BEST task 2.3.1 - Case India: Biomass assessment report

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1. Introduction

India is one of the largest countries in the world with ample resources in different biomass. The potential of agriculture and forestry residues was estimated at 18 000 MW in the year 2012. The use of this potential is low and renewable energy as whole covers only a small proportion of the whole primary energy supply (TERI 2013). The use of biomass-based energy, however, is growing rapidly.

The major biomass sources for energy are agriculture residues, forest and forest product residues, and the biomass growing on wastelands. Wastelands also possess great potential to increase the amount of available biomass by plantation of energy crops for suitable wasteland areas. Without good maps of the distribution of the biomass, planning of biomass utilization for energy production will be difficult. With decent maps, the areas of interest can be identified and further studies can be allocated to those regions.

The whole BEST case India project task 2.3, is divided into five different subtasks: subtask 2.3.1 concentrates on biomass resources; subtask 2.3.2 on biomass production and supply chains; subtask 2.3.3 on optimization of the biomass resource usage while taking in count sustainability; subtask 2.3.4 on the general challenges in the use of biomass in India; last subtask 2.3.5 is about strengthening cooperation and relationships between the two countries, Finland and India.

Subtask 2.3.1 aim was to map the available existing biomass resources for bioenergy utilization. This mapping was done using multi-source information gathered like field studies, available literature, as well as remote sensing data and best available land use/land cover (LULC) maps. The study was done on two different levels, for state-level and for more detailed pilot-level. The state-level covers three states in India, Madhya Pradesh, Maharashtra and Tamil Nadu. The pilot-level consisted of two cities and surroundings within the selected states. For states the mapping was done in taluk-level as well as in grid-level. For pilot areas the mapping was done only for grid-level. The grid-level mapping had unit size of 5 km x 5 km. The second aim was to map also the available wasteland areas in the aforementioned states.

2. Materials

2.1 Study area

2.1.1 State-level

The study area was narrowed down to three states of interest. The selected states were Madhya Pradesh, Maharashtra and Tamil Nadu. Both Madhya Pradesh and Maharashtra have area of more than 300 000 km^2 and Tamil Nadu more than 130 000 km^2. The study areas cover nearly quarter of the whole country's area and more than one fifth of the total population lives in the aforementioned states.

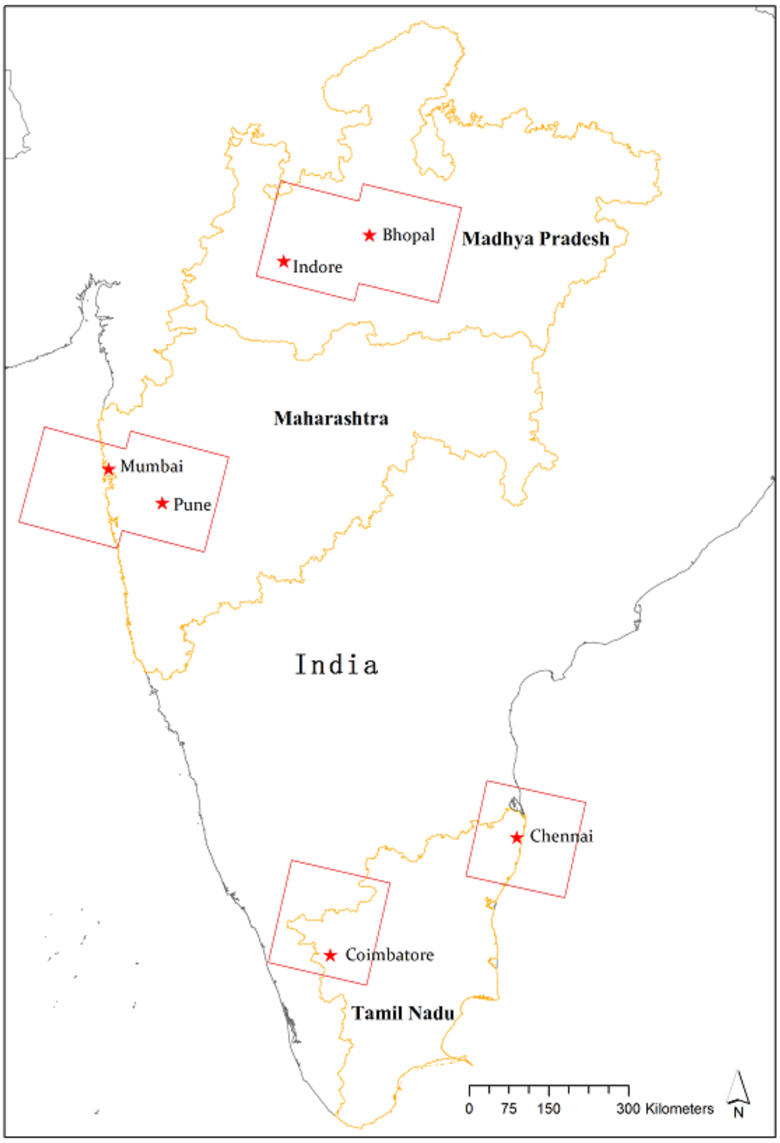

Figure 2-1: State-level study regions and selected pilot cities including the mapped pilot region.

2.1.2 Pilot-level

From the three selected states, six cities were selected for pilot-level study. The selected cities were Bhopal and Indore (Maharashtra), Mumbai/Thane and Pune (Madhya Pradesh), and Chennai and Coimbatore (Tamil Nadu). The selected cities were all the largest cities in each state. The full pilot area covered the city and the surrounding rural area. The actual border for the pilot areas were determined by the Landsat 8 image border, as each of the cities were used as the center point when looking for satellite images.

2.2 Biomass data

2.2.1 Field data

For the mapping of the available biomass resources in pilot area, results from field data were used. The questionnaire study was conducted in the rural parts of each pilot area. Tools were translated into Hindi, Marathi and Tamil to conduct the pen-and-paper based survey. After having consultations with various stakeholders and based on previous experience, a sample size of 75 was selected for household survey across the selected districts. It was thought that it could provide a good sense of biomass supply and use at household level. During preliminary discussions with the stakeholders, it was realised that farmers across different socioeconomic categories could have different production, use and supply pattern. Hence, farmers were divided into three categories of small (less than 5 acres), medium (5 -10 acres) and large farmers (More than 10 acres). An equal sample of 25 was drawn from all three categories. Subsequently these samples were divided across various blocks and villages to have a wide representation of the geographical area in each district. After this stratification, households were randomly surveyed from the villages. The study was designed by UEF and conducted by UEF/TERI. The households answered questions on the annual biomass production, yield, and residue production and the consumption of that residue biomass.

The questionnaire data was transferred from paper forms to digital format and further analyzed to calculate per hectare production and consumption of agro residue and horticulture residue biomass and eventually the total surplus biomass for agriculture land use. These surplus biomass figures were used as the amount of surplus biomass in the biomass mapping stage.

2.2.2 Other sources

For the state-level biomass mapping and for covering other land use classes than agriculture in the pilot-level mapping, literature sources were used to search the best possible biomass surplus estimates. For Madhya Pradesh and Maharashtra the Biomass Resource Atlas of India (CGPL 2014) was used to acquire the biomass values for agriculture, forest and wasteland classes. The biomass figures were for the years 2000 – 2004 and the biomass information was listed separately for states, districts and taluks. Biomass information for the Atlas was acquired using data from multiple sources including remote sensing data and field data. The Atlas gives area of production per specific location (state, district or taluk) and land use (Agro, forest or wasteland), and production of total biomass for all land uses as well as the crop biomass for agriculture. The surplus biomass is derived from the production and consumption of residue biomass, though consumption is not given in the table. Also the power potential was given, but no clear information was available for the calculation process of the potential, therefore, the power potential was not used for this purpose.

The district-wise information was decided to be used, because it was the best combination spatial detail and data reliability. The taluk-wise information was not used because there were many differences with the administrative taluk border layer used and the Atlas' taluk division. The district-wise biomass surplus and production figures were used for agriculture, forest and wasteland land use classes. The biomass consumption was calculated based on the aforementioned figure. The values in the Atlas were given as kilotons of biomass per year. The area of specific land use within each district was used to calculate the tons of biomass per hectare figures which were later used in map production.

The district-wise biomass information for Tamil Nadu was acquired from a study conducted by Tamil Nadu Energy Development Agency (TEDA) and the Institute for Energy Studies (IES). The Districtwise Biomass Resource Assessment Study – Tamil Nadu was conducted in 2009 – 2010. The power production potential in each district has been calculated based on the surplus biomass availability after taking into account biomass generation (from existing field level, plantation crops, agro industry, non-irrigated wasteland), and utilization (basic, domestic and industries). The study also evaluated the potential for biomass production through energy plantations in non-irrigated wastelands.

Settlement biomass was considered as Municipal Solid Waste (MSW) in this study. A comprehensive master's thesis study called Sustainable Solid Waste in India (Annepu 2012) was used as the source data for the MSW. The data tables of the study were freely available and by using those tables the total MSW production per year in each state was calculated. The MSW per land use cell was then calculated by dividing the total MSW by the amount of cells in settlement class within each state. This MSW figure was then used in the map production. The data concerning the consumption of MSW biomass was not available and thus the surplus MSW could not be used for this mapping.

2.3 Remote sensing data

The LULC classification for the pilot areas was done using Landsat 8 OLI imagery (Table 2-1). The original imagery was downloaded from USGS website (http://glovis.usgs.gov) as Level 1 GeoTIFF Data Product. Table 1 describes the metadata for the individual Landsat 8 images. The Landsat 8 images are medium-resolution (30 m), 16 bit images with 11 bands. Only the bands 2 to 7 were selected for further processing. All the images were set in WGS84 Universal Transverse Mercator (UTM) coordinate system.

Table 2-1: Metadata for Landsat 8 images used in pilot area LULC classification.

	Location	Image ID	Path/ Row	Data type	Date acquired	Cloud cover, %
1	Chennai, Tamil Nadu	LC81420512013137LGN01	142/51	L1T	17.05.2013	0.07
2	Coimbatore, Tamil Nadu	LC81440522013279LGN00	144/52	L1T	06.10.2013	13.54
3	Bhopal, Madhya Pradesh	LC81450442013142LGN01	145/44	L1T	22.05.2013	0.00

4	Indore, Madhya Pradesh	LC81460442013133LGN01	146/44	L1T	13.05.2013	0.05
5	Pune, Maharashtra	LC81470472013108LGN01	147/47	L1T	18.04.2013	2.93
6	Mumbai, Maharashtra	LC81480472013115LGN01	148/47	L1T	25.04.2013	0.50

The images were selected so that they would be from the same year and season. All the images were from 2013 and all but one image were from between April and May. The Coimbatore image was from October due to cloud cover. Even the October image still had a considerable cloud cover (~13.5 %), but this was the least cloudy image in the recent years for that location.

After download the Digital Number (DN) values of the images were transformed into Top of Atmosphere (TOA) reflectance values. The spectral and textural features were later calculated from the reflectance values (see section 3.1.1).

2.4 Land use/land cover maps

To be able to generate the biomass maps for the three states first the LULC classification map was needed. Because the area of the three states is so large, ready LULC maps was decided to be used. The formally accepted LULC maps in India area generated annually in the National Remote Sensing Centre (NRSC), Hyderabad. The most recent LULC classification is the eight cycle and is from the years 2011 – 2012 were used (NRSC & NESAC 2012). The data was received through TERI to this project.

The LULC maps are generated using Resourcesat AWiFS satellite imagery to classify whole India into 19 classes of land use (Table 2-2). The original classes were reclassified into six classes for biomass mapping (Table 2-2). Snow was not present within the three states, therefore in the final map there were five classes. The reclassification was done to ensure that reliable biomass values can be found for each of the class. The reclassification of the wasteland class was done using the same class divisions as on the NRSC wasteland classification (Ministry of Rural Development & NRSC 2011). The LULC map was mapped on scale 1:250 000 which meant that the cell size was about 55 meters varying slightly from north to south.

