GACC Yale-UNAM Project

Geospatial Analysis and Modeling of Non-Renewable Biomass: WISDOM and beyond

Tier II :

Karnataka, India

WISDOM Karnataka

Analysis of woodfuel supply, demand and sustainability in Karnataka, India

Rudi Drigo, Robert Bailis, Adrian Ghilardi and Omar Masera

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Acronyms and abbreviations

ad	Air-dry, assuming 12 % moisture content
AGB	Aboveground Biomass
DEB	DendroEnergy Biomass (aboveground biomass less leaves, twigs and stumps)
DTM	Digital Terrain Model
ESA	European Space Agency
FAO	Food and Agriculture Organization of the United Nations
KFD	Karnataka Forestry Department
KSRSAC	Karnataka State Remote Sensing Application Centre
fNRB	fraction of Non Renewable Biomass (in this study taken as % of total harvesting)
NRB	Non Renewable Biomass (in this study taken as t od of non-sustainable harvesting)
Fw	Fuelwood
GACC	Global Alliance for Clean Cookstoves
GDB	Geodatabase
GIS	Geographic Information System
HH	Household
Mt	Million tons
kt	kilo tons ('000 metric tons)
t	metric ton
TOF	Trees outside forest
LC	Land Cover
MAI	Mean Annual Increment
od	Oven-dry, at 0% moisture content
RWEDP	Regional Wood Energy Development Programme (FAO Project)
WCMC-IUCN	World Conservation Monitoring Centre - International Union for the Conservation of Nature
WISDOM	Woodfuel Integrated Supply/Demand Overview Mapping

1. INTRODUCTION

The study "Geospatial Analysis and Modeling of Non-Renewable Biomass: WISDOM and beyond", commissioned by the Global Alliance for Clean Cookstoves (GACC) and supported by UN Foundation, is implemented by the Yale School of Forestry and Environmental Studies (FES) in partnership with the Centro de Investigaciones en Geografía Ambiental (CIGA) and the Centro de Investigaciones en Ecosistemas (CIEco) of the National Autonomous University of Mexico (UNAM).

Scope of the project is to develop and, in select cases, validate multi-scalar geospatial estimates of the fraction of non-renewable biomass (fNRB) harvested for woodfuel, including firewood and charcoal, at national and sub-national levels in Sub-Saharan Africa, Tropical Asia and Latin America. This will enable clean cookstove and fuel substitution programs to better understand their impact on land use/land cover change (LU/LCC) and allow for more accurate and consistent accounting of carbon offsets.

At the national and regional level, there are large variations in location, method, and volume of biomass harvesting. Country-level estimates based on national statistics cannot capture the geographic specificity of biomass harvesting and may result in incorrect assumptions about the impact of fuelwood on land cover change. In contrast, spatially explicit estimates of fNRB reflect the variability that characterizes woodfuel demand, supply potential and harvesting intensity, but require more complex analyses. Geospatial approaches like the Woodfuel Integrated Supply/Demand Overview Mapping (WISDOM) methodology support strategic planning and prioritize areas for project implementation.[1]

The project follows a 3-tiers approach to draw comparisons between three different geographic scales of analysis:

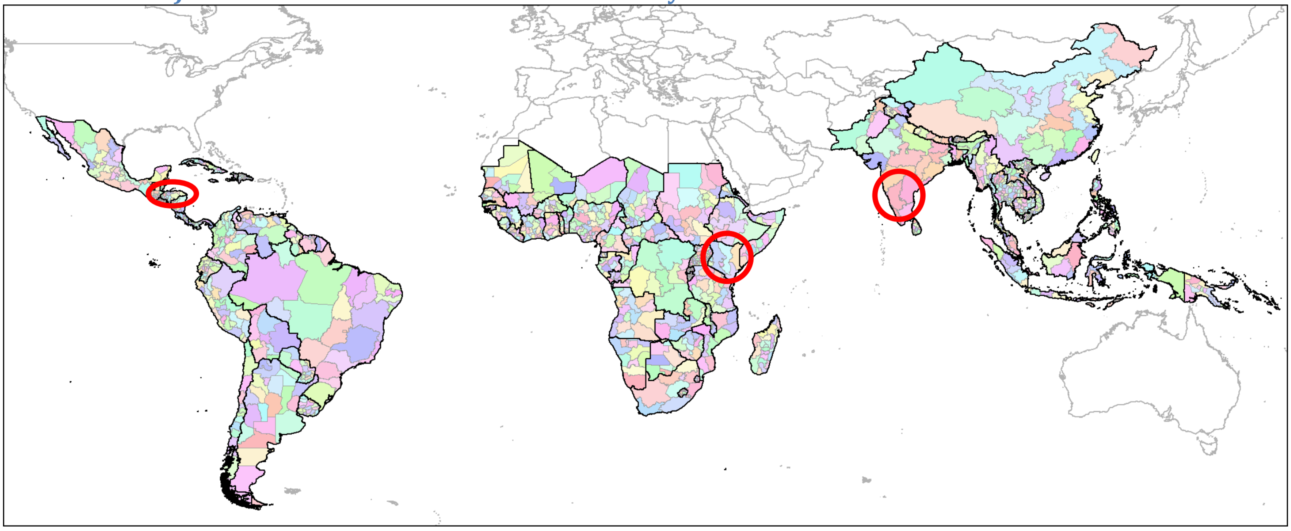
- Tier 1 - Pan-tropical (90 countries). Approach: WISDOM analysis based on existing global data [6]
- Tier 2 – National/State level in Africa (Kenya), Asia (Karnataka) and Latin America (Honduras). Approach: WISDOM analysis based on existing national data
- Tier 3 – Local level (selected sites within the Tier 2 study areas). Approach: Dynamic spatial and temporal aspects of woodfuel harvesting based on new field data

Tier 1 coverage and selected Tier 2 study sites are shown in Figure 1.

The Indian State of Karnataka has been selected for Tier 2 and Tier 3 analyses. Tier 2 analysis, object of the present report, is based on the State-level analysis of woodfuels supply and demand through the application of the WISDOM model. Tier III analysis, object of a separate report, is based on detailed field-based research in selected Village areas in the District of Koppal.

[1] For an overview of WISDOM methodology and over twenty studies from around the world, see http://www.wisdomprojects.net/global/.

Figure 1: Map showing countries included in Tier I analysis (includes 90 countries divided into 1480 sub-national units) and selection of Tier II and Tier III analyses locations.



1.1 SCOPE OF TIER II ANALYSIS - WISDOM KARNATAKA

The scope of this activity, carried out in the framework of the GACC NRB Project as Tier II case study, is to analyze woodfuels consumption and supply potential, to estimate the intensity, locations and Non Renewable fraction (fNRB) of woodfuels harvesting.

The objectives of this study are to (i) analyze the sustainable supply potential and the demand for woodfuels in Karnataka, and produce spatially explicit results on supply/demand balance for local and commercial woodfuels use and identify surplus and deficit areas through the Woodfuel Integrated Supply/Demand Overview Mapping (WISDOM) model, (ii) provide estimates of the sustainable /unsustainable harvesting related to wood energy demand (i.e."fraction of Non-Renewable Biomass" -fNRB), and (iii) compare state-level results with Tier I results [6] in order to identify main discrepancies and the underlying data or analytical factors.

At the same time, WISDOM Karnataka may serve to strengthen wood energy planning and enhance inter-sectoral and interdisciplinary decision making processes, strategic planning and policy formulation.

The analysis is intended as interdisciplinary and cross-sectoral, including forestry, energy, territorial and socio-economic components, as is typical for WISDOM analyses. Given the large variety of data sources and the limited resources available, the analysis is based primarily on existing information.

1.2.1 Main features of the WISDOM method

WISDOM is the fruit of a collaborative effort between the Wood Energy Programme of FAO and the Centro de Investigaciones en Ecosistemas (CIECO) of the National Autonomous University of Mexico (UNAM) [5, 7, 16] and has been implemented in over 25 countries worldwide in a variety development and research programmes (see www.wisdomprojects.net for a review of WISDOM case studies).

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[2] analysis**. This second stage of the analysis uses the result of the WISDOM Base to delineate the sustainable supply zone of selected consumption sites [7]. 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.

[2] 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) [7].

The specific steps of analysis are summarized below while a graphic overview is shown in Figure 2.

WISDOM Base

The application of the standard WISDOM analysis producing supply and demand balance mapping at the local level involves five main steps [5]:

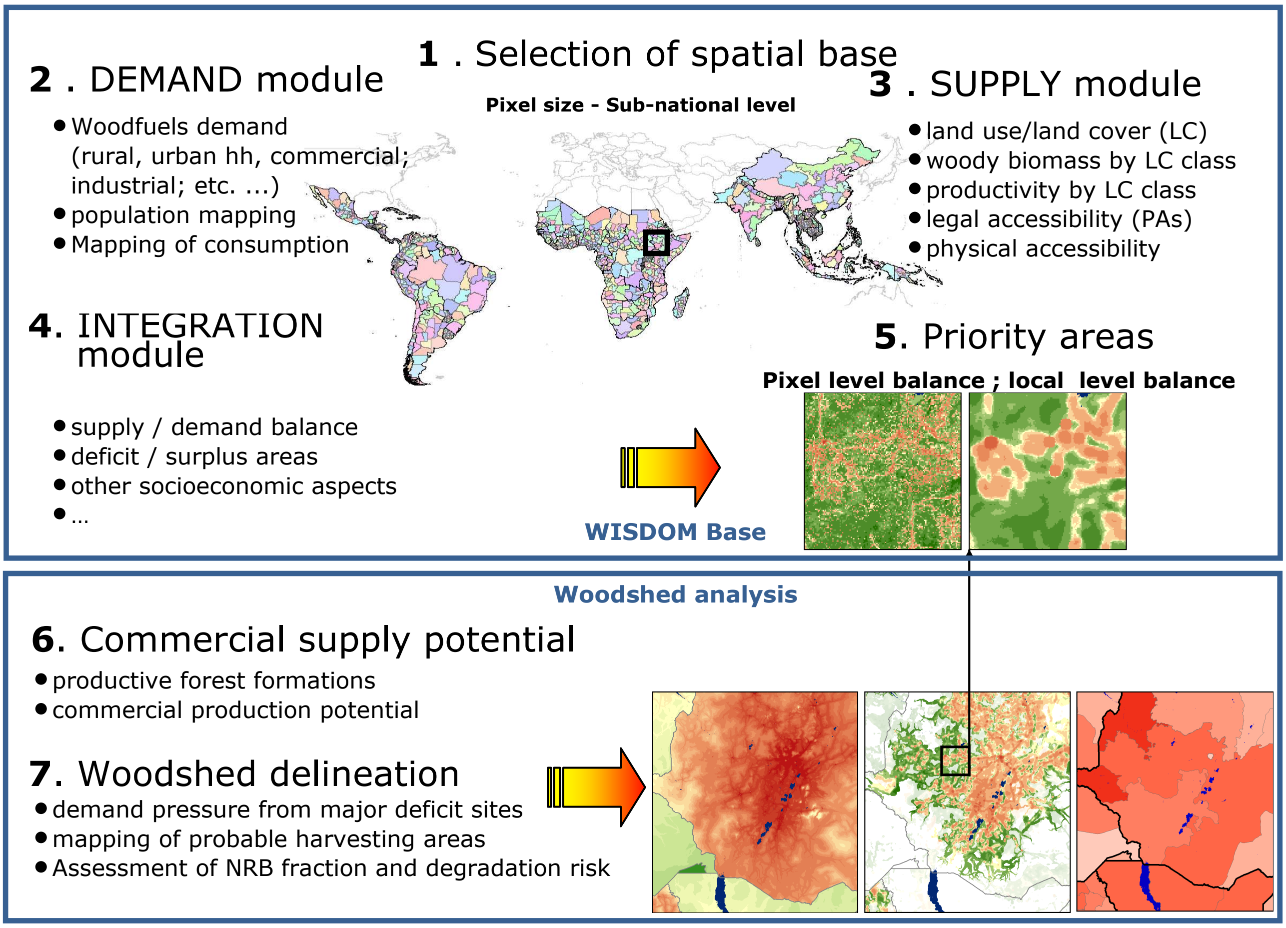
1. Definition of the minimum administrative *spatial* unit of analysis.
2. Development of the *demand* module.
3. Development of the *supply* module.
4. Development of the *integration* module.
5. Selection of the *priority* areas or woodfuel “hot spots” under different scenarios.

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 woodshed, or probable harvesting area, based on the level of demand, woodfuels production potentials and physical accessibility parameters.

Figure 2: WISDOM analytical steps. WISDOM Base (steps 1 to 5) and Woodshed analysis (steps 6, 7)



2.
WISDOM ANALYSIS

2.1 SELECTION OF SPATIAL BASE OF ANALYSIS

Mapping details:

Projection: Preferred/common projection for Karnataka: Everest_Bangladesh_Polyconic;

Cell size of raster layers: 100 meters (1-ha cells)

Administrative units used for population mapping:

Taluks (176 units, subdivision of 30 Districts), as per Census 2011. Additional parameters such as rural/urban distinction are derived from map of Villages (over 29,000 units).

Census results related to the fuels used for cooking are at District level (30 units).

Reference years of WISDOM analysis

Concerning the Supply Module, in absence of most recent land cover data, KFD map of 2001 is used as reference. Concerning the Demand Module, the reference year is set by the last demographic census, i.e. 2011. Given the relatively stable land cover situation in Karnataka[3] the land cover map is considered adequate in spite of the ten-years gap and therefore 2011 may be considered as reference year of WISDOM analysis .

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 3 and described in the following Sections.

2.2.1 Reference data

Household sector

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

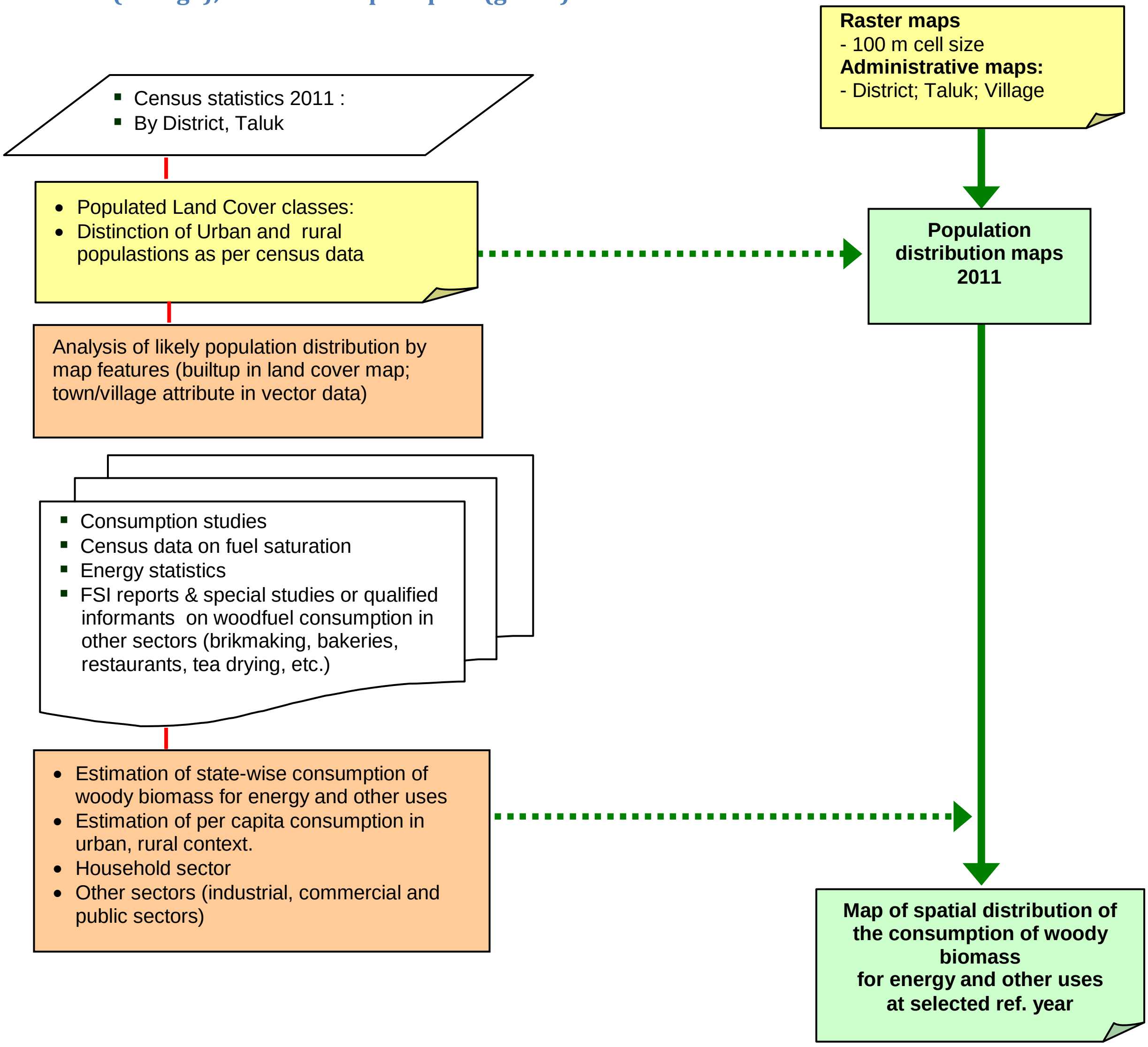
(i) Census 2011 results at lowest administrative level on the fraction of households using fuelwood as primary cooking fuel in rural and urban areas.

