum20km_mn.shp	**Peak deficit locations - Total demand – Minimum Supply variant** Points with cumulative deficit in Nepal estimated on a 20 km radius Create point map placing points on peak deficit locations (based on 20km deficit map) Assign deficit value to the points from def1mn_20km**, def1md_20km,** def1mx_20km and define PointID code
pnts_defsum20km_md.shp pnts_defsum20km_mx.shp	**Peak deficit locations - Conventional demand** Points with cumulative deficit in Nepal estimated on a 20 km radius Create point map placing points on peak deficit locations (based on 20km deficit map) Assign deficit value to the points from **def2md_20km,** def2mx_20km and define PointID code
	Mapping commercial harvesting pressure based on Dinamica EGO
cross_m_m.tif	**Friction map** = Export cross_m_m in tiff format
pnt_id.tif	**Categorical map** With ID of major deficit points map extent to matching that of cross_m_m.tif = PointToRaster Pnts_20kmdefisum.shp; pnt_ID; MOST_FREQUENT; NONE; snap to cross_m_m.tif
	Lookup Tables With ID points (fieldname: key) and deficit values (fieldname: value; positive)
id_def2_md.csv	**Values from pnts_defsum20km_md.shp**
id_def2_mx.csv	Values from pnts_defsum20km_mx.shp
	wcd_def1_prec2_mn.egoml : **(Total Demand)**
wcd_def1_mn.tif	Precision 2 (2 iterations) **Final cumulative map of all individual points interpolation maps (weighted cost distance)** cost##.tif : Individual point interpolation map (temporary, not saved on disk) sumcost##.tif : Progressively cumulative maps of individual points interpolation maps (temporary, saved on disk in folder **Woodshed_update\wcd1_mn**) . Last map= sumcost**.tif
wcd_def1_mnf1.tif	focalmean (circle, 1) to fill the NoData at point position
wcd_def1_mn	Final grid version of weighted cost distance maps with gaps at point locations filled in and clipped on mutm_msk
wcd_d1_mn_c2	**Weight to be used to distribute pressure on surplus resources** Segmentation of **wcd_def1_mn** into 175 classes reflecting the weighted cost distance values (weighted on wcd values See segmentation in **reclass_x_weighted_segmentation_02.xlsx** recl_wcd_value_w_cat_02.txt
	wcd_def2_prec2_m*(d,x)**.egoml :** **(Conventional Demand)**
wcd_def2_md.tif	Precision 2 (2 iterations)

wcd_def2_mx.tif	**Final cumulative map of all individual points interpolation maps (weighted cost distance)** cost##.tif : Individual point interpolation map (temporary, not saved on disk) sumcost##.tif : Progressively cumulative maps of individual points interpolation maps (temporary, saved on disk in folder **Woodshed_update\wcd2_m* (d,x)**) . Last map= sumcost**.tif
wcd_def2_mdf1.tif wcd_def2_mxf1.tif	focalmean (circle, 1) to fill the NoData at point position
wcd_def2_md wcd_def2_mx	**Final grid version of weighted cost distance maps with gaps at point locations filled in and clipped on mutm_msk**
wcd_d2_md_c2 wcd_d2_mx_c2	**Weight to be used to distribute pressure on surplus resources** Segmentation of **wcd_def2_m*(d,x)** into 175 classes reflecting the weighted cost distance values (weighted on wcd values) See segmentation in **reclass_x_weighted_segmentation_02.xlsx** recl_wcd_value_w_cat_02.txt

	Travel time from major deficit sites
time_wcd2_pnt	Transport time (going and back) from major deficit points. Values in minutes cost distance (deficit points; cross_m_m)
wcd2_hours	Transport time (going and back) from major deficit points of wcd02 woodshed. Values in hours Reclass(time_wcd2_pnt using symbology)
h12h_msk	Mask of harvesting zone, combining woodshed 12h (wcd2_hours <= 12) and local harvesting areas (cons_adkg_3; focal 3km: cons_3_3km; cons_3_3kmmsk) Con("wcd2_12h_msk" + "cons_3_3kmmsk" == 0,0,1)