Table 2-2: NRSC LULC original land use classes and reclassified classes.

Original class	Reclassified class
Built-up	Settlement
Kharif only	Agriculture
Rabi only	Agriculture
Zaid only	Agriculture
Double/triple	Agriculture
Current fallow	Agriculture
Plantation/orchard	Forest

Evergreen forest	Forest
Deciduous forest	Forest
Scrub/degraded forest	Wasteland
Littoral swamp	Wasteland
Grassland	Wasteland
Other wasteland	Wasteland
Gullied	Wasteland
Scrubland	Wasteland
Waterbodies	Water
Snow covered	Snow
Shifting cultivation	Wasteland
Rann area	Wasteland

2.5 Plot data

Two sets of plots were created for the LULC classification. The first set was made for the classification of the Landsat images as training data, and the other set was made for independent reference data set for accuracy assessment.

The training data set for the classification was with the ArcMap version 10.0 Image classification toolbox. The toolbox was used to create a number of polygons within each Landsat image which represented the various land uses in the image. The polygons were all shapes and sizes, and there were always multiple polygons for all land uses. The amount of different land uses depended on the area. The training data was made separately for each of the images. After creating the reference polygons, they were combined with the image feature data set and a so-called signature file was created using the Iso Cluster Unsupervised Classification -tool. The signature file depicts the relation between each of the classes and the image features.

The selection and classification of the accuracy assessment plots were based on methodology created for EU funded project, ReCover (Sirro et al. 2013, Häme et al. 2013). The plots were created inside each Landsat image covering each of the pilot areas. The plots were distributed as a systematic sample to cover all classes. There were altogether 864 sample plots and they were distributed to Madhya Pradesh, Maharashtra and Tamil Nadu as 378, 259 and 227, respectively. The plots were square plots and each the reference plot coincided with a cell in the in the state-level map. This ensured that there were no mixed pixels. The pilot-level map was assessed with the same reference data set and, thus, the cells were not aligned, because the cell size of the pilot-level map was smaller than that of the reference data set. In that case the map class was calculated from the LULC map as area-weighted median.

The classification of the accuracy assessment plots was done based on the reclassified LULC map classes, i.e. they were classified into five classes used in LULC maps. The classification of wasteland class was done based on the instructions in NRSC wasteland classification document (Ministry of Rural Development & NRSC 2011). Each plot was classified into the classes based on majority rule as in largest class in total area was selected. The classification was done based on Google Earth and ESRI ArcGIS Online high-resolution imagery, which were majority from the years 2010-2013.

3. Methods

3.1 Classification

3.1.1 Image features

For the purpose of producing LULC map for the pilot areas, image features were extracted from the Landsat 8 reflectance images. The image features are any spectral, textural as well as the direct image reflectance values.

Three indices were calculated from all the images. The indices were Normalized Difference Vegetation Index (NDVI) (Eq. 1), Atmospherically Resistant Vegetation Index (ARVI) (Eq. 2), and Modified Soil-Adjusted Vegetation Index (MSAVI) (Eq. 3).

$$NDVI = \frac{NIR - RED}{NIR + RED} \qquad \text{Eq. 1}$$

$$ARVI = \frac{NIR - rb}{NIR + rb} \qquad \text{Eq. 2}$$

where

$$rb = RED - \gamma(BLUE - RED)$$

$$MSAVI = \frac{\left(2 * NIR + 1 - \sqrt{(2 * NIR + 1)^2 - 8 * (NIR - RED)}\right)}{2} \qquad \text{Eq. 3}$$

In all equations NIR, RED and BLUE are reflectance of near infrared, red and blue bands, respectively, and γ (gamma value) is a weighting function that depends on the aerosol type. γ of 1 was used in this study based on Kaufman and Tanre (1992).

Furthermore to enhance the classification, the reflectance bands were used to calculate textural features. The Haralick’s textural features (Haralick et al. 1973) were calculated from each of the images. Haralick’s textural features consist of 13 features which are angular second moment, contrast, correlation, sum of squares, inverse difference moment, sum average, sum variance, sum entropy, entropy, difference variance difference entropy, two information measures of correlation and maximal correlation coefficient (see Haralick et al. 1973). The 13 features were calculated using NDVI and ARVI images, which gave a total of 26 image features. Because there were so many features, a principal component analysis was used to combine the information from the textural features and decrease the total amount of image features.

Image features are very commonly highly correlated and, thus, incorporate a lot of the same information. In classification process a high amount of features can make the classification worse. Principal Component Analysis (PCA) combines information from the original features into new uncorrelated image features, called principal components. The amount of principal components is always less than or equal to the amount of the original features. The first principal component explains majority of the variation in the initial data, the second component explains majority of the variation left unexplained, etc. In this project the amount of principal components was set to six, which all were used in the classification

On top of the ratio and textural feature, the direct reflectance values were included from Landsat 8 bands 2-7. This means that a total of 15 image features were used in the classification. These 15 feature images were combined into one multiband image, which was given as input for the Maximum likelihood classification.

3.1.2 Maximum likelihood classification

The image feature imagery was used to classify the six pilot areas into homogenous land use classes. The initial amount of classes was more than the final five classes and was different in each area depending on the type of land uses within the area.

The classification was done in ESRI ArcMap version 10.0 with the Image classification toolbox and more specifically the Maximum Likelihood Classification -tool. The signature file, created based on the training data and image feature data set, was set as the input for the tool. Maximum Likelihood Classification -tool is a supervised classification method, because it uses user-defined input which defines the classes beforehand, i.e. the signature file. The same image feature data set which was used to create the signature file was also used as the input imagery for the classification. An iterative process was used for each area where first all cells in the area were classified. Secondly, a thorough visual checking of the classification was performed, the signature file was updated and the classification was redone, or the classification was accepted. The visual checking was done against the Landsat 8 imagery and against ESRI high-resolution satellite imagery available from ArcGIS Online. To learn more about Maximum Likelihood and the Maximum Likelihood Classification –tool see e.g. Le Cam (1990) and ESRI (2012).

When each of the initial classifications were approved, the maps were reclassified into the same land use classes as in the state-level map, i.e. Settlement, Agriculture, Forest, Wasteland, and Water. After reclassification the LU maps were ready, the biomass distribution maps were produced and the LU maps could be assessed for accuracy.

3.2 Biomass mapping

After acquiring the biomass values for each of the land use classes and finishing the LULC classification maps, the biomass distribution maps could be easily created by using these two datasets. The workflow for the mapping was the same for both the state-level and the pilot-level maps. The only differences were in the result unit size, and the fact the pilot area LULC maps had cloud and shadow classes which were absent from the state-level maps. For state-level the mapping was done using two different result units, taluk-wise mapping and grid-wise mapping with 5 km x 5 km cell size. For pilot-level the mapping was done only for grid. For the grid results, on top of the surplus biomass, also the production and consumption of biomass was calculated.

First, the number of land use cells within each result unit (taluk or cell) was calculated for each of those units. This was done for each land use class separately. Based on the amount of cells and the known cell size of the LULC map, the approximate area of different land uses within the result units was computed. After the area of each land use class was known, the area could be used to determine the amount of biomass. This was done by multiplying the area of each land use within a cell by the corresponding biomass value of that land use class. This resulted on the initial biomass distribution map.

The pilot maps which had cloud cover were further processed after creating the initial map. Because the real land use was unknown within the cloud or shadow classes, it was assumed that the distribution in the result unit for those two classes is the same as it is within the uncloudy part of the unit. The cloudy part of the result unit was then distributed for the other classes (Settlement, agriculture, forest, wasteland and water) and their biomass was increased according to that area. This means that, if a grid cell was partly covered by clouds and shadow, the cloud adjusted biomass of class i would be calculated in the following way:

$$B_i = B_{i\_init} + (B_{i\_init} * \left(\frac{A_i}{A_{tot} - (A_{cloud} + A_{shadow})} * \frac{A_{cloud} + A_{shadow}}{A_{tot}}\right) \qquad \text{Eq. 4}$$

Where B_i is the cloud cover adjusted biomass for class i, B_{i_init} is the initial biomass for class i, A_i, A_{cloud} and A_{shadow} are the areas of the class i, cloud and shadow, respectively, within the 5 km x 5 km result unit, A_{tot} is the total area the result unit.

Because the LULC classification and the biomass values incorporate error, it is important take that into consideration in the map. Because good accuracy assessment was done for the LULC classification (see section 3.3), it was possible to consider it in the biomass maps. The accuracy assessment computed a level of reliability for each land use class. It can be reasoned that if a class has for example an error-level of 50 %, then in the biomass map result unit that specific class can have in reality 50 % less area. In that case, also total biomass of that class within the result unit would be 50 % smaller. Based on this premise, a conservative biomass estimate (CBE) was calculated for each class. The CBE was calculated simply by multiplying the initial biomass with the classification accuracy of the corresponding class. This methodology does not, however, take into consideration the fact that in the case of misclassification the class would be in reality some other class. Therefore, the CBE values are not summable between classes, meaning that a total CBE cannot be calculated.

3.3 Accuracy assessment

There are two main sources of error in the biomass mapping were the LULC classification and the biomass values. The LULC classification can have misclassifications and these misclassifications can affect especially the grid level map, because the result unit is small. The level of error in the classification decrease when the size of the result unit is increasing. The biomass values can have multiple sources of error depending on the way the values have been generated.

3.3.1 Biomass values

The error levels for the biomass values cannot be fully assessed, because of limited documentation and lack of data. The Biomass Resource Atlas of India lists a general level of accuracy that the figures in the Atlas have. The figures are from various sources and have varying quality. According to the Atlas the biomass production figures have accuracy of 5 to 25 percent. The biomass consumption figures on the other hand have accuracy level of 20 to 40 percent (CGPL 2014). The total accuracy for the surplus figures is not told and cannot be calculated based on the given data. The accuracy level for the figures used for Tamil Nadu in state-level are unknown, but can be assumed to be close to the level of accuracy in the biomass Atlas.

3.3.2 Land use/land cover map

The level of accuracy in the LULC classification in state-level and in pilot-level was assessed by doing a cell-level accuracy assessment using an independent reference plot data. The plot data was created to cover all of the pilot areas and to cover all land use classes to get an unbiased estimate for the accuracy. The reference plots were visually assessed to mark every plot with a reference class, which were compared to the classified classes using confusion matrix. Using the confusion matrix naïve and kappa statistics were calculated.

Multinomial accuracy tests can be used to assess errors of individual classes in a thematic map. Such tests show the error frequencies by thematic class. Multinomial tests are based on a confusion matrix which shows the number of observations (reference data) against the mapped (classified) data. The confusion matrix is the most commonly applied method for the accuracy assessment of thematic maps (Foody 2002). The columns of the matrix represent the observations and the rows the mapped classes. The matrix diagonal contains the number of correctly classified observations, while off-diagonal cells represent miss-classification. Based on such matrix, it is possible to derive the user's accuracy and producer's reliability, and overall accuracy. These statistics are commonly called naïve statistics, as they do not take into consideration the difference in class size or take into consideration the effect of change. The user's accuracy of a thematic class is the portion of observations for that class that have been mapped (classified) correctly. In other words, if the user goes into some particular location on the map, the user's accuracy gives the probability that the land use is correct in the map. The producer's reliability is, on the other hand, the portion of the mapped samples in a class that are correctly classified. So, this gives the producer of the map the probability of a class to be correctly classified. The overall accuracy is the amount of correctly classified cells. The overall accuracy can be derived by considering all off-diagonal cells in the matrix as misclassifications (Olofsson et al. 2013).