(ii) Consumption surveys providing estimates of the quantities consumed by fuelwood and charcoal users (per household or per capita). The most useful available reference has been the study by Ranganathan, Subba Rao and G.S. Prabhu based on 3000 surveyed households. Additional references are Ramachandra, 2007, FSI 1996 and local field survey conducted in Koppal Districs in 2012.

Detailed District-wise per capita consumption parameters and total household consumption by fuel type are reported in Annex 1 (Tables A1.1 and A1.2). On such basis, the estimated household consumption is 16.2 million tons od (15.2 in rural areas and 1 in urban areas)

[3] Hansen et al., 2013, indicate a net annual forest loss of 16 km^2, or 0.04 % over the period 2000-2012.

Figure 3: Demand Module Flowchart - Input data: cartographic (yellow); statistical (white); estimated variables (orange); thematic map outputs (green)



Other sectors of consumption

The use of woodfuels in other sectors (cottage industries, rituals, hotels, etc.) and the use of construction material[4] is included in the analysis and estimated/mapped in the best possible way. In the absence of detailed information, reference is made to FSI reports [10, 23], on which basis the estimated woodfuels consumption in other sector is 3 million tons od and that of construction material is 1.4 million tons od.

The District-wise consumption in other sectors and as construction material as well as total consumption including household sector are reported in Annex 1 (Table A1.3).

2.2.4 Mapping population distribution and woodfuels consumption

Urban and rural population mapping: Statistical and cartographic information relative to the distribution of **the population at the level of Administrative Unit are from Census 2011. Figure 4 shows the main** cartographic layers used to map the distribution of rural and urban population.

[4] Construction material, used for fencing, stables, house repairs, etc., belong to the same supply chain as woodfuels and for this reason is added to woodfuels in the Demand Module. On the contrary, industrial roundwood and timber, that follow a separate supply chain are accounted for separately and deducted from the supply potential in Supply Module.

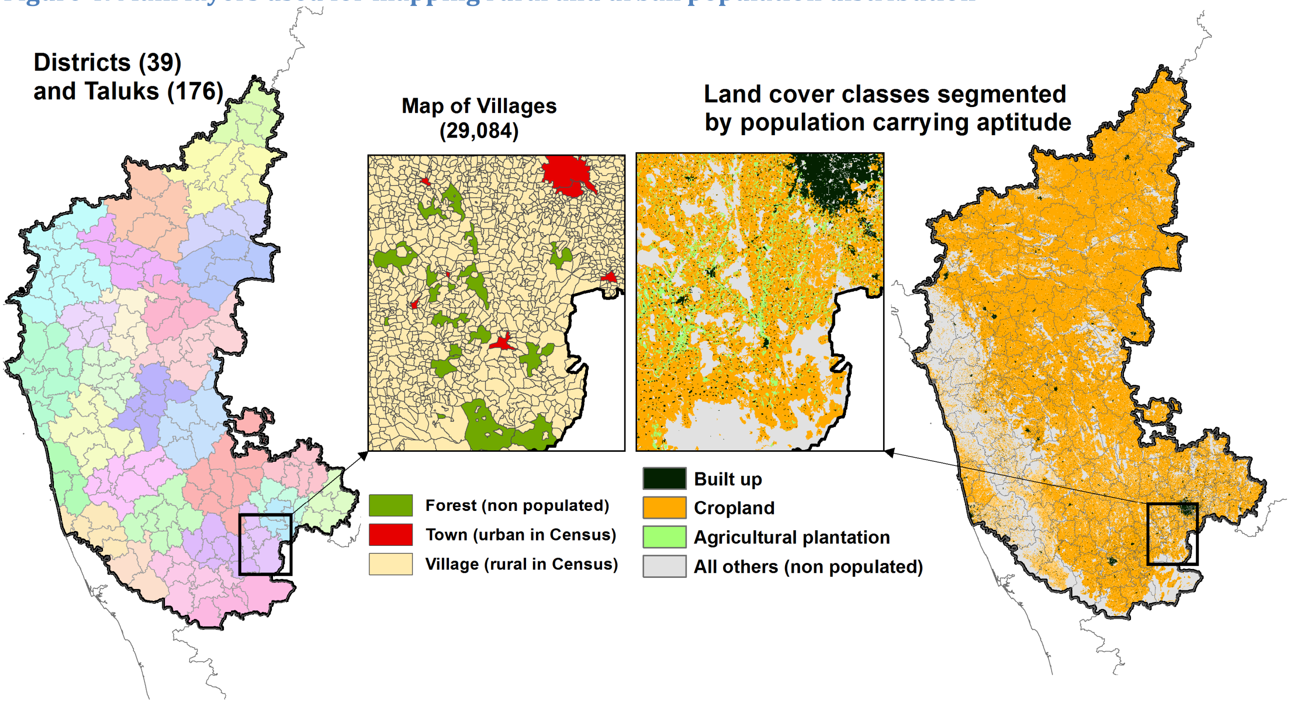
Location of Rural population:

The mapping of rural population (as defined by 2011 census or by interpolation to reference year) respects the values reported at admin unit level (Taluk). Within such units, the spatial distribution of the population is based on additional cartographic elements/attributes from the administrative map of 29,084 Villages and from the map of land cover that indicate population presence, such as built-up areas, farming areas, etc., and others that indicate absence of population such as water bodies, swamp areas, barren rocks. These are be used 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 and by interpolation to reference year) is done respecting the definitions and values reported by the census. Within urban admin units, the spatial distribution of the population is based on additional cartographic elements or spatial proxies, such as urban boundaries.

Figure 4: Main layers used for mapping rural and urban population distribution



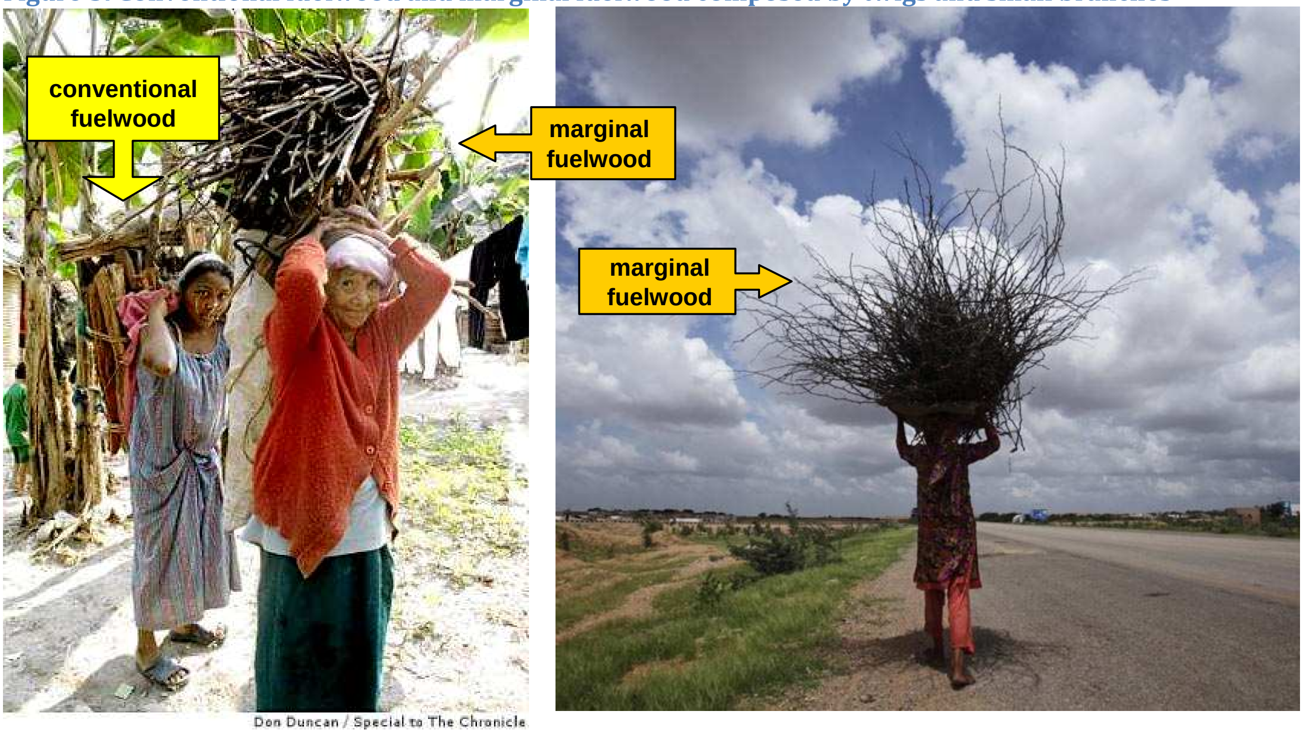
In the case of Karnataka, the household sector dominates woodfuel consumption, and the population map is instrumental to mapping the relative consumption. No data is available on the spatial distribution of forest products consumption in other sectors, such as woodfuels used by cottage industries and commercial food producers or the use of timber as construction material. We assume these are spatially correlated to population concentrations and to residential use of woodfuels in the household sector. In the absence of more precise data on the distribution of these uses, the distribution of household consumption was used as spatial proxy to map consumption of other sectors.

2.2.5 *Conventional* vs *non-conventional* fuelwood sources and assortments

Woodfuels consist of a wide variety of woody biomass assortments ranging from stem wood or branch wood to twigs, smaller branches, and shrub wood (Figure 5). Stems and large branches are typically well documented in forest inventories. In contrast, twigs, small branches and shrubs are marginal forms of woodfuel that are often excluded from forest inventories and thus not accounted for among the conventional supply sources.

Consumption data among rural households is based on survey data that does not distinguish between conventional and marginal fuelwood. It would be misleading to consider consumption reported in these surveys to consist entirely of conventional fuelwood. Because we are comparing consumption volumes to forest inventory data, we must be careful to account for marginal forms of woodfuel that may not be accounted for in forest inventories. In rural areas where forest cover is thin or non-existent, but wood is still a common household fuel, it is very likely that rural households rely on a high proportion of non-conventional wood resources such as twigs and small branches from prosopis juliflora and annual pruning of farm trees and shrubs[5]..

Figure 5: Conventional fuelwood and marginal fuelwood composed by twigs and small branches



Woodfuel consumption surveys do not differentiate between conventional and marginal resources. Therefore, we have no data indicating the quantity of marginal wood products used in rural households. In order to account for the likely use of these resources, we consider two scenarios: .

Scenario A. **Total Demand**	**Scenario B.** **Conventional demand**
The demand is considered entirely, without distinction between conventional and marginal fuelwood (total demand:20,6 Mt)	Only the demand for "conventional" fuelwood, is considered, excluding "marginal" fuelwood in rural deficit areas, (conventional demand: 17,2 Mt)

In scenario A we make no distinction between conventional and marginal woodfuel. The entire demand is considered in each phase of analysis.

In scenario B we assume that urban consumption is taken entirely conventional (as in scenario A), but in rural areas, where the local supply is insufficient, we assume that 50% of the fuelwood gap (i.e. the difference between the demand and locally available supply) is satisfied by "marginal" fuelwood.

Rural deficit areas are identified by calculating local supply/demand balance assuming full fuelwood demand (as per scenario A) accessible within a 6km radius. In deficit areas, we assume 50% of the deficit is satisfied by “marginal woody biomass.

The total annual consumption according to Scenario A is 20.6 Mt. In Scenario B,annual consumption is 17.2 Mt. In other words, our assumptions lead us to estimate that 3.4 Mt/year are obtained from marginal sources of woody biomass that are not included in forest inventories and conventional productivity estimates [district-level consumption for both Scenarios is shown in Table 2].

The 50% limit in the substitution of conventional fuelwood by marginal wood products was arbitrarily selected

[5] To be noted that annual or periodic pruning of farm trees may contribute significantly to woodfuel supply. For instance, pruning of coffee trees in El Salvador and pruning of vine trees in Argentina provide large amounts of fuelwood for residential and industrial use. The key factor for the analysis is that the productivity of these non-conventional sources is not represented by conventional MAI data.

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 is applied only on rural areas, which depend primarily on local and informal sources of supply, and is concentrated in the eastward-sloping plains of the Karnataka Plateau, known as the Maidan.

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 soil nutrient cycling.

2.3 SUPPLY MODULE

The scope of the WISDOM Supply Module is to produce a spatial representation of the sustainable woodfuels supply potential from natural and man-made sources. More specifically, it analyze the stock and production potential of DendroEnergy Biomass (DEB), i.e. the fraction of aboveground biomass that is conventional source of fuelwood and for charcoal production[6]. The analysis includes components that may serve other non-energy uses such as industrial roundwood.

The estimation and mapping of the DEB supply potential is based on land cover information, describing the vegetation types and their location, and on field observations quantifying the stock and productivity, such as forest inventory data.

The flowchart in Figure 6 shows the source data and the main analytical steps of the Supply Module.

2.3.1 Cartographic layers

Land cover

Land cover data was provided by Karnataka Forestry Department (KFD). The map (mapname "forest_type.shp"), was produced by KFD with KSRSAC assistance, based on IRS PAN data (5.6m), photointerpretation and IRS LISS data (23m) multi-seasonal for forest type separation. The map depicts 2001 situation. The original vector map was converted to raster (1 ha cell size) with some thematic editing to fill data gaps and overlaps. Since the floristic aspects of natural forests (moist deciduous, semi-evergreen, semi-deciduous, etc.) are not reflected in available reference data, these were not kept in the final raster version. The resulting raster map has 30 classes, including important details such as 5 density classes for natural forests and plantation species (see land cover map and legend in Annex 2).

2.3.2 Stock and productivity data

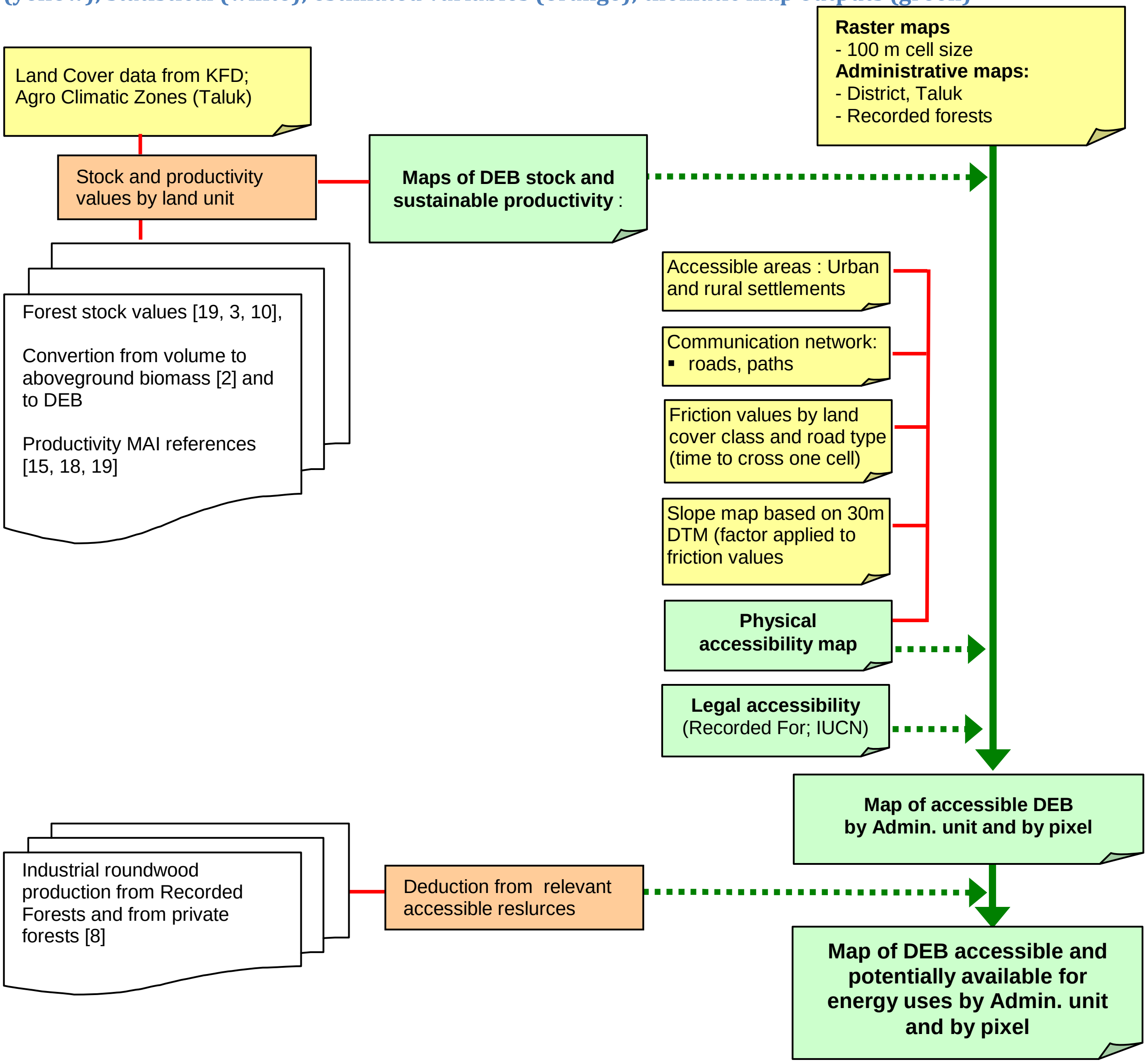
Woody biomass stock

District-wise estimates of per hectare volumes for dense forests from the comprehensive study of demand and supply of fuelwood in Karnataka [19] are used as basis for the estimation of the stock of DEB for the forest areas of the land cover map and modulated according to density classes. See Table A2.1 in Annex 2 for stock reference values.

