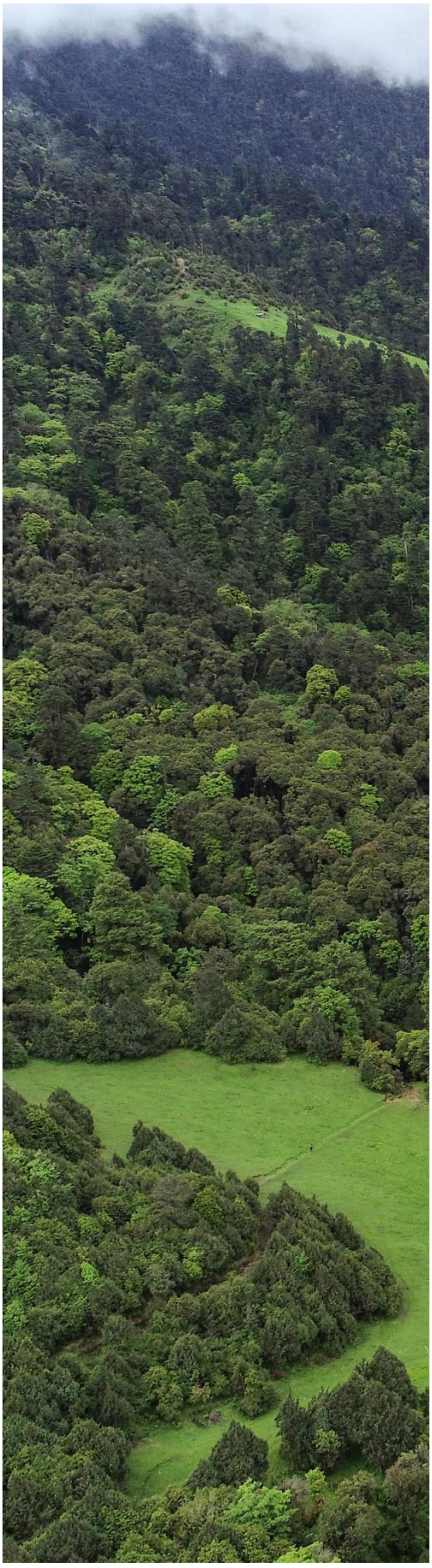
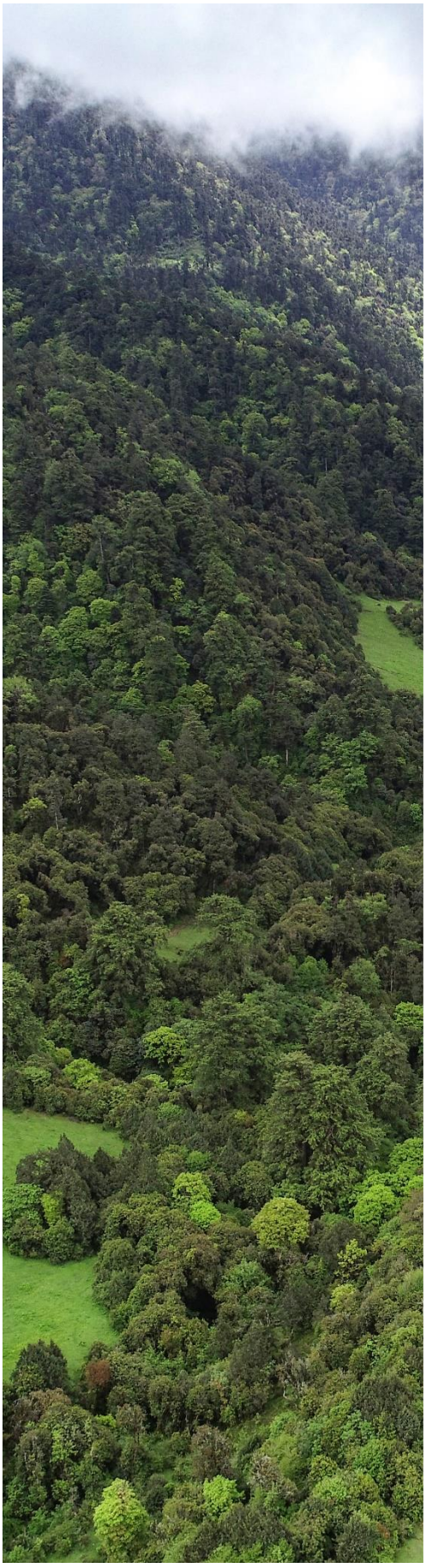
FOREST MONITORING AND INFORMATION DIVISION





FOREST COVER MAPPING REPORT 2022

DEPARTMENT OF FORESTS AND PARK SERVICES

Forest Cover Mapping Report, 2022

FOREST MONITORING AND INFORMATION DIVISION
DEPARTMENT OF FORESTS AND PARK SERVICES

TECHNICAL WORKING GROUP

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དཔལ་ལྡན་འབྲུག་གཞུང་། རྒྱལ་ཁྱབ་དང་རང་བཞིན་སྐྱེད་སྐྱོང་ལྷན་ཐག། ནགས་ཚལ་དང་གྲིང་ཀ་ཞབས་ཏོག་ལས་ཁུངས།
ROYAL GOVERNMENT OF BHUTAN
Ministry of Energy and Natural Resources
Department of Forests and Park Services

FOREWORD

Forests hold immense importance in Bhutan, both for the country's ecological wellbeing and people livelihoods and cultural heritage. Further, forest act as natural carbon sink, absorbing carbon dioxide and mitigating the impact of climate change. The Department of Forests and Park Services has been at the forefront of forest conservation and management, and accurate forest cover extent plays a pivotal role in our endeavors. We strive to ensure the sustainable utilization of forests, while also protecting their ecological integrity for future generation.

Accurate and up-to-date information on forest cover is essential for effective conservation and management of our precious natural resources. The application of remote sensing techniques, especially leveraging the use of Landsat imageries, has significantly enhanced our ability to monitor and evaluate changes in forest cover over time.

It is with great pleasure that I present his report on Forest Cover Mapping of Bhutan, 2022. The report provides a comprehensive analysis of the forest cover across the country, offering detailed insights into the changes that occurred during the year. It is an invaluable tool for the policymakers, planners, researchers, and conservationists, providing a foundation for evidence-based decision-making and the formulation of effective strategies.

I would like to extend my heartfelt appreciation to the dedicated team of professionals who have worked to compile this report. Their expertise, commitment and unwavering dedication have been instrumental in ensuring the accuracy and quality of the information presented.

As we move forward, let us embrace the insights provided by this report and use them to guide our actions. I encourage all stakeholders, including government agencies, researchers, and conservation organizations, to make use of this information.

Lobzang Dorji
DIRECTOR

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1. Introduction

Bhutan, a landlocked country nestled in the eastern Himalayas is located between longitude of $88^0$45' and $92^0$10' East and latitude of $26^0$40' and $28^0$15' North. It is bordered by India to the south, east, and west, and by China to the north. Bhutan's topography is characterized by towering mountains, deep valleys, and swift-flowing rivers. The rugged terrain contributes to the formation of distinct microclimates, creating a wide range of ecological niches. The country experiences a varied climatic pattern, with the southern region experiencing a subtropical climate and the northern parts exhibiting alpine and sub-alpine conditions. This diversity of climate zones fosters a wide array of vegetation types, including dense forests, alpine meadows, and high-altitude scrublands.

Forests hold immense importance in Bhutan, both culturally and ecologically. Bhutan has a deep-rooted belief in the intrinsic value of nature. Forests are considered sacred and are integral to Bhutanese spirituality and way of life. The country has made a remarkable commitment to maintaining at least 60% of its land under forest cover for all time to come. Forests play a crucial role in preserving water resources, mitigating climate change, providing habitat for diverse flora and fauna, and supporting the livelihoods of local communities through sustainable forest management and eco-tourism initiatives. Bhutan's forests are also a significant carbon sink, contributing to global efforts in combating climate change and promoting environmental sustainability.

With the country's constitutional mandate of maintaining 60% of forest cover in perpetuity and its global commitment of remaining carbon neutral, periodic mapping and monitoring of forest cover has become a priority. In this endeavor, the utilization of remote sensing technology emerges as a critical tool for accurately mapping and monitoring forest cover in Bhutan. Remote sensing techniques offer a comprehensive and efficient means to assess the extent, health, and changes in forest cover over time. This technology not only enables Bhutan to effectively manage its forest resources but also contributes to its efforts in achieving its ambitious conservation goals and maintaining a harmonious balance between economic development and environmental preservation.

Bhutan's history of mapping land use and land cover back dates to 1970s. However, the systematic mapping of land use and land cover (LULC) in Bhutan began in the 1990s, primarily using the aerial photography. The first national land use and land cover was produced in 1995 using SPOT imageries of 1980-1990 and aerial photographs. The second land use and land cover mapping were

caried out in 2010 using ALOS (ANVIR-2). Again, the map was updated in 2016 using the Landsat 8. Currently National Land Commission Secretariat is updating the country's land use and land cover.

This forest cover mapping exercise is performed as part of the forest monitoring efforts, utilizing Landsat satellite images from 2021 and 2022, in a parallel exercise to the national forest inventory (NFI) for determining the spatial estimates of the extent of forest cover in the country.

2. Objectives

Main objective of this exercise is to:

1. To generate the updated spatial information on the extent of the forest cover at national level.
2. To study the trend of forest cover changes at national level

3. Material and Methods

3.1 Satellite data

Landsat imagery is widely used for mapping forest cover due to its numerous advantages and cost-effectiveness. Unlike some other satellite data sources, Landsat data is freely available, eliminating the financial barrier to access. Landsat's primary advantage lies in its long history of consistent data collection, spanning over four decades. This extensive time series enables the monitoring of forest dynamics and changes over time, essential for understanding deforestation, afforestation, and forest health. Moreover, Landsat's medium spatial resolution (30 meters) strikes a balance between capturing fine-scale details and covering large areas, making it ideal for regional or national-scale forest assessments.

Three Landsat 8 scenes cover the entire geographical area of Bhutan. Following Landsat 8 scenes were used to carry out the forest cover mapping. Landsat 8 has 11 bands.