The kappa index of agreement can be used as a measure of classification accuracy. It is derived from the confusion matrix. The kappa index compensates for the effect of differences in class sizes in the sampled data (observations). The usual form of the kappa index (unweighted kappa) considers all errors as equally important. The kappa index can be calculated as described by Rossiter (2004). Kappa index gives a value between -1 and 1. If kappa is more than zero, the classification is considered to be better than mere change.

4. Results and discussion

4.1 Land use/land cover mapping

4.1.1 State-level mapping

The land use mapping on the state-level was done in NRSC, ISRO. Therefore, due to restriction on use of the data, the original land use map is not shown on this report. In figure 4-1 the reclassified land use map is shown. The map shows land use in all three states of interest, Madhya Pradesh, Maharashtra and Tamil Nadu. While the original LULC map had 19 classes, the reclassified has only 5. It can be assumed that the reclassified map has better overall accuracy because there are fewer classes. However, the classification accuracy of the original map was not calculated. On the other hand, the classification accuracy of the reclassified map can be seen from the table 4-1. The table shows the accuracy in the three different states separately. The overall accuracy in Madhya Pradesh, Maharashtra and Tamil Nadu is 78 %, 55 % and 53 %, respectively. The overall accuracy was relatively low, especially in Maharashtra and Tamil Nadu, only about 50 %. Also, the corresponding kappa values were also quite low, 0.55, 0.37 and 0.32, respectively. One reason why the figures are so low can be that the LULC map itself had a slight misalignment when compared to the satellite imagery. The reason for that misalignment was unclear, though, NRSC does mention that the thematic accuracy is within 1 to 3 pixels. Because the accuracy assessment was done in pixel-by-pixel basis, therefore, the misalignment of even one pixel can cause a specific area to have incorrect class corresponding to it.

While the overall accuracy of the map is low, the individual class accuracies give a clearer picture on the situation. In all states the wasteland-class has the lowest user accuracy. However, it differs in different states that how misclassifications around the wasteland-class behave. In all of the three states wasteland-class is clearly misclassified mainly as agriculture, meaning that areas that are in reality wasteland are classified as agriculture. However, in in Tamil Nadu and Maharashtra also some of the agriculture areas are misclassified as wasteland, and in Madhya Pradesh some forest and agriculture areas are misclassified as wasteland. This tells about the difficulty to classify the wasteland class, which withholds lots of different kind of subclasses and of which many are close to agriculture or like in the case of degraded forest very close to forest.

4.1.2 Pilot-level mapping

The results for the accuracy assessment of the pilot area LULC maps are presented in table 4-2. The accuracy level of the pilot area maps is on the same level as that of the state-level maps. The “easiest” state to classify has been clearly Madhya Pradesh. The reason for that most likely is that the difference between agriculture and wasteland is clearest there. One surprising notion is that the classification of forest is turning up to be quite difficult. This is most likely due to the fact that was mentioned earlier, that the degraded forest (which is classified as wasteland) is really common and is been mixed up with the forest class and vice versa. This means that there should be more work done to look into the means to differentiate these two from one another.

The LULC maps for the pilot areas can be found from figure 4-2. The maps have the same classes as the state-level maps, with one exception. Because some of the Landsat satellite images had partial cloud cover in them, also the LULC maps have both cloud and shadow classes included. The only are where the cloud cover was extensive was Coimbatore region in Tamil Nadu. That is also the only region where the cloud adjusted biomass calculations really affected the results was the same region. There was some units where the biomass values are unsure due to the fact that almost the whole cell was covered by cloud and thus there was very little information of the land use distribution itself. This, however, is very regional problem and is not affecting majority of the area.

The biomass maps can be found from appendixes 1 (state-level) and 2 (pilot-level). The data is available also from the ProMS web service:

URL: powerline.arbonaut.com/best/
Username: best
Password: erft$5f3

The results can also be downloaded from the Arbonaut ftp-server:

Host: ftp.arbonaut.com
Username: BEST
Password: DUn5qHZ8

4.1.3 Wasteland mapping

The wasteland mapping was based on the state-level NRSC/ISRO LULC maps. The LULC maps were reclassified based on the NRSC wasteland classification documentation. The figure 4-3 shows the wasteland classes represented in the three project states. There were six different wasteland classes present in the area. Majority of the wastelands are scrubs/degraded forest, scrubland or other wasteland. On top of the major classes, there are three minor classes which are present only in very local cases. Major part of wastelands in Madhya Pradesh are scrub/degraded forest and a mix of scrublands and other wasteland, while in Maharashtra and Tamil Nadu the wastelands are a mix of scrubland and other wasteland. Madhya Pradesh has also minor aggregation of gullied wasteland in the northern part of the state.

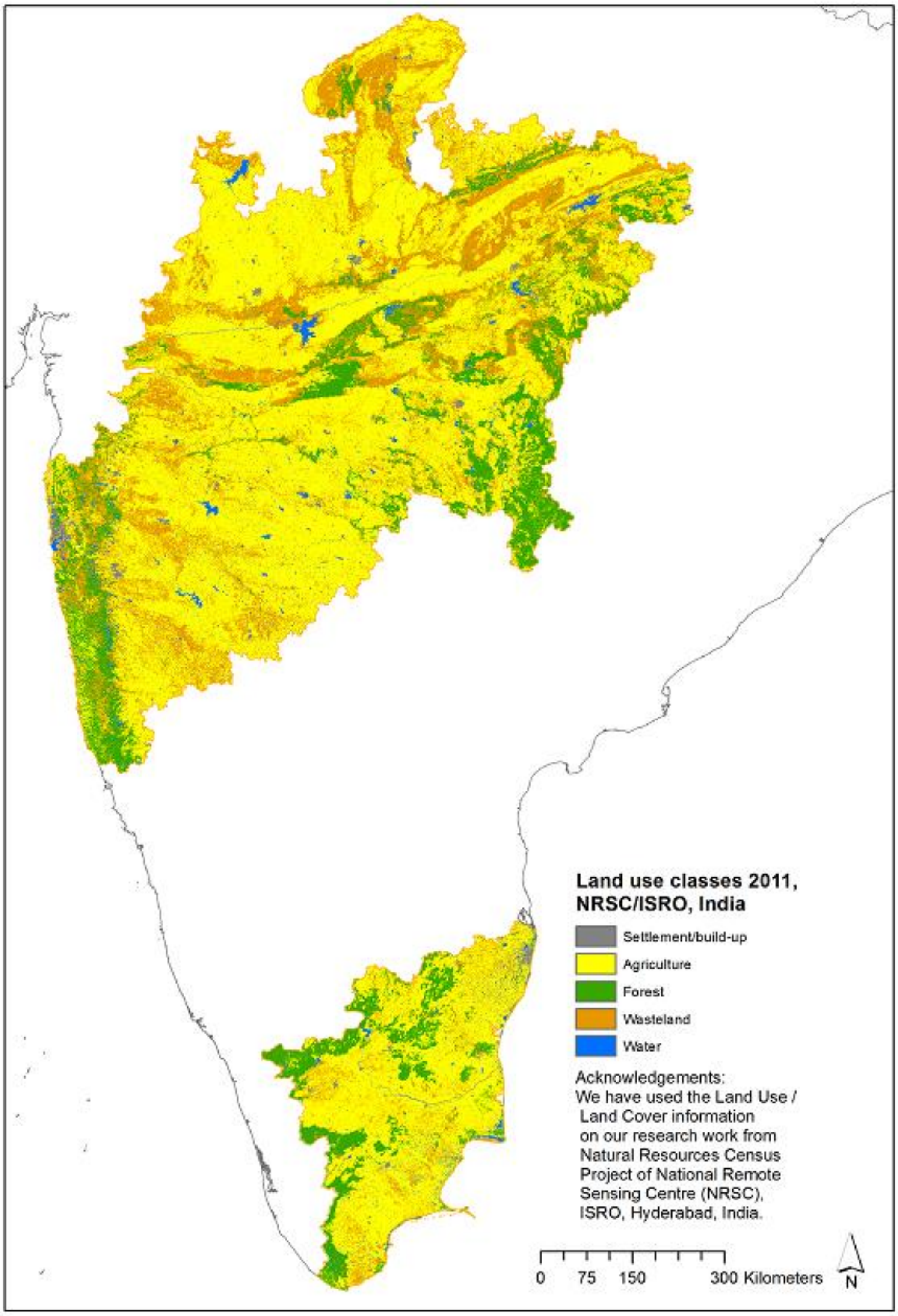

Figure 4-1: Reclassified state-level LULC map for Madhya Pradesh, Maharashtra and Tamil Nadu.

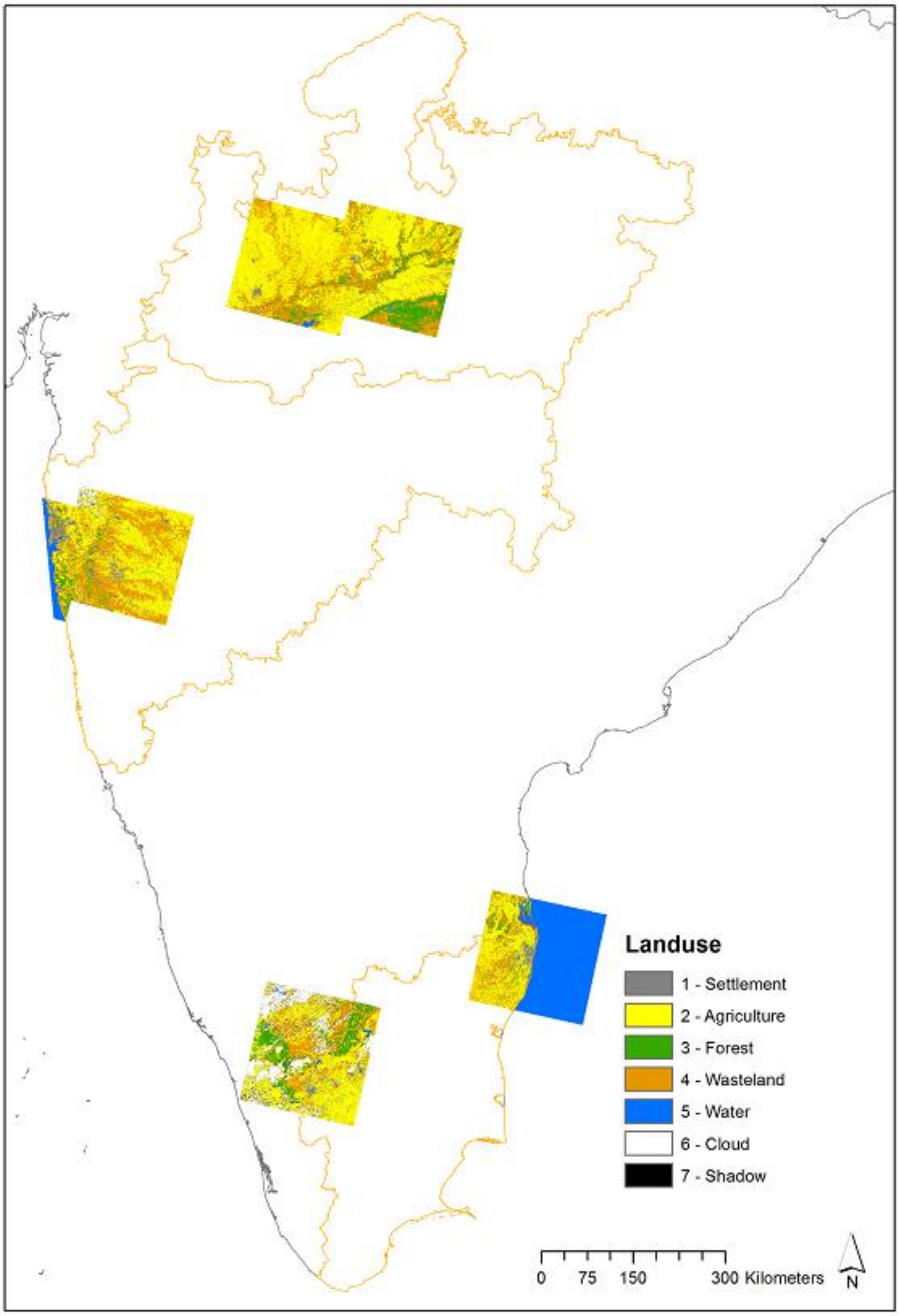

Figure 4-2: Pilot-level LULC maps for six pilot areas in Madhya Pradesh, Maharashtra and Tamil Nadu.