Assumptions and variants for woodshed analysis

Supply variants

- Minimum = Average DEB stock and MAI values <minus> 95% confidence interval (based on NFI results for the 26 strata)
- **Medium** = Average DEB stock and MAI values (based on NFI results for the 26 strata)
- Maximum = Average DEB stock and MAI values <plus> 95% confidence interval (based on NFI results for the 26 strata)

Demand variants

- **A - Total demand** = total conventional and marginal fuelwood consumption, including HH, industrial and commercial sectors, cremation wood and construction material.
- **B - Conventional demand** = Total demand <minus> the consumption of "marginal" fuelwood in wood-scarce rural deficit areas of Terai, which is assumed to fill 1/2 of the gap within a 6km horizon.

Market variants

- **FM - Full Market** = all conditions of local deficit, including urban and rural areas, originate commercial harvesting of distant resources. Under the "Full Market" scenarios, we assume that demand in rural deficit sites, like urban sites, is met by commercial harvesting rather than overexploitation of rural resources. This assumption shifts pressure toward accessible forest resources and other areas with surplus biomass**.**
- **PM - Partial Market** = the "Partial Market" scenario, we assume that urban demand is satisfied by commercial harvesting, but demand in rural deficit sites is met by a combination of local overexploitation and commercial supplies. Lacking specific data, we assume these two sources contribute equally to meeting local rural demand so that half of the excess demand is met by overexploitation of local rural biomass resources and half is met by commercial harvesting. This assumption reduces commercial harvesting pressure in comparison to the Full Market scenario and increases the overexploitation of woody biomass in farmlands and woodlands close to sources of rural demand.

Commercial Woodshed delineation

- **8 hrs = Commercial harvesting is limited to 8 hours transport time from major demand sites**
- **12 hrs = Commercial harvesting is limited to 12 hours transport time from major demand sites**
- Note: The commercial woodshed is determined by transport time considerations. The "nominal" sustainable supply zone is not used to delimit the commercial woodshed

Use of LCC by-products

Using as reference the ICIMOD LCC study (2000-2010), the annual byproducts becoming available represent 10% of the demand. With reference to Hansen et al., they represent 4% of the demand. In several areas LCC byproduct are likely to have a significant impact on direct woodfuel harvesting. While the ICIMOD change map is being evaluated, the Hansen dataset is used as reference. Two scenarios are considered:

- **LCC by-products are NOT used as fuel (N)**. All fuelwood is procured through direct harvesting.
- **LCC by-products are FULLY used as fuel (L).** LCC by-products from sites located within the harvesting zone (either within the commercial woodshed or within the local harvesting horizon =

h12h_msk) are used as woodfuel. The fraction of LCC by-products available/used as fuel is assumed to be 70% of the total amount..

Harvesting system assuming a sub-optimal resource management

- "FAO hypothesis" based on the fraction of Nepal forests under management plans (41%) and assuming that there is a spontaneous management of resources (harvesting is more convenient in non exploited areas than in recently exploited ones). Tentatively, **the Sustainable Increment Exploitation Factor (SIEF) for Nepal is assumed as 0.8** (i.e. 20 % of the annual increment remains unexploited, which means that in areas of limited resources a corresponding fraction of the harvested wood is unsustainable).