DEB stock values for forest and agricultural plantations are based on limited reference data provided by [3] and [18]. DEB stock values for croplands are tentatively estimated on the basis of FSI data [10] on average "tree cover" in the broad zones Coast, Hilly, Transition and Dry. For the land cover classes for which no reference could be found, tentative preliminary values are assigned.

[6] DEB is defined as the total aboveground biomass less leaves, twigs and stumps.

Figure 6: Flowchart of the main analytical elements of the Supply Module. Input data: cartographic (yellow); statistical (white); estimated variables (orange); thematic map outputs (green)



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).

Prabhu, in [19] offers some MAI estimates for natural forests based on the review of previous Working Plans, which is used as reference for the estimation of forest productivity. See Table A2.1 in Annex 2 for forest MAI reference values from [19].

To accommodate the lack of data, MAI was estimated with a simple equation relating stock and MAI (as percent of stock) for broadleaved formations from a set of field observations in similar ecological conditions [13, 14, 15, 22]. See Figure A2.2 in Annex 2.

$$\mathbf{MAI\% = 37.06 \times DEB^{-0.588}} \qquad [1]$$

Total DEB MAI estimated using [19] and using equation 1 give comparable results: 22.9 and 24.2 million tons od per year, respectively (maps of DEB MAI are shown in Annex 2, Figure A2.3). The results using Equation 1 appear more consistent, because the MAI distribution based on [19] result in discontinuities along administrative boundaries. Therefore, we use this result in further phases of the analysis.

2.3.3 Accessibility

2.3.3.1 Physical accessibility

The estimation of the physical accessibility of biomass resources is based on estimated round-trip transport time to the nearest village or motorable road. This is done following and adapting the procedure adopted for Tier I [1, 6]. The transport time map is the result of an accessibility model that considers the cost, or friction surface, based on terrain and land cover data. The analysis and results are described in Annex 3.

The result of this analysis shows that, given the high density of roads and of populated places, Karnataka's woody biomass resources are highly accessible. 86% of DEB MAI lies within one hour from the nearest road or village. Thus, with an 8-hour limit, 98.3% of resources are accessible.

2.3.3.2 Legal accessibility

The legal accessibility to woody biomass resources is determined on the basis of protection status by which forest exploitation is prohibited and assuming that outside such areas the sustainable and regulated production of woodfuels and timber is allowed.

The Protected Areas considered include those shown in the World Database of Protected Areas (WDPA) published by WCMC-IUCN whose boundaries are found in the KFD map of Karnataka Recorded Forests (RF). In several areas, the WDPA map does not match RF boundaries, presenting significant and irregular shift with respect to the areas they are supposed to represent (see map in Annex 4). This discrepancy appears as the effect of poor cartographic accuracy in the reference data used during the compilation of the WDPA dataset. The reconciled dataset was used as legal accessibility layer, assigning NO access within protected areas and FULL access outside.

2.3.3 Available resources

Some accessible MAI is unavailable for fuelwood or construction material due to competition from other uses such as wood processing industries. We account for these competing uses by taking annual production data from EMPRI [8], derived from comprehensive statistics on Karnataka's timber industry, including timber sourced from private lands and from State Forests. In addition, for State Forests, more recent data is provided by FSI [10]. . Altogether, timber production from State Forests and private lands is 34,300 and 662,900 od tons, respectively.

In the absence of data on the location of industrial roundwood production sites, the deduction was spatially distributed on accessible forest resources.

The products of the Supply Module for each phase of analysis are presented in Section 3.2.

2.4 INTEGRATION MODULE

The Integration Module combines the parameters developed in the demand and supply modules by discrete land units (pixel-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 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 is carried out at the following three levels:

(i) Cell-level balance, which combining supply and demand within single pixels,

(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 woodfuels production systems serving distant consumption sites.

2.4.1 Pixel-level balance

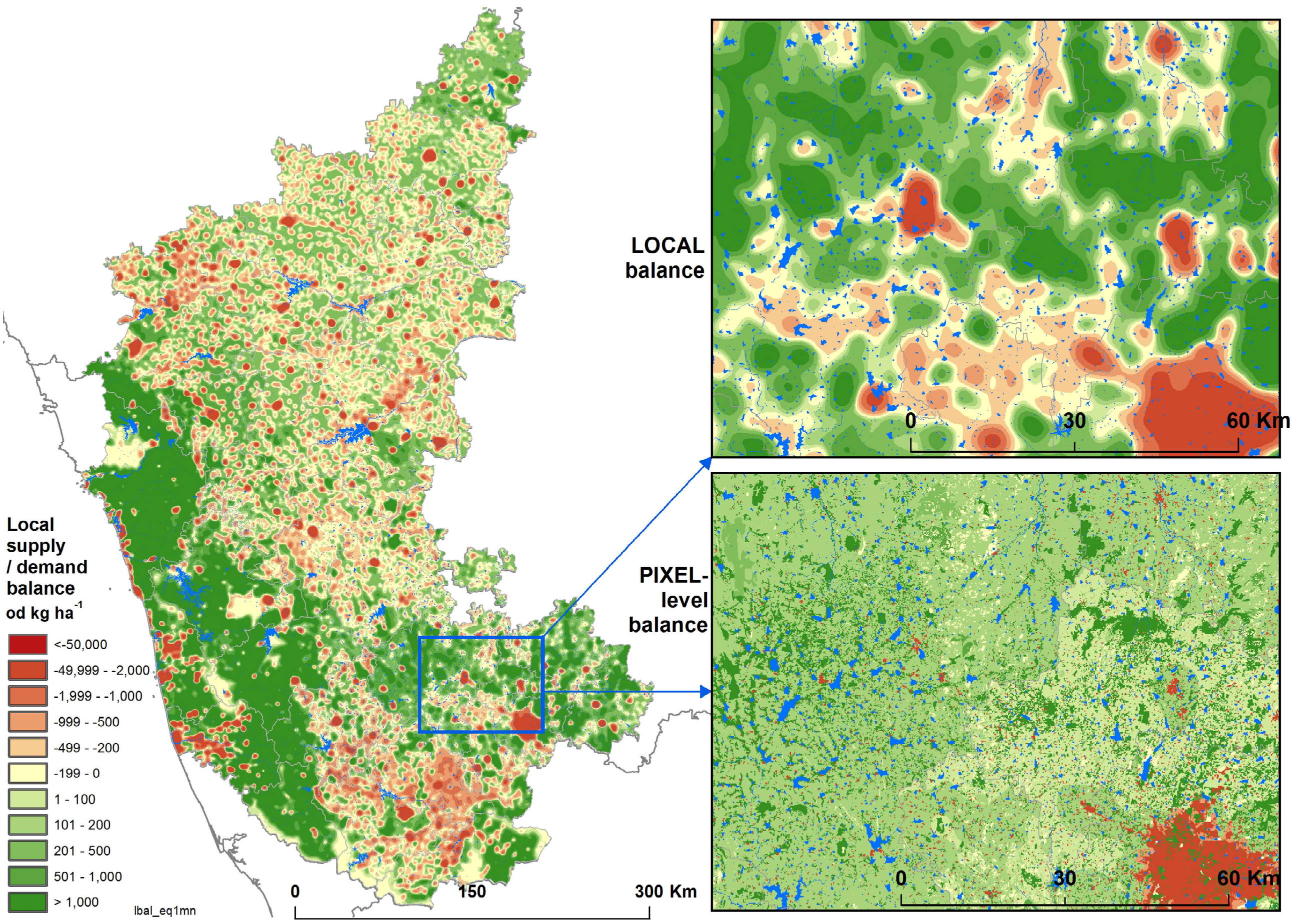
At the pixel-level, supply/demand balance is calculated by subtracting demand from available DEB MAI.. The balance by individual 1-hectare cell has an useful accounting function but it represents a somewhat virtual balance since individual pixels are usually either a production or a consumption site. An example of pixel-level balance is shown in Figure 7. (bottom-right inset).

2.4.2 Local balance

Local balance is calculated by assuming a small horizon of fuelwood collection on foot or by simple means of transportation typical for rural areas like bicycles or oxcarts. This horizon may vary with environmental and socio-economic conditions. Travel distance for subsistence woodfuel collection is typically below 3 km in biomass rich areas [24, 25], but may be farther in biomass-poor areas [26]. In this study we use a single supply horizon radius of 4 km to define likely area of subsistence harvesting. Results (Figure 7) show areas of <u>local surplus</u>, where woodfuels harvesting is less than supply (defined by available DEB MAI), and <u>local deficit</u>, where the supply within a 4-km radius is insufficient to meet demand.[7]

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.

Figure 7: Local balance calculated on a 4-km context with details of local-level vs pixel-level. Scenario B: considering only "conventional" fuelwood, excluding "marginal" fuelwood in wood-scarce rural areas



[7] Note both pixel- and local-balances assume optimal harvesting. The non-optimal exploitation is introduced in a subsequent phase of analysis.

2.4.3 "Commercial" balance

Our assessment of commercial balance is based on the assumption that woodfuel provision for urban and high-deficit rural areas is accomplished through a woodfuel market. Market actors exploit *legally and physically accessible* rural areas (defined above). They utilize the surplus DEB that remains after local demand is satisfied. However, they limit exploitation to accessible resources that are economically viable given their transport and management costs. To simulate these operating principles, we define two quantitative thresholds:

- **Minimum stock required for profitable commercial exploitation**: This assumes that DEB stock below a certain threshold would not be economically viable to exploit given transportation costs. We set this value at 15 t/ha of air-dry DEB (12.3 t/ha oven-dry DEB/ha). Below this, research has shown that charcoal production is unlikely to be profitable [27].
- **Minimum MAI**: This assumes that only the areas with sufficient productivity to permit rotation lengths less than 30 years will be commercially exploited. This implies MAI $\geq$ 0.41 odt/ha-yr.

These thresholds are theoretical because they imply that resources are exploited rationally, without leading to long-term depletion of forest stocks. Thus, these thresholds are useful for defining theoretical limits of sustainable forest management, but do not necessarily represent existing processes. Current exploitation is often unregulated, leading to exploitation that exceeds sustainable limits in some areas and exploitation below sustainable limits in others. We address this below. The products of the Integration Module for local and commercial balance for both demand scenarios are presented in Section 3.3.

2.5 WOODSHED ANALYSIS

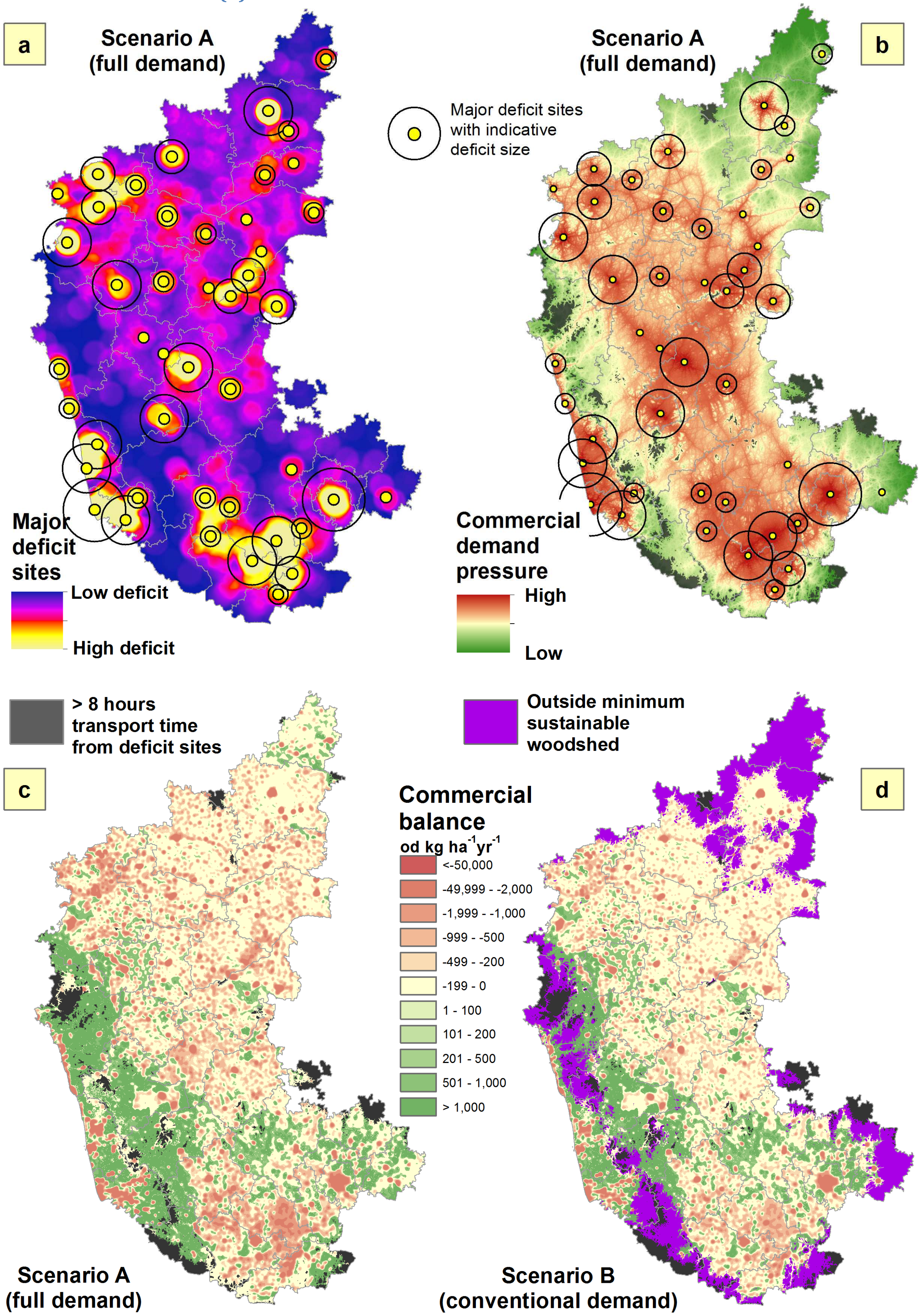
Woodshed analysis is used to develop a spatial projection of commercial demand of major woodfuels consumption sites (urban and high-deficit rural areas) in order to outline the harvesting areas and/or the potential sustainable supply zones, accounting for consumption of other surrounding consumers. We define these zones as "woodsheds" in analogy with the geographic concept of watersheds [7]. For a given center of demand, the sustainable woodshed is the minimum area in which the woodfuel balance is nearly zero. When a single consumption site is considered, the woodshed is determined by the physical accessibility of the available surplus resources. However, when multiple sites are considered simultaneously, the woodshed is determined by the combined effect of physical accessibility of available resources and the aggregated demand of all sites. In order to combine these components, the analysis is carried out using an inverse distance weighted (IDW) interpolation in the Dinamica EGO processing environment [28], where the variable is woodfuels demand and distance is replaced by the transport time relative to any given pixel using a friction map (expressing in minutes per meter the transport time needed to cross each cell twice, unloaded and loaded). The woodfuel demand is represented by a map of deficit peaks, defined in a lookup table. For this, we defined local deficits within a 15 km radius (Figure 8.a). This radius is chosen to represent the cumulative demand of even the largest urban and peri-urban areas in a single point. We defined 45 such points in Karnataka.

The resulting map is a cumulative "pressure" determined by the intensity and location of major deficit areas (Figure 8.b).