Table 4-1: Accuracy assessment results for state-level LULC maps. Accuracy results are presented by state with overall, user's and producer's accuracy and confidence intervals.

MADHYA PRADESH

Map \ Reference	Settlement	Agriculture	Forest	Wasteland	Water		User's accuracy	CI lower limit	CI upper limit
Settlement	9	0	1	2	0	12	75 %	46 %	104 %
Agriculture	5	227	2	27	2	263	86 %	82 %	91 %
Forest	0	0	5	1	0	6	83 %	45 %	121 %
Wasteland	1	21	19	52	0	93	56 %	45 %	67 %
Water	0	2	0	0	2	4	50 %	-12 %	112 %
	15	250	27	82	4	378			
Producer's reliability	60 %	91 %	19 %	63 %	50 %				
CI lower limit	32 %	87 %	2 %	52 %	-12 %				
CI upper limit	88 %	95 %	35 %	74 %	112 %				
Overall accuracy	78 %	**Overall kappa**	0.55						
CI lower limit	74 %								
CI upper limit	82 %								

MAHARASHTRA

Map \ Reference	Settlement	Agriculture	Forest	Wasteland	Water		User's accuracy	CI lower limit	CI upper limit
Settlement	17	1	0	3	0	21	81 %	62 %	100 %
Agriculture	8	66	7	23	5	109	61 %	51 %	70 %
Forest	0	3	12	10	0	25	48 %	26 %	70 %
Wasteland	10	28	8	33	1	80	41 %	30 %	53 %
Water	1	3	3	3	14	24	58 %	37 %	80 %
	36	101	30	72	20	259			
Producer's reliability	47 %	65 %	40 %	46 %	70 %				
CI lower limit	30 %	56 %	21 %	34 %	47 %				
CI upper limit	65 %	75 %	59 %	58 %	93 %				
Overall accuracy	55 %	**Overall kappa**	0.37						
CI lower limit	49 %								
CI upper limit	61 %								

TAMIL NADU

Map \ Reference	Settlement	Agriculture	Forest	Wasteland	Water		User's accuracy	CI lower limit	CI upper limit
Settlement	12	2	1	3	0	18	67 %	42 %	91 %
Agriculture	19	69	35	14	2	139	50 %	41 %	58 %
Forest	0	2	23	0	0	25	92 %	79 %	105 %
Wasteland	3	17	3	9	2	34	26 %	10 %	43 %
Water	0	3	0	0	8	11	73 %	42 %	104 %
	34	93	62	26	12	227			
Producer's reliability	35 %	74 %	37 %	35 %	67 %				
CI lower limit	18 %	65 %	24 %	14 %	36 %				
CI upper limit	53 %	84 %	50 %	55 %	98 %				
Overall accuracy	53 %	**Overall kappa**	0.32						
CI lower limit	47 %								
CI upper limit	60 %								

Table 4-2: Accuracy assessment results for pilot-level LULC maps. Accuracy results are presented by state with overall, user's and producer's accuracy and confidence intervals.

MADHYA PRADESH

Map \ Reference	**Settlement**	**Agriculture**	**Forest**	**Wasteland**	**Water**		**User's accuracy**	CI lower limit	CI upper limit
Settlement	7	5	0	2	0	14	50 %	20 %	80 %
Agriculture	4	194	3	14	2	217	89 %	85 %	94 %
Forest	1	2	5	7	0	15	33 %	6 %	61 %
Wasteland	3	45	13	56	1	118	47 %	38 %	57 %
Water	0	0	0	0	1	1	100 %	50 %	150 %
	15	246	21	79	4	365			
Producer's reliability	47 %	79 %	24 %	71 %	25 %				
CI lower limit	18 %	74 %	3 %	60 %	-30 %				
CI upper limit	75 %	84 %	44 %	82 %	80 %				
Overall accuracy	72 %	**Overall kappa**	0.47						
CI lower limit	67 %								
CI upper limit	77 %								

MAHARASHTRA

Map \ Reference	**Settlement**	**Agriculture**	**Forest**	**Wasteland**	**Water**		**User's accuracy**	CI lower limit	CI upper limit
Settlement	27	8	1	2	1	39	69 %	53 %	85 %
Agriculture	7	57	7	19	4	94	61 %	50 %	71 %
Forest	0	1	2	1	0	4	50 %	-12 %	112 %
Wasteland	1	36	18	49	1	105	47 %	37 %	57 %
Water	1	0	1	1	14	17	82 %	61 %	103 %
	36	102	29	72	20	259			
Producer's reliability	75 %	56 %	7 %	68 %	70 %				
CI lower limit	59 %	46 %	-4 %	57 %	47 %				
CI upper limit	91 %	66 %	18 %	80 %	93 %				
Overall accuracy	58 %	**Overall kappa**	0.41						
CI lower limit	51 %								
CI upper limit	64 %								

TAMIL NADU

Map \ Reference	**Settlement**	**Agriculture**	**Forest**	**Wasteland**	**Water**		**User's accuracy**	CI lower limit	CI upper limit
Settlement	22	10	0	6	1	39	56 %	40 %	73 %
Agriculture	6	68	8	16	2	100	68 %	58 %	78 %
Forest	0	1	5	2	0	8	63 %	23 %	102 %
Wasteland	1	14	14	4	2	35	11 %	-1 %	23 %
Water	1	0	0	0	6	7	86 %	53 %	119 %
	30	93	27	28	11	189			
Producer's reliability	73 %	73 %	19 %	14 %	55 %				
CI lower limit	56 %	64 %	2 %	0 %	21 %				
CI upper limit	91 %	83 %	35 %	29 %	89 %				
Overall accuracy	56 %	**Overall kappa**	0.34						
CI lower limit	48 %								
CI upper limit	63 %								

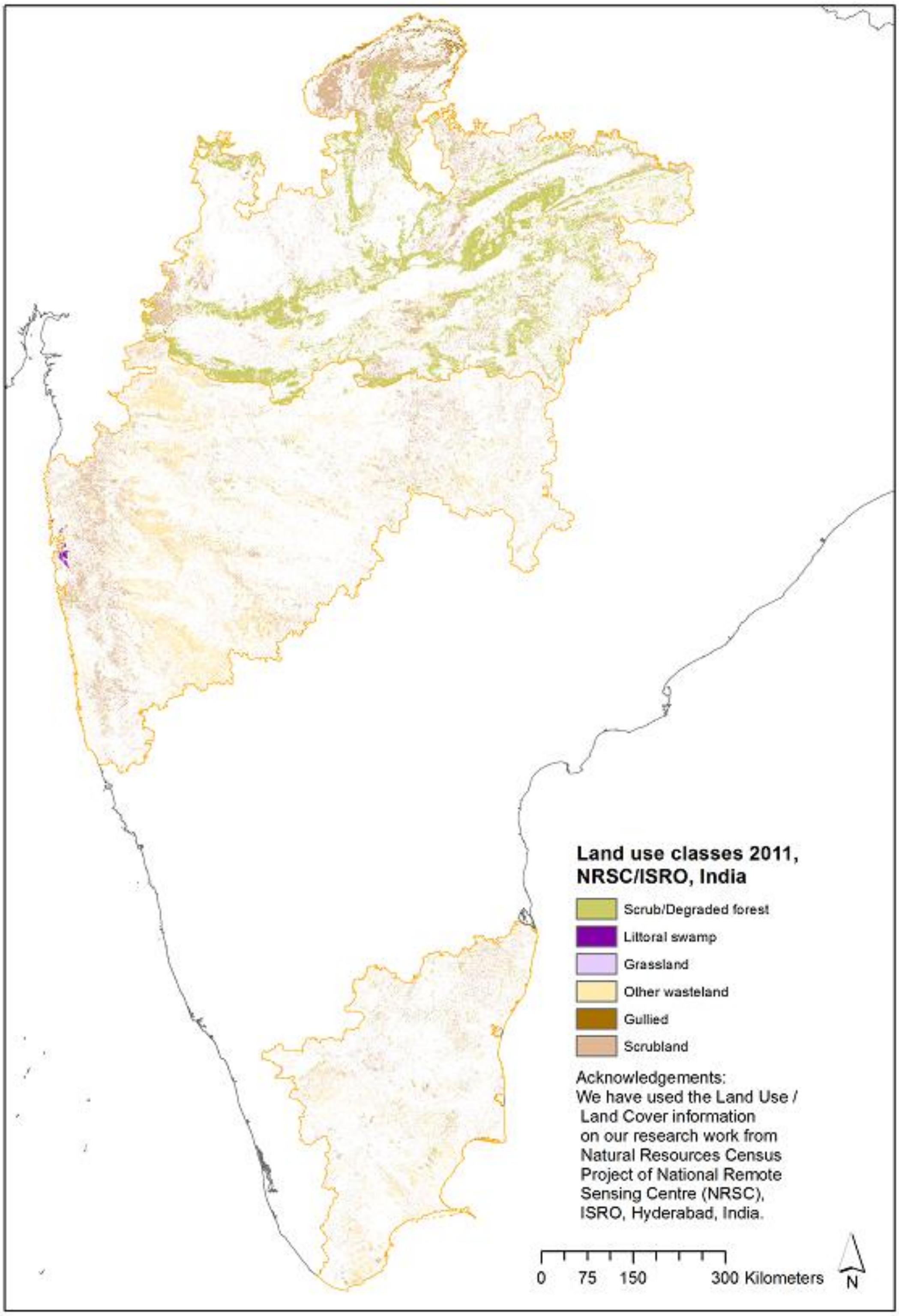

Figure 4-3: State-level wasteland map for Madhya Pradesh, Maharashtra and Tamil Nadu.

5. Conclusions

The aim of the study was to create a distribution map of available biomass for bioenergy within three states in India. This mapping was done based on best available literature sources and LULC maps. On top of the state-wise mapping, also six pilot regions were selected within those three states to develop and test a methodology for LULC mapping. The main reason for the mapping was that the information would be used for bioenergy plant optimization exercise. While the main focus was on the mapping side, there was important information gathered on the strengths and weaknesses of the methodology used, and the possible focus points for the future which should be improved on and further developed.

While the LULC accuracy is currently quite low that should not inhibit the use of the maps for the optimization task. The distribution map is well suited for the optimization. However, more work needs to be done concerning the LULC mapping. One major obstacle in the pilot-level LULC mapping was the Landsat imagery itself and more specifically the time of acquisition of the images. It will be hugely important in the future that the imagery to be used for a LULC mapping will be either a combination of multiple seasons or if single image is used it should be from a time where the different land use classes are the most prominently distinguishable. At least in Tamil Nadu the imagery were from a drier time of the year. This caused that the wasteland was more easily mixed with the other classes. Furthermore, there were seasonal lakes in the area which were at the time of the image acquisition dry and were also difficult to correctly classify. These kinds of problems are in the core of the needed improvements and more work should be done to improve these points.