1 – Leading Scenario

Scenario B Md N PM 8h

assumptions:
Conventional demand(A) – Medium Supply variant (md) – Partial Market (PM 30pc) - Woodshed 8 Hours (8h) - Intermediate use of LCCbp (N)
Folder: Scen_B_Md_PM

lh_22md_8h	**Rural and minor urban deficit generating unsustainable local harvesting** 1/2 of the local rural deficit (within the 8hr zone) remains on site as unsustainable local harvesting up to a maximum of 30% of the local stock, while the rest of the deficit generates commercial harvesting. Outside the 8hr zone, the deficit remains entirely on site as unsustainable harvesting Con("l_bal22_md" < 0,Con("wcd2_hours" <= 8,Con("rural_msk" == 1,Con(- "l_bal22_md" / 2 <= ("stk_md_3km" * 0.3),"l_bal22_md" / 2,-("stk_md_3km" * 0.3)),0),"l_bal22_md"),0) zst_d_reg_physio_lh_22md_8h.dbf = **-962,701,083 odkg**
c_def22_md_8h	Commercial deficit including total urban deficit and the fraction of the rural deficit within 8 hours (transport time) from major deficit sites that is not harvested locally. Con("wcd2_hours" <= 8,Con("combal2_md" < 0,"combal2_md" - "lh_22md_8h",0),0) zst_d_reg_physio_c_def22_md_8h.dbf Tot commercial deficit: **-1,868,253.683 odkg**
wcsur22_md_8h	Creation of the weighted surplus value (surplus * pressure level) within the woodshed zone of 8-hours around major deficit points for the distribution of the commercial deficit as harvesting . Con("wcd2_hours" <= 8, Con("combal2_md" > 0,"combal2_md" * "wcd_d2_md_c2",0),0) zst_mutm_msk_wcsur22_md_8h.dbf total weighted surplus : **227,496,001,536**
ch22_md_8hpm	Commercial harvesting by pixel : tot deficit (sum c_def22_md_8h) 1868250000 / total weighted surplus (sum wcsur22_md_8h) 189539000000 = 0.00985681 (multiplier of wcsur22_md_8h) "wcsur2_md_8h" * 0.00985681
h_22md8h	Total harvesting, including: • sustainable local harvesting (sus_l_h_r2md) • Rural and minor urban deficit generating unsustainable local harvesting (lh_22md_8h) • Commercial harvesting (ch22_md_8hpm) "sus_l_h_r2md" + "ch22_md_8hpm" - "lh_22md_8h"
chs22md8h80pm	Commercial harvesting sustainability assuming a **SIEF of 0.8** Con("ch22_md_8hpm" > 0,"combal2_md" * 0.8 - "ch22_md_8hpm",0)
nrch22md8h80p	Non-Renewable commercial harvesting within 8 hrs from major deficit sites assuming a SIEF of 0.8 Unsustainable fuelwood extraction in od kg. = measure of (forest) degradation Con("chs22md8h80pm"<0, "chs22md8h80pm",0) zst_d_reg_physio_nrch22md8h80p.dbf = **-177,543,938 adkg**
tnrh22md8h80p	TOTAL Non-renewable harvesting merging unsustainable local harvesting (**lh_2md_8h**) and unsustainable commercial harvesting (**nrch2md8h80p)** "nrch22md8h80p" + "lh_22md_8h" (both negatives) zst_d_reg_physio_tnrh22md8h80p**.dbf = -1,140,245,504 adkg**
b2mdpm8h_rank	Ranking of degradation areas Con("tnrh22md8h80p" < 0,Con("tnrh22md8h80p" < - 100,Con("tnrh22md8h80p" < - 500,3,2),1),0)
dprnk_b2md8pm	Degradation risk ranking by Dev Region, Physiographic zone "d_reg_physio" * 100 + "b2mdpm8h_rank"
rnkfrf_b2md8p	Degradation risk ranking in FRF by Dev Region, Physiographic zone "dprnk_b2md8pm" * "frf_msk"