Table 1 Path, Row and image acquisition date of Landsat 8

Path and Row	Acquisition Date
137/41	1st December 2022
138/41	3rd January 2021
139/41	29th November, 2022

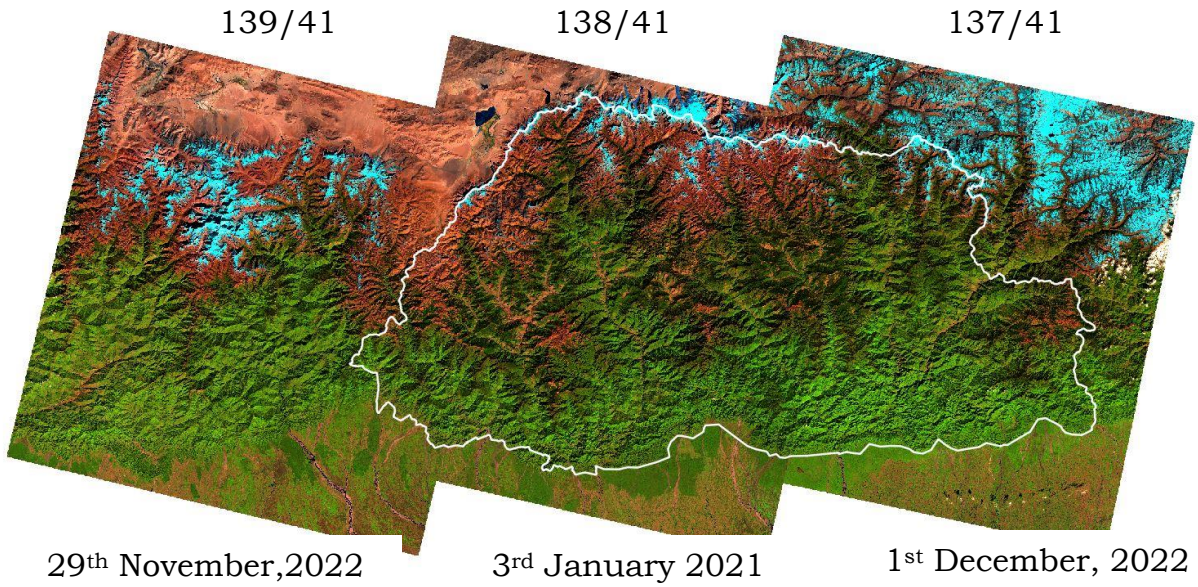


Figure 1 Landsat imageries

Each scene was converted into Top of Atmosphere (ToA) reflectance in QGIS. Individual bands stacked and each scene was re-projected to Bhutan's national projection system called "Drukref03". Three individual scenes were mosaicked in ArcGIS Pro to form a single scene for entire country.

In order to enhance the classification, various band rationing was carried out. Band ratioing is one of the most common techniques used to reduce the topographical interference in remote sensing. Following indices were created through band ratioing.

Table 2 Indices derived from Landsat 8

Indices	
Normalized Difference Vegetation Index	(NIR - Red) / (NIR + Red)
Normalized Difference Built-up Index	(SWIR1 – NIR) / (SWIR1+ NIR)
Normalized Difference Snow Index	(Green-SWIR1) / (Green+SWIR1)
Normalized Difference Water Index	(Green – NIR) / (Green + NIR)
Modified Bare Soil Index	((SWIR1-SWIR2-NIR) / (SWIR1+SWIR2+NIR)) + f f = 0.5
Modified Normalized Difference Water Index	(Green-SWIR1)/(Green+SWIR1)

Further, Tasseled Cap Transformation (TCT) was performed using the coefficient developed by Baig et al. (2014). TCT is widely used spectral transformation technique in remote sensing that convert multi-spectral data into a set of orthogonal components known as brightness, greenness and wetness. TCT was developed for Landsat MSS data by Kauth and Thomas (1976) and later it was was improved and extended for other Landsat as well.

3.2 Digital Elevation Model

Digital Elevation Model (DEM) is often used for forest cover mapping due to the significant influence of terrain on forest ecosystem. DEM provides detailed information about the topography, including slope, aspect and elevation, which directly impact the forest distribution, structure and composition. For this exercise ALOS PALSAR DEM with the spatial resolution of 12.5m was used.

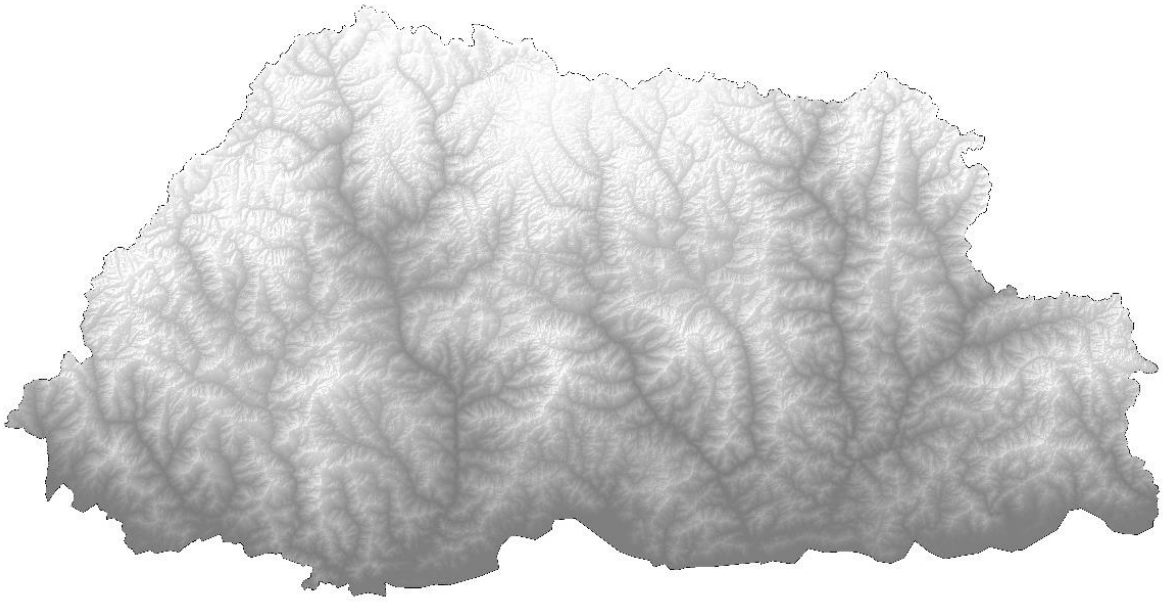


Figure 2 Digital Elevation Model

3.3 Sample data

Sample data was extracted from national forest inventory, high resolution satellite image (Google Earth) and land use and land cover 2016. Sample data was divided into training sample (80%) and validation sample (20%). The training sample was utilized to train the model and validation sample was used for carrying out accuracy assessment.

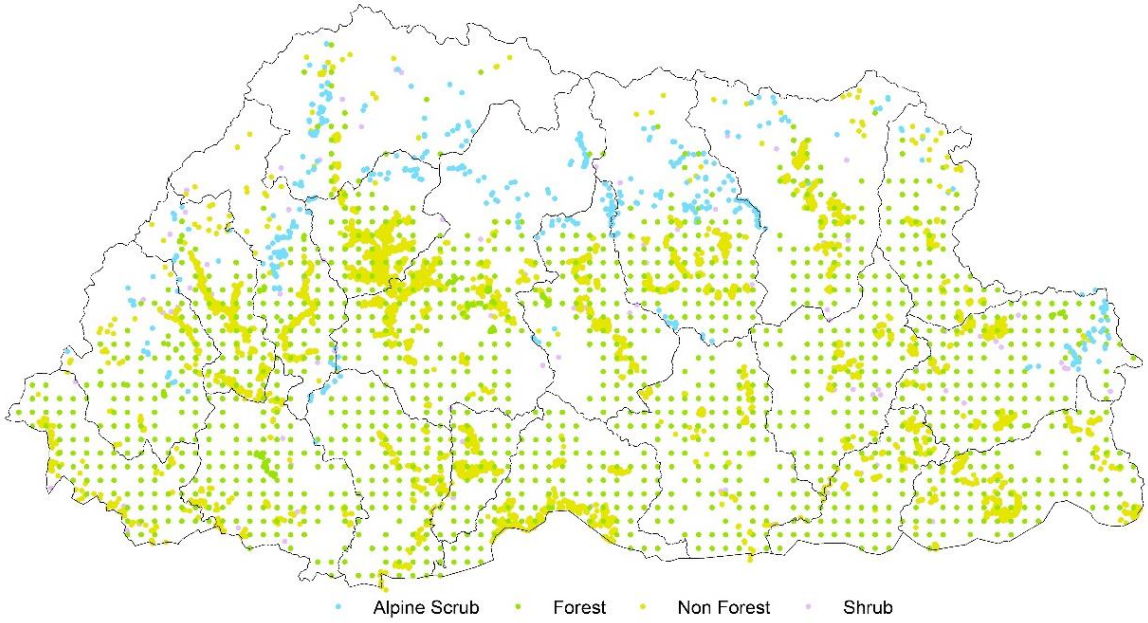


Figure 3 Training Sample

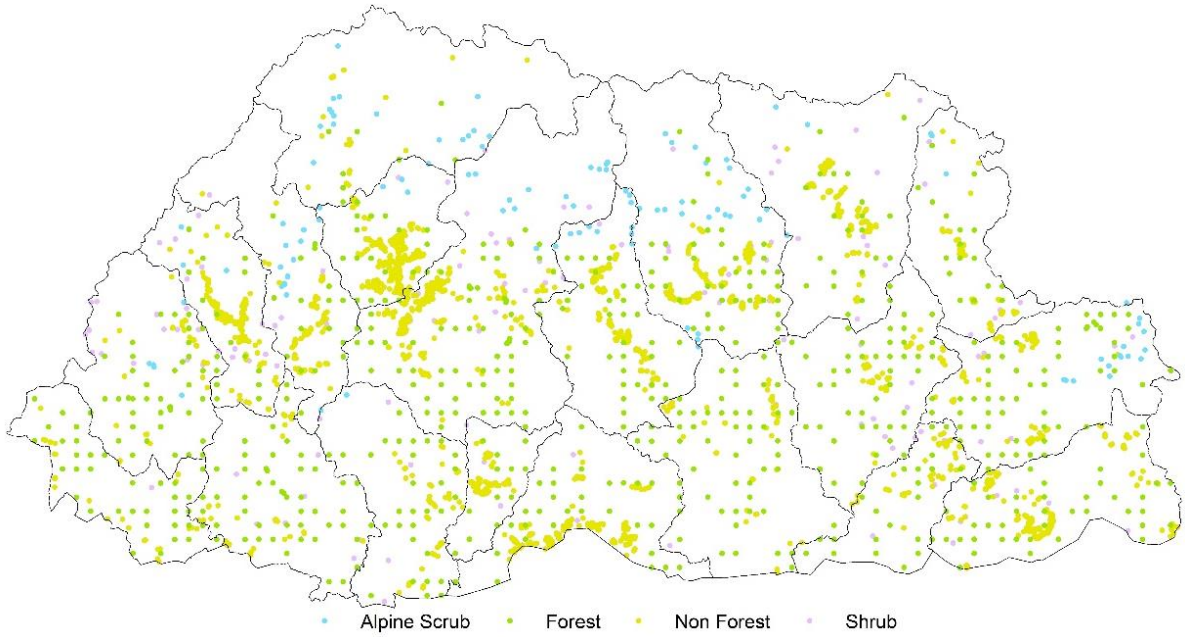


Figure 4 Validation Sample

3.4 Image segmentation

Image segmentation was carried in eCognition 9.1.3 using the multi-resolution segmentation algorithm. Image segmentation is generally defined as a process of partitioning an image into homogenous group or pixel (Dey et al., 2010). Image segmentation plays a crucial role in classification by partitioning image into distinct, homogenous regions, enabling more accurate and efficient classification. A scale value of 30 was chosen to ensure an appropriate level of detail in the segmentation process, while the shape and compactness parameters of 0.1 and 0.9 were set respectively to promote smoothness and compactness in the resulting segments. The image layer weights for all bands were uniformly assigned a value of 1, except for the Near-Infrared (NIR) band, which was given a weight of 2 to emphasize its significance in the segmentation analysis.

