SiteRight

Accelerating solar and wind energy in India by reducing socio-ecological risks

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INTRODUCTION

The projected buildout for renewable energy in India will require vast stretches of land (Kiesecker et al. 2020). Poorly sited solar and wind projects can have significant impacts on wildlife and habitats while also severely affecting rural communities that are highly dependent on common lands for livelihoods and subsistence (Beck and Nesmith 2001; Chopra and Dasgupta 2002; Kiesecker and Naugle 2017; Lakhanpal and Chhatre 2018; Rehbein et al. 2020; Santangeli et al. 2016). These socio-ecological impacts can lead to conflict which delays and increases project costs, thereby slowing the transition to a low-carbon energy future for India (Worsdell and Sambhav 2020). To minimize delays and costs, siting considerations must be evaluated early in the project development process and guided to areas of lower impacts for people and nature. If we take steps today to guide the expansion of RE to areas with lower social and environmental impacts, we can develop more than enough RE – in fact, we can achieve more than 10 times our 2022 capacity goal (Kiesecker et al. 2020)

Many sources of information exist that can support lower impact solar and wind development. Central and state wildlife and natural resource agencies, rural and tribal development Ministry and departments, science-based civil society organizations, and academic institutions provide information that can and should support lower impact siting. However, despite the wealth of data and information to date this has not been packaged in a way that would help identify lower impact areas.

Decision-support tools can help in operationalizing regulatory guidelines and performance standards and enhance effectiveness of their implementation. The tools complement such frameworks in the following ways:

- Cost: Implementation of frameworks such as the one highlighted above for all major solar and wind projects will need significant investment by developers. In the absence of early screening tools, projects in areas of conflict will move forward and later encounter problems leading to higher project costs.
- Lack of independent verification: There is no independent process to verify that voluntary socioenvironmental impact assessments were rigorous, used the best available science, or identified risks to environment or people that can be adequately mitigated. Besides, there is no independent confirmation that demonstrated a commitment to abandoning high-risk projects. Tools can ensure that only verified information is used for assessments.
- Lack of transparency: Detailed results of such assessments even if carried out are seldom shared, making it difficult to ascertain the specific information used, which stakeholders were consulted, the rigor of the overall analysis, what concerns were identified, and whether impacts to sensitive species can be adequately mitigated. This means that outside parties, including power purchasers and investors, often struggle to understand the nature and extent

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of identified issues and whether conclusions are based on the best available science. A widely accessible tool can help in bring greater transparency to this process.

- Project investments occur before the assessment: Such assessments are typically carried out after site has been identified and site-level investments have occurred, creating a disincentive to abandon even those projects that pose significant socio-ecological risk. Tools can help in quick initial screening of project sites before investments occur.

The Nature Conservancy believes that the use of such environmental and social management frameworks can drive solar and wind facilities to lower impact sites when (a) these frameworks are used early in the project development process, (b) when rigorously applied, and (c) when there is commitment to abandoning projects that have significant impacts which cannot be mitigated.

To follow these frameworks and support low-conflict solar and wind development, The Nature Conservancy and partners created the SiteRight Tool. SiteRight tool promotes a positive vision for renewable energy by demonstrating that ambitious solar and wind development goals are achievable on sites with minimal risk of biodiversity or social conflicts. Power purchasers acquiring solar or wind-generated electricity from lower impact sites may meet renewable energy goals while avoiding impacts to sensitive habitats or rural communities. Likewise, developers are less likely to encounter socioecological-related project delays and cost overruns in lower impact areas, thus resulting in a more reliable and efficient deployment of renewable energy.

The SiteRight tool is created to identify areas where solar and wind development is less likely to encounter socio-ecological conflicts, thereby helping to reduce project delays and cost overruns. This document summarizes the data and assumptions included in the SiteRight tool, as well as how we intend the tool to be used.

SITERIGHT TOOL

The Nature Conservancy's SiteRight tool is designed using the best available data to serve as an important source of information to support screening earlier in the project siting process. It should be one of the sources of information that developers, policymakers, financial institutions, and power purchasers can consider when making decisions about siting. **The tool is not intended to replace detailed site-level analysis of impacts or consultation with relevant agencies before making siting decisions.**

The SiteRight tool has three distinct modules (Figure 1) to support siting decisions in various contexts.

As a proof of concept, the Site Assessment and Planning modules focus on only the two states of Madhya Pradesh and Maharashtra. The two states together account for nearly 20 percent of the country's capacity goal of 160GW from solar and wind energy by 2022 (MNRE 2018). This region also has some of India's best natural habitats, including forests and grasslands, in addition to a large proportion of India's rural communities that are heavily dependent on land for their livelihoods and subsistence. Further work will be directed toward implementing these two modules in other critical states.

Figure 1: Modules of SiteRight Tool

<u>Awareness Module</u>

The awareness module helps demonstrate the extent of potential ecological conflicts if renewable energy development is pursued with the singular aim of maximizing resource potential. The analysis is based on achieving India's goals for solar and wind energy by the year 2022, and has been published in a peer reviewed journal (Kiesecker et al. 2020). The awareness module has been designed with the intention to help users understand the results of the analysis in an interactive and visually engaging manner.

The module presents two scenarios – (a) BAU and (b) Development of low conflict lands

(a) BAU: This scenario estimates extent of impacts to agriculture, forest, and other natural habitats if solar and wind energy is developed only based on resource potential, which is typically how development has occurred in the past. One can understand impacts at the pan-India level or for individual states, and explore maps to identify regions with potential impacts. It is also possible to explore a scenario where India's or a state's rooftop solar goals are not met, and the corresponding impacts if capacity is met through additional ground-based solar projects. The module can be explored just for solar or wind or both RE sources together.
(b) Low conflict lands: This scenario provides the extent of lower impact lands, at pan-India or individual state level, with viable solar and wind energy development potential.

<u>Site Assessment Module</u>

This module provides an initial assessment of potential ecological and social risks for solar or wind energy development for a user-defined area. It generates a report identifying ecological and social values that could be impacted by project development which could lead to conflicts. The intention is to support developers, policymakers and financial institutions in initial screening of potential sites for solar and wind projects for socioecological impacts, and hence (a) undertake a more focused on-the-ground assessment to validate the findings and accordingly design a management plan to mitigate impacts, or (b) abandon site for project development if the impacts are deemed significant and irreversible.

Planning Module

This module can be used to proactively guide siting of solar and wind development to lower impact areas at the regional or landscape level. It should be noted that the output of this module which is a map of lower impact sites is not intended to be used as a "go/no-go map". The map is intended to provide one source of information to inform siting at the regional level, but it should not be the only source of information used. As indicated earlier, it is not intended to serve as a substitute for an on-the-ground assessment but rather used in conjunction with other appropriate information on ecological and social values. However, if the proposed project is in areas of high conservation or social value, we recommend that projects proposed in these areas make the information derived from this tool available to relevant agencies and stakeholders.

SUPPORTING DATA

Conservation Values

The SiteRight tool identifies sensitive natural habitats and distributions of wildlife species that may be adversely impacted by solar and wind energy development. These include:

List A: Reported in the Assessment Module and treated as Exclusions in the planning Module

- Protected Areas: National Parks, Wildlife Sanctuaries, and Tiger Reserves (WII, 2018)
- Tiger Corridors (WII, 2018)
- Forest Cover (NRSC 2018)

List B: Reported in the Assessment Module but not treated as Exclusions in the planning Module

- Important Bird Areas (Bird Life International, 2019)
- Key Biodiversity Areas (KBA Secretariat, 2019)
- Areas with high reforestation potential (see appendix D)
- Threatened and Endangered Species ranges (Nayak and Vaidhyanathan 2016)

Social Values

Based on an index using 2011 census data at the village level, the SiteRight tool identifies potential areas with high social values for common lands that may be adversely impacted by solar and wind development. The variables used to calculate the index include:

- Percentage of unirrigated agriculture area
- Percentage of Scheduled Caste population
- Percentage of Scheduled Tribe population
- Livestock holding per household
- Percentage of common land
- Percentage of forest land
- Percentage of households using grass, thatch, bamboo, wood or mud as wall materials
- Percentage of households dependent on fuelwood for cooking

- Availability of markets
- Availability of pucca (sealed or paved) roads
- Distance from the block headquarter (district sub-division)

Engineering and Land-use Constraints

In addition to conservation and social values, the SiteRight tool identifies suitable areas for solar and wind development based on a suite of other indicators that determine land suitability. These include

- Solar Resource Potential
- Wind Resource Potential
- Transmission lines
- Substations
- Road and rail network
- Slope
- Agriculture areas
- Recommended setbacks from population centres, water bodies, and airports

Sources and delineation methods for individual layers listed above are detailed in Appendix D. All datasets, except a few under data sharing agreements, can be made available on request.

ANALYSIS AND RESULTS

Awareness Module

A detailed description of methods deployed for the analysis presented in the Awareness module is included in Kiesecker et al. (2020).

We find developing renewable energy on lands degraded by human activities, rather than placing new infrastructure within natural habitats or areas of high production agriculture, would reduce cumulative impacts and minimize land use conflicts. We estimate that lower impact lands have the potential capacity of 1789 GW across India, which is >10 times the 2022 goals. The results of these analyses indicate that we can accelerate a clean lower impact energy future for India – one that advances energy, climate, livelihood, and biodiversity goals in tandem.

At the same time, the total land footprint needed to meet India's 2022 renewable energy target in terms of generation is large, ranging from ~55,000 to 125,000 km^2. If renewable energy is advanced with the singular aim of maximizing resource potential, approximately 6700–11,900 km^2 of forest land and 24,100–55,700 km^2 of agricultural land could be impacted.

Site Assessment Module

The user-defined area is overlapped with layers on ecological and social values to generate a site assessment report. Only relevant variables that occur in the area of interest are identified in the report.

The assessment report provides the following information:

- Project size, and location (sub-district)

- Extent of low conflict area within the project area, estimated power capacity and power generation on suitable low conflict lands
- Social assessment: cumulative social value score, and score for each of the 11 indicators that comprise the cumulative score
- Environmental assessment
    - Extent of project area overlapping with exclusion layers (see Appendix A)
    - List of potentially present Threatened and Endangered Species in the project area
    - Extent of project area with high reforestation potential
    - List of important conservation areas (Tiger Reserves, National Parks, Wildlife Sanctuary, Tiger Corridor, Important Bird Areas, and Key Biodiversity Areas) within 10 km of the project area
- Technical assessment
    - Slope and other technical constraints

Planning Module

To demonstrate the potential for lower impact solar and wind development within the two states, we combined the data on ecological and social values with spatial information on engineering and land-use constraints identified through expert consultations and recommended guidelines consistent with the historical pattern of solar and wind development in India. Data sources and methods for modelled restrictions are detailed in Appendix A-D. We recognize that additional factors may affect development potential in specific locations, including the ability of transmission to evacuate the power, type of land ownership and willingness of landowners.

Solar: Input data were rasterized at a spatial resolution of 50m. We generated a preliminary binary map of areas suitable for solar development by excluding land with potential engineering and land-use restrictions (See Table A1 in Appendix A). To delineate suitable solar development areas with low potential for ecological conflicts, layers for conservation values in List A (see page 4) were subtracted from the preliminary Boolean suitability map. Finally, to eliminate isolated areas too small to support commercial solar development, patches less than $1km^2$ in size were removed. For each state or district, we quantified solar development potential on all suitable lands, as well as the subset of suitable lands identified as lower impact, based on a nameplate capacity density of 26 MW/km^2. Lower impact lands were then ranked according to a spatial model of suitability for solar development that is based on their vicinity to transmission lines, sub-stations and road network (See Appendix B). The top 10 most suitable parcels in a user-defined administrative unit are displayed to the user.

Wind: Input data were rasterized at a spatial resolution of 50m. We generated a preliminary binary map of areas suitable for wind development by excluding land with potential engineering and land-use restrictions (See Table A2 in Appendix A). To delineate suitable wind development areas with low potential for ecological conflicts, layers for conservation values in List A (see page 4) were subtracted from the preliminary Boolean suitability map. Finally, to eliminate isolated areas too small to support commercial wind development, patches less than $1km^2$ in size were removed. For each state or district, we quantified wind development potential on all suitable lands, as well as the subset of suitable lands identified as lower impact, based on a nameplate capacity density of 2 MW/km^2. Lower impact lands were then ranked according to a spatial model of suitability for wind development that is based on their vicinity to transmission lines, sub-stations and road network (See Appendix B). The top 10 most-suitable parcels in a user-defined administrative unit are displayed to the user.