	Harvesting, harvesting sustainability and degradation from direct harvesting AFTER use of 35% of LCC by-products – Leading scenario
	LCC by-products becoming available from land cover change (LCC), LCCbp potentially available as fuel and assumed LCCbp used as fuel in substitution to direct harvesting See data in **LCCbyproducts_FRL_ForestChangeArea.xlsx**
dh_red_fact01	Direct harvesting reduction factor by d_reg_physio: recl_d_reg_physio_harv_fac_01.txt
d_h_22md8h	Direct harvesting after use of LCCbp "h_22md8h" * "dh_red_fact01" / 1000
suslh_r2md_r1	Reduced sustainable harvesting (already sustainable, hence not relevant for degradation estimate) "sus_l_h_r2md" * "dh_red_fact01" / 1000 demand_update\suslh_r2md_r1
lh_22md_8h_r1	Reduced Rural and minor urban deficit generating unsustainable local harvesting after use of FRL LCCbp "lh_22md_8h" * "dh_red_fact01" / 1000 \Scen_B_Md_PM\ lh_22md_8h_r1
ch22md8hpm_r1	Reduced Commercial harvesting after use of FRL LCCbp (ch22_md_8hpm) "ch22_md_8hpm" * "dh_red_fact01" / 1000 \Scen_B_Md_PM\ch22md8hpm_r1
chs22md8h_r1	Commercial harvesting sustainability after use of FRL LCCbp assuming a **SIEF of 0.8** Con("ch22md8hpm_r1" > 0,"combal2_md" * 0.8 - "ch22md8hpm_r1",0)
nrch22md8h_r1	Non-Renewable commercial harvesting within 8 hrs from major deficit sites assuming a SIEF of 0.8 Unsustainable fuelwood extraction after use of FRL LCCbp in od kg. = measure of (forest) degradation Con("chs22md8h_r1"<0, "chs22md8h_r1",0) zst_d_reg_physio_nrch22md8h_r1.dbf = **-165,559,996adkg**
tnrh22md8h_r1	**TOTAL Non-renewable harvesting merging unsustainable local harvesting (lh_22md_8h_r1) and unsustainable commercial harvesting (nrch2md8h_r1) after use of FRL LCCbp** "nrch22md8h_r1" + "lh_22md_8h_r1" (both negatives) zst_d_reg_physio_tnrh22md8h_r1**.dbf = -1,107,406,362adkg**
	Non-renewable harvesting within Forest-Remaining-Forest (FRF) after use of FRL LCCbp Sum of tnrh22md8h_r1 within FRF by physiographic zone and development region (d_r_phy_frf_i) zst_d_r_phy_rf_i_tnrh22md8h_r1.dbf

2 – Maximum degradation Scenario

	Scenario A Mn N PM 8h **assumptions:** **Total demand(A) – Minimum Supply variant (mn) – No Use of LCCbp (N) – Partial Market (PM 30pc) - Woodshed 8 Hours (8h)** **Folder: Scen_A_Mn_PM**
lh_12mn_8h	Rural and minor urban deficit generating unsustainable local harvesting 1/2 of the local rural deficit (within the 8hr zone) remains on site as unsustainable local harvesting up to a maximum of 30% of the local stock, while the rest of the deficit generates commercial harvesting. Outside the 8hr zone, the deficit remains entirely on site as unsustainable harvesting Con("l_bal12_mn" < 0,Con("wcd2_hours" <= 8,Con("rural_msk" == 1,Con(- "l_bal12_mn" / 2 <= ("stk_mn_3km" * 0.3),"l_bal12_mn" / 2,-("stk_mn_3km" * 0.3)),0),"l_bal12_mn"),0) zst_d_reg_physio_lh_12mn_8h.dbf = **-1,481,251.585 odkg**
c_def12_mn_8h	Commercial deficit including total urban deficit and the fraction of the rural deficit within 12 hours (transport time) from major deficit sites that is not harvested locally. = Con("wcd2_hours" <= 8,Con("combal12_mn" < 0,"combal12_mn" - "lh_12mn_8h",0),0) zst_d_reg_physio_c_def12_mn_8h.dbf Tot commercial deficit: **-2,686,204,013 odkg**