For analytical purposes, the continuous map resulting from the weighted interpolation analysis is segmented into buffers; cities with high demand produce wide woodshed buffers and cities with low demand produce narrow buffers, which simulates the territory under pressure from urban and high-deficit rural areas. Woodsheds are defined by using zonal statistics to calculate the supply/demand balance of each buffer, progressively expanding the area until the commercial balance, initially negative, achieves a positive value, which indicates that supply potential has met demand. But positive values are not always achieved, depending on the commercial balance of the study area (see balance results in Table 4). For Scenario A (Total Demand), the commercial balance of Karnataka is negative and therefore there is no sustainable woodshed, while for Scenario B (Conventional demand) the commercial balance is positive, allowing a finite "theoretically sustainable" woodshed within the State (Figure 8.d).

Note this approach assumes optimal harvesting of DEB. It does not reveal actual harvesting patterns. Nevertheless, it provides a sense of the area that is likely to come under urban influence. In addition, it defines the areas in which overlap of local, rural demand and non-local, commercial demand are likely to occur and could be useful for developing policy interventions.

Figure 8: Major deficit sites calculated on a 15-km context (a); pressure zone map resulting from weighted IDW interpolation with transport time above 8 hours (b); woodshed for Scenario A (c) ; woodshed for Scenario B (d)



Transport time threshold

The woodshed zone is determined by the availability of local surplus resources and commercial demand, which may include resources that are distant from the market. For commercial supply, we adopted a threshold of 8-hour transport time between point of harvest and market. To define the territory within such threshold we conduct a cost-distance analysis on the same major deficit points used for woodshed analysis and using transport time as cost factor.

Figures 8.b-d show the small areas that are over 8 hours from major deficit sites. The resources within woodshed and time thresholds are likely to undergo the greatest harvesting pressure

Converting local deficit in commercial harvesting

What fraction of the local deficit converts to commercial harvesting?

The demand for woodfuels in urban areas create always a local deficit and it is safe to assume that they depend entirely on the commercial supply of fuelwood and charcoal. More complex is the situation in rural areas, where the supply is prevalently local and informal. Rural areas that are densely populated or that simply lack adequate accessible wood resources create deficit conditions whose outcome might induce (i) excessive harvesting of the limited resources locally available, (ii) shifting towards non-conventional fuelwood assortments (annual pruning, twigs, etc.) and crop residues and (iii) depend on commercial supply.

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

1. **"Full Market"** scenario: All local deficits, (urban or rural) gives origin to commercial harvesting.
2. **"Urban Market"** scenario: Only major deficit areas (urban areas, mainly) give origin to commercial harvesting, while deficit in rural areas remains local (using 10 km radius to include rural fuelwood market) and produces a strong impact on surrounding biomass resources.

Combined with the Scenarios A and B, which distinguish between the use of "marginal" fuelwood, we present four scenarios in total, described in Table 1.

Table 1: Scenarios of NRB estimates and relative assumptions

	Demand scenarios	
Woodfuels market scenarios	**A. Total Demand** The demand is considered entirely, without distinction between conventional and marginal fuelwood	**B. Conventional demand** Only the demand for "conventional" fuelwood, is considered, excluding "marginal" fuelwood in rural deficit areas
1. Full market: all conditions of local deficit, including urban and rural areas, originate commercial harvesting of distant resources	**Scenario A1**	**Scenario B1**
2. Urban market: only urban deficit originates commercial harvesting while the impact of rural deficit remains local	**Scenario A2**	**Scenario B2**

Spatial distribution of commercial harvesting

Under the consideration that the harvesting intensity within the harvesting areas defined through woodshed analysis is not evenly distributed, we assume that the expected amount of harvesting in any given pixel depends on the commercial demand pressure (Figure 8.b) and on the commercial surplus available, as per the Equation 2:

$$Har_i = w\_s_i * (\sum c\_d / (\sum w\_s) \qquad [2]$$

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.

2.6 ESTIMATING NON RENEWABLE FRACTION OF WOODFUEL HARVESTING

The nonrenewable fraction 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 renewable (or sustainable); when the harvesting is greater than the sustainable supply, the quantity exceeding the supply represents non-renewable component of harvesting (NRB), and fNRB is then estimated as the non-renewable percent of total harvesting (NRB / total harvesting *100).

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 <u>minimum NRB</u> (mNRB) resulting from optimal management, but this is not a realistic estimation of the actual exploitation practices.

In Tier 1 analysis, we estimated the <u>expected NRB</u> (eNRB) by applying a reduction factor representing sub-optimal resource management. Lacking reliable parameters describing actual exploitation, we used FAO country statistics on the fraction of forest resources under management plans [6]. This “Sustainable Increment Exploitation Factor” (SIEF) ranges between 0 and 1, where 1 represents optimal management (optimal rotation) and 0 represents worst-case exploitation (stock depletion without rotations). For India, the SIEF applied to commercial harvesting is 0.8, owing to the relatively high fraction of forests under management plans and/or planted. We apply the same value of SIEF for commercial harvesting in Karnataka.

3. RESULTS

3.1 Woodfuels demand

According to Scenario A-"Total Demand", the estimated total woodfuels consumption in Karnataka in 2011 is 20.6 Mt od of woody biomass. In Scenario B, "Conventional Demand", which excludes the consumption of "marginal" fuelwood in wood-scarce rural deficit areas, consumption is 17.2 Mt od of woody biomass.

Figure 9 shows population distribution in 2011 (left) and woodfuel consumption in Scenario A (right). District estimates of according both scenarios are shown in Table 2. Consumptions by sector and rural/urban areas are reported in Annex 1.

Figure 9: Population distribution and total consumption of woodfuels and construction material (Scenario A: Total Demand)

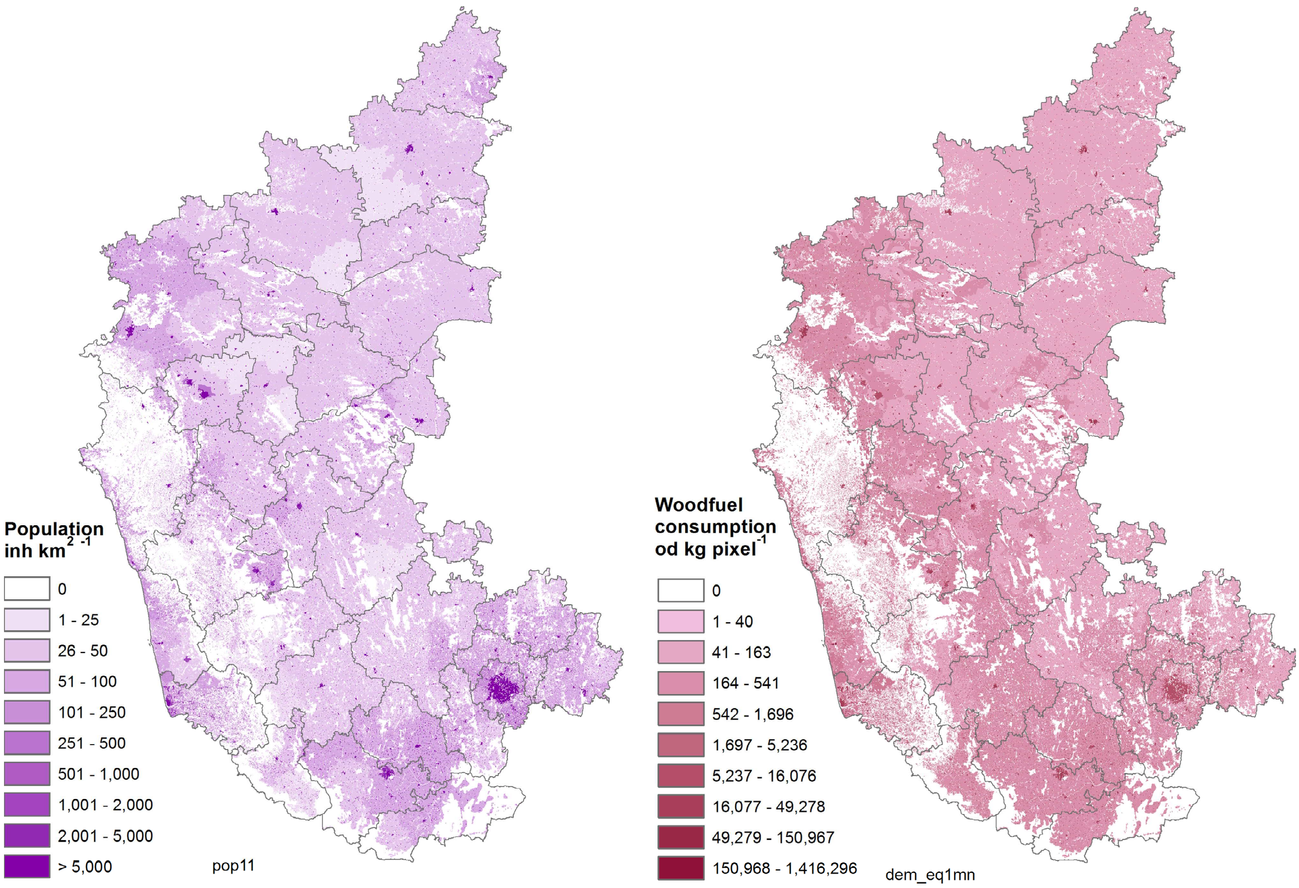


Table 2: District-level woodfuels consumption scenarios

District	Scenario A: Full demand (conventional + marginal woodfuels) kt od (wood eq.)	Scenario B: Conventional woodfuels only (excluding marginal assortments) kt od (wood eq.)
BELGAUM	1,800	1,411
BAGALKOT	677	519
BIJAPUR	813	640
BIDAR	365	343
RAICHUR	720	573
KOPPAL	564	424
GADAG	392	324
DHARWAD	461	417
UTTARA KANNADA	1,030	889
HAVERI	600	550
BELLARY	734	589
CHITRADURGA	787	638
DAVANAGERE	674	539
SHIMOGA	633	575
UDUPI	772	593
CHIKMAGALUR	533	508
TUMKUR	812	760
BANGALORE	403	384
MANDYA	869	661
HASSAN	1,142	974
DAKSHINA KANNADA	1,127	894
KODAGU	410	397
MYSORE	1,032	811
CHAMARAJA NAGAR	533	428
GULBARGA	878	718
YADGIR	489	377
KOLAR	329	314
CHIKBALLAPUR	290	280
BANGALORE RURAL	324	304
RAMANAGAR	450	381
Karnataka	**20,645**	**17,216**

3.2 Woodfuels supply potential

The total estimated MAI of DEB is 24.2 Mt od/yr, which represents the "gross" supply potential. The high density of human settlements and dense road network lead to high physical accessibility; only 1.7 % of the DEB MAI is physically inaccessible. Additionally, 8.3 % of the resources are located in protected areas, leaving 21.8 Mt od/yr of physically and legally accessible resources. 2.9 % are used as industrial roundwood for the timber industry, leaving some 21.1 Mt od/yr resources potentially available for energy use. This resource is spatially distributed as shown in Figure 10; District-level values are shown in Table 3.

Figure 10: MAI of legally and physically accessible Dendro-energy Biomass (DEB)

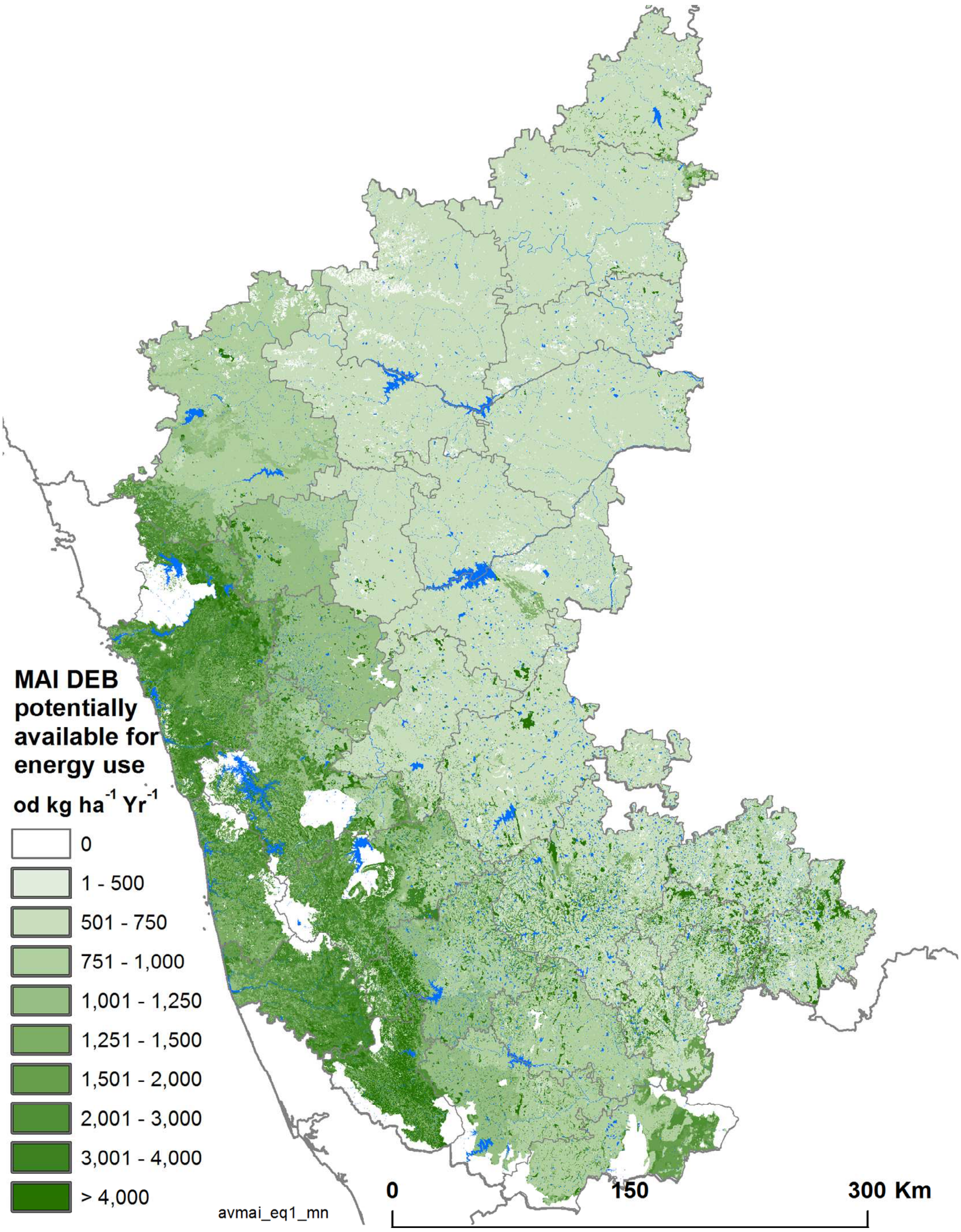


Table 3: District-level supply potential

District	Tot MAI kt od	Physically accessible MAI kt od	Phy. & Legal accessible MAI kt od	Available MAI kt od
BELGAUM	1,416	1,401	1,401	1,355
BAGALKOT	366	365	365	353
BIJAPUR	541	541	541	519
BIDAR	465	465	465	447
RAICHUR	467	466	466	448
KOPPAL	302	301	301	289
GADAG	286	285	285	275
DHARWAD	522	521	521	503
UTTARA KANNADA	2,984	2,863	2,477	2,456
HAVERI	648	647	595	574
BELLARY	514	512	509	492
CHITRADURGA	608	606	606	584
DAVANAGERE	449	446	446	431
SHIMOGA	1,690	1,670	1,363	1,322
UDUPI	920	887	719	693
CHIKMAGALUR	1,606	1,584	1,382	1,332
TUMKUR	1,203	1,201	1,201	1,157
BANGALORE	321	321	318	305
MANDYA	535	534	520	500
HASSAN	1,115	1,104	1,104	1,063
DAKSHINA KANNADA	1,215	1,165	1,127	1,093
KODAGU	1,298	1,229	955	921
MYSORE	918	911	697	670
CHAMARAJA NAGAR	901	865	544	530
GULBARGA	631	630	630	606
YADGIR	284	283	283	272
KOLAR	604	602	602	582
CHIKBALLAPUR	504	503	503	486
BANGALORE RURAL	433	433	433	417
RAMANAGAR	432	430	415	403
Karnataka	**24,180**	**23,773**	**21,775**	**21,079**

3.3 Supply / demand balance

Balance analysis clearly shows the distribution of deficit and surplus areas (Figure) and supports the calculation of summary values, such as those shown in Table 4. But summary values may be misleading because, in the analysis of NRB, the spatial distributions of supply and demand are more important than the respective quantities. For instance, the state-level summary of **Local balance** is positive for both demand scenarios (+0.4 in A and +3.9 Mt od in B), which may induce some initial optimism, but over half of the Districts in the state show negative values in both scenarios.

For **Commercial balance**, which provides a more realistic perception of the resources potentially available, state level summary for Scenario A is negative (-0.9 Mt) while for Scenario B is still positive (+2.4 Mt) but negative Districts increase significantly.

For NRB estimates some further analysis is needed in order to assess the amount and probable distribution of commercial harvesting, as discussed below. Nevertheless, the Balance map is useful in ranking the communities according to local balance conditions, which is particularly relevant for poor rural communities that depend primarily on local resources.