3.5 Random Forest Training and classification

For classification, Random Forest classifier in the eCognition 9.1.3 was used. Random Forest is a machine learning algorithm commonly used in land use and land cover (LULC) mapping. Random Forest classifier, developed by Breiman (2001), has gained significant popularity for its effectives in various mapping purposes. It is an ensemble learning approach based on a decision tree that integrates with huge ensemble regression and classification trees. One of the key advantages of Random Forest is its ability to handle large and complex datasets with high-dimensional features. The entire process of classification is summarized in the following flowchart.

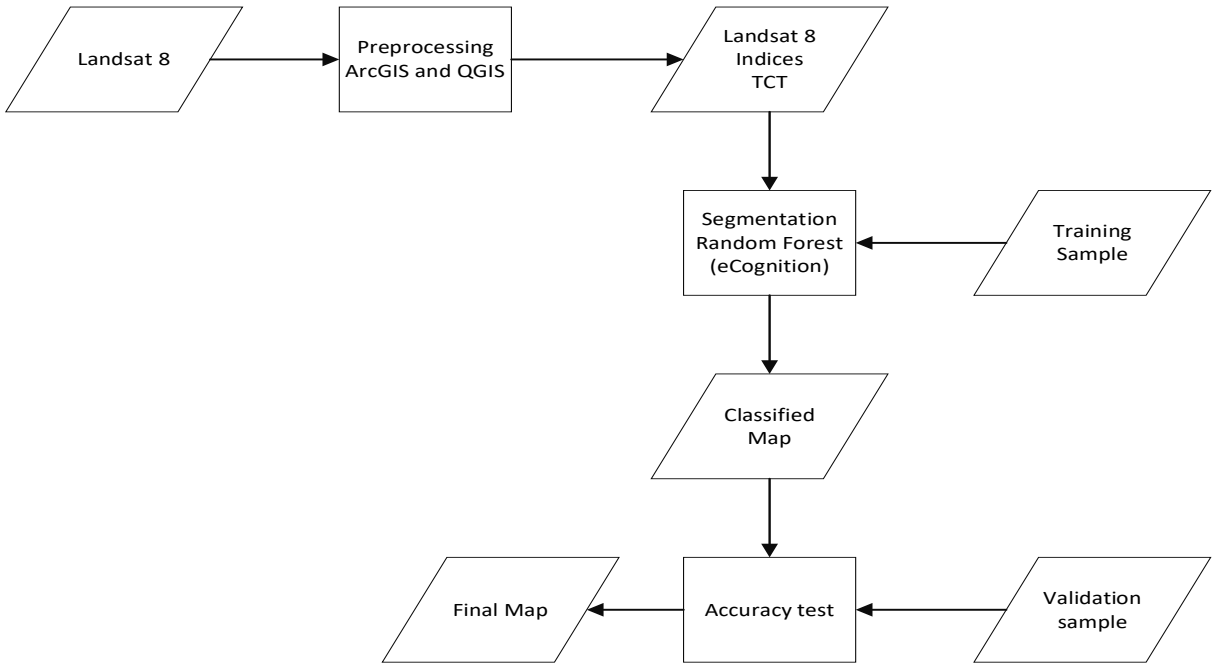


Figure 5 Flowchart for overall classification

4. Accuracy Assessment

Accuracy assessment is a critical step in the process of forest cover mapping as it provides an objective evaluation of the reliability and quality of the mapping results. Accurate forest cover information is crucial for various applications, including land management, biodiversity conservation, carbon stock estimation, and climate change monitoring. Without a thorough accuracy assessment, the users of the mapping results would have limited confidence in the information and its implications for decision-making processes.

For the accuracy assessment in this exercise, error matrix method, also known as a confusion matrix was used. The error matrix provides a systematic tabulation of the observed and predicted forest cover classes. This matrix also allows for the calculation of accuracy metrics such as producer's accuracy, user's accuracy, and kappa coefficient, which provide a comprehensive evaluation of the correctness and agreement between the mapped forest cover and the reference data. 20% of the sample were used for carrying out the accuracy assessment. The overall accuracy of the map is 90% with the kappa coefficient of 0.8.

5. Results

Four classes namely; forest, alpine scrub, shrub and non-forest were classified to understand their extent and spatial distribution. The results of the classification revealed distinct spatial patterns and distribution of classes across the study area. The forest accounted for the largest extent, covering approximately 69.7% of the total geographical area of Bhutan which is equivalent to 26,747.41 square kilometer (2,674,741.16hectare).

Alpine scrub constituted approximately 6.6% of the study area which is equivalent to 2,532.85 square kilometer (253,284.79 hectare). These areas are characterized by shrubby vegetation, sparse tree cover, and occur at higher elevations. The presence of alpine scrub indicates transitional zones between forested areas and alpine environments.

Around 1,409.75 square kilometer (140,974.58 hectare) of the total geographical area of the country is covered with shrub which constitute around 15% of the study area and is characterized by low-lying vegetation with a mixture of shrubs and grasses.

The non-forest, encompassing the remaining 20.1% of the study area which is equivalent to 7,703.99 square kilometer (770399.46 hectare). Non-forest includes various land cover types such as grasslands, agricultural fields, water bodies, settlements, rocky outcrops and barren land.

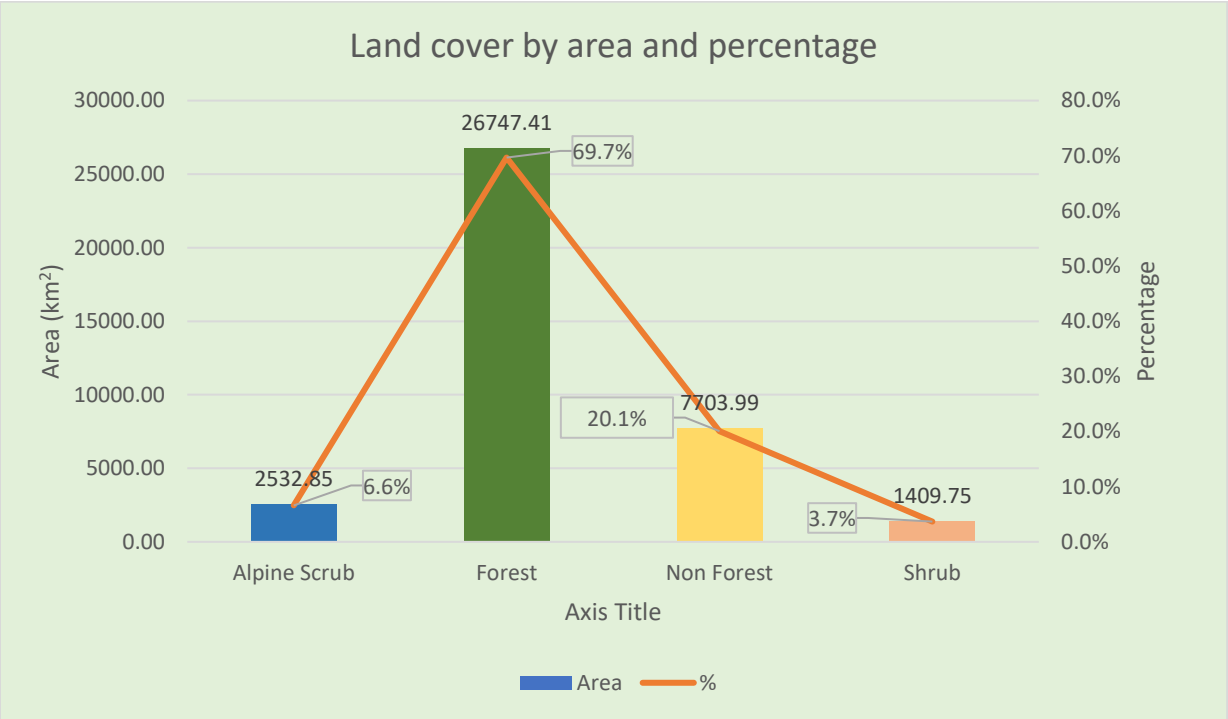


Figure 6 Land cover by area and percentage

The forest cover mapping results for all Dzongkhags in Bhutan reveal valuable insights into the extent of forested areas across the country. Among the Dzongkhags, it is observed that Zhemgang Dzongkhag has the highest forest cover percentage (95%), indicating a significant portion of its land area covered by forests. On the other hand, Gasa Dzongkhag has the lowest forest cover percentage (17%), suggesting comparatively less forested land within its boundaries. Wangduephodrang Dzongkhag, being the largest Dzongkhag also has exhibited the maximum forested area among all the Dzongkhags.