wcsur12_mn_8h	Creation of the weighted surplus value (surplus * pressure level) within the nominal woodshed zone of 8-hours around major deficit points for the distribution of the commercial deficit as harvesting . = Con("wcd2_hours" <= 8, Con("**combal12_mn**" > 0,"**combal12_mn**" * "**wcd_d1_mn_c2**",0),0) zst_mutm_msk_wcsur12_mn_8h.dbf total weighted surplus **: 163,633,000,000**
ch12_mn_8hpm	Commercial harvesting by pixel : tot deficit (sum c_def12_mn_8h**) 2,686,204,013**/ total weighted surplus (sum wcsur12_mn_8h**) 163,633,000,000= -0.01641603 (**multiplier of wcsur12_mn_8h) "wcsur12_mn_8h" * **0.01641603** zst_d_reg_physio_ch12_mn_8hpm.dbf
chs12mn8h80pm	Commercial harvesting sustainability assuming a **SIEF of 0.8** Con("ch12_mn_8hpm" > 0,"combal12_mn" * 0.8 - "ch12_mn_8hpm",0)
nrch12mn8h80p	Non-Renewable commercial harvesting within 12 hrs from major deficit sites assuming a SIEF of 0.8 Unsustainable fuelwood extraction in od kg. = measure of (forest) degradation = Con("chs12mn8h80pm"<0, "chs12mn8h80pm",0) zst_d_reg_physio_nrch12mn8h80p.dbf = **-758,014.295 adkg**
tnrh12mn8h80p	TOTAL Non-renewable harvesting merging unsustainable local harvesting (**lh_1mn_8h**) and unsustainable commercial harvesting (**nrch12mn8h80p)** = "**nrch12mn8h80p**" + "**lh_12mn_8h**" (both negatives) **zst_d_reg_physio_**tnrh12mn8h80p**.dbf = -2,239,266.603 adkg**

1 – Minimum degradation scenario

	Scenario B Mx N FM 12h **assumptions:** **Conventional demand(A) – Maximum Supply variant (mx) –Full Market (FM) - Woodshed 12 Hours (12h) – Full Use of LCCbp** **Folder: Scen_B_Mx_FM**
def2_wmx_12h	Deficit map within 12 hours from major deficit points Con("wcd2_hours" <= 12,Con("combal22_mx" < 0,"combal22_mx",0),0) tot deficit (ad kg)**: - -2,566,574,480 adkg**
wcsur2_mx_12h	Creation of the weighted commercial surplus value (c_surplus * pressure level) within 12-hours for the distribution of the deficit as harvesting . Con("wcd2_hours" <= 12,Con("combal22_mx" > 0,"combal22_mx" * "wcd_d2_mx_c2",0),0) tot weighted surplus : **297,226,000,000**
ch2_mx_12h	Commercial harvesting by pixel : tot deficit (sum def2_wmx_12h**) 2,566,574,480** / total weighted surplus (sum wcsur2_mx_12h**) 297,226,000,000= ---0.00863509 (**multiplier of wcsur2_mx_12h) "wcsur2_mx_12h" * **0.0086350**
chs2_mx_12h80	Commercial harvesting sustainability assuming a **SIEF of 0.8** Con("ch2_mx_12h" > 0,"combal22_mx" * 0.8 - "ch2_mx_12h",0)
nrch2_mx12h80	Non-Renewable commercial harvesting within 12 hrs from major deficit sites assuming a SIEF of 0.8 Unsustainable fuelwood extraction in od kg. = measure of (forest) degradation = Con("chs_mx_12h80"<0, "chs_mx_12h80",0) zst_d_reg_physio_nrch2_mx12h80.dbf = **-112,054.513-adkg**
	TOTAL Non-renewable DIRECT harvesting after Full USE of LCC by-products located within local and commercial harvesting area. This value refer to all DEB resources, including Forests, Other Wooded Lands and Other Lands Computed as: if(LCCbpH-Md > nrch2_mx12h80, 0, nrch2_mx12h80 - LCCbpH-Md) Total Degradation (all land cover classes) = **-59,375,596 adkg**

ANNEX 7: LAND COVER CHANGE (LCC) BY-PRODUCTS

The average annual forest area change over the period 2000-2010 was derived from the bias-corrected land cover change statistics produced by ICIMOD for the FRL submission.