However, the maps are a very valid representation of the current available biomass distribution situation on the state-level, which has been generated with limited resources. This data can be used for for example optimization or other tasks as input data. The accuracy of the map must always be remembered, however, when using the data.

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APPENDIX 1: State-level biomass maps

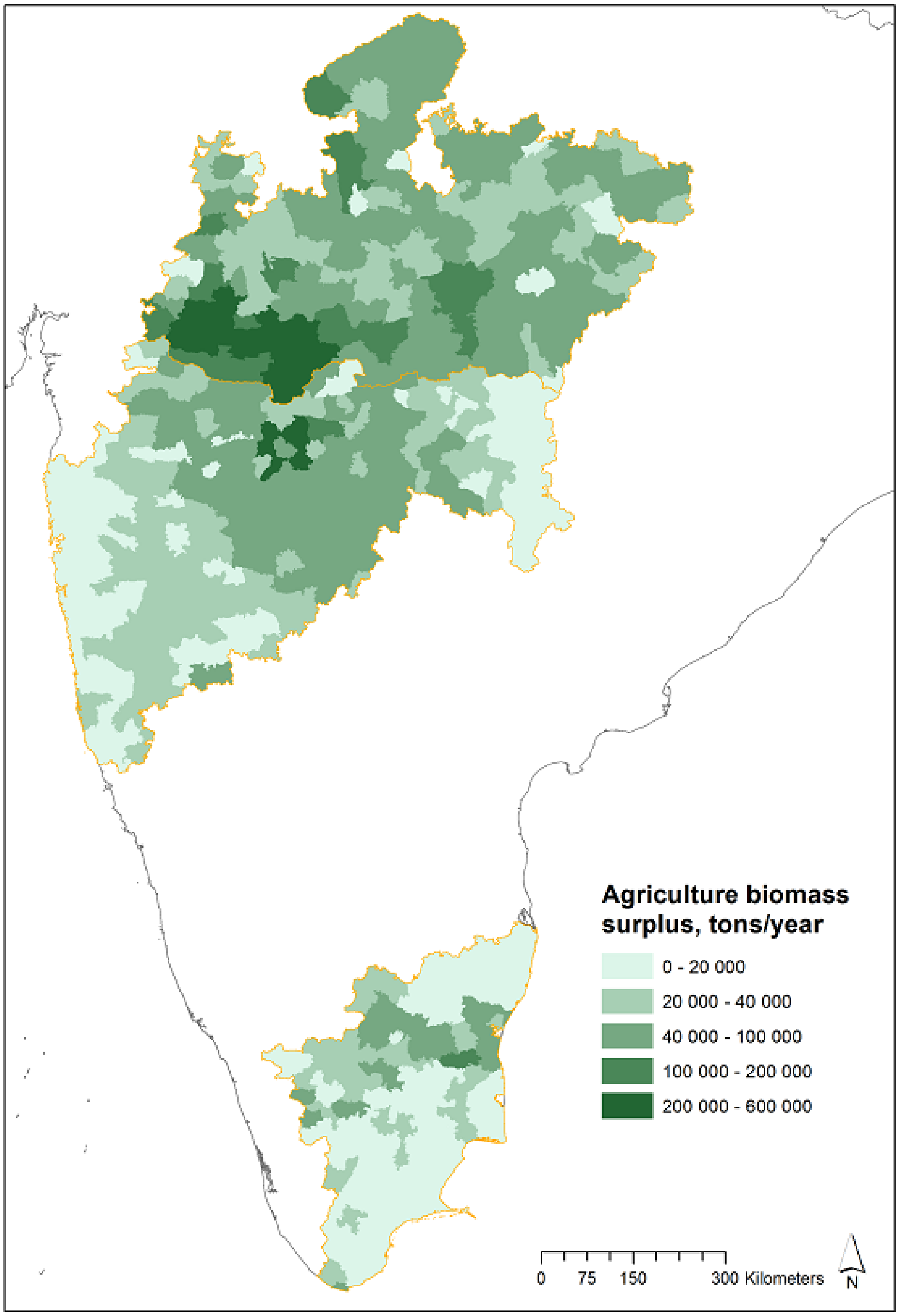

Figure A1-1: State-wise taluk-level agriculture biomass distribution map.

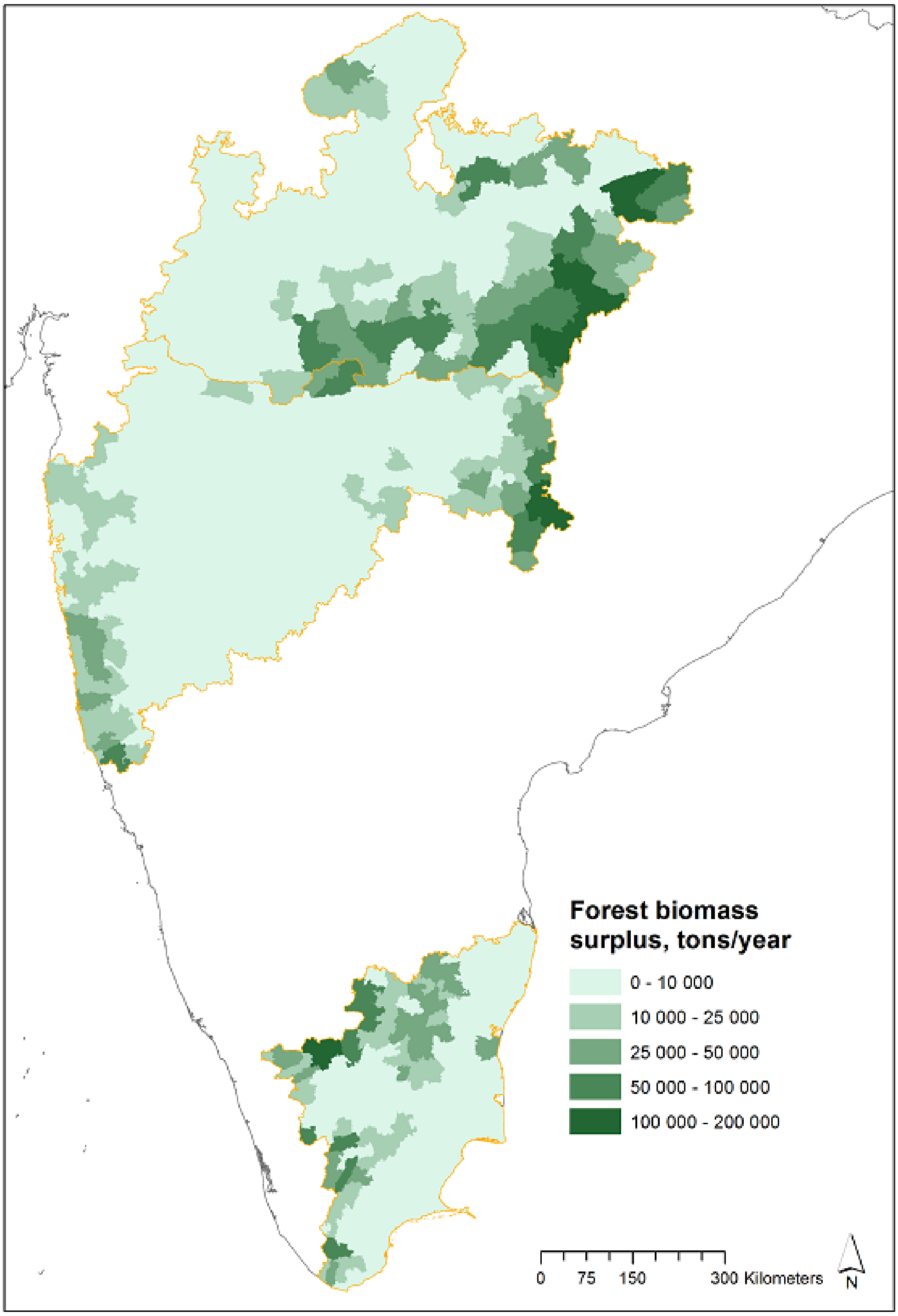

Figure A1-2: State-wise taluk-level forest biomass distribution map.

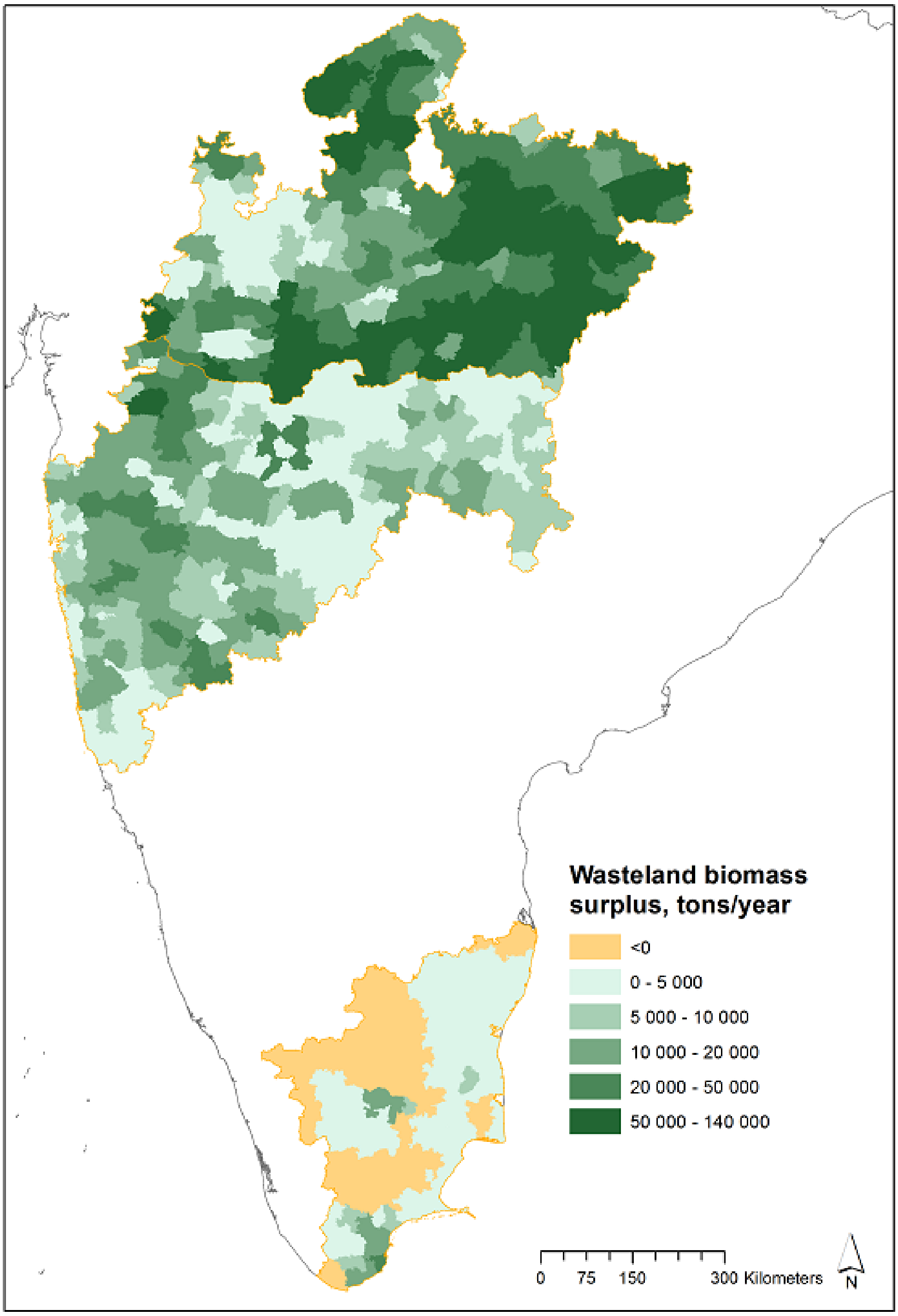

Figure A1-3: State-wise taluk-level wasteland biomass distribution map.