Table 3 Forest cover by Dzongkhag

Dzongkhag	Area (km^2)	Area (Ha)	Percentage
Bumthang	1,354.23	135,422.52	50.3%
Chhukha	1,643.02	164,301.71	88.3%
Dagana	1,483.19	148,318.87	86.9%
Gasa	536.71	53,670.82	17.3%
Haa	1,244.85	124,485.29	66.0%
Lhuentse	1,777.60	177,760.41	62.8%
Mongar	1,759.84	175,984.46	91.4%
Paro	646.42	64,641.80	50.7%
Pemagatshel	928.60	92,859.73	91.7%
Punakha	903.09	90,309.45	82.2%
Samdrup Jongkhar	1,682.67	168,267.17	90.5%
Samtse	1,014.95	101,494.52	78.5%
Sarpang	1,446.84	144,684.17	88.3%
Thimphu	669.33	66,932.51	37.6%
Trashigang	1,766.87	176,686.66	81.0%
Trashi Yangtse	999.73	99,973.46	69.7%
Trongsa	1,505.17	150,517.32	83.8%
Tsirang	559.00	55,900.05	88.5%
Wangdue Phodrang	2,552.32	255,231.54	63.9%
Zhemgang	2,272.99	227,298.68	95.0%

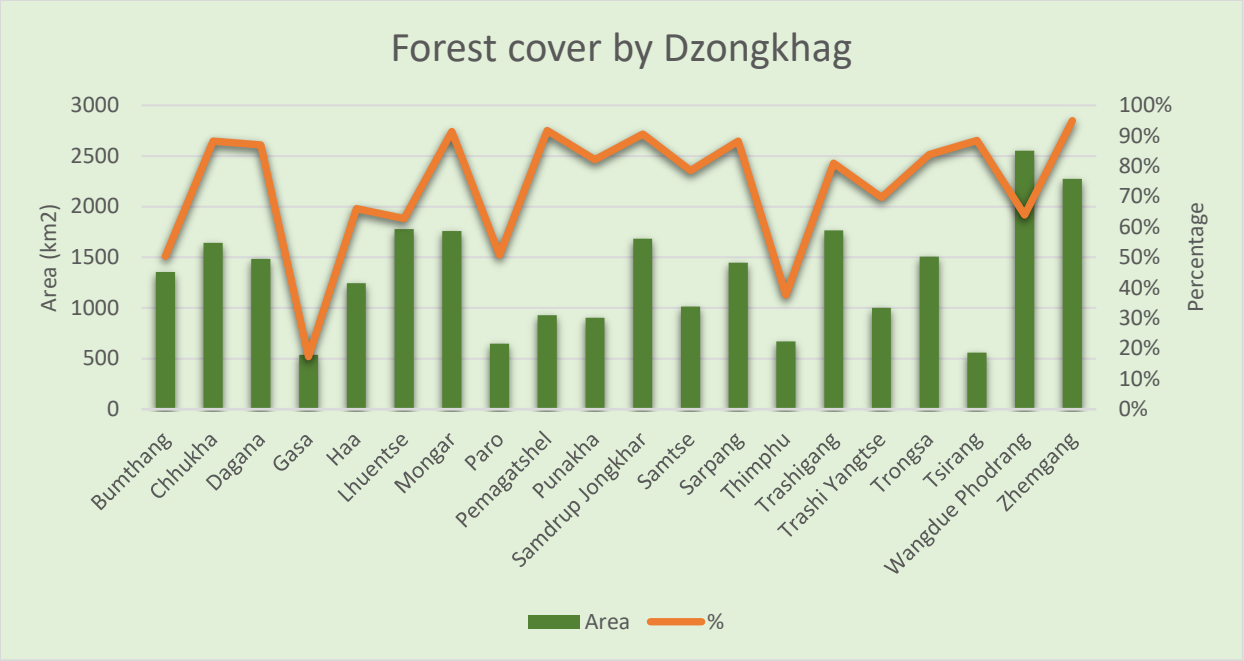


Figure 7 Forest cover by Dzongkhag

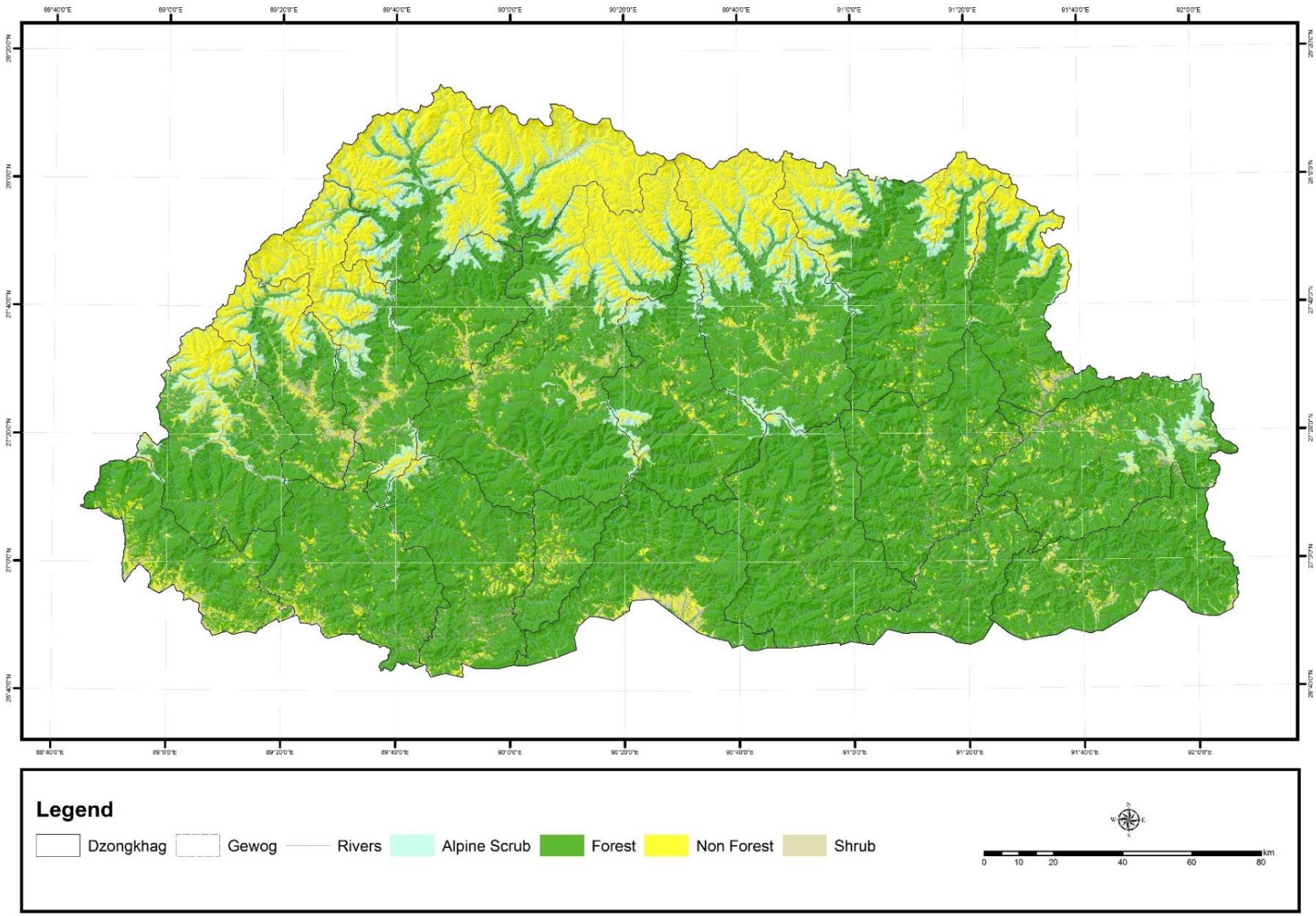


Figure 8 National Forest cover map of Bhutan

6. Forest cover within the Protected Area

The analysis of forest cover within the Protected Area (PA) revealed that approximately 11,165.14 km^2 (1,116,514.28 hectare) of forest exists inside various parks, wildlife sanctuaries, strict nature reserves and biological corridors. This constitutes around 29.08 % of the total geographical land of Bhutan. Table shows the details forest cover inside the PA.

Protected Area	Area (km^2)	Area (Ha)	%
Bumdeling Wildlife Sanctuary	108.41	10,840.92	2.31%
Jigme Dorji Wangchuck National Park	287.35	28,734.66	2.84%
Jigme Khesar Strick Nature Reserve	396.24	39,623.86	1.08%
Jigme Singye Wangchuck National Park	561.36	56,135.66	4.15%
Jomotsangkha Wildlife Sanctuary	196.34	19,634.16	0.86%
Phibsoo Wildlife Sanctuary	222.38	22,237.77	0.70%
Phrumsengla National Park	392.06	39,205.54	2.19%
Royal Botanical Park	483.30	48,330.33	0.23%
Royal Manas National Park	887.13	88,713.17	2.67%
Sakteng Wildlife Sanctuary	1088.53	108,853.23	1.35%
Wangchuck Centennial National Park	415.32	41,531.79	3.82%
Biological Corridor 1	1593.92	159,391.52	0.28%
Biological Corridor 2	328.94	32,893.50	0.75%
Biological Corridor 3	268.74	26,873.61	1.03%
Biological Corridor 4	839.98	83,998.47	1.46%
Biological Corridor 5	90.12	9,012.06	0.51%
Biological Corridor 6	1023.22	102,322.35	0.58%
Biological Corridor 7	516.99	51,699.19	1.02%
Biological Corridor 8	1464.82	146,482.48	1.26%
Total	**11165.14**	**1,116,514.28**	**29.08%**