The map of social values has been derived based on census data at village level from a set of 11 variables. More information on choice of variables and methodology for arriving at the cumulative score can be found in Appendix C.

Within the states of Madhya Pradesh and Maharashtra, we found that nearly 1,564,000 million hectares of land may be suitable for solar development (based on GHI, terrain, recommended setbacks, unsuitable land use, and small / isolated sites). Similarly, nearly 15,057,000 million hectares of land may be suitable for wind development (based on wind speed, terrain, recommended setbacks, unsuitable land use, and small / isolated sites). Some of these sites may be already developed since information on previously developed sites is not available and hence not incorporated in the analysis.

We demonstrate that over 2,130 GW of solar and wind energy may be developed in Madhya Pradesh and Maharashtra in areas of lower impacts to biodiversity and ecological values. More than 11% of this potential lies in areas where the potential of social conflict is relatively lower (cumulative social value score of less than or equal to 0.5) based on our initial assessment.

The results of these analyses indicate that we can accelerate a clean lower impact energy future for India – one that advances energy, climate, livelihood, and biodiversity goals in tandem.

CAVEATS

The output of the Planning Module should not be used as a final or conclusive determination of suitable or unsuitable sites. Identified land parcels – those that have relatively low conservation or social value – are not “go areas” just as remaining areas are not “no-go areas.” The outputs of these modules do not replace other data and information outlined in relevant environmental and social management frameworks, policies or regulations, consult communities as well as relevant agencies on wildlife, tribal or rural development at the central or state level, or conduct detailed site-level analyses of impacts.

Appendix A – Solar and Wind Energy Exclusion Criteria

Table A1: Solar Energy Exclusions

Exclusion	Source (see Appendix D for details)	Rationale
Population centers and buffer zones	To delineate cities, towns, villages, and buffer zones, areas of urban landcover = “Built-up” (NRSC 2018) were extracted and classified as cities, towns, or villages according to place locations in the OSM Places dataset (OSM 2019). Additional village areas were delineated as areas with Urban cover fraction > 60% (Buchhorn et al. 2020). Urban areas of cities and towns were buffered by 200 meters and village areas were buffered by 100 meters.	Construction and operation of large utility-scale solar power plants is not feasible in population centers.
Airports and 2 km buffer zones	Airport locations (OurAirports 2019) and 2 kilometer buffer zone.	Construction and operation of utility-scale solar power plants is not feasible in or near airports.
State and national highways and 50m buffer zone.	State and national highways (MapMyIndia 2017b) and 50 meter buffer zone.	Construction and operation of utility-scale solar power plants is not feasible on or near major roads.
Railways and 100m buffer zone.	Railways (MapMyIndia 2017a) and 100 meter buffer zone.	Construction and operation of utility-scale solar power plants is not feasible on or near railways.
Forested lands	Land cover = Evergreen Forests, Deciduous Forests, or Shrub/Degraded Forests (NRSC 2018)	Construction of utility-scale solar power plants is not suitable in forests because of large canopy cover.
Agricultural lands: kharif, rabi, zaid, double/triple crop, current fallow, or plantation.	Land cover = kharif, rabi, zaid, double/triple crop, current fallow, or plantation (NRSC 2018).	Construction and operation of utility-scale solar power plants is not desirable in agricultural lands.
Protected areas: national parks, wildlife sanctuaries, tiger reserves, and tiger corridors.	Nationally-designated parks (IUCN Category II), wildlife sanctuaries (IUCN Category IV), Tiger Reserves, and Tiger Corridors (WII 2018). This includes the original border of the Great Indian Bustard Sanctuary as designated in 1979. The sanctuary area was reduced significantly in 2012 and again in 2015 but the current sanctuary border is not publicly available.	Construction of utility-scale solar power plants is prohibited in national protected areas.

Steep slopes (slope > 8 degrees)	SRTM DEM, 1 arc-second (approx. 30 meters) resolution (NASA JPL 2017). Calculated topographic slope to delineate areas with slope greater than 8 degrees.	Construction of utility-scale solar power plants is not feasible on slopes >= 8 degrees.
Water bodies and buffer zones	Land cover = water min, water max, or littoral swamp (NRSC 2018). Permanent water bodies were buffered 500 meters. Ephemeral water bodies buffered 100 meters. Littoral swamp buffered 100 meters.	Construction and operation of utility-scale solar power plants is not feasible in water bodies or wetlands. Case for floating solar is not examined.

Table A2: Wind Energy Exclusions

Exclusion	Source (see Appendix D for details)	Rationale
Population centers and buffer zones	To delineate cities, towns, villages, and buffer zones, areas of urban landcover = "Built-up" (NRSC 2018) were extracted and classified as cities, towns, or villages according to place locations in the OSM Places dataset (OSM 2019). Additional village areas were delineated as areas with Urban cover fraction > 60% (Buchhorn et al. 2020). Urban areas of cities and towns were buffered by 200 meters and village areas were buffered by 100 meters.	Construction and operation of large utility-scale wind power plants is not feasible in population centers.
Airports and 10 km buffer zones	Airport locations (OurAirports 2019) and 10 kilometer buffer zone.	Construction and operation of utility-scale wind power plants is not feasible in or near airports.
State and national highways and 50m buffer zone.	State and national highways (MapMyIndia 2017b) and 50 meter buffer zone.	Construction and operation of utility-scale wind power plants is not feasible on or near major roads.
Railways and 100m buffer zone.	Railways (MapMyIndia 2017a) and 100 meter buffer zone.	Construction and operation of utility-scale wind power plants is not feasible on or near railways.
Forested lands	Land cover = Evergreen Forests, Deciduous Forests, or Shrub/Degraded Forests (NRSC 2018)	Construction of utility-scale wind power plants in forest areas is linked to deforestation and habitat fragmentation and hence considered unsuitable.
Wind speed < 5 m/s	Wind speed at 80 meters hub height according to a global 10 year weather model (Vaisala 2016), at 2 arc-minutes (approximately 5 km.) resolution, classified to identify areas with wind speed of less than 5 meters/second.	Utility-scale wind power requires wind speeds greater than 5 meters/second.

Protected areas: national parks, wildlife sanctuaries, tiger reserves, and tiger corridors.	Nationally-designated parks (IUCN Category II), wildlife sanctuaries (IUCN Category IV), Tiger Reserves, and Tiger Corridors (WII 2018). This includes the original border of the Great Indian Bustard Sanctuary as designated in 1979. The sanctuary area was reduced significantly in 2012 and again in 2015 but the current sanctuary border is not publicly available.	Construction of utility-scale wind power plants is prohibited in national protected areas.
Steep slopes (slope > 13.5 degrees)	SRTM DEM, 1 arc-second (approx. 30 meters) resolution (NASA JPL 2017). Calculated topographic slope to delineate areas with slope greater than 13.5 degrees.	Construction of utility-scale wind power plants is not feasible on slopes >= 13.5 degrees.
Water bodies and buffer zones	Land cover = water min, water max, or littoral swamp (NRSC 2018). Permanent water bodies were buffered 500 meters. Ephemeral water bodies buffered 100 meters. Littoral swamp buffered 100 meters.	Construction and operation of utility-scale wind power plants is not feasible in water bodies or wetlands.

Appendix B – Ranking of lower impact parcels

We used spatially referenced point observation data representing current wind and solar development to specify each model with parameters representing infrastructure, physical, and anthropogenic factors that may influence development potential. The training data was filtered to validated observations. Our pool of parameters included distance to roads, urban development transmission towers and electrical substations ≥ 10 acres in size. We also included wind speed, solar potential and a slope-aspect transformation [slope*cos(aspect)] (Stage 1976). Raster data representing our pool of model parameters (n=9) was extracted to the point training data. We applied collinearity (pairwise correlations) and multicollinearity (scaled multivariate redundancy) tests (Evans and Murphy 2014) to screen parameters that replicated variation in the model.

Because small sample sizes in the wind data would affect power and spatial estimate bias in other modelling approaches, we employed a novel nonparametric kNN imputation approach (Crookston and Finley 2007) using Independent Component Analysis (ICA) (Hyvärinen and Oja 2000). ICA finds a linear representation of non-gaussian data, through a latent variable mixture model, so that the components are statistically independent. This allows us to find nearest neighbours (observations most similar to each given training point), in the linearized multivariate space and derive scaled multivariate distances. These distances can be projected onto a matrix, based on the represented parameters space, through an imputation model. This is done by fitting an initial model based on our sampled parameter space (wind and solar development data). This model is then used to find nearest neighbours and associated multivariate distance (illustrating similarity) across the entire geographic parameter space. The ICC algorithm treats the data as deterministic quantities thus removing hard boundary limitations. Based on the imputation of the sampled locations to geographic parameters space we can assign multivariate distances to each raster cell. These multivariate distances represent the similarity between the sample locations and a given geographic "pixel". These distances can be standardized to represent a similarity index that can be thresholded to represent suitability of a resource, given its current observed characteristics. This allows us to estimate resource suitability based on current development patterns. Since, in some cases, the resource is not well developed across a geography, commonly used methods that use binominal data are not well supported. The imputation and ICA models were implemented in the spatialEco (Evans 2015), yaImpute (Crookston and Finley 2007) and fastICA (Marchini, Heaton, and Ripley 2019) R packages. We applied a model selection approach (Murphy, Evans, and Storfer 2010) in the rfUtilities R package (Evans and Murphy 2014; Murphy et al. 2010) to remove potential noise in the multivariate distances. Spatial model predictions were conducted using the R raster package (Hijmans 2020).

Solar and Wind model parameters

dist_roads – Distance to roads (OSM 2019)
dist_substations– Distance to substations (>10 acre) (OSM 2019)
den_substations (d= 45, 65, 110) – Density of substations (>10 acres)
dist_transmission – Distance to transmission (OSM 2019)
dist_urban – Distance to urban settlements (OSM 2019)
slpcosasp – Slope/Aspect interaction slope*cos(aspect)
solar_potential - Solar potential (solar model) (Vaisala 2017)
wind_speed – Wind speeds (wind model) (Vaisala 2016)

Model Results

		Solar Imputation Model	Wind Imputation Model
Madhya Pradesh	n	28	593
	Selection Parameters	den_substations65K, dist_substations, solar_potential	wind_speed, dist_substations, den_substations65K, den_substations110K
	Validation	Log Loss = 0.1614745 PCC = 91.07143 AUC = 0.8214286 Kappa = 0.7297 Type I error = 0.3571429 Type II error = 0 Gain = 0.9812265 Matthews coefficient = 0.7579367	Log Loss = 0.03776683 PCC = 99.32 AUC = 0.9865093 Kappa = 0.9818 Type I error = 0.02698145 Type II error = 0 Gain = 0.9978127 Matthews coefficient = 1
Maharashtra	n	45	1948
	Selection Parameters	solar_potential, den_substations110K, dist_urban, den_substations65K, dist_substations	den_substations110K, den_substations65K, dist_roads, dist_substations, dist_urban, wind_speed
	Validation	Log Loss = 0.2452331 PCC = 85.55556 AUC = 0.7111111 Kappa = 0.5229 Type I error = 0.5777778 Type II error = 0 Gain = 0.9800758 Matthews coefficient = 0.5950103	Log Loss = 0.02499717 PCC = 99.1582 AUC = 0.9833162 Kappa = 0.9774 Type I error = 0.03336756 Type II error = 0 Gain = 0.9972624 Matthews coefficient = 1

Appendix C – Estimating and mapping social values

Field research establishes that common lands such as community pastures, community forests, the so called 'wastelands', and river banks are resources where every member has access and usage rights with specified obligations (Jodha 1986). These lands contribute US$5 billion annually to the incomes of poor households in India(Beck and Nesmith 2001). The importance of common lands is, however, not only economic; they are also central to many cultural and social activities of poor communities(Pala et al. 2014; Posey 1999). The significance of common lands is even more critical in areas with rainfed agriculture where these lands provide the foundation for agriculture and livestock based production systems(FES 2012; Jodha 2001). Therefore, the key hypothesis that formed the basis for developing the framework for mapping economic, social and cultural values of land is that the value of land (common lands) is higher in the context of areas where: (a) Commons is a predominant form of land use, (b) areas where agriculture is primarily rainfed, livestock population is high and there is high dependence on these lands for livelihoods, (c) areas inhabited by marginalized communities such as those from Scheduled Caste (SC) or Scheduled Tribes (ST) populations and (d) areas that are geographically remote (i.e. distant from markets and administrative centres). Table C1 identifies the indicators and the relationship these indicators have on social values. Each indicator is placed in the four broad categories mentioned previously. While this is not an exhaustive list of indicators, a pre-condition for selection of these 11 indicators has been the availability of secondary data. Data for each of the 11 indicators was normalized and then combined to derive a composite value. A higher composite value indicates higher dependence of the local community on these lands, and therefore any changes in the land-use will have a higher impact on the lives and livelihoods of the local communities.