Estimated woody biomass by-products of land cover change processes, fraction potentially available for energy uses and fraction probably used according to the Leading Scenario (values are '000 tons air-dry).

development region	**physiographic zone**	**annual loss** Ha yr^{-1}	**annual gain** Ha yr^{-1}	**average FRF forest stock Med var.** ad t /ha	**average FRF forest MAI Med var.** ad t /ha	**annual loss (based on Stock)** kt ad yr^{-1}	**annual gain (based on MAI)** kt ad yr^{-1}	**byproduct potentially available (70%)** kt ad yr^{-1}	**Leading scenario: LCCbp used (50% of potential)** kt ad yr^{-1}
Far Western	HighHimal	0.6	2.4	226	0.39	128	1	90	**45**
Far Western	HighMount	52.6	39.8	284	1.76	14,947	70	10,512	**5,256**
Far Western	Mid Mount	43.8	98.6	132	2.47	5,791	244	4,224	**2,112**
Far Western	Siwaliks	106.8	15.8	162	2.77	17,295	44	12,137	**6,069**
Far Western	Terai	397.5	93.8	182	2.54	72,389	238	50,839	**25,420**
Mid Western	HighHimal	11.2	12.0	238	0.40	2,661	5	1,866	**933**
Mid Western	HighMount	120.6	118.8	282	1.95	34,014	232	23,972	**11,986**
Mid Western	Mid Mount	16.9	135.8	105	2.30	1,780	313	1,465	**733**
Mid Western	Siwaliks	144.0	50.3	137	1.89	19,667	95	13,833	**6,917**
Mid Western	Terai	132.5	111.3	188	1.73	24,871	192	17,544	**8,772**
Western	HighHimal	9.4	17.1	220	0.52	2,067	9	1,453	**726**
Western	HighMount	26.7	82.3	303	2.16	8,078	177	5,779	**2,890**
Western	Mid Mount	27.6	198.5	111	2.37	3,057	471	2,470	**1,235**
Western	Siwaliks	28.4	64.0	163	2.71	4,634	174	3,365	**1,683**
Western	Terai	21.7	22.0	173	3.00	3,761	66	2,679	**1,339**
Central	HighHimal	1.4	4.8	185	0.20	263	1	185	**92**
Central	HighMount	34.8	29.0	234	1.56	8,155	45	5,740	**2,870**
Central	Mid Mount	45.0	70.3	96	2.18	4,340	153	3,145	**1,572**
Central	Siwaliks	317.4	55.5	184	1.96	58,381	109	40,943	**20,472**
Central	Terai	409.0	20.6	179	2.72	73,050	56	51,174	**25,587**
Eastern	HighHimal	8.3	0.4	191	0.33	1,593	0	1,116	**558**
Eastern	HighMount	40.9	12.1	241	2.12	9,849	26	6,912	**3,456**
Eastern	Mid Mount	8.8	48.9	102	2.22	892	108	700	**350**
Eastern	Siwaliks	55.9	5.2	136	2.59	7,610	14	5,336	**2,668**
Eastern	Terai	141.7	41.0	213	3.22	30,134	132	21,186	**10,593**
	HighHimal	31	37			6,712	16	4,709	**2,355**
	HighMount	276	282			75,043	550	52,915	**26,458**
	Mid Mount	142	552			15,860	1,289	12,004	**6,002**
	Siwaliks	653	191			107,587	435	75,615	**37,808**
	Terai	1,102	289			204,205	684	143,423	**71,711**
Far Western		601	250			110,549	597	77,802	**38,901**
Mid Western		425	428			82,993	836	58,681	**29,340**
Western		114	384			21,597	897	15,746	**7,873**
Central		808	180			144,189	364	101,187	**50,593**
Eastern		256	108			50,078	280	35,250	**17,625**
Total Nepal		**2,204**	**1,351**			**409,406**	**2,975**	**288,667**	**144,333**