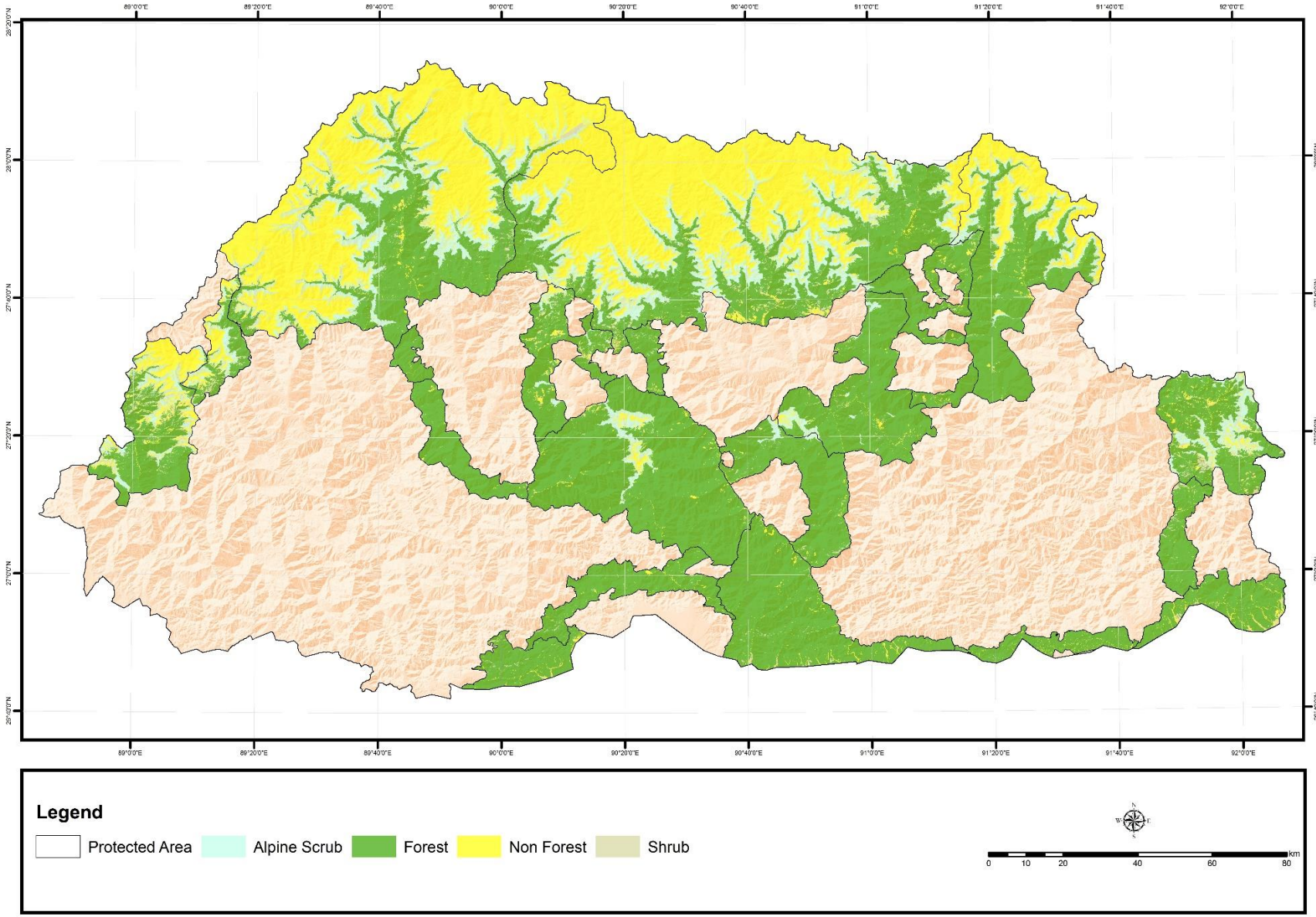
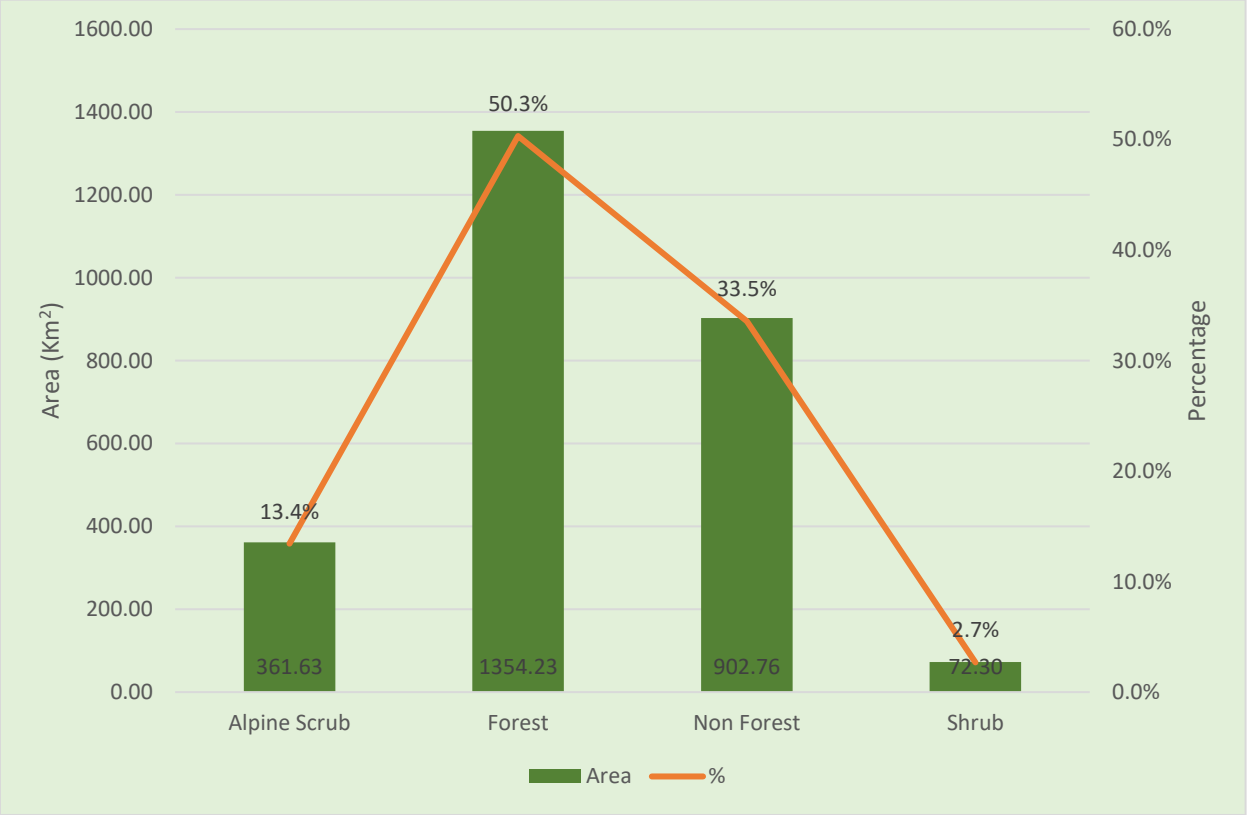
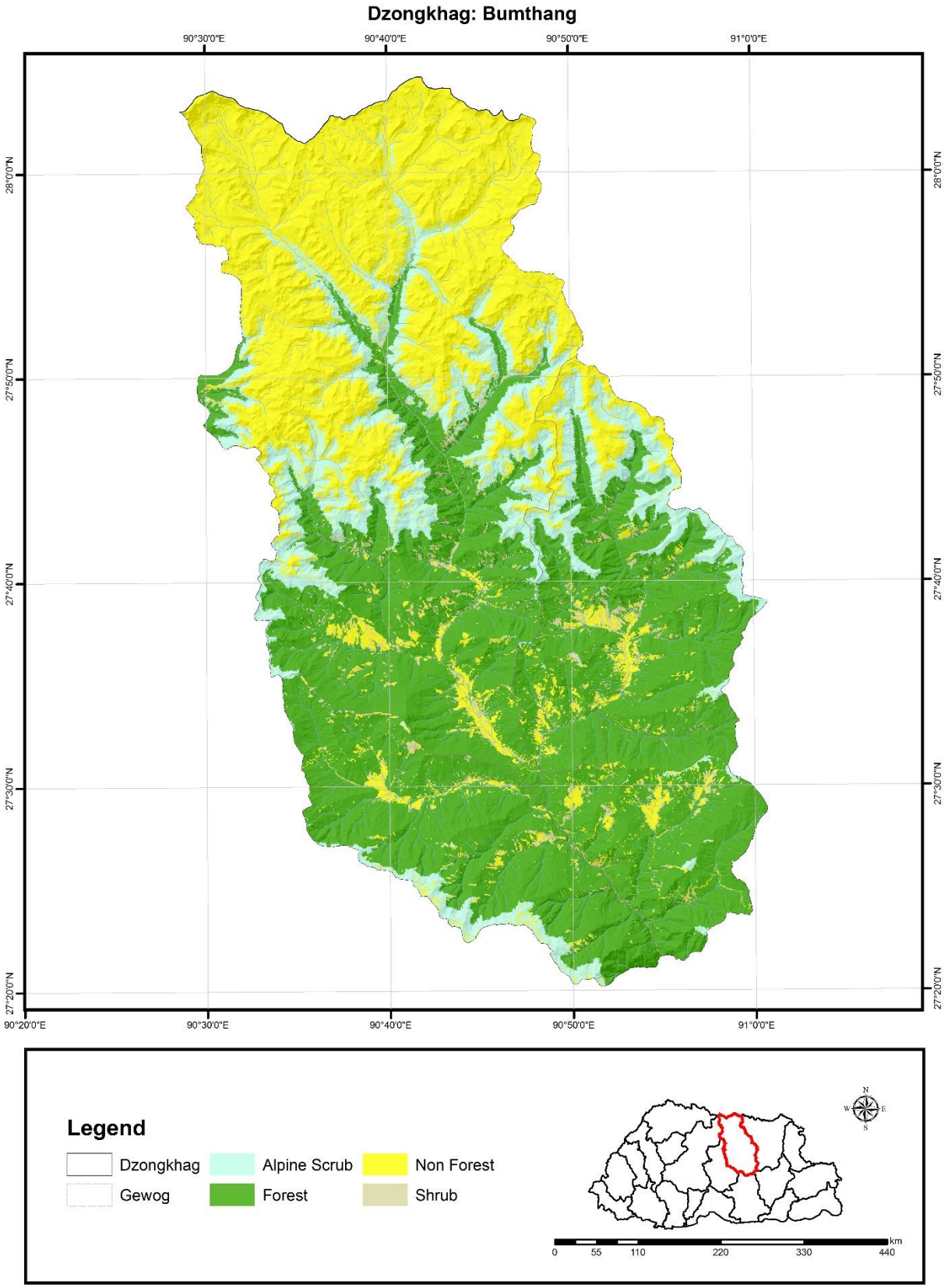


Figure 9 Forest cover within the Protected Area

7. Bumthang

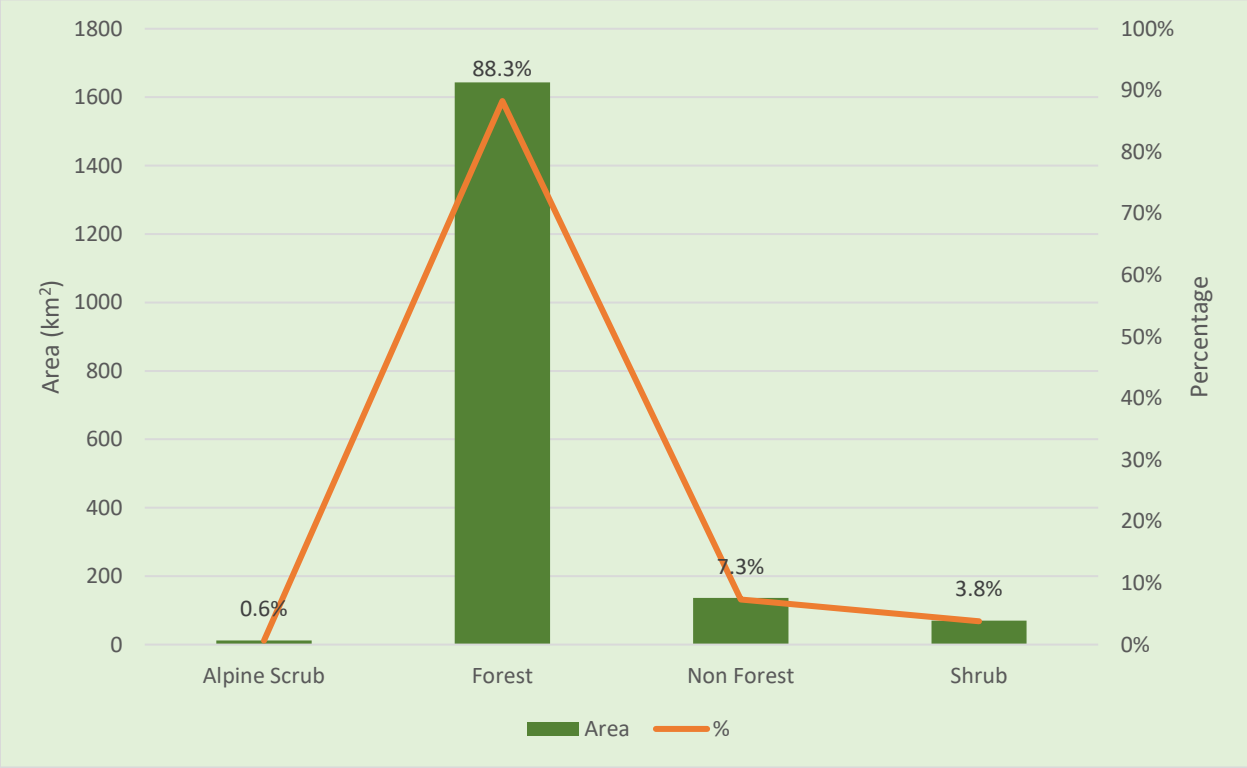
Class	Area (km²)	Area (Ha)	Percentage
Alpine Scrub	361.63	36,162.87	13.4%
Forest	1,354.23	135,422.52	50.3%
Non Forest	902.76	90,275.60	33.5%
Shrub	72.30	7,230.20	2.7%