Table C1. Social indicators mapped and used in composite social values map.

Broad Criterion	Indicator	Logic
Predominance of common land	% of forest land to total geographical area	Higher the % of forest land to total geographical area, higher the value
	% of other common land (grazing land, culturable wasteland and non-current fallows) to total geographical area	Higher the % of other common land to total geographical area, higher the value
Dependence on Commons	Livestock holding per household	Higher the livestock holding per household, higher is the dependence on Commons & thus higher value
	% of households depended on fuelwood for cooking	Higher the % of households depended on fuelwood, higher is the dependence and thus higher value
	% of unirrigated (rainfed) land to total agricultural land	Higher the % of rainfed land, higher is the dependence and thus higher value

	% of households with walls made of grass, thatch, bamboo, wood, mud	Higher the % of households with walls made of grass, thatch, bamboo, wood, mud, higher is the dependence on land and thus higher value
Marginalized communities	% of Scheduled Caste (SC) population to total population	Higher the % of Scheduled Caste (SC) population to the total population, higher the value (since they are more critically dependent on these lands)
	% of Scheduled Tribes (ST) population to total population	Higher the % of Scheduled Tribes (ST) population to the total population, higher the value (since they are more critically dependent on these lands)
Degree of remoteness	Availability of markets	Non-availability of markets indicates remoteness; more the remoteness, higher is the dependence
	Availability of pucca road	Non-availability of pucca roads indicates remoteness; more the remoteness, higher is the dependence
	Distance from Block headquarter	Greater distance from the Block headquarter indicates remoteness; more the remoteness, higher is the dependence

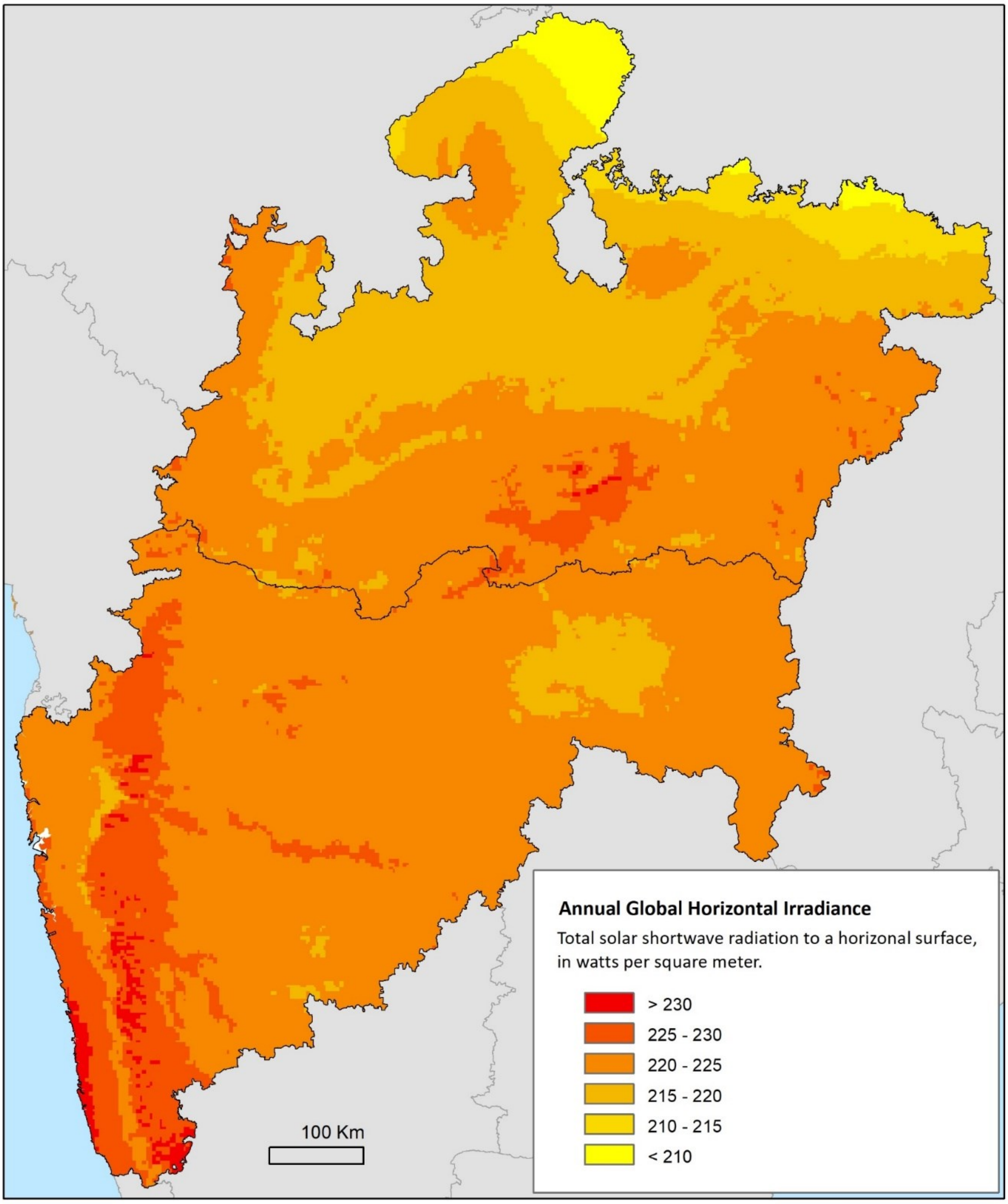
Data Source: Census, 2011; Livestock Census, 2012

Notes on Developing the Composite Social Values Map:

- Village level data for all the indicators have been extracted and collated.
- Urban areas, forest areas (other than village forest)/water bodies/military areas have been excluded from the data set.
- Villages that do not have data values for <=5 of the 11 indicators have been removed from the dataset. This represented 2% of the total villages in both the States. Additionally, if the village has a negative value for % of unirrigated area, then those values are treated as null values in the dataset.
- 7 of the 11 indicators (% of forest land, % of common land, % of unirrigated land, % of SC population, % of ST population, % of households with grass, thatch, bamboo, wood and mud as material of wall, % of households dependent on fuelwood) are in percentage form. They have been divided by the maximum percentage value of the specific indicator and re-scaled between 0 to 1 value for data normalization.
- 2 of the 11 indicators (livestock holding per household and distance to block headquarters) are numeric. Data for livestock holding per household was positively skewed for both the States and was therefore converted by using the following formula: log (value + 1) followed by max normalizing. Data for distance to block headquarter was positively skewed for both the States and was therefore converted by taking the square root followed by max normalizing.
- 2 of the 11 indicators (availability of market and availability of pucca road) are categorical in nature and have been given the value of 0 for non-availability and 1 for availability.
- Composite value has been calculated by taking an average of the values derived of the 11 indicators.