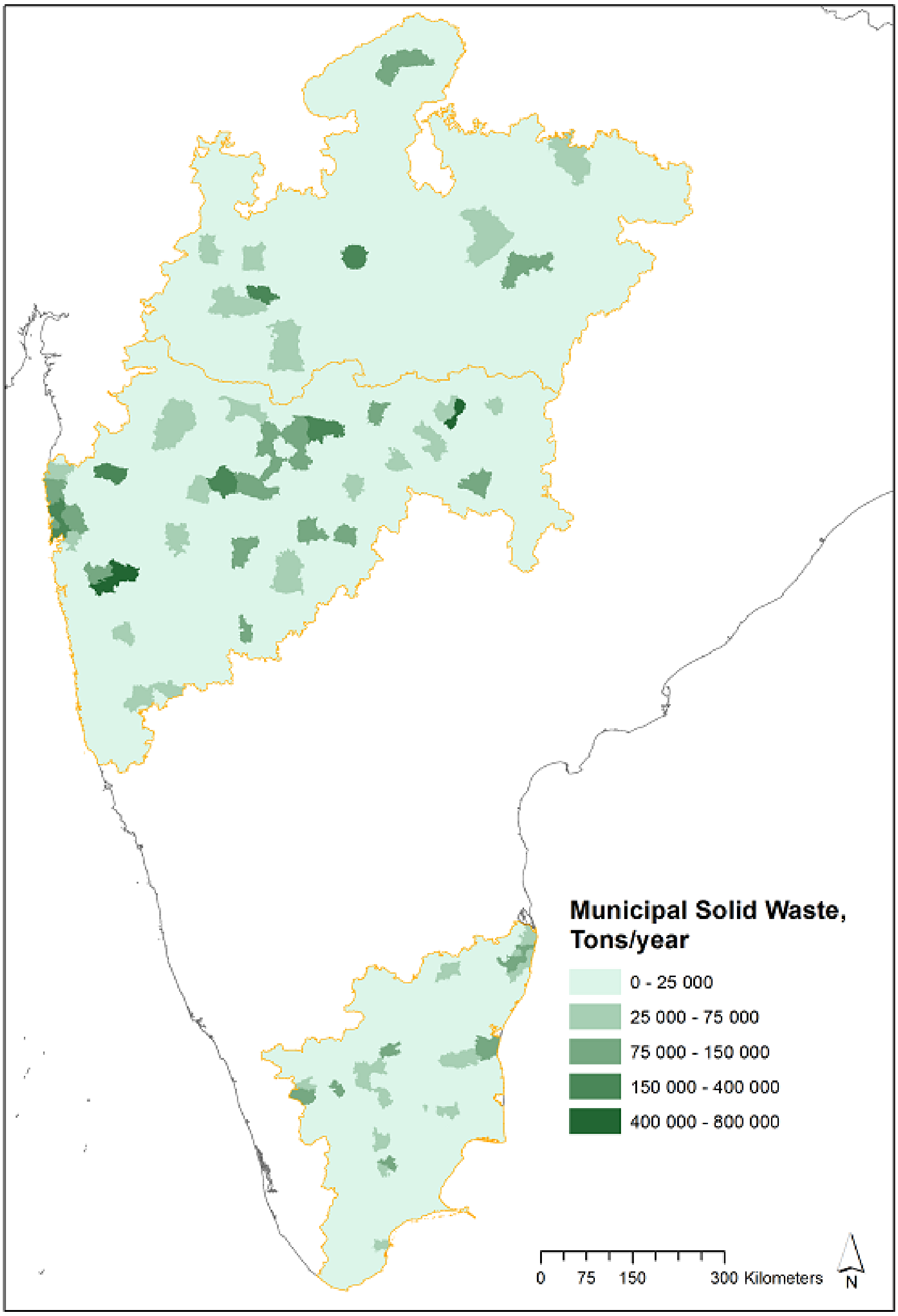

Figure A1-4: State-wise taluk-level municipal solid waste biomass distribution map.

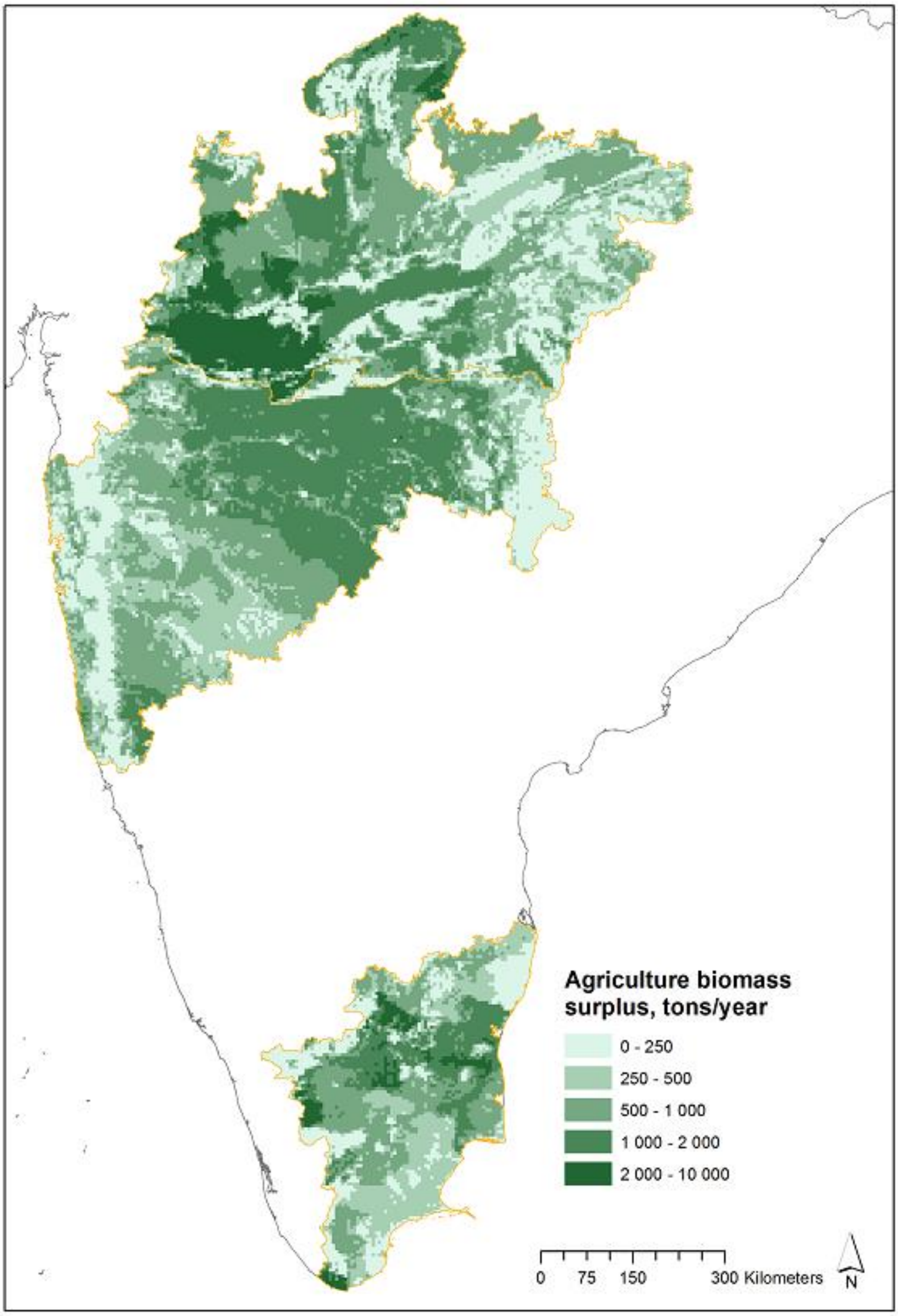

Figure A1-5: State-wise grid-level agriculture biomass distribution map.

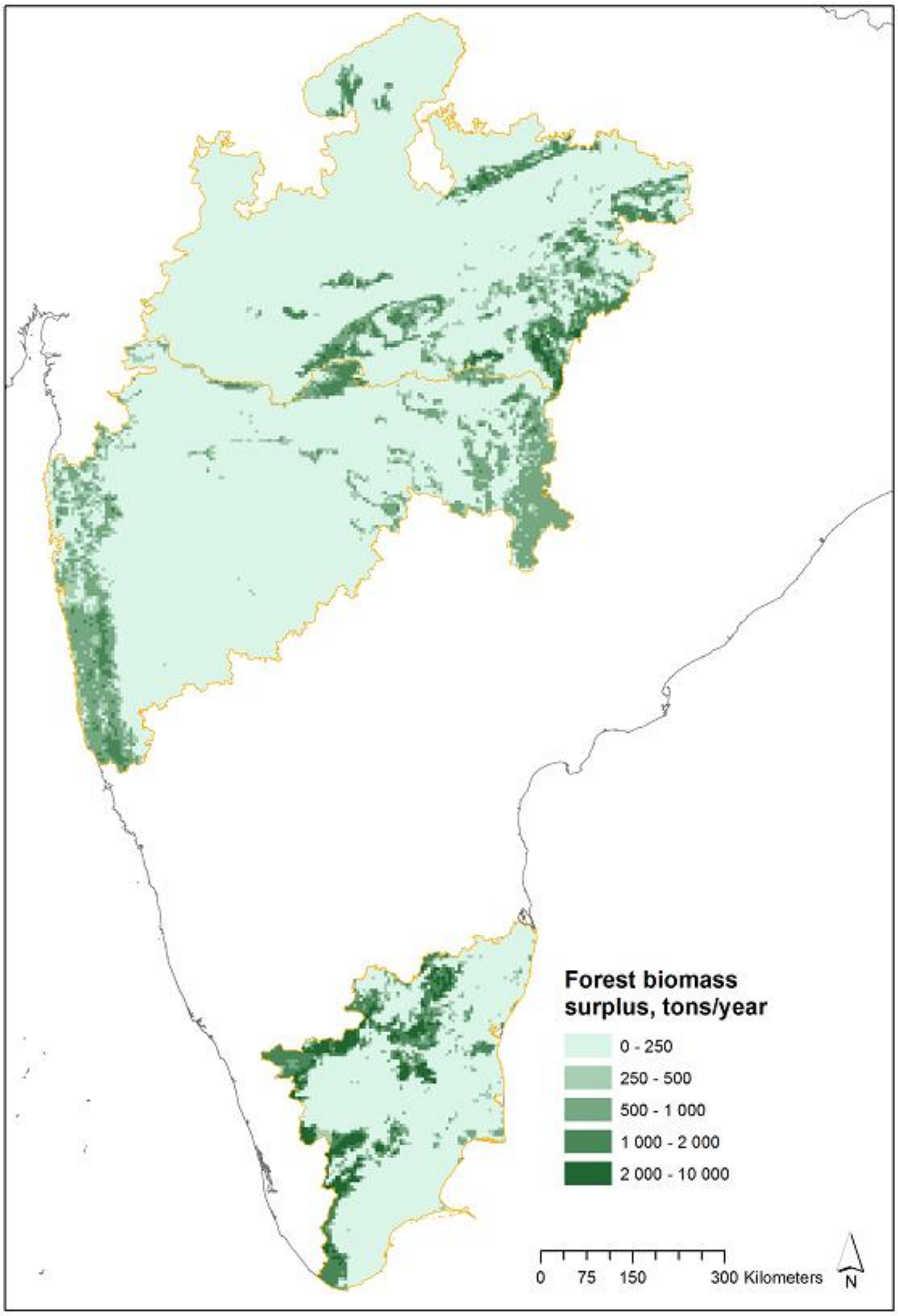

Figure A1-6: State-wise grid-level forest biomass distribution map.