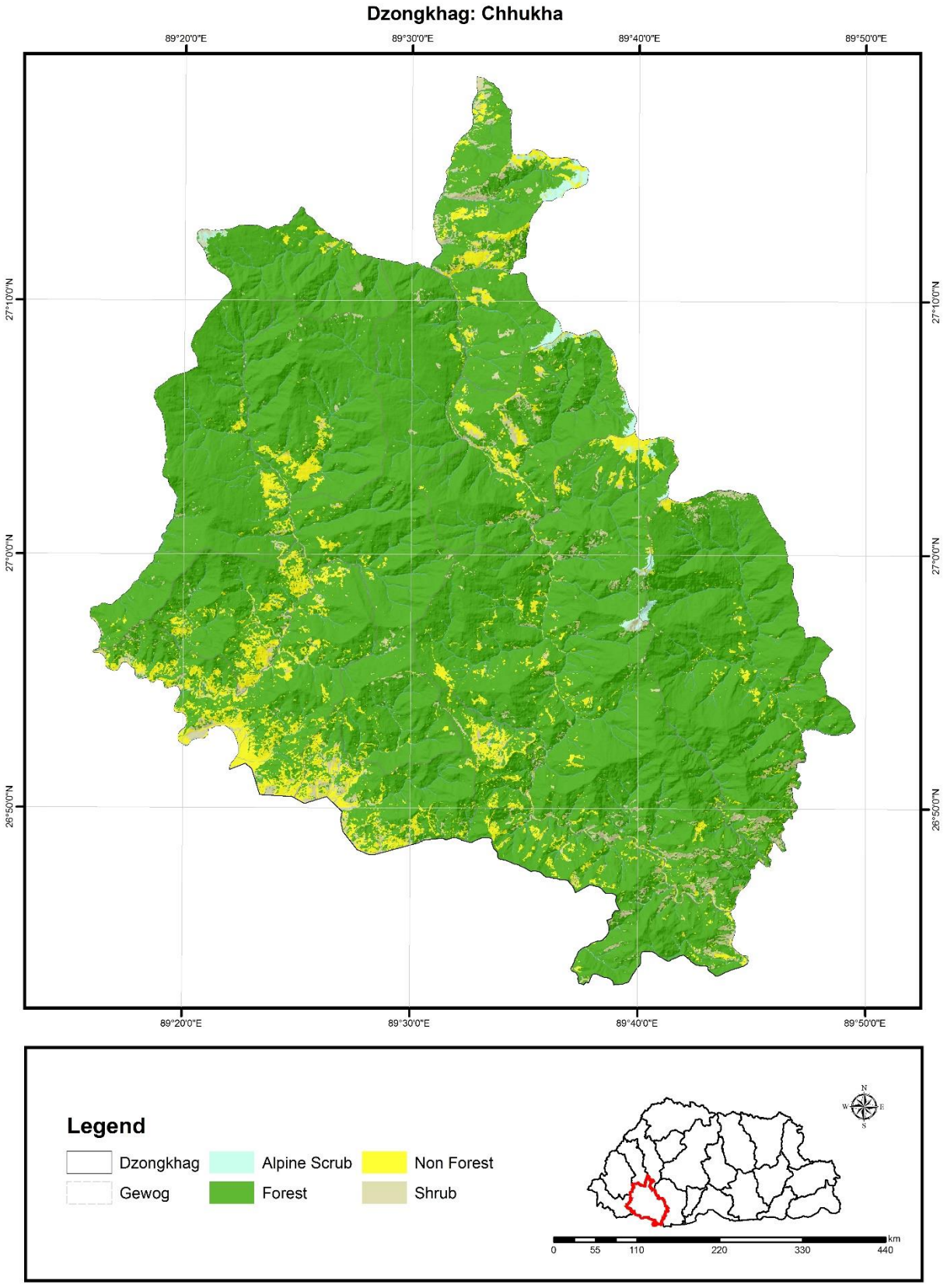



Dzongkhag: Bumthang
90°30'0"E
90°40'0"E
90°50'0"E
91°0'0"E
28°0'0"N
27°50'0"N
27°40'0"N
27°30'0"N
27°20'0"N
90°20'0"E
Legend
Dzongkhag
Gewog
Alpine Scrub
Forest
Non Forest
Shrub
N
W
E
S
0
55
110
220
330
440
km

8. Chhukha

Class	Area (km²)	Area (Ha)	Percentage
Alpine Scrub	11.82	1,182.10	0.6%
Forest	1,643.02	164,301.71	88.3%
Non Forest	136.34	13,634.47	7.3%
Shrub	70.31	7,030.98	3.8%




Dzongkhag: Chhukha
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89°30'0"E
89°40'0"E
89°50'0"E
27°10'0"N
27°0'0"N
26°50'0"N
Legend
Dzongkhag
Gewog
Alpine Scrub
Forest
Non Forest
Shrub
N
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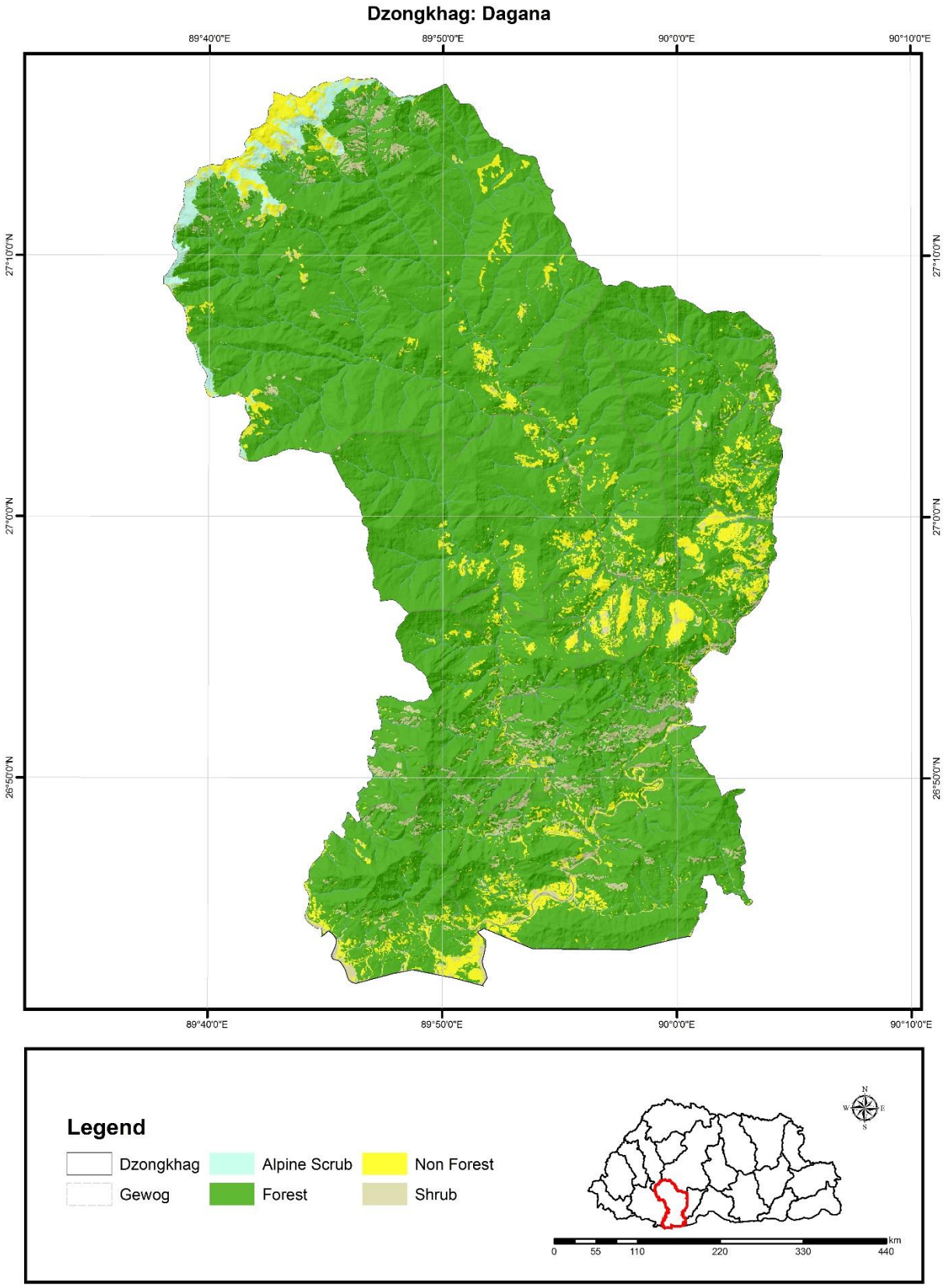
0
55
110
220
330
440
km