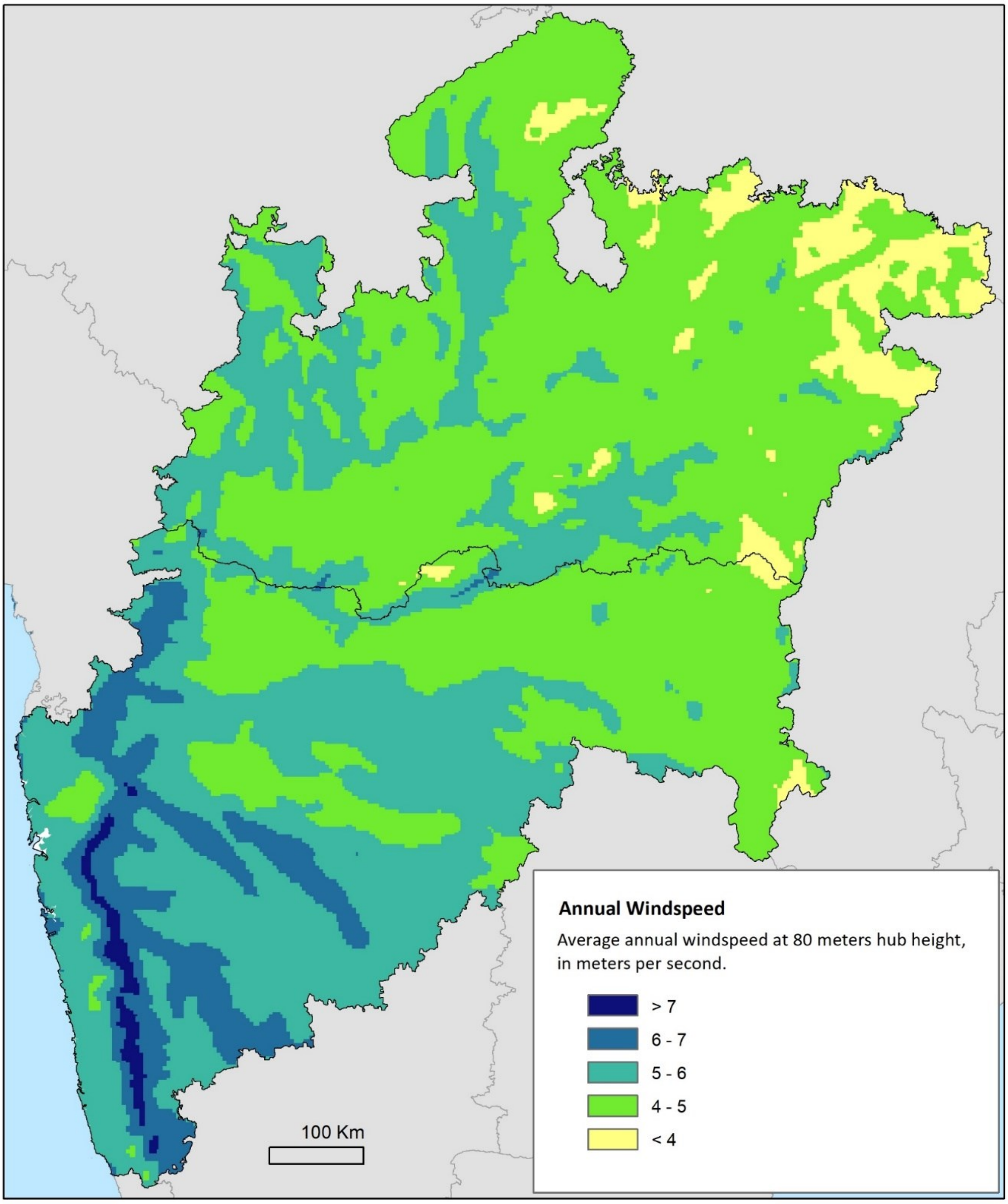
Appendix D – Layer Descriptions

Solar Energy Resource Potential



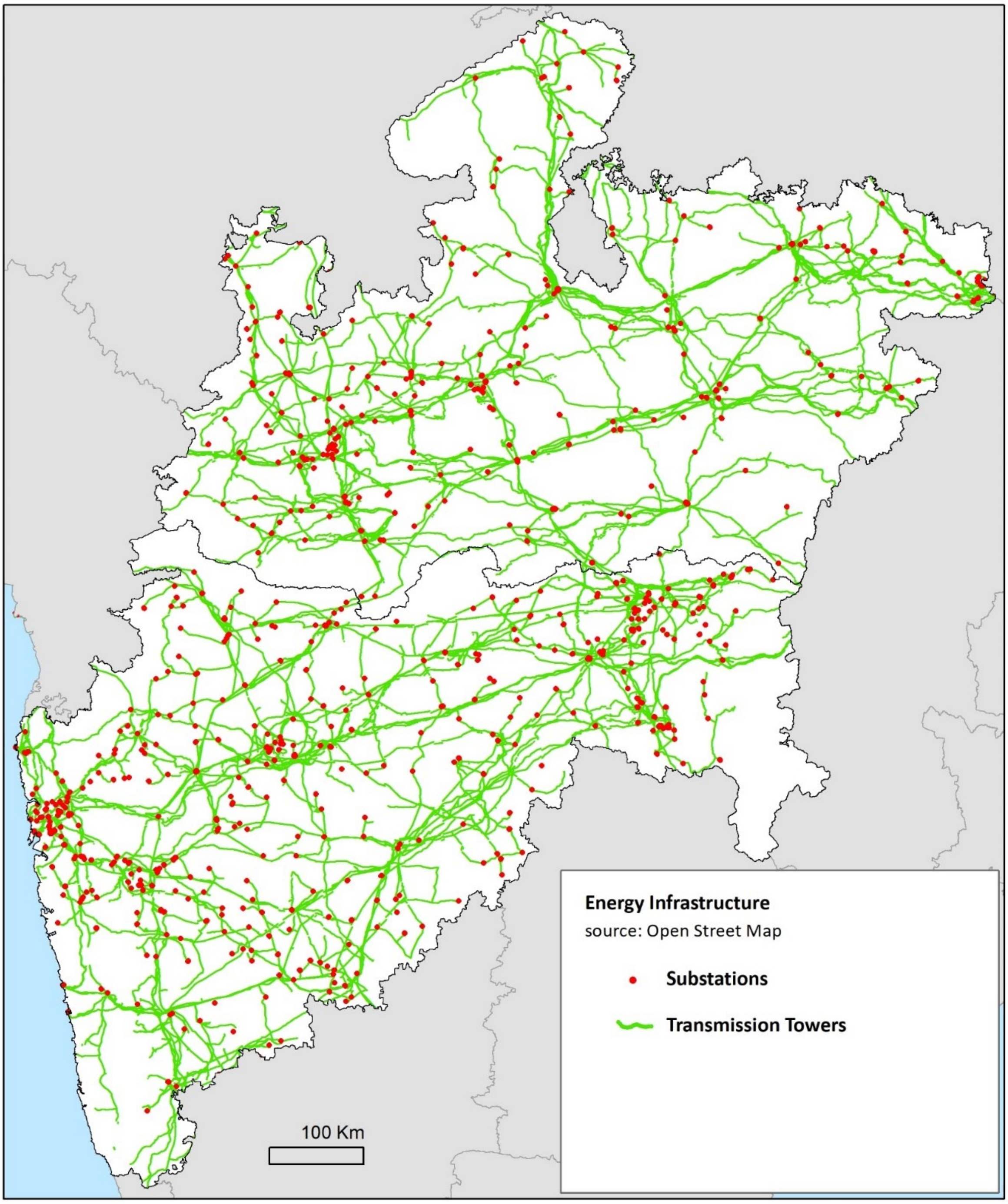
<u>Annual Global Horizontal Irradiance</u>: Raster dataset of solar radiation per unit area as an indicator of potential solar energy (resolution 0.033 decimal degrees or approximately 4 sq.km.). ***Source:*** (Vaisala 2017)

Wind Energy Resource Potential



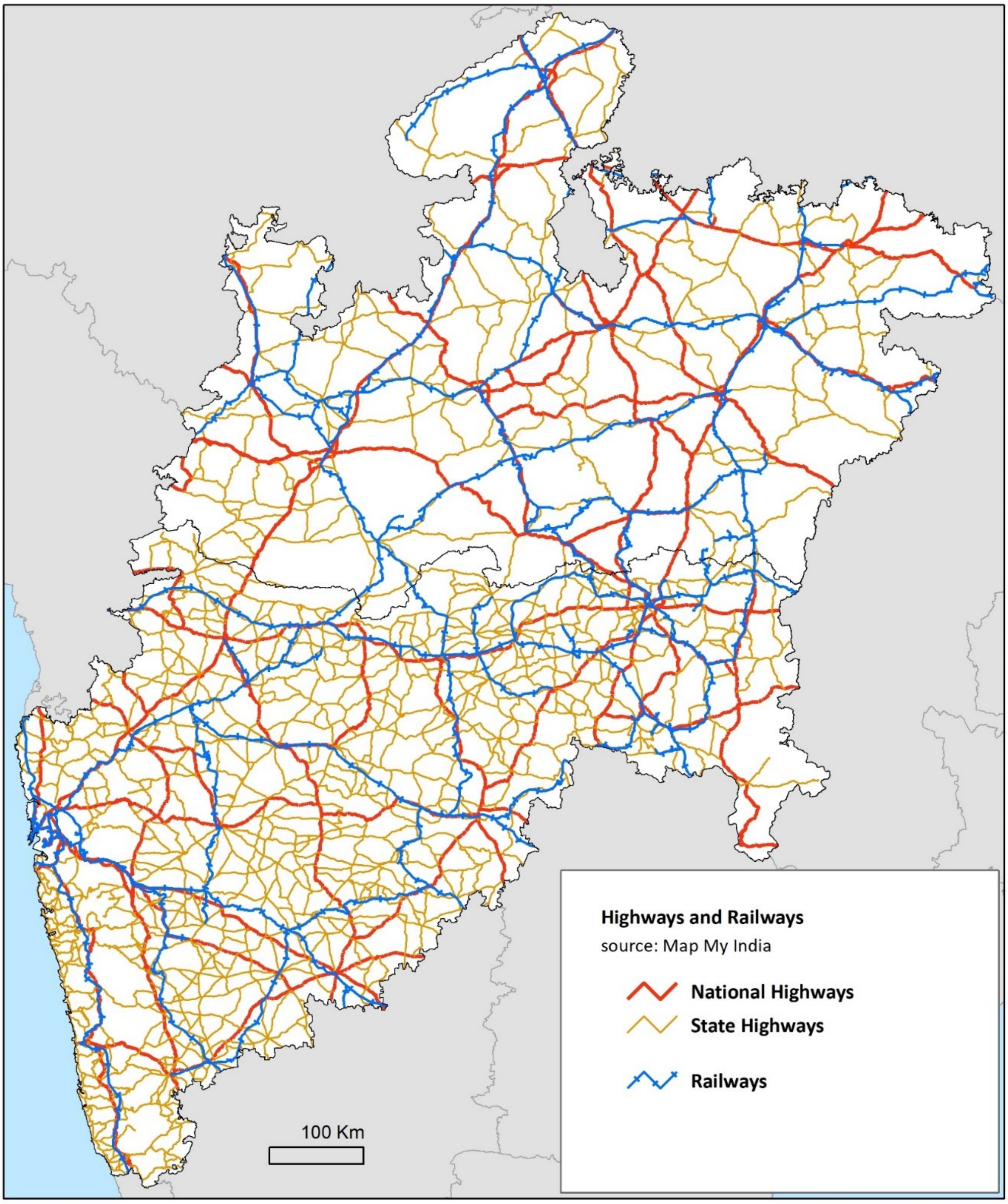
<u>Wind speeds less than 5 m/s (wind exclusion only)</u>: Raster dataset (50m resolution) classifying lands without wind speeds to produce viable utility-scaled wind power, less than 5 m/s at 80m height. ***Source:*** VAISALA, 2016 (3Tier 5 km resolution, global wind resource map at 80 meters hub height). Projected wind resource raster dataset to UTM 43 North with a WGS84 geoid (WKID: 32643) with a selected resolution of 5 km for those cells located within either Madhya Pradesh or Maharashtra. Selected all cells with an annual mean wind speed of less than 5 meters/second and assigned these cells a value of 1. This binary dataset was then resampled to 50 m resolution cell size.

Energy Infrastructure



Substations: Mapped polygon features identifying the location of substations.
Source: OpenStreetMap (OSM), downloaded 12/14/2019. In QGIS, selected linear features with query *"other_tags" LIKE '"power"=>"substation"%'* exported as a shapefile, then converted to polygons for display purposes.
Transmission towers: Mapped point features locating steel lattice towers used to support high-voltage power lines. ***Source:*** OpenStreetMap (OSM), downloaded 12/14/2019. In QGIS. selected point features using query *"other_tags" LIKE '"power"=>"towers"%'* and exported as shapefile. OSM datasets downloaded from Geofabrik website https://download.geofabrik.de/asia/india.html
See https://wiki.openstreetmap.org/wiki/Map_Features#Power

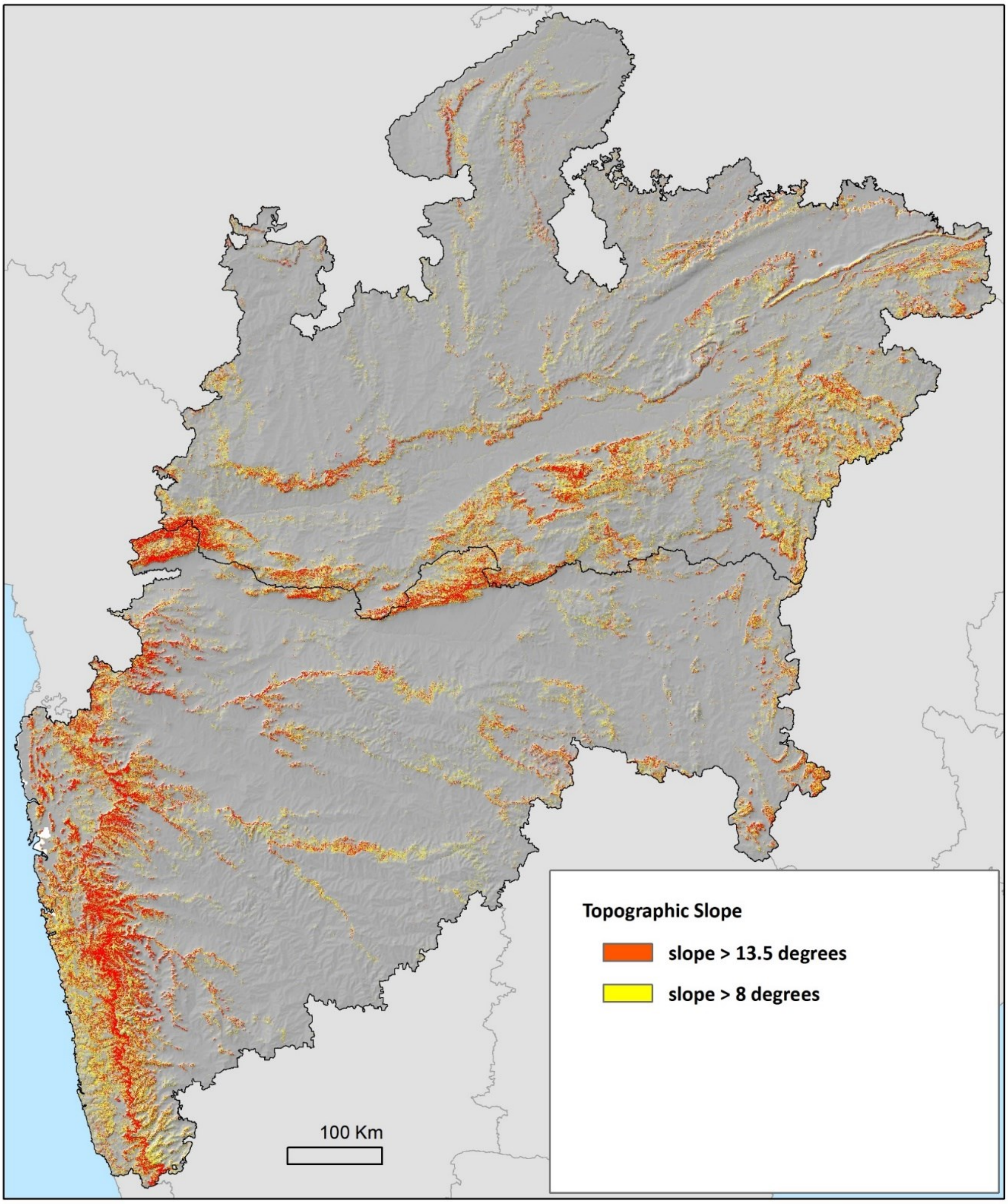
Transportation Infrastructure



Roads and 50 m buffer: Raster dataset (50m resolution) delineating major roads (national or state highways) and a 50m buffer. ***Source:*** Major roads delineated by MapMyIndia and delivered to TNC on November 23, 2017. National and state highways were buffered by 50 m and then converted to a 50m resolution, raster dataset with the cell-centroid method.