Figure 11: Local supply demand balance maps according to Scenario A (Total Demand, left map) and to Scenario B (Conventional Demand, right map)

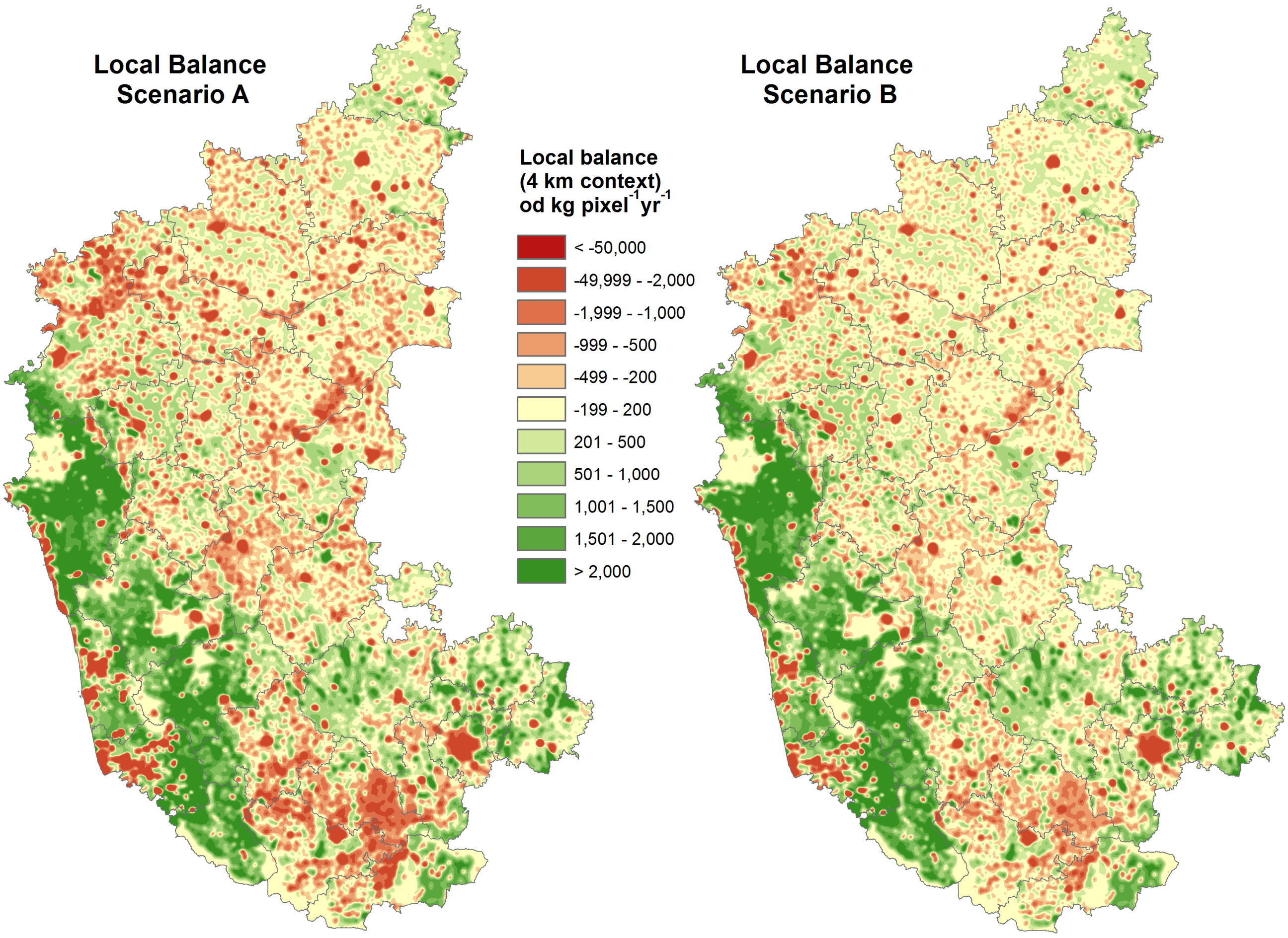


Table 4: District-level Supply / demand balance

		Scenario A			Scenario B		
District	Available MAI kt od	Tot demand kt od	Local balance kt od	Commercial balance kt od	Conventional demand kt od	Local balance kt od	Commercial balance kt od
BELGAUM	1,355	1,801	-445	-514	1,411	-55	-136
BAGALKOT	353	677	-324	-364	519	-166	-214
BIJAPUR	519	813	-290	-369	640	-118	-211
BIDAR	447	366	78	7	343	101	29
RAICHUR	448	720	-273	-329	573	-125	-190
KOPPAL	289	565	-268	-290	424	-130	-158
GADAG	275	392	-110	-151	324	-43	-88
DHARWAD	503	461	33	10	417	78	53
UTTARA KANNADA	2,456	1,030	1,421	1,347	889	1,562	1,485
HAVERI	574	600	-34	-64	550	16	-18
BELLARY	492	734	-245	-294	589	-99	-157
CHITRADURGA	584	787	-192	-229	638	-44	-88
DAVANAGERE	431	674	-237	-255	539	-101	-122
SHIMOGA	1,322	633	691	588	575	749	645
UDUPI	693	772	-77	-108	593	102	70
CHIKMAGALUR	1,332	533	788	708	508	814	733
TUMKUR	1,157	812	332	246	760	386	297
BANGALORE	305	405	-108	-120	384	-86	-98
MANDYA	500	869	-360	-374	661	-153	-169
HASSAN	1,063	1,142	-66	-105	974	100	58
DAKSHINA KANNADA	1,093	1,127	-30	-57	894	202	174
KODAGU	921	410	517	457	397	526	466
MYSORE	670	1,032	-381	-400	811	-155	-177
CHAMARAJA NAGAR	530	533	2	-27	428	105	74
GULBARGA	606	878	-273	-354	718	-112	-205
YADGIR	272	489	-216	-235	377	-104	-130
KOLAR	582	329	251	214	314	266	229
CHIKBALLAPUR	486	290	194	150	280	204	159
BANGALORE RURAL	417	324	100	87	304	119	105
RAMANAGAR	403	450	-44	-62	381	25	4
Karnataka	**21,079**	**20,648**	**431**	**-887**	**17,216**	**3,864**	**2,420**

Note: Local balances differ from the arithmetic result of Available MAI <minus> Demand (as per pixel-level balance) due to the 4 Km context of analysis.

3.4 NRB estimates

"Full market" variants (scenarios A1 and B1)

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 the state's forest resources, which are located primarily in the Western Ghats.

District-level NRB values for scenarios A1 and B1 are shown in Table 5. Districts experiencing fNRB greater than the district average are highlighted. State-wide fNRB is 13.3% for Scenario A1 and 5.3% for Scenario B1.

There is a wide variability among Districts with some values significantly higher than the state average. In Sc. A1, fNRB values over 20% occur in Gadag, Uttara Kannada, Davanagere, Shimoga, Chikmagalur, Dashina Kannada and Chikballapur. In Sc. B1, fNRB values over 8% occur in Shimoga, Chikmagalur, Udupi, Bangalore, Bangalore Rural, Darwad and Uttara Kannada. These are the Districts where forest resources are under greatest pressure for commercial harvesting.

Table 5: NRB values according to Full Market Scenarios. A1 & B1 (Full market-tot & conv. Demand)

	Scenario A1 "full market - full demand"			Scenario B1 "full market - conventional demand"		
	NRB harvesting	Total harvesting	fNRB	NRB harvesting	Total harvesting	fNRB
District	kt od	kt od	%	kt od	kt od	%
BELGAUM	-116	1,324	**8.74**	-39	1,160	**3.39**
BAGALKOT	-6	320	**1.85**	-3	308	**0.97**
BIJAPUR	-2	442	**0.52**	-1	425	**0.25**
BIDAR	-17	371	**4.69**	-1	280	**0.30**
RAICHUR	-3	393	**0.88**	-1	379	**0.25**
KOPPAL	-2	267	**0.92**	-1	260	**0.29**
GADAG	-58	247	**23.39**	-6	234	**2.72**
DHARWAD	-80	527	**15.22**	-40	484	**8.33**
UTTARA KANNADA	-517	2,447	**21.13**	-120	1,477	**8.15**
HAVERI	-26	561	**4.70**	-19	537	**3.63**
BELLARY	-51	465	**10.95**	-18	437	**4.13**
CHITRADURGA	-32	572	**5.64**	-19	539	**3.49**
DAVANAGERE	-113	439	**25.74**	-15	415	**3.70**
SHIMOGA	-324	1,392	**23.25**	-121	1,111	**10.85**
UDUPI	-106	753	**14.11**	-66	666	**9.93**
CHIKMAGALUR	-348	1,397	**24.88**	-109	1,093	**9.98**
TUMKUR	-146	1,161	**12.61**	-83	1,050	**7.90**
BANGALORE	-45	321	**14.03**	-27	301	**8.83**
MANDYA	-79	511	**15.54**	-17	490	**3.51**
HASSAN	-60	1,071	**5.65**	-34	942	**3.62**
DAKSHINA KANNADA	-224	1,117	**20.03**	-40	770	**5.17**
KODAGU	-59	786	**7.57**	-6	427	**1.38**
MYSORE	-41	671	**6.08**	-19	633	**2.95**
CHAMARAJA NAGAR	-35	476	**7.38**	-7	334	**1.98**
GULBARGA	-22	515	**4.27**	-1	479	**0.13**
YADGIR	-41	255	**16.21**	0	241	**0.09**
KOLAR	-35	538	**6.52**	-12	336	**3.54**
CHIKBALLAPUR	-90	424	**21.33**	-16	345	**4.62**
BANGALORE RURAL	-41	444	**9.35**	-36	410	**8.77**
RAMANAGAR	-18	402	**4.46**	-18	364	**4.93**
Karnataka	**-2,741**	**20,608**	**13.30**	**-895**	**16,929**	**5.29**

"Urban market" variants (scenarios A2 and B2)

Under the "Urban market" scenarios, we assume that only urban demand is satisfied by commercial harvesting, while demand in rural deficit sites is met primarily by overexploitation of rural biomass resources. This assumption reduces the commercial harvesting pressure on forest resources in comparison to the Full market scenario and focuses the majority of harvesting pressure on farmlands and sparsely vegetated areas throughout the northen half of the state.

District-level NRB results are shown in Table 6. The state-wide fNRB is 13.0% for Scenario A2 (full demand) and 6.2% for Scenario B2 (conv. demand), which are comparable to the “Full market” scenarios. The differences arise in the specific Districts experiencing higher pressure. In these scenarios, variability of fNRB values is larger than the "Full market" scenarios. Here, the highest fNRB occurs in Yadgir (40 %), with Bagalkot, Bijapur and Raichur exceeding 30%. Scenario B2 shows similar results, but with lower magnitudes.

Table 6: NRB values according to Urban Market Scenarios. A2 & B2 (Urban market-tot & conv. Demand)

	Scenario A2 "urban market - full demand"			Scenario B2 "urban market - conventional demand"		
	NRB harvesting	Total harvesting	fNRB	NRB harvesting	Total harvesting	fNRB
District	kt od	kt od	%	kt od	kt od	%
BELGAUM	-402	1,700	**-23.7**	-166	1,419	**-11.7**
BAGALKOT	-210	567	**-37.0**	-96	445	**-21.6**
BIJAPUR	-242	758	**-31.9**	-98	598	**-16.3**
BIDAR	-23	382	**-6.1**	-13	365	**-3.5**
RAICHUR	-195	638	**-30.6**	-86	516	**-16.6**
KOPPAL	-108	408	**-26.6**	-46	334	**-13.7**
GADAG	-82	356	**-22.9**	-38	302	**-12.7**
DHARWAD	-21	483	**-4.4**	-7	454	**-1.5**
UTTARA KANNADA	-52	1,734	**-3.0**	-19	1,649	**-1.1**
HAVERI	-39	591	**-6.6**	-18	561	**-3.2**
BELLARY	-138	616	**-22.3**	-59	521	**-11.4**
CHITRADURGA	-163	743	**-22.0**	-71	634	**-11.2**
DAVANAGERE	-57	488	**-11.7**	-25	441	**-5.7**
SHIMOGA	-22	976	**-2.3**	-10	954	**-1.0**
UDUPI	-5	605	**-0.8**	-1	585	**-0.2**
CHIKMAGALUR	-24	977	**-2.5**	-10	952	**-1.1**
TUMKUR	-46	1,024	**-4.5**	-18	978	**-1.8**
BANGALORE	-6	275	**-2.2**	-3	270	**-1.1**
MANDYA	-31	528	**-5.9**	-14	498	**-2.7**
HASSAN	-115	1,102	**-10.4**	-52	1,017	**-5.2**
DAKSHINA KANNADA	-31	954	**-3.2**	-9	894	**-1.0**
KODAGU	-6	600	**-1.0**	-2	591	**-0.3**
MYSORE	-118	785	**-15.1**	-52	700	**-7.4**
CHAMARAJA NAGAR	-39	476	**-8.1**	-16	435	**-3.7**
GULBARGA	-200	762	**-26.2**	-83	635	**-13.0**
YADGIR	-191	474	**-40.3**	-90	367	**-24.7**
KOLAR	-30	457	**-6.7**	-20	442	**-4.5**
CHIKBALLAPUR	-16	375	**-4.3**	-10	365	**-2.8**
BANGALORE RURAL	-15	390	**-3.9**	-7	376	**-1.9**
RAMANAGAR	-49	422	**-11.6**	-23	386	**-5.8**
Karnataka	**-2,678**	**20,648**	**-13.0**	**-1,161**	**18,685**	**-6.2**

Summary of scenarios

State-level NRB estimates according to the scenarios considered are presented in Table 7, from which it is evident that Demand scenarios influence NRB levels, while Market scenarios influence the spatial distribution of excessive harvesting.

Table 7: Overview of NRB estimates according to main scenarios

fNRB values (M tons and % of tot harvesting)	**Demand scenarios**	
Woodfuels market scenarios	**A. Total Demand** 20,6 Mt	**B. excluding "marginal" wood in rural deficit areas** 17,2 Mt
1. Full market: all deficit originates commercial harvesting	Sc. A_1 **NRB: 2.7 Mt ; fNRB: 13.3 %** Highest impact in forest areas	Sc. B_1 **NRB: 0.9 Mt ; fNRB: 5.3 %** Highest impact in forest areas
2. Urban market: only urban deficit originates commercial harvesting	Sc. A_2 **NRB: 2.7 Mt ; fNRB: 13 %** Highest impact in rural areas	Sc. B_2 **NRB: 1.2 Mt ; fNRB: 6.2 %** Highest impact in rural areas

The spatial distribution of unsustainable harvesting according to scenarios' assumptions are best rendered in Figures 12 and 13.

Figure 12 shows the sustainability of harvesting according to the four scenarios. Commercial harvesting is clearly influenced by assumptions about how rural supply deficits are accommodated, If the rural supply deficit is accommodated with commercial harvesting on forest areas (as in scenarios A1 and B1), then commercial harvesting exceeds sustainable levels, with clear impacts throughout the forested areas of the Western Ghats. However, if the rural supply deficit is accommodated by overexploitation of local resources (as in scenarios A2 and B2) then commercial harvesting on forest areas remains above sustainable levels (green in map) and unsustainable harvesting is concentrated in rural areas, primarily in the northern half of the state.

Figure 13 shows an alternate perspective, with harvesting shown as a percentage of the stock of DEB. This indicates the expected rate of degradation induced by excessive woodfuel exploitation in each scenario. In A1 and B1, unsustainable harvesting occurs in forest areas where DEB stock is relatively high and degradation rates remain below 10%. In contrast, with scenarios A2 and B2, unsustainable harvesting takes place in poorly stocked rural areas, with high degradation rates ranging from 10 to 50%.

Probably, none of the options considered is entirely true but they are useful in showing the range of NRB values and the different locations where excessive harvesting could take place. These factors are strongly inter-related and influenced by land use patterns and economic factors. Mid-range assumptions concerning Demand scenarios and Market scenarios are probably more realistic than any of the extreme ones. It is in fact reasonable to assume that the deficit in rural areas originates at the same time: (i) excessive harvesting of the limited resources locally available (local NRB), (ii) shifting towards marginal fuelwood assortments (annual pruning, twigs, etc.) and crop residues and (iii) commercial harvesting of distant resources (possible remote NRB). Economic factors are probably key to determine the proportions of the three responses to rural deficit and may serve as weighting factor in future analyses.