9. Dagana

Class	Area (km²)	Area (Ha)	Percentage
Alpine Scrub	23.58	2,358.34	1.4%
Forest	1,483.19	148,318.87	86.9%
Non Forest	134.40	13,439.63	7.9%
Shrub	64.91	6,491.08	3.8%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26°50'0"N
Legend
Dzongkhag
Gewog
Alpine Scrub
Forest
Non Forest
Shrub
N
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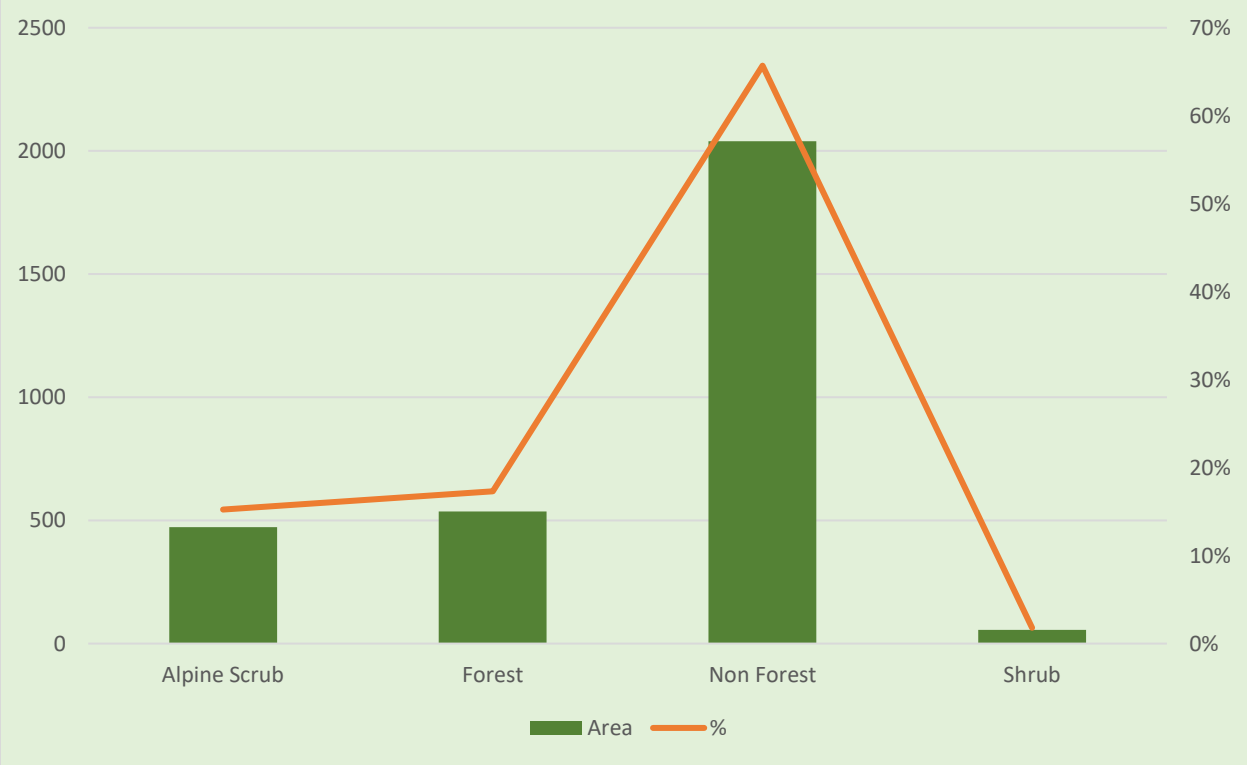
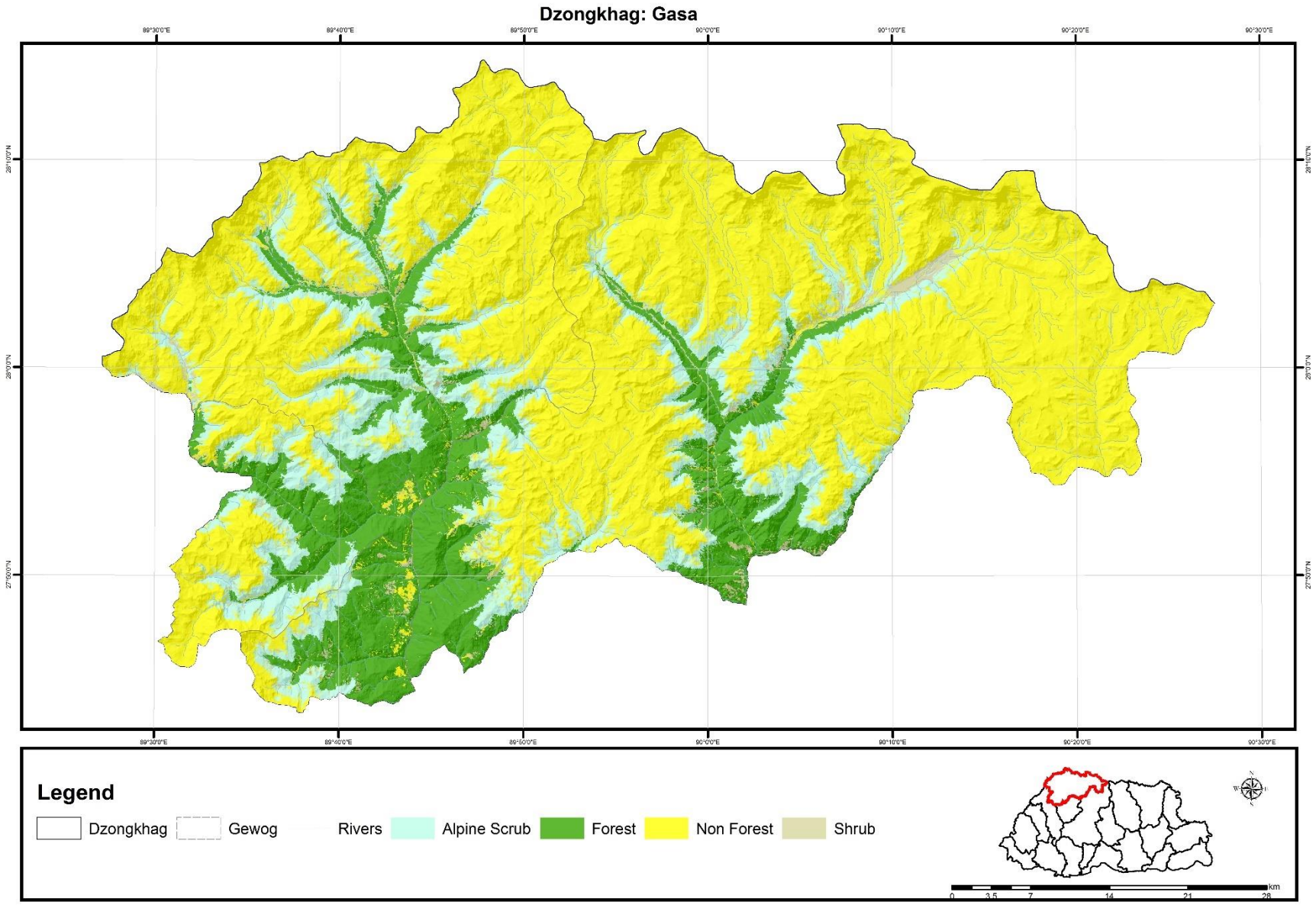
110
220
330
440
km

10. Gasa

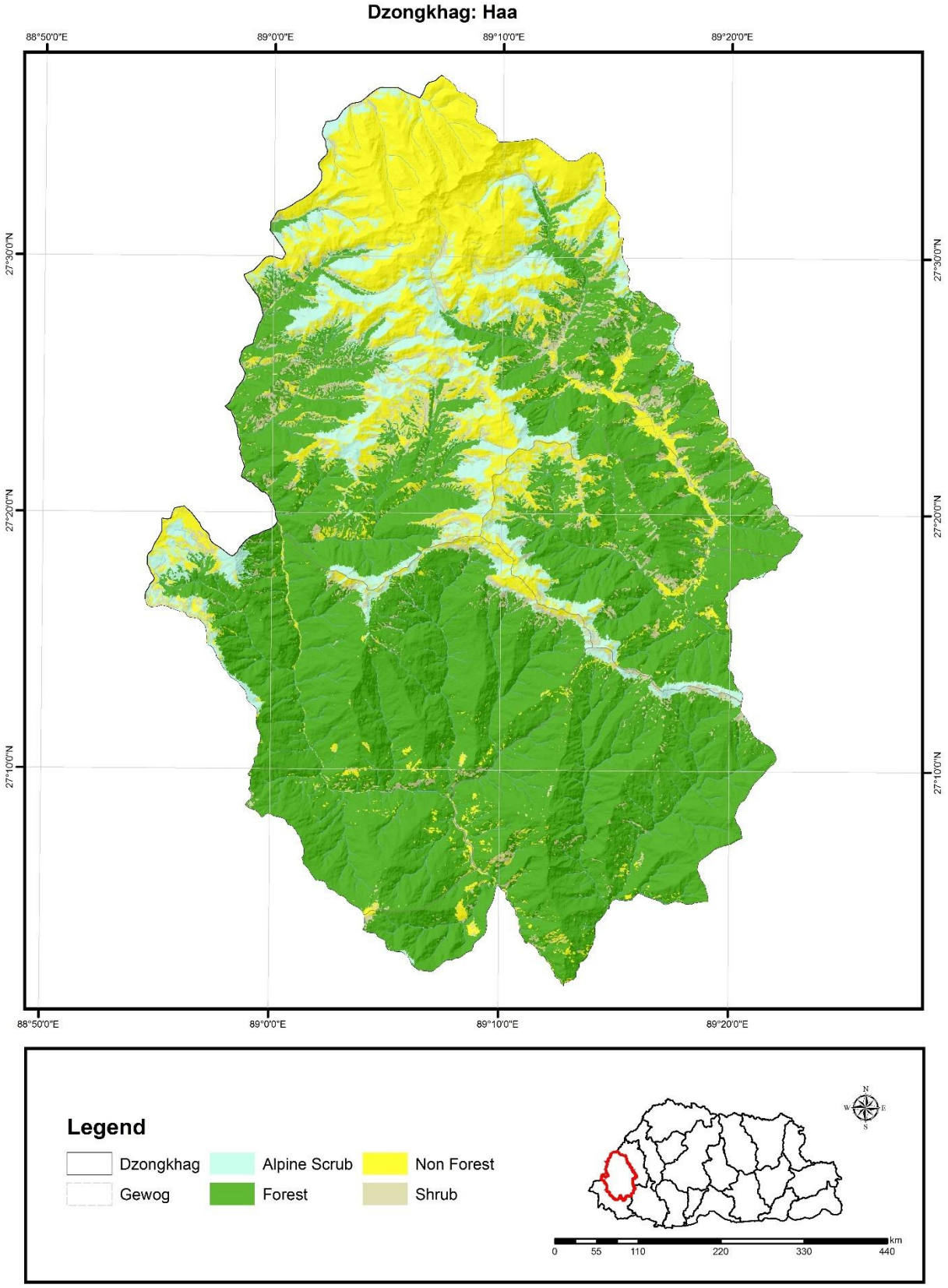
Class	Area (km²)	Area (Ha)	Percentage
Alpine Scrub	472.57	47,256.59	15.2%
Forest	536.71	53,670.82	17.3%
Non Forest	2,039.04	203,904.48	65.7%
Shrub	55.66	5,565.86	1.8%




Dzongkhag: Gasa
89°30'0"E
89°40'0"E
89°50'0"E
90°0'0"E
90°10'0"E
90°20'0"E
90°30'0"E
28°10'0"N
28°0'0"N
27°50'0"N
Legend
Dzongkhag
Gewog
Rivers
Alpine Scrub
Forest
Non Forest
Shrub
km
0
3.5
7
14
21
28