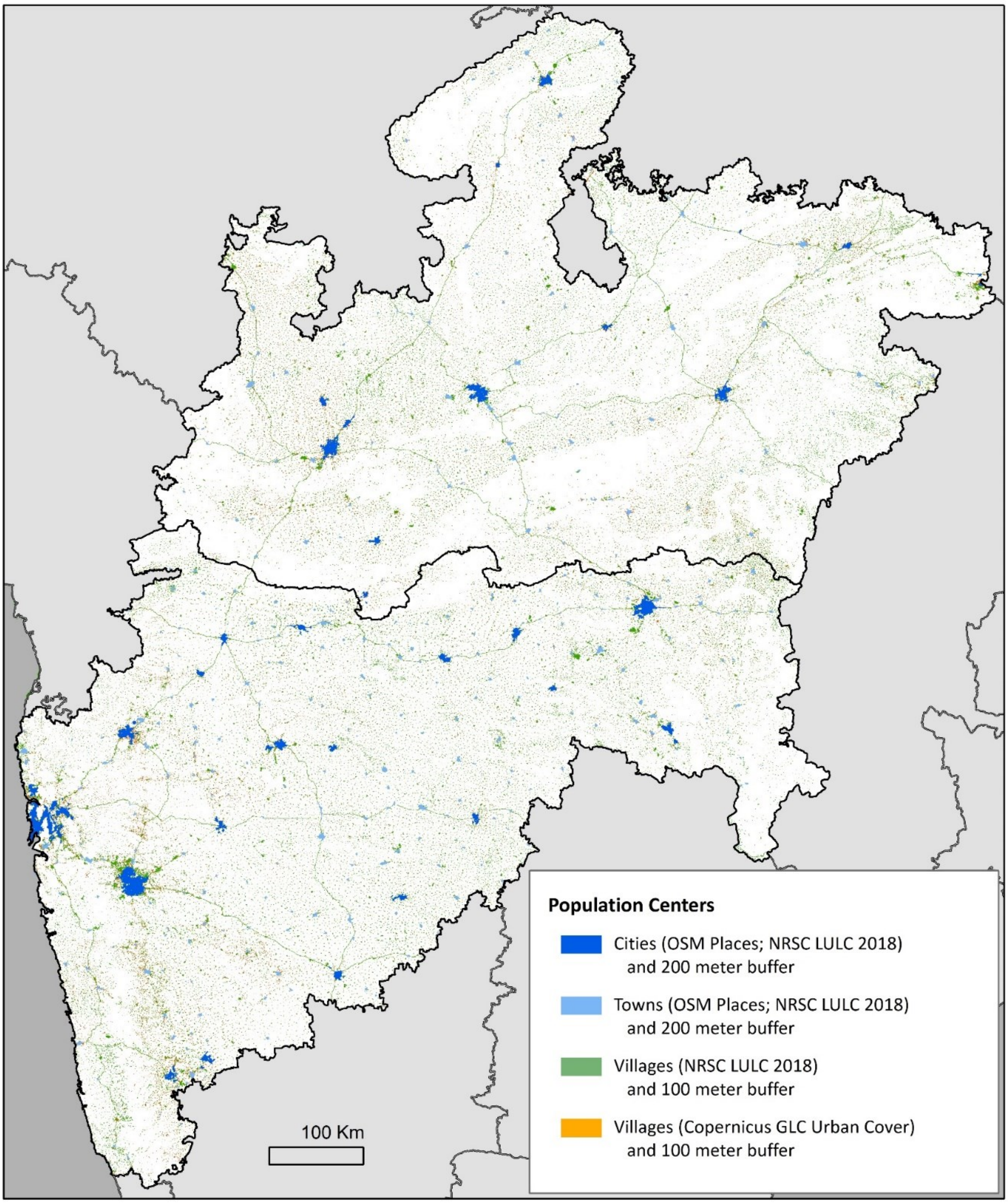
Railways and 100 m buffer: Raster dataset (50m resolution) delineating railways and a 100m buffer. S*ource:* Railways delineated by MapMyIndia and delivered to TNC on November 23, 2017. Railways were buffered by 100 m and then converted to a 50-m resolution, raster dataset with the cell-centroid method.

Topographic Slope



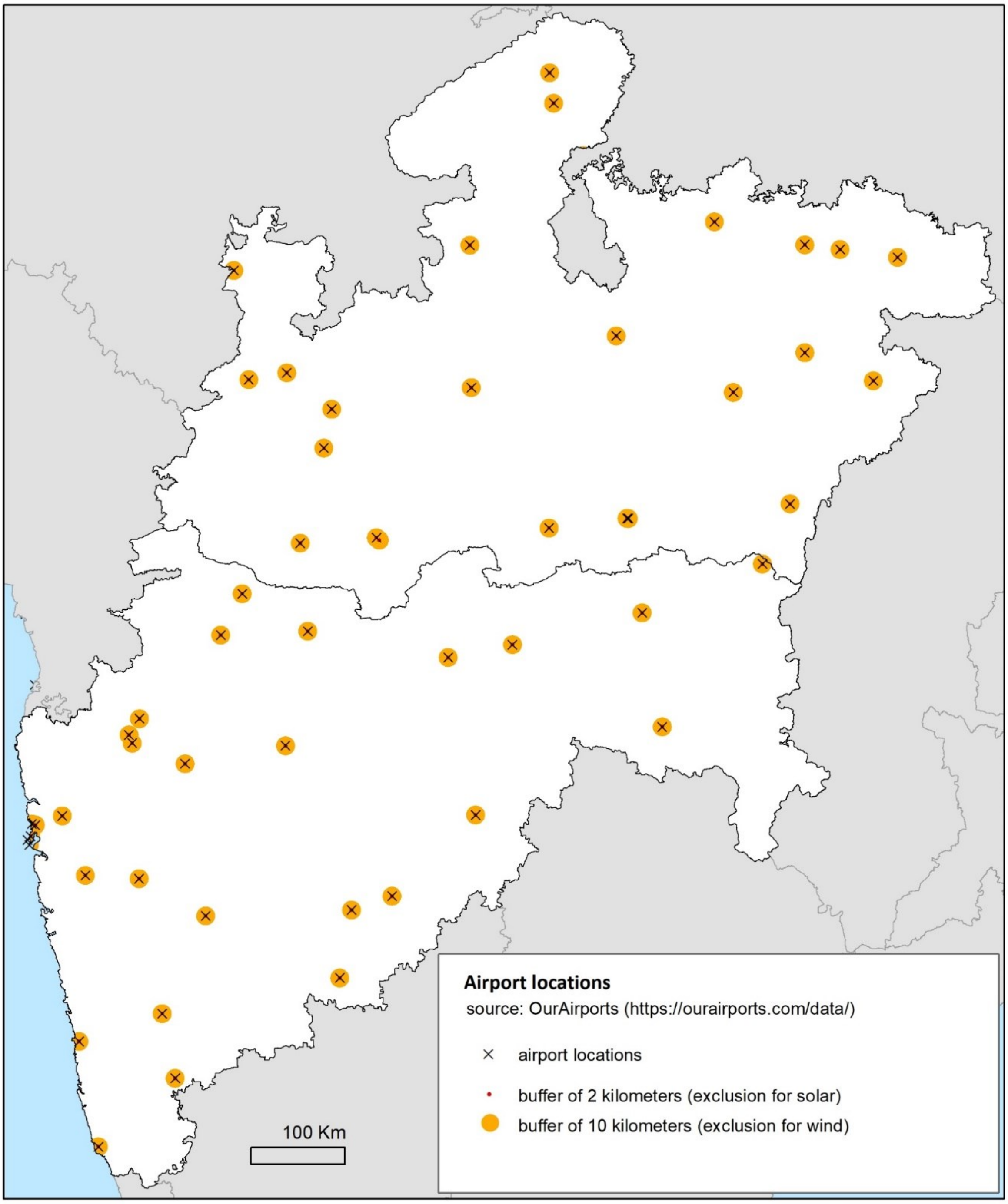
<u>Slopes greater than 8 degrees (solar exclusion) and 13.5 degrees (wind exclusion)</u>: Raster dataset (50m resolution) topographic slope greater than 8 degrees (solar exclusion) and 13.5 degrees (wind exclusion). ***Source:*** SRTM DEM, 1 arc-second resolution, downloaded from https://earthexplorer.usgs.gov/ on November 3, 2017. Projected UTM 43 North with a WGS84 geoid (WKID: 32643) with a resolution of 30 m which is supported by the 1 arc-second original cell resolution. Calculated topographic slope and selected cells with slope greater than 8 degrees and greater than 13.5 degrees and assigned these cells a value of 1. These selected cells were resampled to 50 m to produce the final exclusions for solar and wind, respectively.

Population Centres



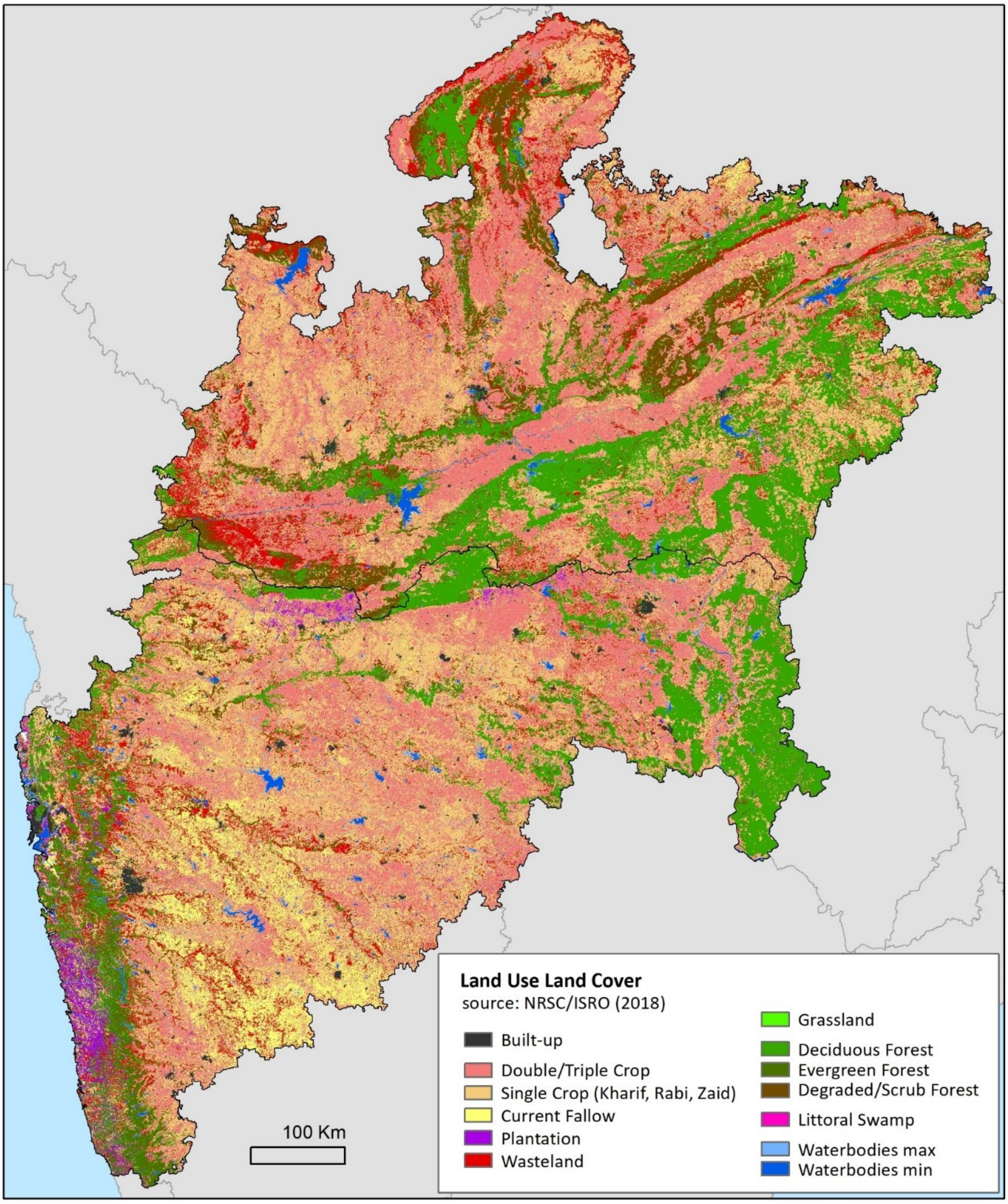
Population centers and buffers: Raster dataset (50m resolution) delineating cities, towns, villages, and buffer zones. Areas of urban landcover (NRSC, 2018 = "Built-up") were extracted and classified as cities, towns, or villages according to place locations in the Open Street Map Places dataset. Additional village areas were delineated by selecting areas classified by the Copernicus Global Landcover as Urban cover fraction > 60% (Copernicus 2018). Urban areas of cities and towns were buffered by 200 meters and village areas were buffered by 100 meters.