Figure 12: Expected harvesting sustainability according to the four considered scenarios

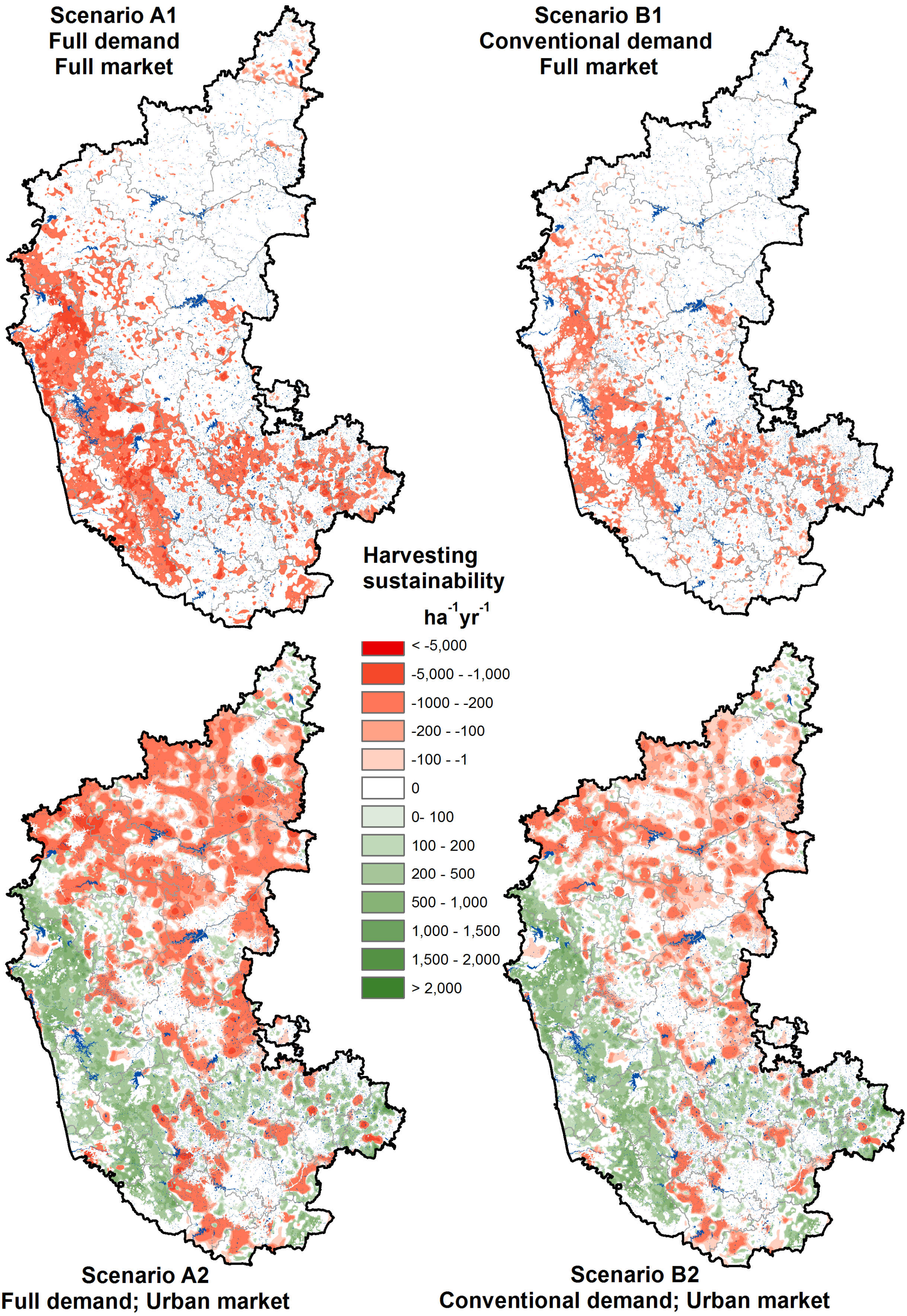
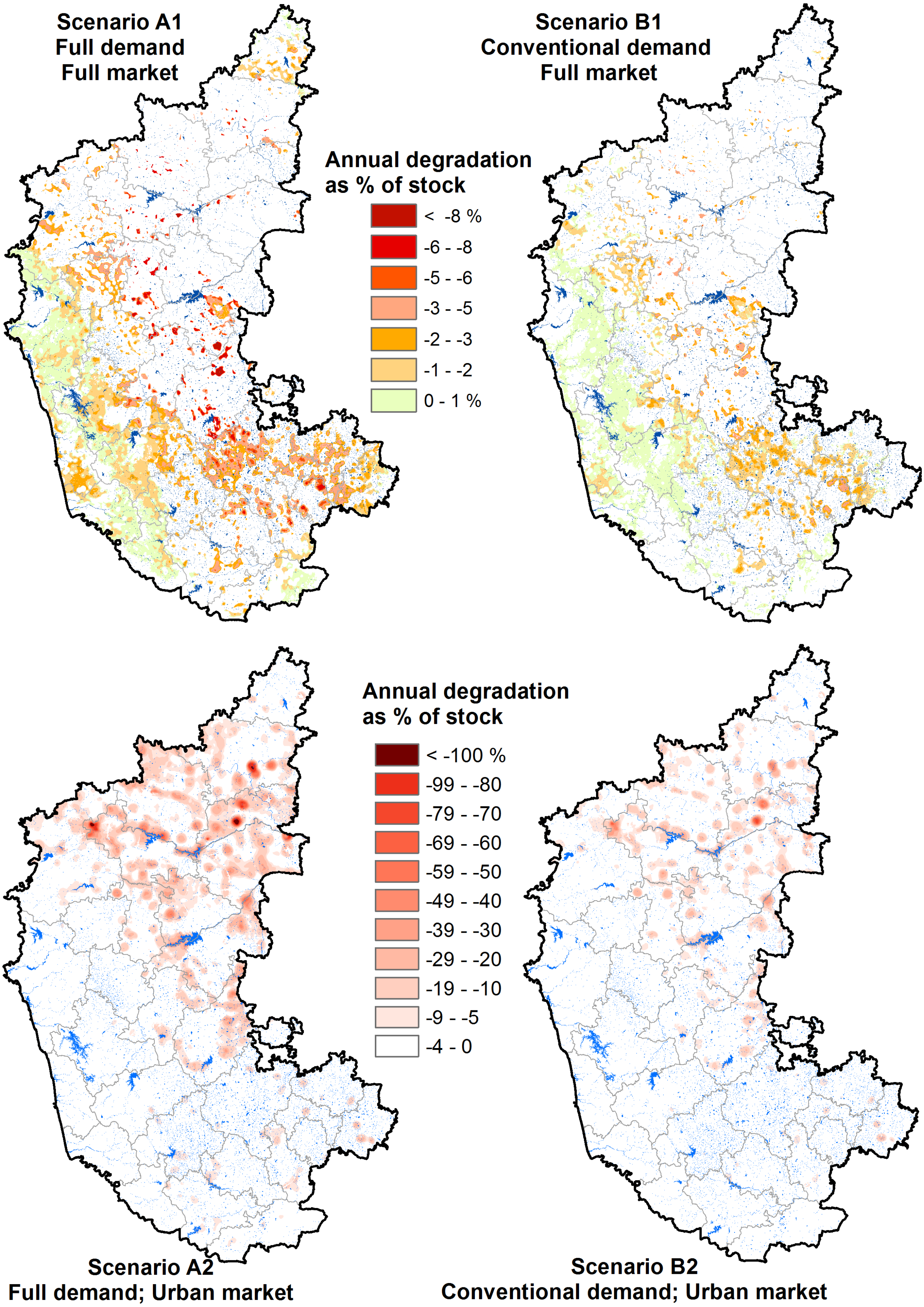


Figure 11: Annual degradation as percent of stock resulting from unsustainable harvesting according to the four considered scenarios



Note the different legends of A1, B1 compared to A2, B2 scenarios, which is due to the low stock in rural areas, where most unsustainable harvesting is taking place according to "Urban Market" scenario.

3.5 PROBABLE FLOW FROM/TO NEIGHBORING STATES

State boundaries pose no limit to the flow of fuelwood and charcoal in and out of Karnataka. It is quite probable (but totally un-documented) that deficit areas attract resources from surplus areas across the border. In order to estimate at least tentatively the probable flow of woodfuels, the commercial balance map from this study is overlaid to the commercial balance from the pan-tropical WISDOM study (Tier 1) from which surplus and deficit conditions just across the state border were estimated, as shown in Figure 14.

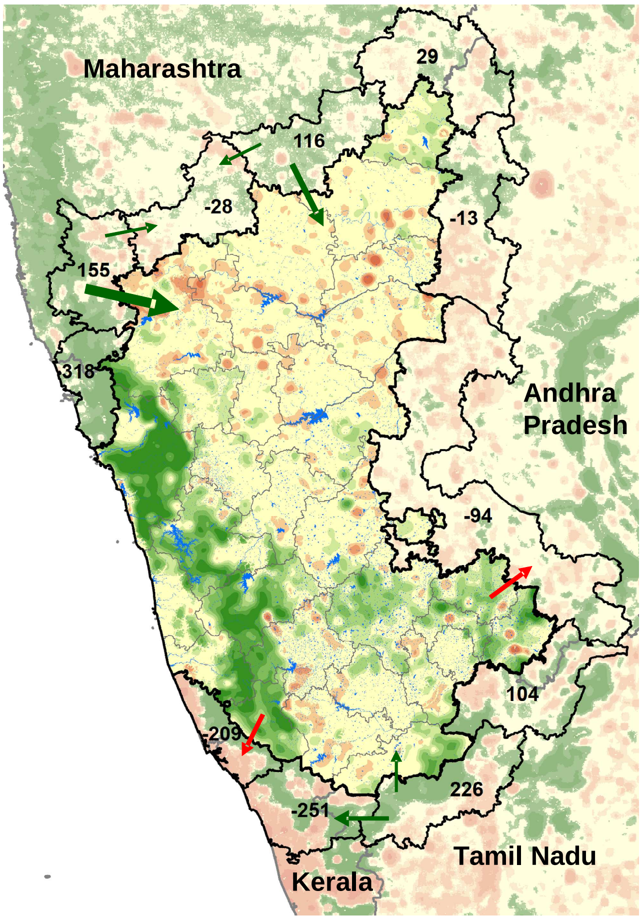
The gradient created by contrasting balance situation are used as indicators of likely in/out flows, assuming that only half of the surplus and deficit quantities across the border may be relevant on Karnataka front (the other half being oriented towards other States' internal areas).

On such basis the probable in/out flow includes:

- in-flow of 200-250 kt from Maharashtra to: Belgaum, Bagalkot, Bijapur and Yadgir
- out-flow from Kodagu and Dakshina Kannada to North Kerala of 200-250 kt
- marginal out-flow from Kolar and Chikballapur to Andhra Pradesh
- marginal in-flow from Tamil Nadu to Chamaraja Nagar

The estimation of in/out flow is only tentative since Tier 2 analysis was limited to Karnataka while the state boundaries do not actually limit in-country woodfuels flows. In general, in order to overcome this problem, WISDOM analyses are carried out over entire countries.

Figure 14: Flow from/to neighboring states



Note: Background Map: Commercial Balance from Pan-tropical WISDOM (Tier 1) [6]. Values in map: ½ of available surplus (positive)or deficit (negative) in kt od.

4. COMPARING TIER 1 AND TIER 2 RESULTS FOR KARNATAKA

In Tier 1 analysis, NRB estimates are produced at first sub-national level and consequently Karnataka is there represented as a single unit. The different supply and demand values applied in Tier 1 and Tier 2 and relative NRB estimates are shown in Table 8. The Tier 2 values shown in the table are relative to the "full market - full demand scenario" (Sc.A1) which matches the assumptions made in Tier 1.

The most relevant difference is in the estimated supply potential, with apparent Tier 1 under-estimation of 29% (28% for "commercial" supply). Demand estimates are closer, but still on the lower side in Tier 1, with 17 % less. These induce a Tier 1 commercial balance of -3 Mt, versus the -0.9 Mt of Tier 2.

The absolute values of NRB harvesting are reasonably close, with Tier 1 estimate 26% greater than Tier 2. When comparing the NRB estimates expressed as *fractions* of total harvesting, the difference appear more relevant (+81% for the expected fNRB) since total harvesting in Tier 1 is significantly smaller because part of Karnataka demand is projected to other Indian states. However, this difference would reduce significantly if the probable in-flow and, to a lower extent, outflow of woodfuels from/to other states is taken into account.

Table 8: Comparing Tier 1 and Tier 2 estimates for Karnataka

Thematic layer	Tier 1	Tier 2 "full market - full demand" scenario A1	Diff. (T1-T2)/T2	Remarks
	M t od	M t od		
Available supply potential	15.0	21.1	-0.29	Tier 1 supply is significantly under-estimated
"Commercial" supply potential	14.2	19.8	-0.28	
Woodfuels demand	17.2	20.6	-0.17	Tier 1 demand is slightly under-estimated
"Commercial" balance	-3.0	-0.9	2.33	
Extent of Woodshed area	Whole area	Whole area		
Total harvesting within the State	15.1	20.6	-.027	In Tier 1 harvesting is smaller than demand since part of Karnataka demand is projected to other states
Minimum NRB (M t)	1.68	1.4	0.20	
mfNRB (% of harvesting)	*11.1 %*	*6.8 %*	0.63	
Expected NRB (M t) (SIEF 0.8)	3.4	2.7	0.26	
efNRB (% of harvesting)	*24.1 %*	*13.3 %*	0.81	

Given the difference of scale and the total independence of source data, the two studies produced comparable results.

Besides the comparison of Tier 1 Tier 2, the Karnataka study provides useful elements on the adoption of different assumptions on the compositions of woodfuels used (conventional vs marginal) and on commercial harvesting mechanisms (full market vs urban market) that should be considered in the next version of the pan-tropical model.

5. CONCLUSIONS

Supply/demand balance

- From simple accounting, Karnataka has a positive balance even if whole demand is taken as conventional fuelwood… however:
- When considering local/commercial supply, the balance becomes negative (-0.9 Mt) if the whole demand is taken as conventional fuelwood (Scenario A) but it's still positive (+ 2.4 Mt) if we exclude the probable use "marginal" fuelwood in wood-scarse rural areas (Scenario B).

Analysis of the probable commercial harvesting and NRB estimates

- In spite of the somewhat balanced situation described above, Karnataka presents non-renewable harvesting fractions (fNRB) even when more optimistic assumptions are made.
- These fNRB values are not high, compared to other countries, but indicate the presence of a progressive process of degradation.
- Statewide fNRB values range between 5-6% for Scenario B and ~13% for Scenario A. District-level fNRB values range up to 30-40% in the most pessimistic scenario (A2). However, even the worst-case scenarios results in estimates that are much lower than fNRB values currently being used to quantify carbon emission reductions in cookstove and biogas projects in Karnataka, which average 87% across 14 projects (29).

Assumptions made and NRB estimates

- Assumptions on the Demand are responsible for the range of fNRB values:
    - 13-13.3 % if whole woodfuel demand is taken without distinction of type and sources, and implicitly taken as "conventional" (Sc. A1, A2)
    - 5.3-6.2 % after estimation and exclusion of marginal fuels in wood-scarce rural areas (Sc. B1, B2)
    - The use of marginal wood products reduces significantly the pressure on forests but it's worth recalling that such practice has a direct impact on soil fertility, although not discussed in this study. The impact is on the reduced re-integration of twigs, leaves and residues' nutrients into the soil of forests, plantations and agricultural fields. If protracted over time, this produces a progressive loss of soil fertility, with consequent reduction of crop productivity and an increased level of vulnerability and worsened living conditions.
- Assumptions on which part of the local deficit is served by commercial harvesting make little change on NRB estimates state-wise, but induce very significant differences concerning the areas that are likely to be overexploited:
    - (**Full Market Scenario**) Assuming that commercial harvesting is originated by all local deficits (i.e. demand for woodfuels that cannot be satisfied by wood resources located within 10 km) including urban and rural deficit
    - with this assumption, rural areas put little pressure on their scarce local resources and good part of the rural demand joins urban demand to generate commercial harvesting that impact accessible forest areas.
    - In this Scenario the District under stronger pressure are:
        - DHARWAD, UTTARA KANNADA, DAVANAGERE, SHIMOGA, UDUPI, CHIKMAGALUR, TUMKUR, BANGALORE, MANDYA, DAKSHINA KANNADA, CHIKBALLAPUR, BANGALORE RURAL
    - (**Urban Market Scenario**) Assuming that commercial harvesting is originated only by major deficit areas (i.e. urban centers and concentration of rural centers) while rural deficit remains local with consequent overexploitation of resources located within 10 km from consumption sites.
    - with this assumption, rural areas put high pressure on their scarce local resources and commercial harvesting is much lighter as is serves almost exclusively urban demand (which

is much less than rural). Consequently, forest harvesting remains below the sustainable production potential while non-commercial overexploitation concentrate on the limited resources located in rural areas.