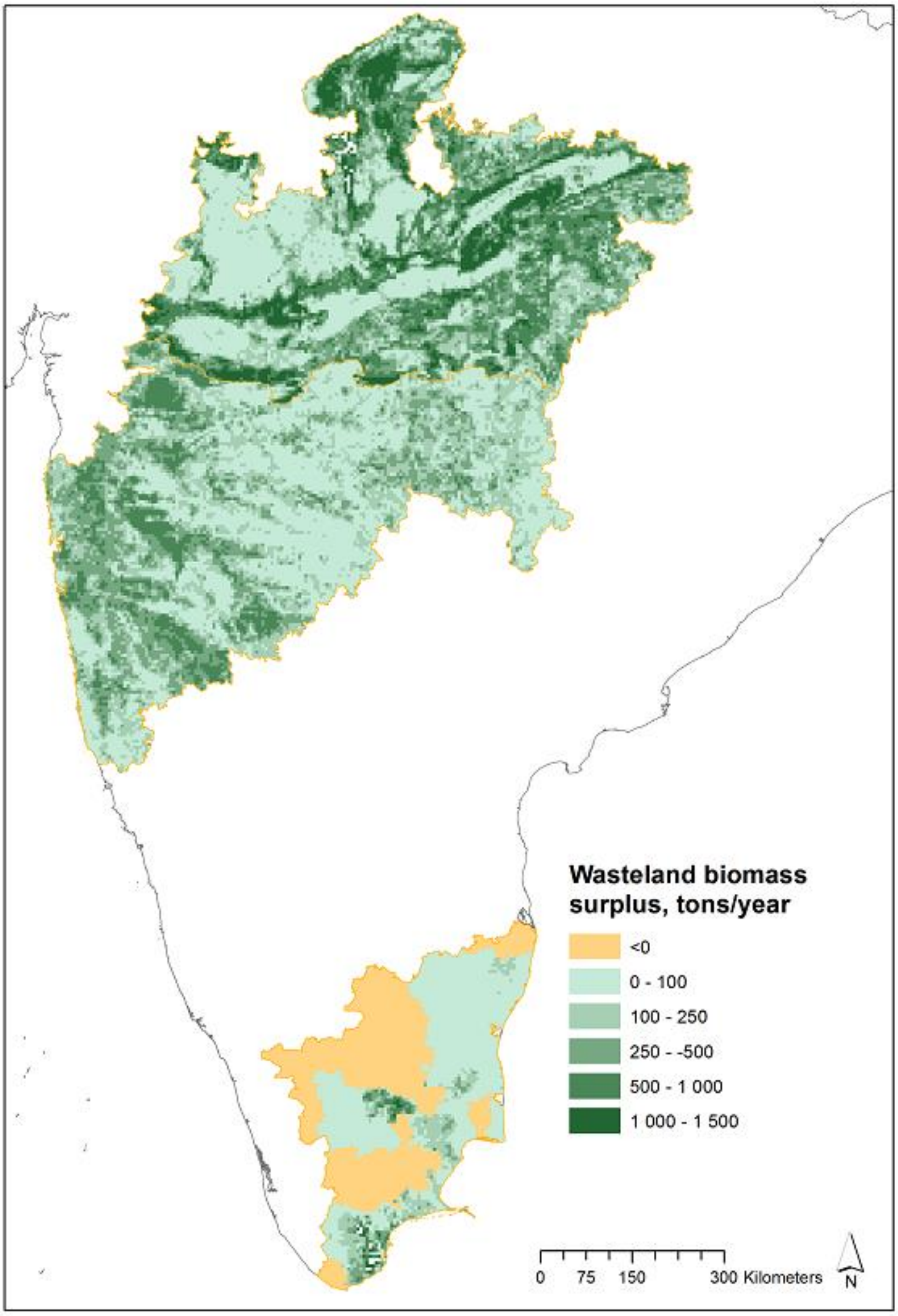

Figure A1-7: State-wise grid-level wasteland biomass distribution map.

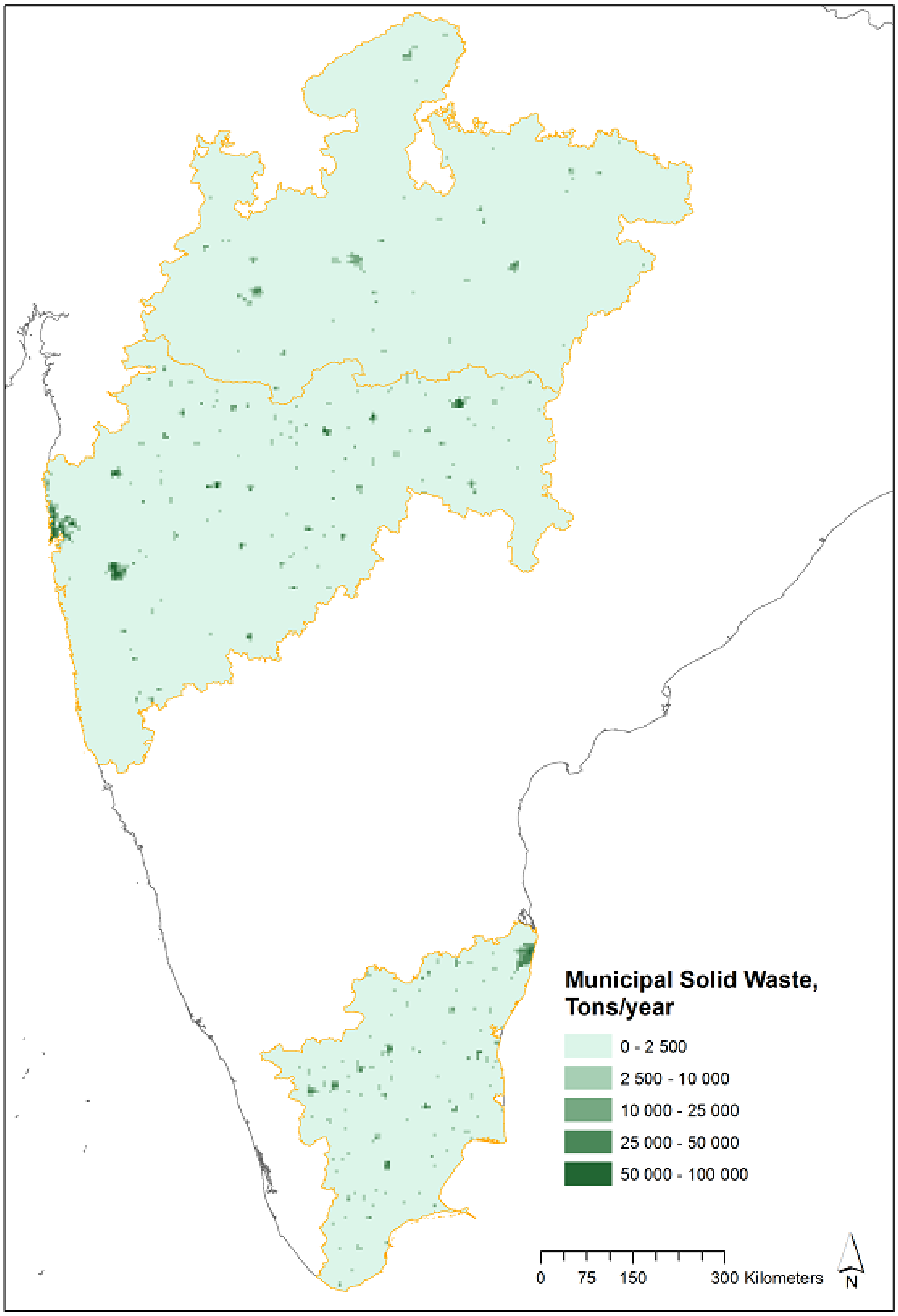

Figure A1-8: State-wise grid-level municipal solid waste biomass distribution map.

APPENDIX 2: Pilot-level biomass maps

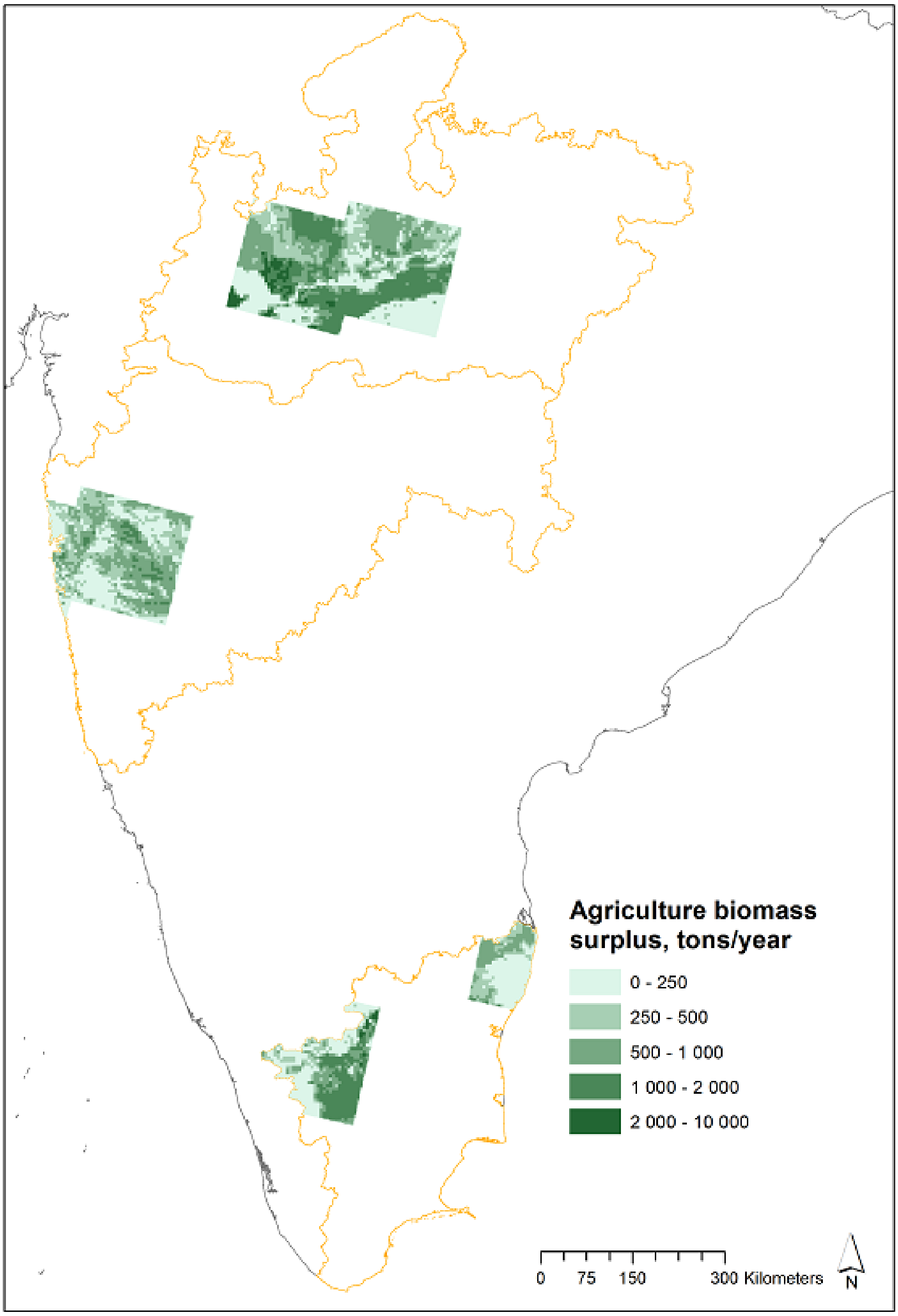

Figure A2-1: Pilot grid-level agriculture biomass distribution map.