Airports and buffers



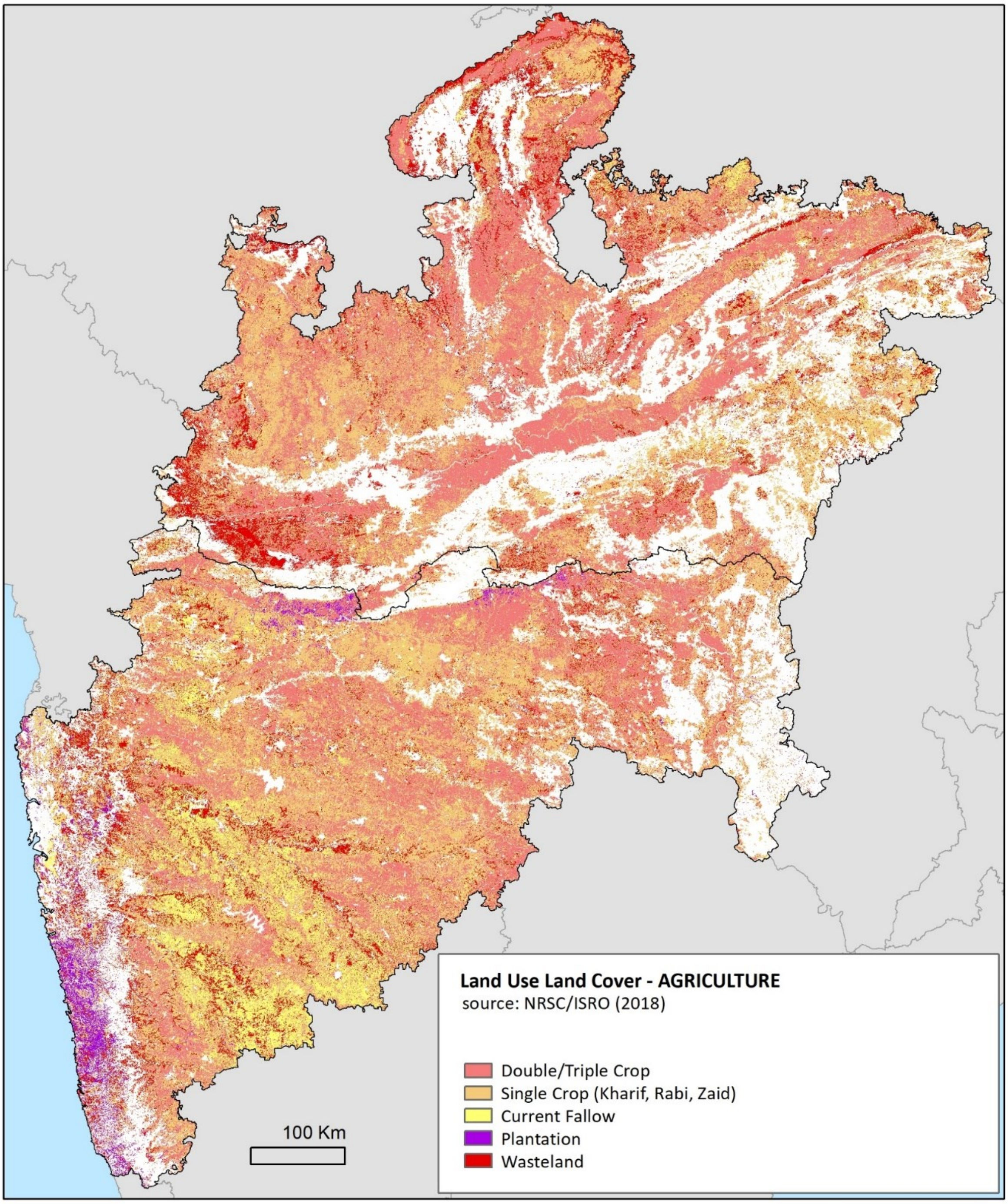
Airports with 2 km buffer (solar exclusion) and 10 km buffer (wind exclusion): Raster dataset (50m resolution) delineating airports and circular buffer with radius of 2 km and 10 km. ***Source:*** Airport locations recorded by OpenFlights.org and Our Airports and downloaded on October 31, 2019. All airport locations buffered 2 km for solar exclusions and 10 km for wind exclusions. Buffered areas were then converted to a raster dataset (50m resolution) using the cell-centroid method.

Land Use Land Cover



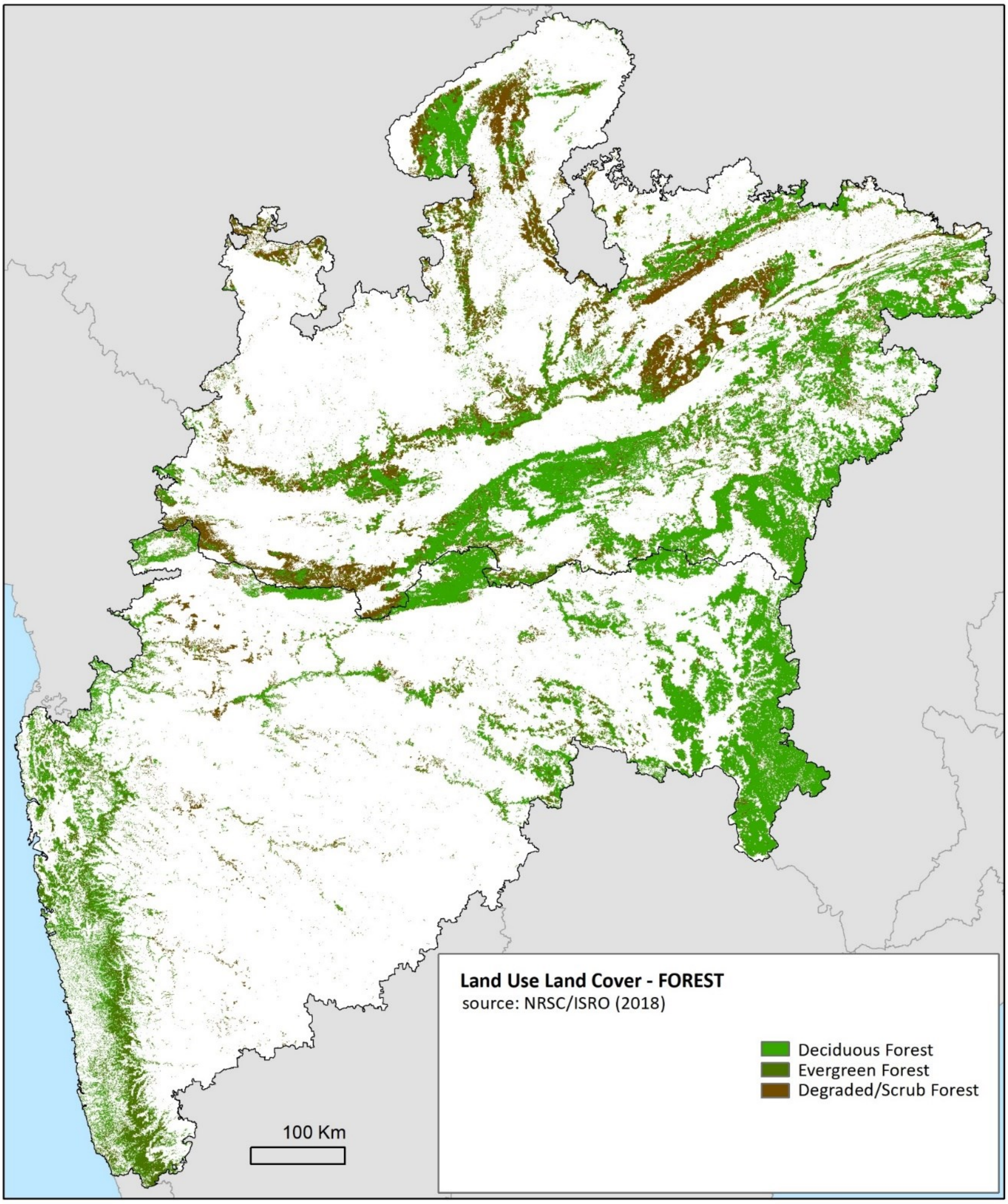
<u>Land Use and Land Cover</u>: Raster dataset (50m resolution). ***Source:*** NRSC/ISRO (2018). Projected UTM 43 North with a WGS84 geoid (WKID: 32643) with a resolution of 50 m which is supported by the original cell resolution of 0.000564679 decimal degrees.

Land Use Land Cover – Agriculture



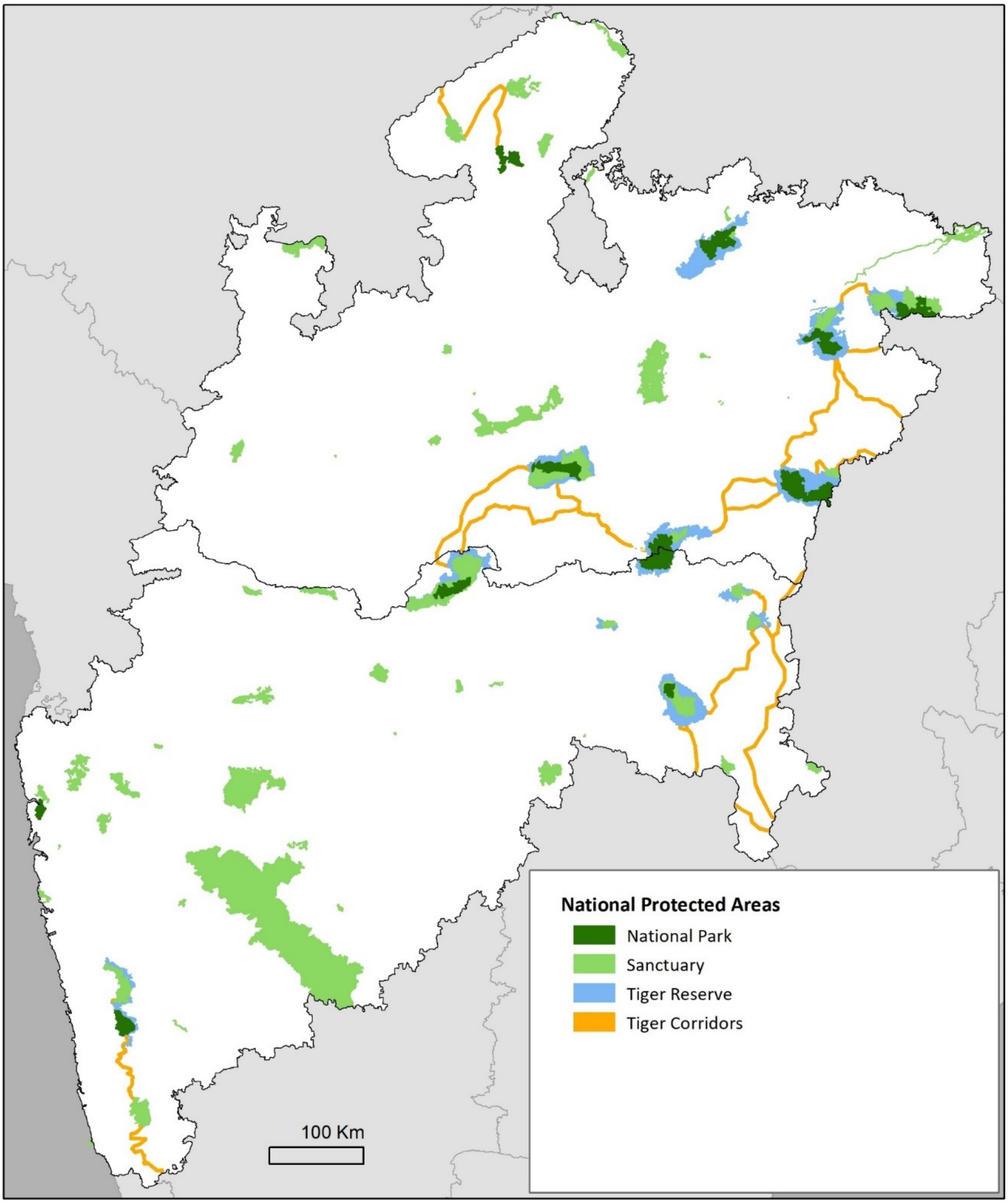
Land Use and Land Cover - Agriculture: Raster dataset (50m resolution). Map shows only agricultural types. ***Source:*** NRSC/ISRO (2018). Projected UTM 43 North with a WGS84 geoid (WKID: 32643) with a resolution of 50 m which is supported by the original cell resolution of 0.000564679 decimal degrees.