- In this case, the Districts under stronger pressure are: BELGAUM, BAGALKOT, BIJAPUR, RAICHUR, KOPPAL, GADAG, BELLARY, CHITRADURGA, MYSORE, GULBARGA, YADGIR

Probable in/out flow of woodfuels

- No records are available on the flow of fuelwood in and out of the State.
- Commercial surplus map from the Pan-tropical WISDOM dataset [6] indicates surplus and deficit areas along Karnataka border .
- Using deficit areas as poles of attraction from surplus resources across the border, probable in/out flow could be estimated.
- This analysis indicates:
    - a significant in-flow from Maharashtra to Belgaum, Bagalkot, Bijapur and possibly Yadgir Districts
    - A significant out-flow from Kodagu and Dakshina Kannada Districts to North Kerala
- Most probable impact of these flows is the mitigation of the deficit in northern Districts and a lower fNRB in forest areas (sc. A1, B1) or in rural areas (sc. A2, B2) of these regions.

Critical assumptions affecting the scenarios:

Among the numerous factors that affect the level and location of NRB harvesting, the following appear particularly relevant and at the same time particularly elusive due to the absence of field observations and reference data:

a) Inclusion/exclusion of “marginal” wood in rural areas

b) Commercial woodfuel markets serving/not serving rural deficit areas

c) Management factor

Alternative scenarios were produced assuming the extremes of the first two factors, in order to simulate what happens in rural areas where woodfuel use is high but wood resources are scarce. None of the assumptions considered is entirely true but they are useful in showing the range of NRB values and the different locations where excessive harvesting could take place. These factors are strongly inter-related and influenced by land use patterns and economic factors.

Mid-range assumptions concerning factors (a) and (b) are probably more realistic than any of the extreme ones. It is in fact reasonable to assume that the deficit in rural areas originates at the same time: (i) excessive harvesting of the limited resources locally available (local NRB), (ii) shifting towards marginal fuelwood assortments (annual pruning, twigs, etc.) and crop residues and (iii) commercial harvesting of distant resources. Economic factors are probably key to determine the proportions of the three responses to rural deficit and may serve as weighting factor in future analyses.

Data gaps and weaknesses

The development of WISDOM Karnataka implied several assumptions and some tentative value attributions to fill in for information gaps, as discussed in the previous sections. In order to improve and consolidate the knowledge base these assumption 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

- The land cover data used is out-of-date and should be replaced by recent and reliable map maintaining good detail on vegetation densities within and outside forests to allow biomass mapping.
- There is little data on sustainable productivity in forests, very little on forest and agricultural plantations 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. For instance, *prosopis juliflora* is becoming more and more relevant in rural fuelwood mix and its current role and real potential should be investigated.

Data weakness on demand

- 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)
- Consumption surveys should make the effort to differentiate “conventional” fuelwood made of stem wood and branches from “marginal” fuelwood made of twigs and smaller branches, which are not considered among forest products, and that are often produced through annual or periodic pruning of farm trees and shrubs, hedges, etc..that are not represented by conventional MAI values.
- 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. and the use of crop residues certainly produce more fuelwood or alternative biomass fuel than it is generally assumed

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A1.2 : FSI reports

FSI publications:

Extent, Composition, Density, Growing Stock and Annual Increment of India's Forests (NFAP) (Price Rs.250/-) [1995]

Karnataka inventory reports

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84. Inventory Report of Non-Forest Area of Bangalore Rural District [2000]
85. Inventory on NFA of Karnataka state (Pilot Survey) [Draft]

ANNEX 1: CONSUMPTION BY SECTOR

Table A1.1 : Per capita consumption of woodfuels users

		Fuelwood		Charcoal
		Rural	Urban	All
District	Region	ad kg/user/year	ad kg/user/year	w.eq. ad kg/user/year
BAGALKOT	Maidhan	442	213	208
BANGALORE	Maidhan	562	213	208
BANGALORE RURAL	Maidhan	562	213	208
BELLARY	Maidhan	427	213	208
BIDAR	Maidhan	263	213	208
BIJAPUR	Maidhan	442	213	208
CHAMARAJA NAGAR	Maidhan	661	213	208
CHIKBALLAPUR	Maidhan	274	213	208
CHITRADURGA	Maidhan	588	213	208
DAVANAGERE	Maidhan	535	213	208
DHARWAD	Maidhan	529	213	208
GADAG	Maidhan	495	213	208
GULBARGA	Maidhan	464	213	208
HAVERI	Maidhan	532	213	208
KOLAR	Maidhan	274	213	208
KOPPAL	Maidhan	460	213	208
MANDYA	Maidhan	611	213	208
MYSORE	Maidhan	661	213	208
RAICHUR	Maidhan	460	213	208
RAMANAGAR	Maidhan	562	213	208
TUMKUR	Maidhan	365	213	208
YADGIR	Maidhan	464	213	208
BELGAUM	Malnad & Coast	558	234	208
CHIKMAGALUR	Malnad & Coast	657	234	208
DAKSHINA KANNADA	Malnad & Coast	1091	234	208
HASSAN	Malnad & Coast	861	234	208
KODAGU	Malnad & Coast	1040	234	208
SHIMOGA	Malnad & Coast	591	234	208
UDUPI	Malnad & Coast	1091	234	208
UTTARA KANNADA	Malnad & Coast	1142	234	208

Main Ref: Ranganathan, Subba Rao and G.S. Prabhu., 1993. Demand and supply of fuelwood in Karnataka

Table A1.2 : Woodfuels consumption in the residential sector

	Rural Households			Urban Households		
	Fuelwood	Charcoal	Tot Woodfuels	Fuelwood	Charcoal	Tot Woodfuels
District	kt od	kt od	kt od	kt od	kt od	% kt od
BELGAUM	1,353	0.3	**1,354**	66	0.3	**66**
BAGALKOT	465	0.1	**465**	68	0.1	**68**
BIJAPUR	600	0.1	**600**	39	0.6	**40**
BIDAR	234	0.2	**234**	38	0.3	**39**
RAICHUR	519	0.3	**519**	48	0.1	**48**
KOPPAL	420	0.2	**420**	26	0.0	**26**
GADAG	267	0.0	**267**	42	0.1	**42**
DHARWAD	303	0.0	**303**	53	0.2	**54**
UTTARA KANNADA	808	0.1	**808**	31	0.0	**31**
HAVERI	438	0.0	**438**	35	0.1	**35**
BELLARY	500	0.1	**500**	71	0.3	**71**
CHITRADURGA	608	0.4	**608**	21	0.1	**21**
DAVANAGERE	488	0.1	**488**	42	0.1	**42**
SHIMOGA	469	0.1	**469**	30	0.2	**30**
UDUPI	601	0.2	**601**	26	0.1	**26**
CHIKMAGALUR	415	0.1	**415**	10	0.0	**10**
TUMKUR	598	0.1	**598**	30	0.1	**30**
BANGALORE	137	0.2	**137**	67	1.0	**68**
MANDYA	678	0.1	**678**	16	0.0	**16**
HASSAN	912	0.1	**912**	13	0.0	**13**
DAKSHINA KANNADA	854	0.1	**855**	57	0.1	**57**
KODAGU	331	0.1	**331**	3	0.0	**3**
MYSORE	786	0.2	**787**	27	0.1	**27**
CHAMARAJA NAGAR	414	0.1	**414**	14	0.0	**14**
GULBARGA	622	0.2	**622**	66	1.0	**67**
YADGIR	363	0.2	**363**	24	0.0	**24**
KOLAR	219	0.1	**219**	27	0.1	**28**
CHIKBALLAPUR	201	0.1	**201**	17	0.0	**17**
BANGALORE RURAL	245	0.1	**245**	8	0.0	**8**
RAMANAGAR	341	0.1	**341**	16	0.1	**16**
Karnataka	**15,189**	**4.1**	**15,193**	**1,032**	**5.3**	**1,037**

Table A1.3 : Other consumptions and total consumption

	Fw in other sectors		Construction material		Total consumption	
	Rural	Urban	Rural	Urban	Rural	Urban
District	kt od	kt od	kt od	kt od	kt od	% kt od
BELGAUM	251	12	99	19	1,704	97
BAGALKOT	86	13	36	9	588	90
BIJAPUR	111	7	47	8	758	55
BIDAR	43	7	36	7	313	52
RAICHUR	96	9	40	8	655	65
KOPPAL	78	5	32	4	530	34
GADAG	50	8	19	6	336	56
DHARWAD	56	10	22	16	381	80
UTTARA KANNADA	150	6	28	6	986	44
HAVERI	81	6	35	6	553	47
BELLARY	93	13	43	14	635	99
CHITRADURGA	113	4	37	5	757	30
DAVANAGERE	90	8	37	10	615	60
SHIMOGA	87	6	31	10	588	45
UDUPI	111	5	23	5	736	36
CHIKMAGALUR	77	2	25	4	517	16
TUMKUR	111	6	58	9	767	45
BANGALORE	25	13	24	135	186	216
MANDYA	126	3	42	5	845	24
HASSAN	169	2	39	6	1,120	21
DAKSHINA KANNADA	158	11	30	15	1,043	83
KODAGU	61	1	13	1	405	5
MYSORE	146	5	49	19	981	51
CHAMARAJA NAGAR	77	3	24	3	514	19
GULBARGA	115	12	48	13	785	93
YADGIR	67	5	27	3	457	32
KOLAR	41	5	29	7	289	40
CHIKBALLAPUR	37	3	27	4	265	25
BANGALORE RURAL	45	2	20	4	310	14
RAMANAGAR	63	3	23	4	427	23
Karnataka	**2,813**	**192**	**1,043**	**366**	**19,050**	**1,595**

ANNEX 2: SUPPLY PARAMETERS

The land cover map in Figure A2.1 (raster format, 1 ha cell size) is based on the land cover data provided by Karnataka Forestry Department (KFD). The original vector map (mapname "forest_type.shp"), was produced by KFD with KSRSAC assistance, based on IRS PAN data (5.6m), photointerpretation and IRS LISS data (23m) multiseasonal for forest type separation. The map depicts 2001 situation.

Figure A2.1 : Land cover basemap

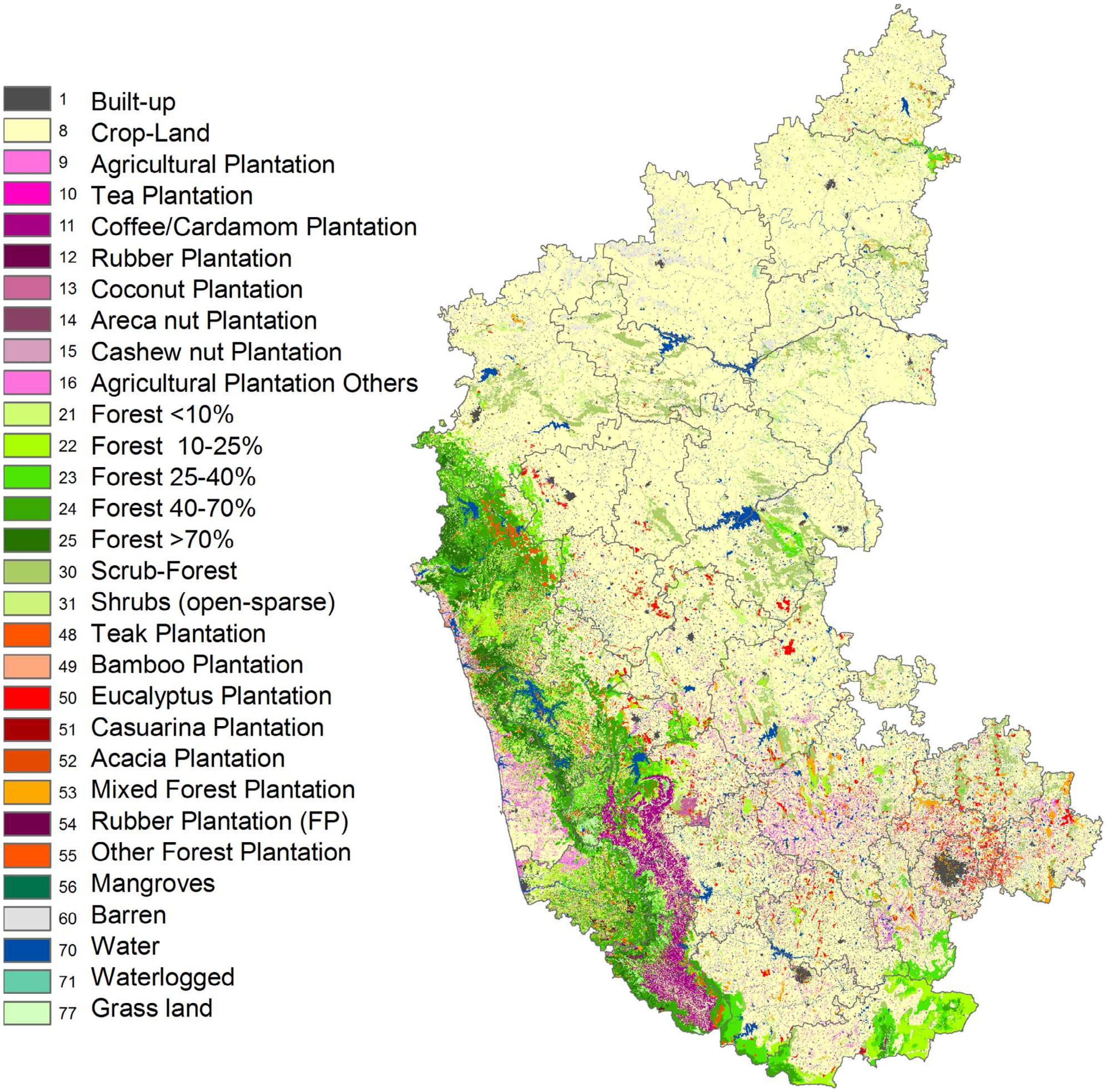


Table A2.1 : Reference District-wise values of stock and MAI of natural forests

	Standing Volume CUM/ha	MAI of volume CUM/ha/yr
BELGAUM	75	0.73
BAGALKOT	26	0.41
BIJAPUR	26	0.41
BIDAR	52	1.06
RAICHUR	26	0.41
KOPPAL	26	0.41
GADAG	26	0.41
DHARWAD	75	0.73
UTTARA KANNADA	150	2.98
HAVERI	75	0.73
BELLARY	26	0.41
CHITRADURGA	26	0.41
DAVANAGERE	26	0.41
SHIMOGA	75	0.73
UDUPI	150	2.98
CHIKMAGALUR	83	1.16
TUMKUR	52	1.06
BANGALORE	52	1.06
MANDYA	52	1.06
HASSAN	139	4.25
DAKSHINA KANNADA	150	2.98
KODAGU	114	2.33
MYSORE	85	3.50
CHAMARAJA NAGAR	85	3.50
GULBARGA	26	0.41
YADGIR	26	0.41
KOLAR	52	1.06
CHIKBALLAPUR	52	1.06
BANGALORE RURAL	52	1.06
RAMANAGAR	52	1.06

Adapted from [19]

Figure A2.2 : Stock vs MAI relations for natural broadleaves and coniferous formations in tropical and sub-tropical zones