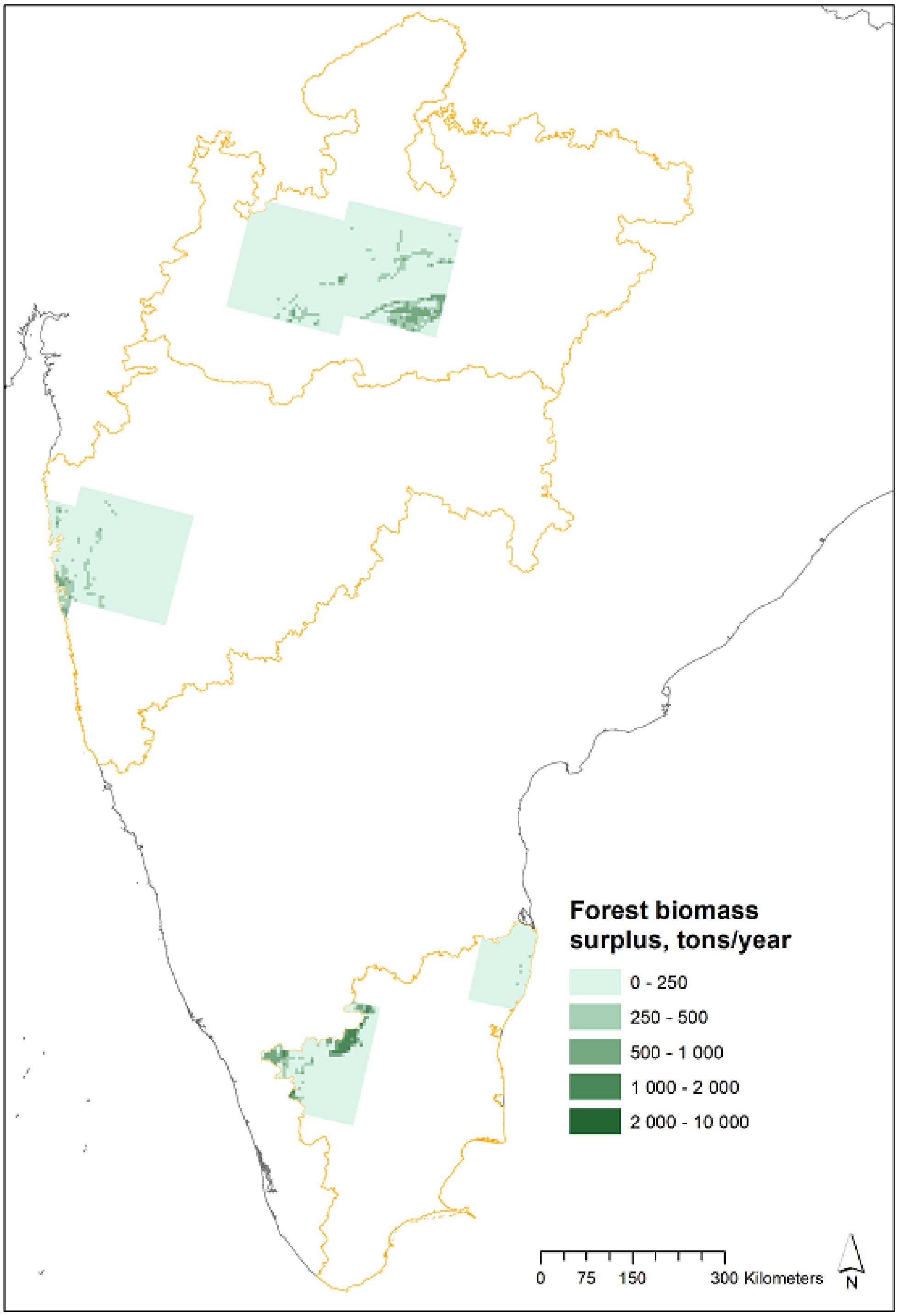

Figure A2-2: Pilot grid-level forest biomass distribution map.

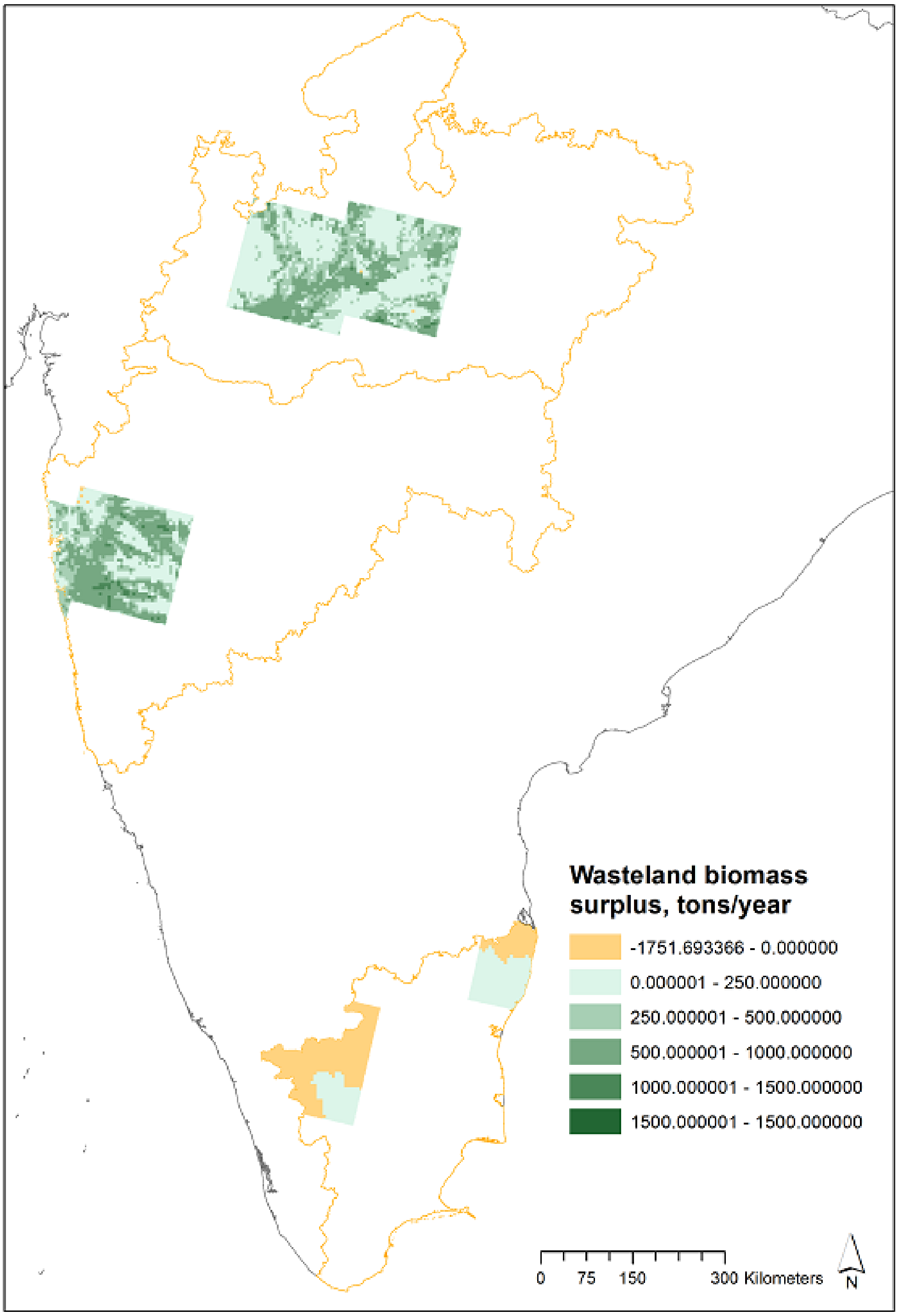

Figure A2-3: Pilot grid-level wasteland biomass distribution map.

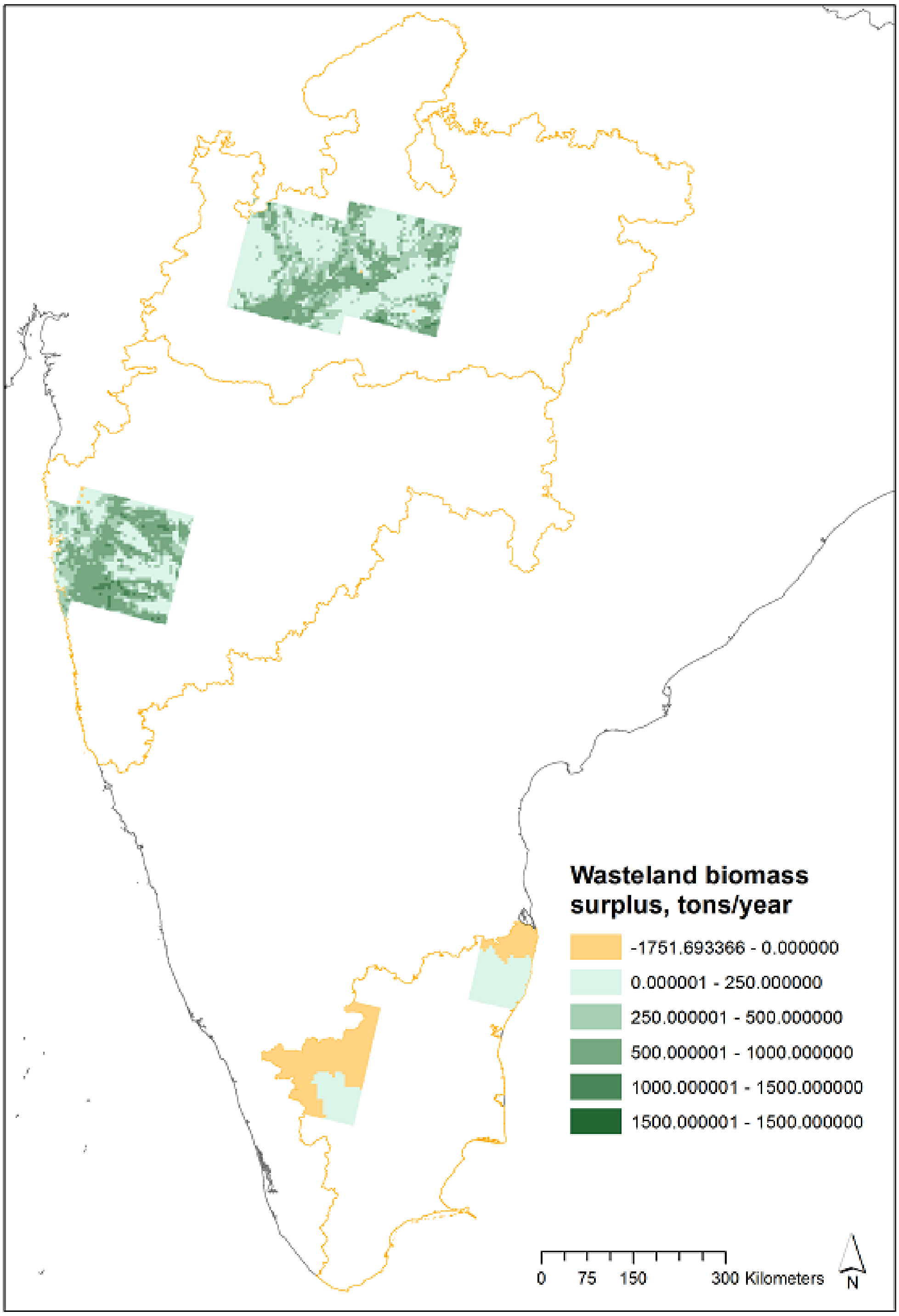

Figure A2-4: Pilot grid-level municipal solid waste biomass distribution map.