Land Use Land Cover – Forest



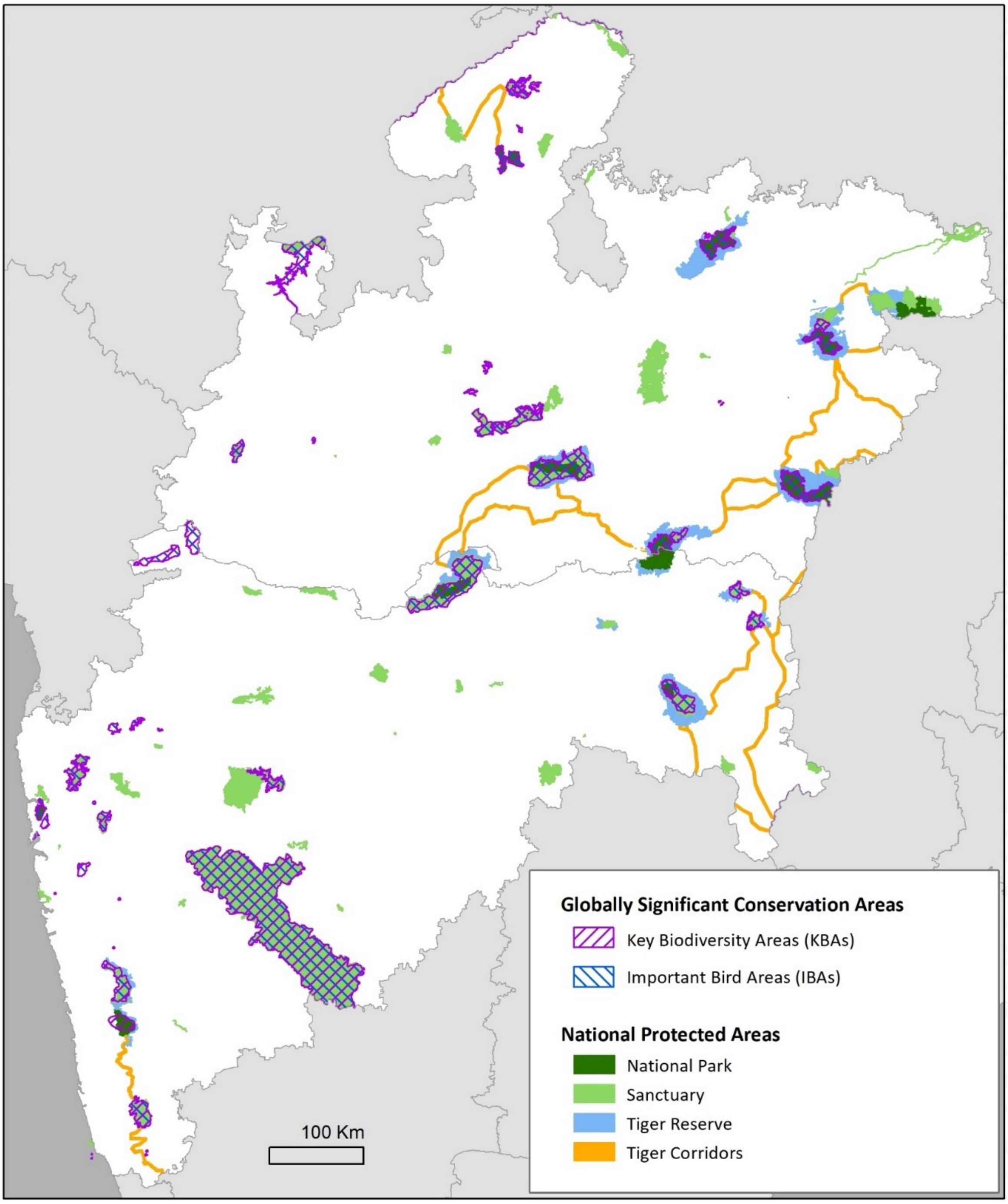
Land Use and Land Cover - Forest: Raster dataset (50m resolution). Map shows only forested types. *Source:* NRSC/ISRO (2018). Projected UTM 43 North with a WGS84 geoid (WKID: 32643) with a resolution of 50 m which is supported by the original cell resolution of 0.000564679 decimal degrees.

Protected Areas



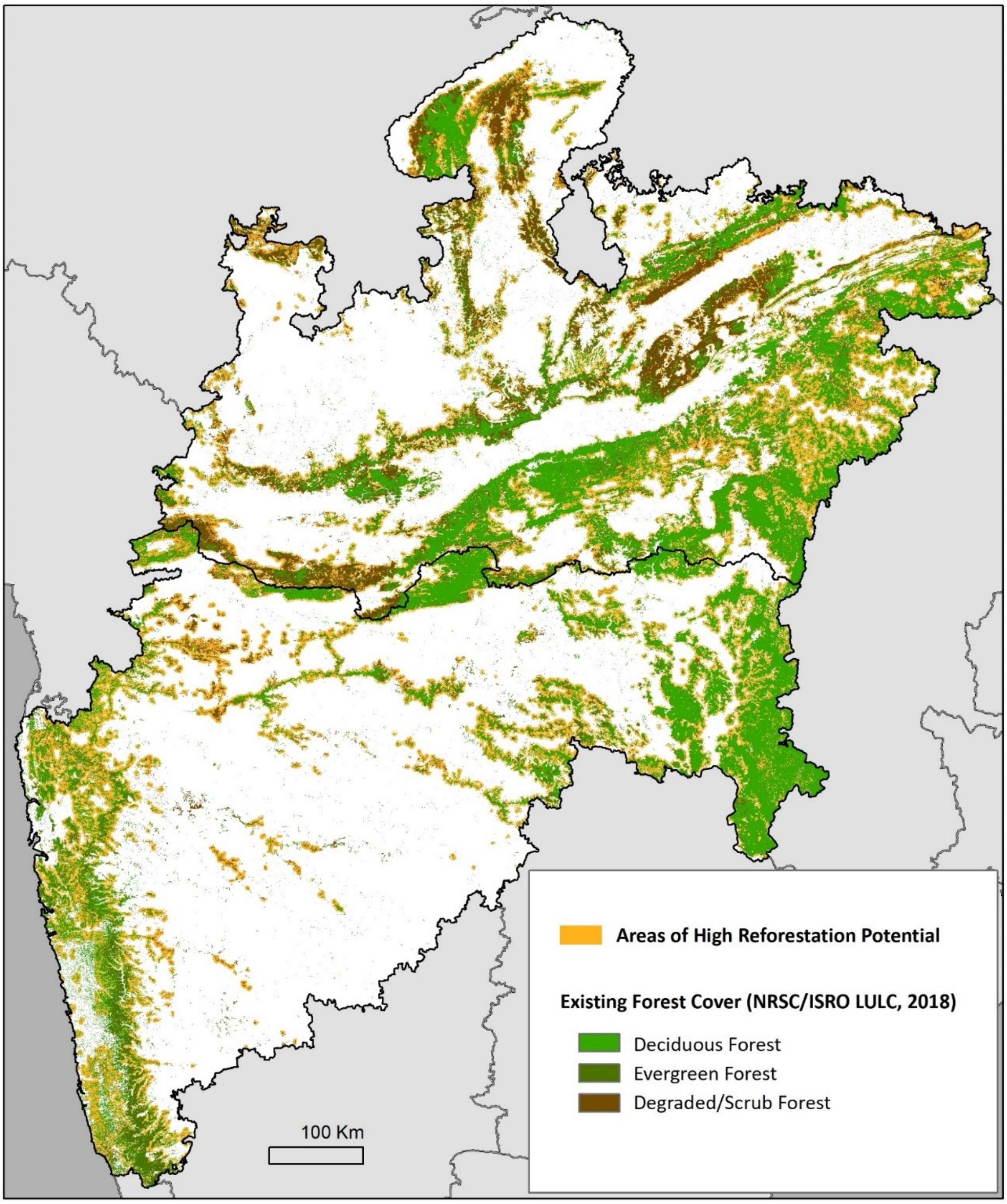
<u>National Protected areas</u>: Mapped polygon features representing nationally-designated parks (IUCN Category II), wildlife sanctuaries (IUCN Category IV), Tiger Reserves, and Tiger Corridors.
Source: Wildlife Institute of India, provided in January 2018. This includes the original border of the Great Indian Bustard Sanctuary as designated in 1979. The sanctuary area was reduced significantly in 2012 and again in 2015 but the current sanctuary border is not publicly available.

Important Conservation Areas



Key Biodiversity Areas (KBAs): Mapped polygon features representing sites designated as contributing significantly to the global persistence of biodiversity according to criteria established by the Key Biodiversity Area Secretariat. ***Source:*** BirdLife International, July 24, 2019. Note that the 44 KBAs designated in Madhya Pradesh and Maharashtra include 43 sites that were previously designated as Important Bird Areas (IBAs) according to criteria established by Bird Life International. Also note that this includes the original border of the Great Indian Bustard Sanctuary as designated in 1979. The sanctuary area was reduced significantly in 2012 and again in 2015 but the current sanctuary border is not publicly available.