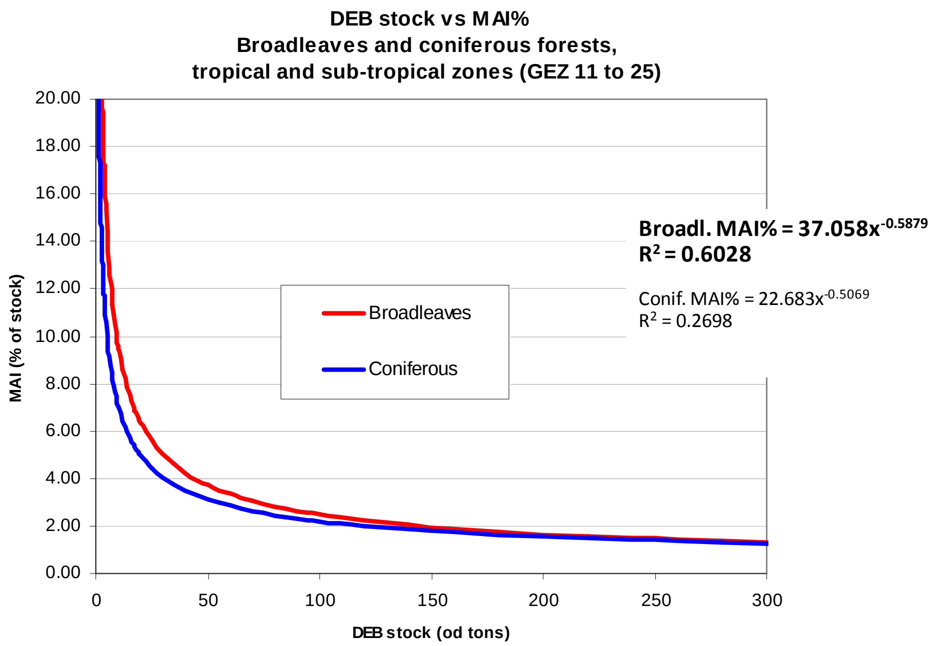
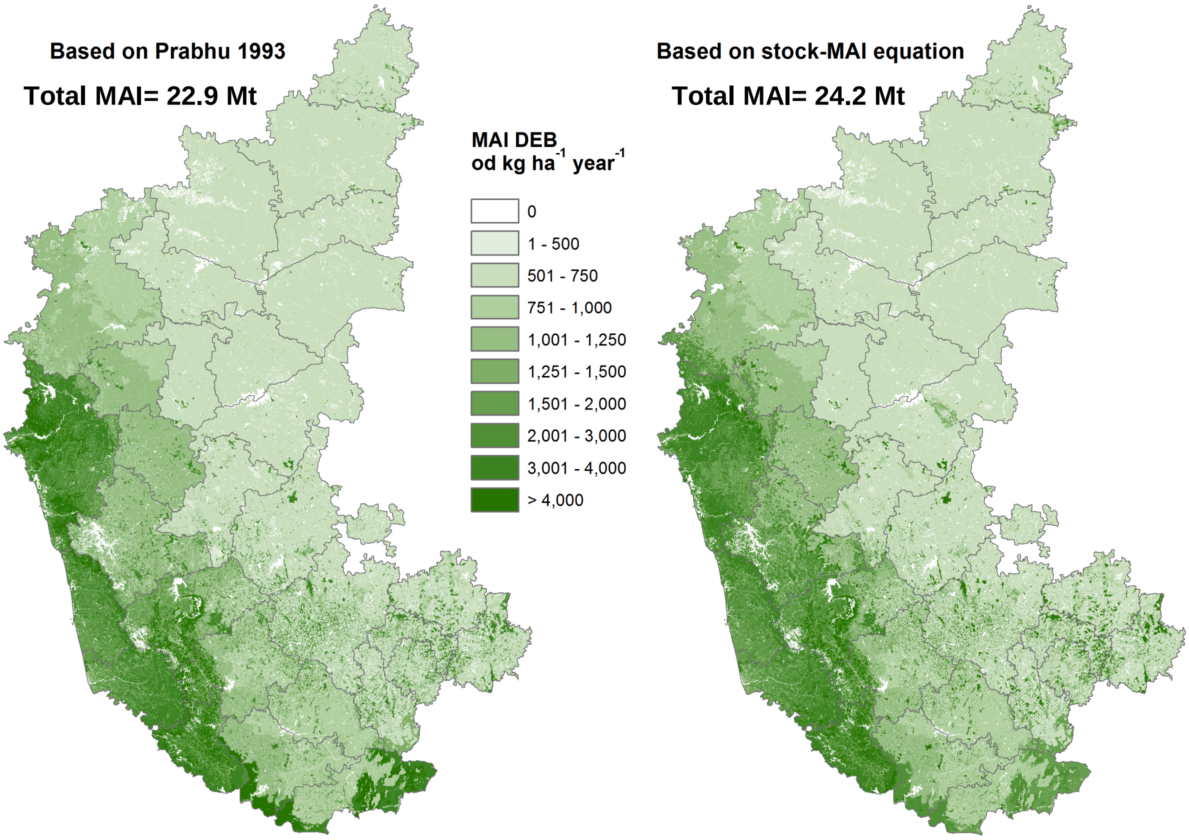


Figure A2.3 : Maps of DEB MAI based on Prabhu values [19] and based on the equation MAI=f(stock)



ANNEX 3: 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) 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 implemented in Tier 1 analysis. The specific features of the Karnataka study include:

- the estimation of woodfuels transport time (rather than travel time) considering the time needed for the return trip with additional friction due to the load of fuelwood or charcoal;
- the redefinition of the target locations based on the most detailed available national maps (road, tracts, trail, footpaths, railways and builtup areas),
- the use of 90m elevation model for slope mapping and
- use of best available land cover data, and the adaptation of friction factors and slope factors to Karnataka situation.

Target locations

The target locations are all accessible areas, including:

1. Populated places,:

    a. Densely populated areas (urban and villages). Defined as rural areas with population density above 500 inh. $km^{2\ -1}$. 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 **pop500_8mn**, derived from the map pop11. The value is 8 for the 8min/km (return trip; @ 15km/hr) assumed [same speed of builtup area])

2. Communication features:

    a. Road network (map: **rd_target_mn**), composed by:

        i. National and State highways (4 mn)
        ii. Secondary metalled road (6 mn)
        iii. Unmetalled road (8 mn)
        iv. Cart track (12 mn)

    Railways are not used as target since the accessible entry points are the stations that are already included in populated area layer.

The target locations (or source features of cost-distance analysis) is composed by the layers described above, merged into a single map (**target_mn**) with pop500_8mn over rd_target_mn.

Friction surface components

Land cover friction

The base friction values applied to land cover classes and communication features, intended as transport time in minutes per km (return trip loaded) assuming flat terrain are reported in Table A3.1.

Table A3.1: Friction values (transport time in minutes / km return trip) applied to land cover classes and communication features, assuming flat terrain.

		Going m/km	loaded factor	Return loaded	tot return trip min/km
Land cover	Built-up	4	1	4	**8**
	Crop-Land	16	1.5	24	**40**
	Agricultural Plantation	18	1.5	27	**45**
	Tea Plantation	18	1.5	27	**45**
	Coffee/Cardamom Plantation	18	1.5	27	**45**
	Rubber Plantation	18	1.5	27	**45**
	Coconut Plantation	18	1.5	27	**45**
	Areca nut Plantation	18	1.5	27	**45**
	Cashew nut Plantation	18	1.5	27	**45**
	Agricultural Plantation Others	18	1.5	27	**45**
	Forest <10%	24	1.5	36	**60**
	Forest 10-25%	27	1.5	40.5	**67.5**
	Forest 25-40%	27	1.5	40.5	**67.5**
	Forest 40-70%	30	1.5	45	**75**
	Forest >70%	30	1.5	45	**75**
	Scrub-Forest	24	1.5	36	**60**
	Shrubs (open-sparse)	20	1.5	30	**50**
	Teak Plantation	20	1.5	30	**50**
	Bamboo Plantation	20	1.5	30	**50**
	Eucalyptus Plantation	20	1.5	30	**50**
	Casuarina Plantation	20	1.5	30	**50**
	Acacia Plantation	20	1.5	30	**50**
	Mixed Forest Plantation	20	1.5	30	**50**
	Rubber Plantation (FP)	20	1.5	30	**50**
	Other Forest Plantation	20	1.5	30	**50**
	Mangroves	40	1.5	60	**100**
	Barren	16	1.5	24	**40**
	Water	60	1	60	**120**
	Waterlogged	40	1.5	60	**100**
	Grass land	18	1.5	27	**45**
Target location layers	dense pop builtup &villages (>500/km2)	4	1	4	**8**
	National Highway	2	1	2	**4**
	State Highway	2	1	2	**4**
	Secondary metalled road	3	1	3	**6**
	Unmetalled road	4	1	4	**8**
	Cart Track	6	1	6	**12**
Other features	Footpath	12	1.33	16	**28**
	Railway	3	1	3	**6**

Land cover friction map: **fric_lc_mnkm**. Friction of land cover classes in minutes per km considering round trip (return trip loaded). This friction map does NOT include footpaths (that are added AFTER application of slope factor)

Elevation factor

No speed reduction factor was applied on account of elevation since the influence of elevation on travel time is assumed to be significant above 2000 msl and the highest place in Karnataka is 1890 msl.

Slope factor

The slope map was produced on the basis of the Digital Elevation Model of 90m spatial resolution (source:

SRTM[8] 3 arc-second). The effect of slope on travel speed is estimated following Nelson's approach, which was based on van Wagtendonk and Benedict (1980)[9] 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 Karnataka 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_fac**). The estimated effect of slope on off-road speed and on crossing time are shown in Table A3.2.

Table A3.2: 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:

- The friction of land cover classes (no roads and paths) considering slope (in minutes per km considering round trip with return trip loaded) [**friclcslp_mkm**]

Adding friction of land cover classes (considering slope) and roads, tracks and footpaths. [**fric2lcslpmkm**]

Final friction map for local accessibility to nearest target feature as minutes per meter : **fric2_m_m** (=fric2lcslpmkm / 1000). Friction and target maps are shown in Figure A3.1.

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

Source: **target_0**; Cost: **fric2_m_m** = **cd_min**

Results of transport time mapping

The results of the analysis are presented in Figure A3.2 that shows the map of travel time to nearest accessible feature (minutes of transport to nearest target feature, return trip).

[8] Digital terrain model data downloaded from : http://dds.cr.usgs.gov/srtm/version2_1/SRTM3/Eurasia/
[9] van Wagtendonk, J. W. and Benedict, P. R. 1980. Travel time variation on backcountry trails. Journal of Leisure Research 12 (2): 99-106.

Figure A3.1: Friction and target features

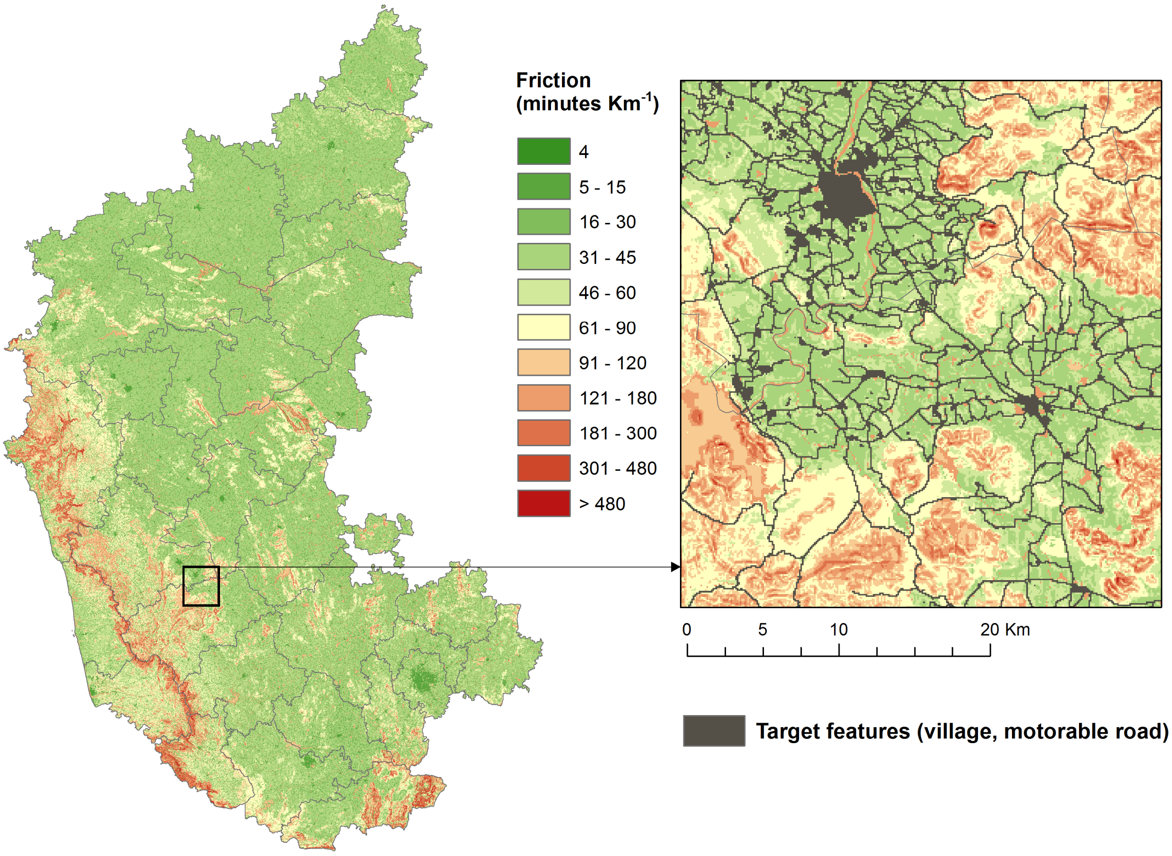
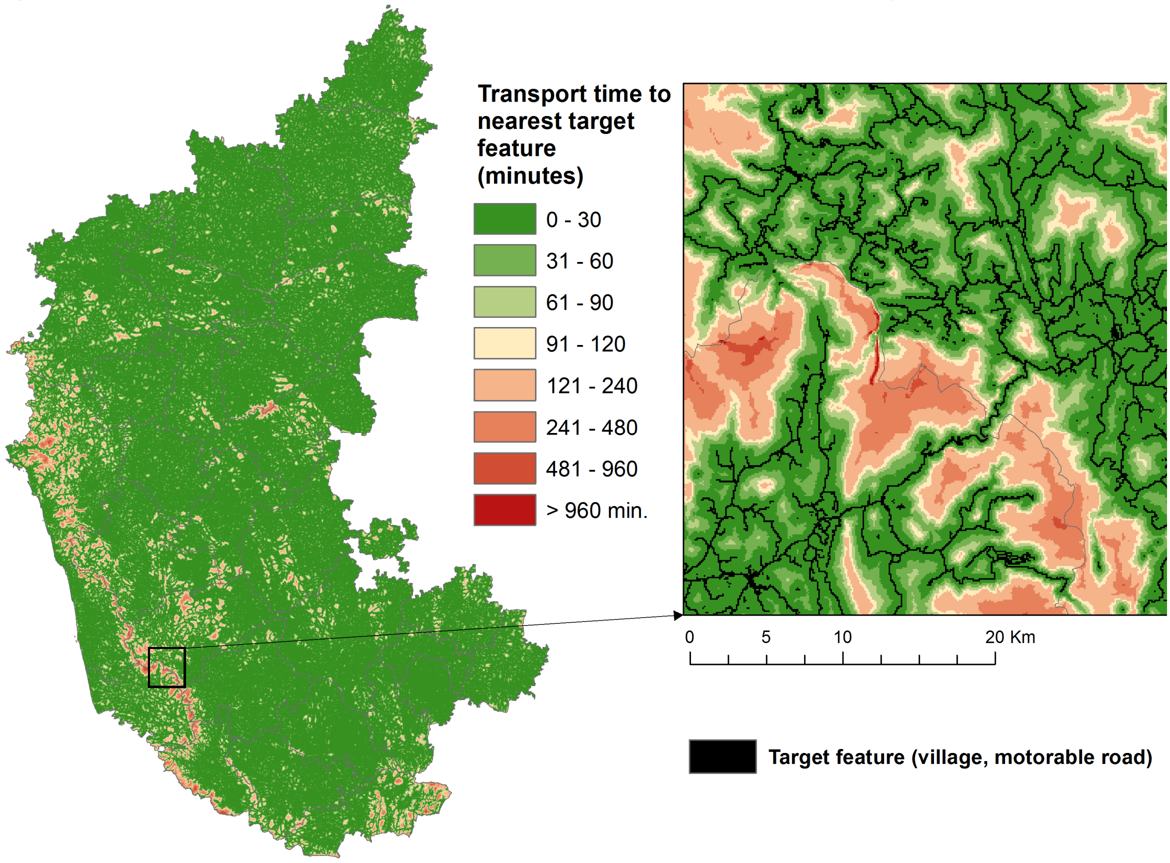


Figure A3.2: Fuelwood transport time map (minutes from the nearest target feature)



Accessibility

Next 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 8 hours off-road transport time to the nearest accessible feature are non accessible. Table A3.3 presents the hypothesis of conversion of travel time into percent of accessibility applied, by which 98.3 % of all resources are physically accessible and only 1.7 % inaccessible.

Table A3.3: Hypothesis of accessibility factors to be applied to DEB MAI resources based on travel time

							Non-accessible MAI (%) :	**1.7**
							Accessible MAI (%) :	**98.3**
	Transport time from nearest target feature							accessible MAI
cd2_20	minutes	hours	work days	MAI odt	% of MAI	access loss (%)	% accessible	kt od
1	60	1	0.1	20,811	86.1		**100**	20,811
2	120	2	0.3	2,035	8.4	3	**97**	1,973
3	180	3	0.4	656	2.7	7	**90**	591
4	240	4	0.5	302	1.3	11	**79**	239
5	300	5	0.6	162	0.7	15	**64**	104
6	360	6	0.8	95	0.4	19	**45**	43
7	420	7	0.9	58	0.2	23	**22**	13
8	480	8	1.0	32	0.1	22	**0**	0
9	540	9	1.1	17	0.1	0	**0**	0
10	600	10	1.3	8	0.0	0	**0**	0
11	720	12	1.5	5	0.0	0	**0**	0
12	840	14	1.8	1	0.0	0	**0**	0
13	960	16	2.0	0	0.0	0	**0**	0
14	1,080	18	2.3	0	0.0	0	**0**	0
15	1,200	20	2.5	0	0.0	0	**0**	0
16	1,440	24	3.0	0	0.0	0	**0**	0
17	1,800	30	3.8	0	0.0	0	**0**	0
18	2,160	36	4.5	0	0.0	0	**0**	0
19	2,880	48	6.0	0	0.0	0	**0**	0
20	> 2,880	> 48	> 6	0	0.0	0	**0**	0
				24,180				23,773

ANNEX 4: PROTECTED AREAS