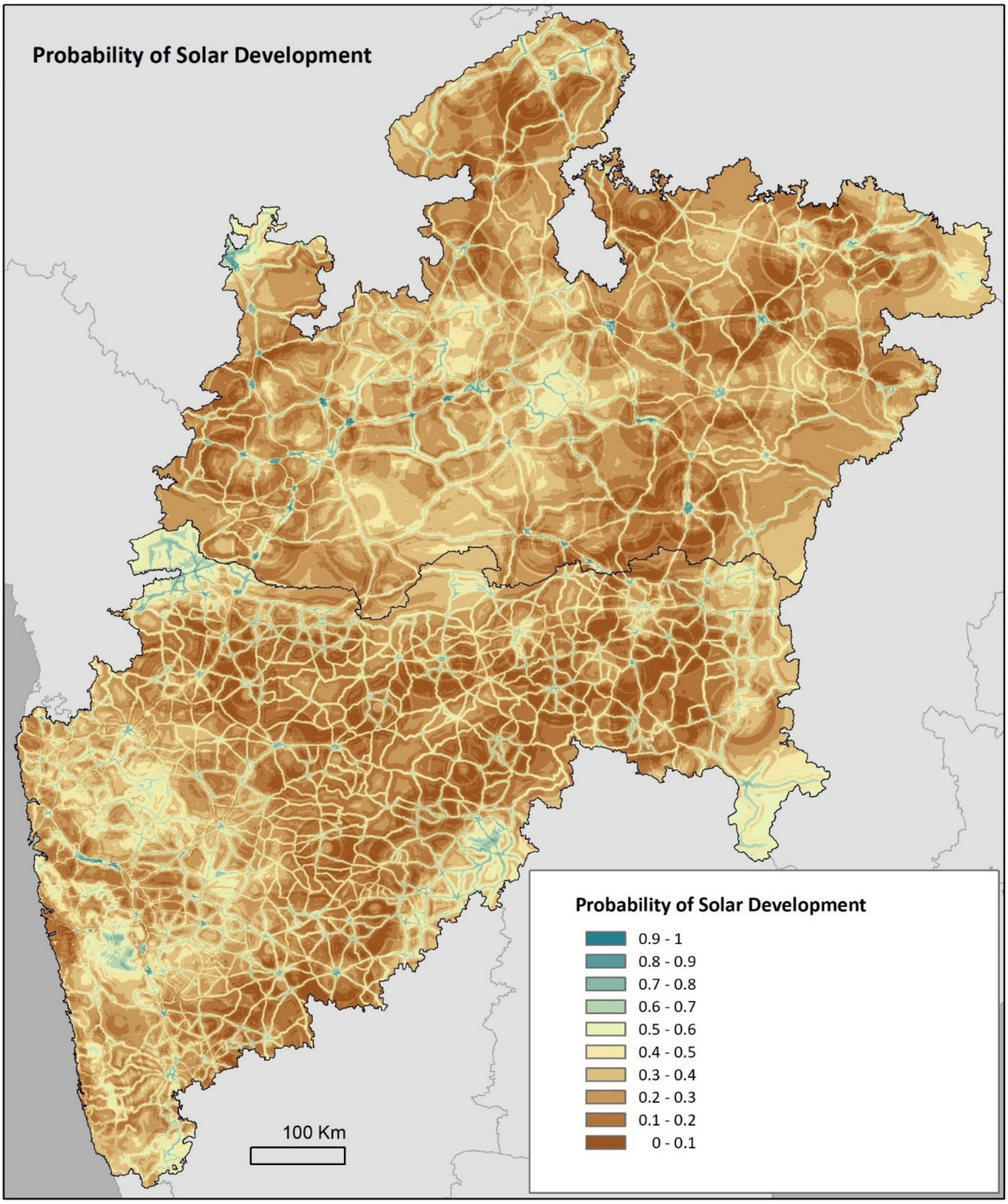
High Reforestation Potential



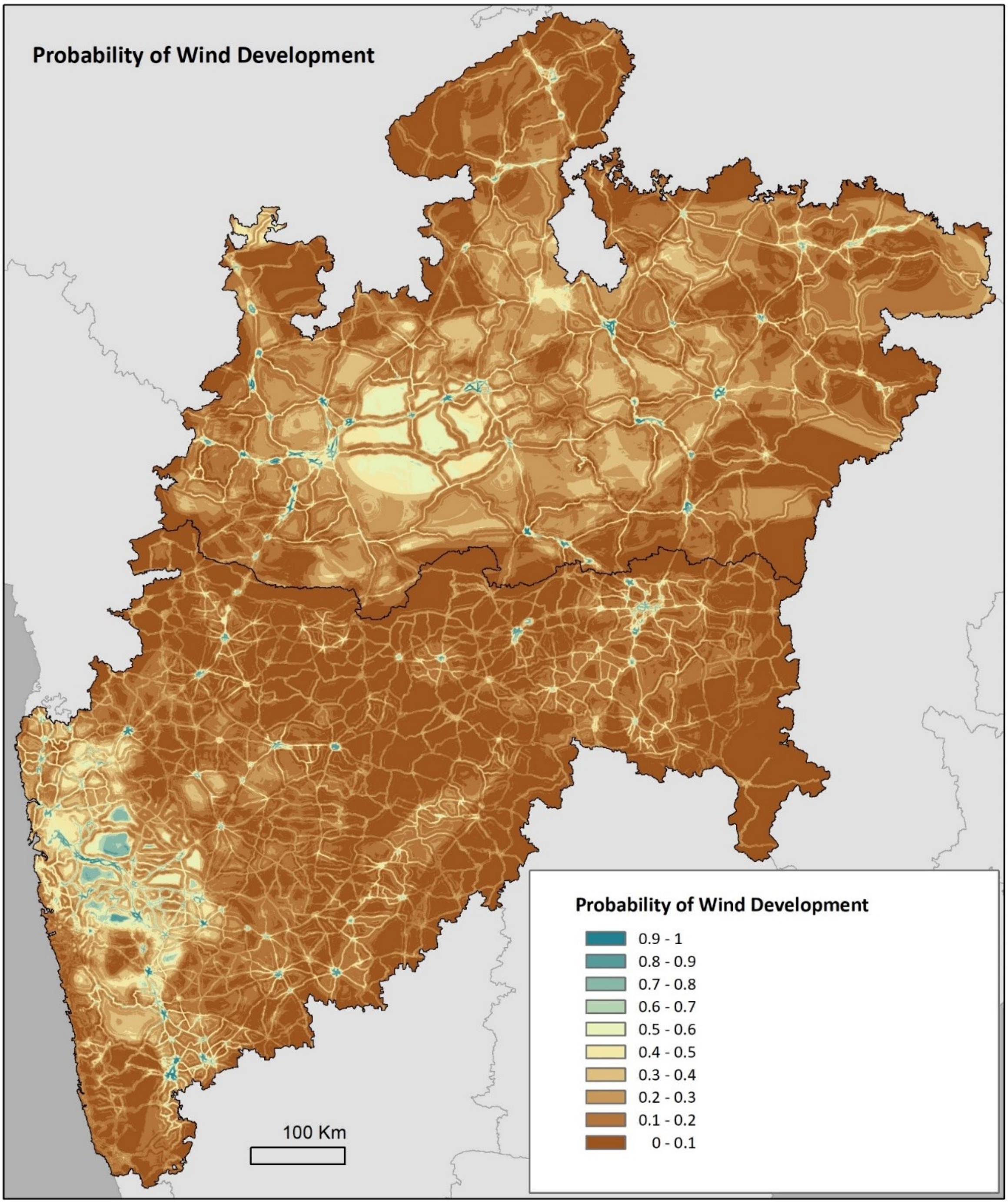
High reforestation potential: Raster dataset (50 m^2 resolution) identifying lands with high potential for forest restoration based on the following criteria:

- Historic (1930) forest fraction > 0% (Reddy et al. 2016).
- Currently classified as non-forested land cover, i.e., *not* deciduous, evergreen, or degraded/shrub (NRSC 2018).
- Are within 2 km of existing forest patches (deciduous, evergreen, or degraded/shrub) > 1 km^2 (NRSC 2018).
- Not in population centers, i.e. cities, towns, and villages (NRSC 2018) and (Copernicus 2018)
- Not high production agriculture, i.e. double/triple crop (NRSC 2018).
- Not permanent or seasonal water bodies (NRSC 2018).

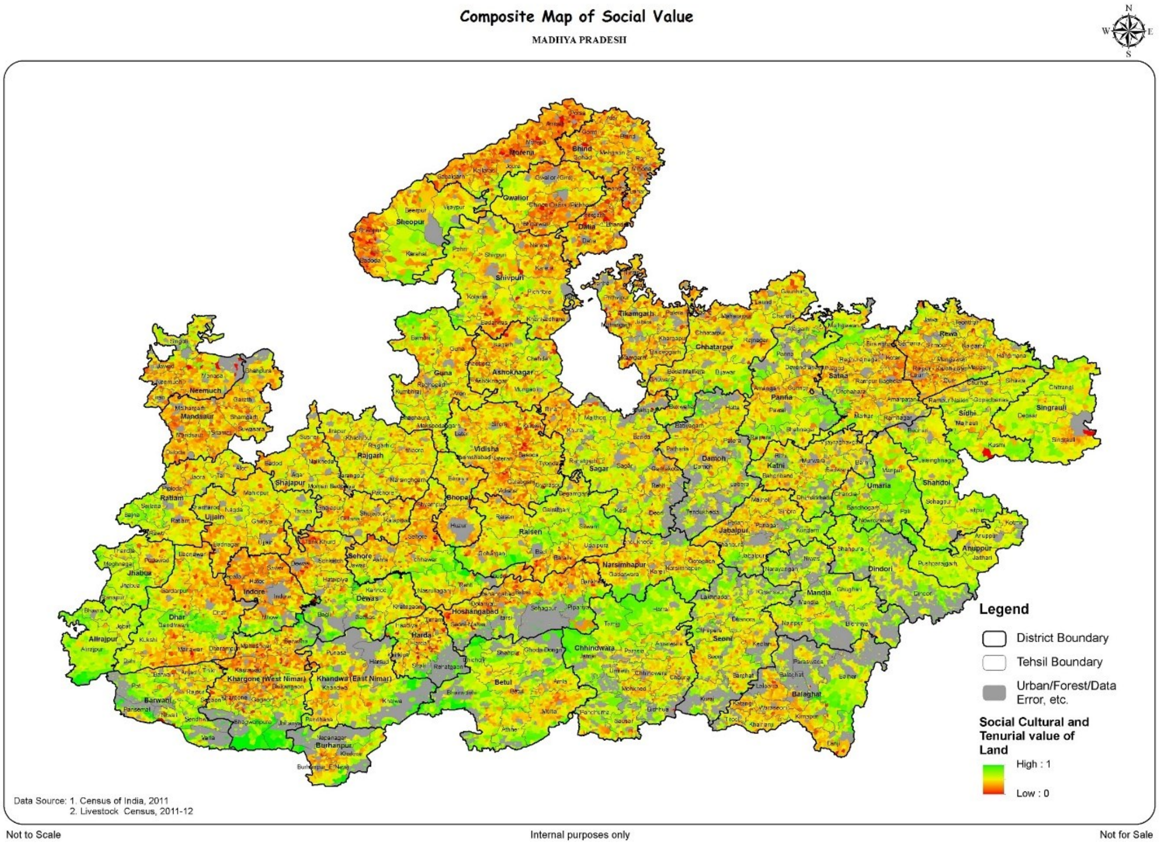
Probability of Solar Development

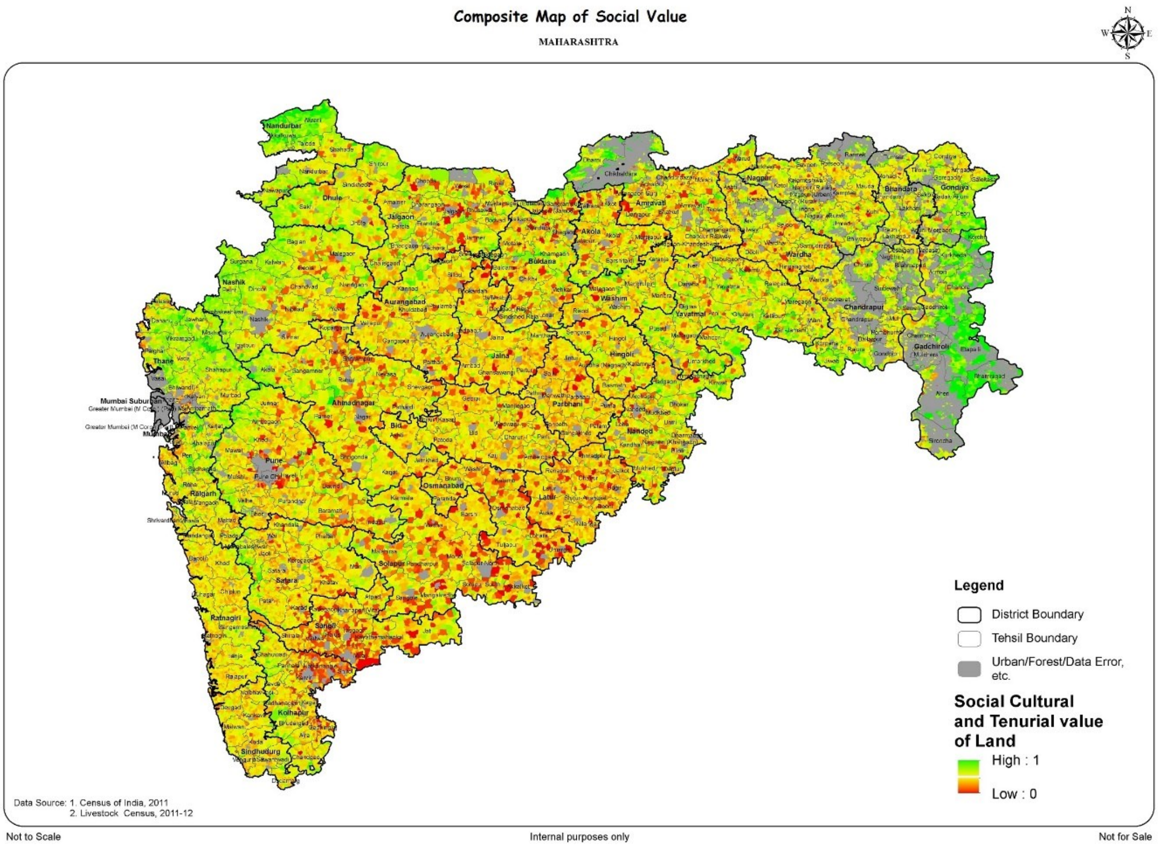


Probability of Wind Development



Composite Map of Social Values





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