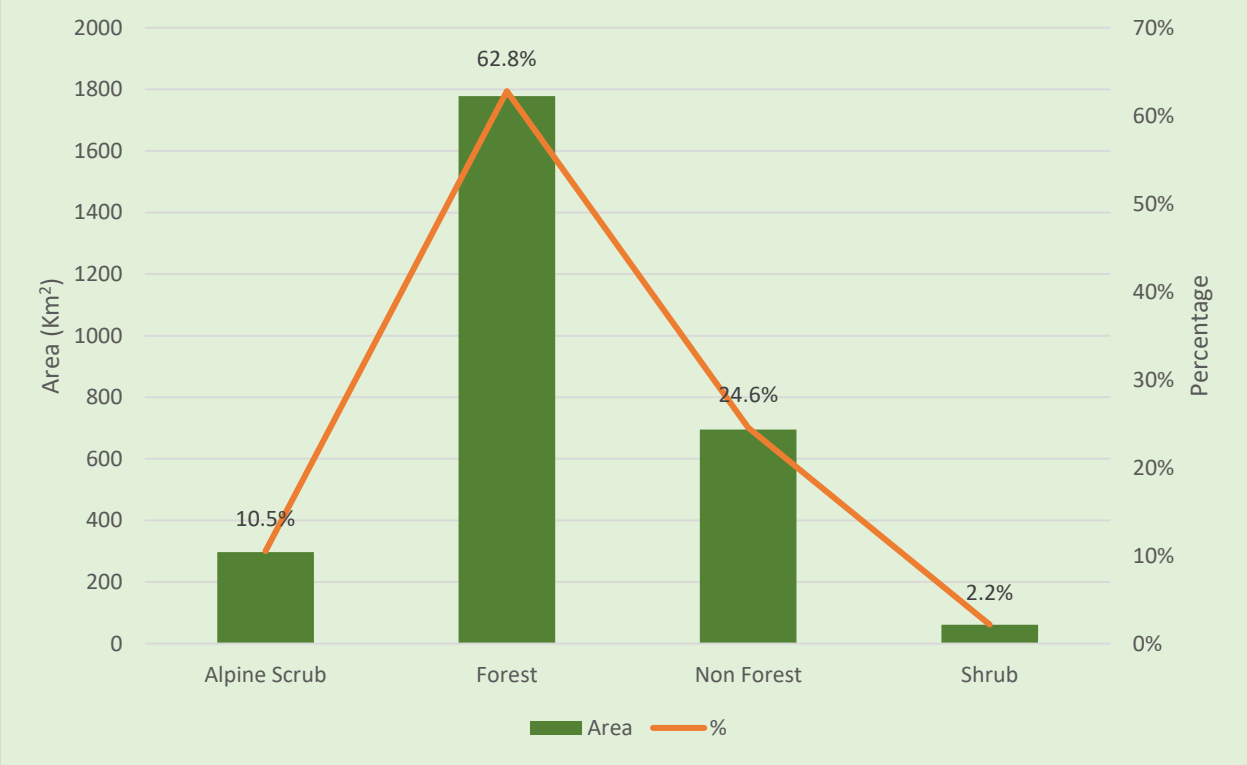
11. Haa

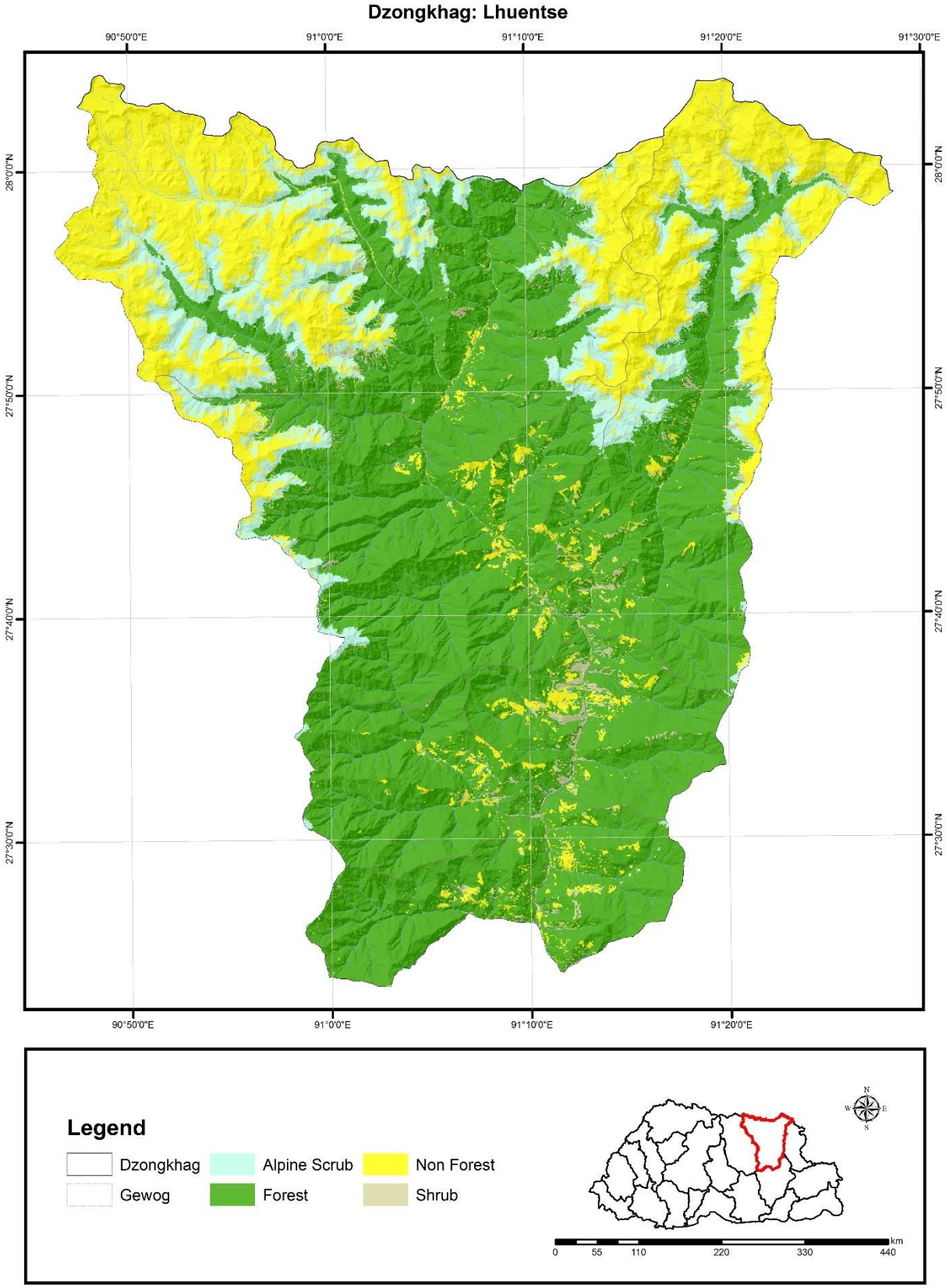
Class	Area (km²)	Area (Ha)	Percentage
Alpine Scrub	171.30	17,130.21	9.1%
Forest	1,244.85	124,485.29	66.0%
Non Forest	348.57	34,857.37	18.5%
Shrub	121.62	12,162.39	6.4%


Dzongkhag: Haa
88°50'0"E
89°0'0"E
89°10'0"E
89°20'0"E
27°30'0"N
27°20'0"N
27°10'0"N
Legend
Dzongkhag
Gewog
Alpine Scrub
Forest
Non Forest
Shrub
N
W
E
S
0
55
110
220
330
440
km

12. Lhuentse

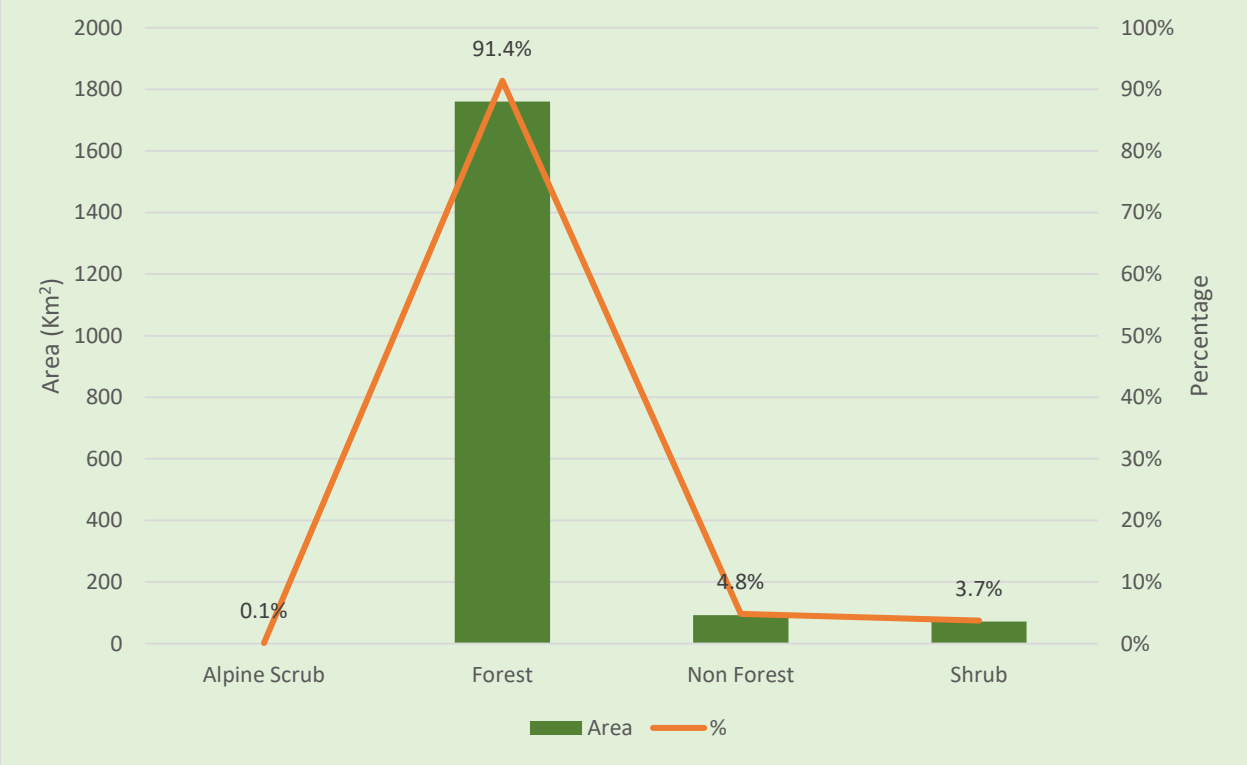
Class	Area (km²)	Area (Ha)	Percentage
Alpine Scrub	297.05	29,704.84	10.5%
Forest	1,777.60	177,760.41	62.8%
Non Forest	695.25	69,525.40	24.6%
Shrub	61.00	6,099.98	2.2%

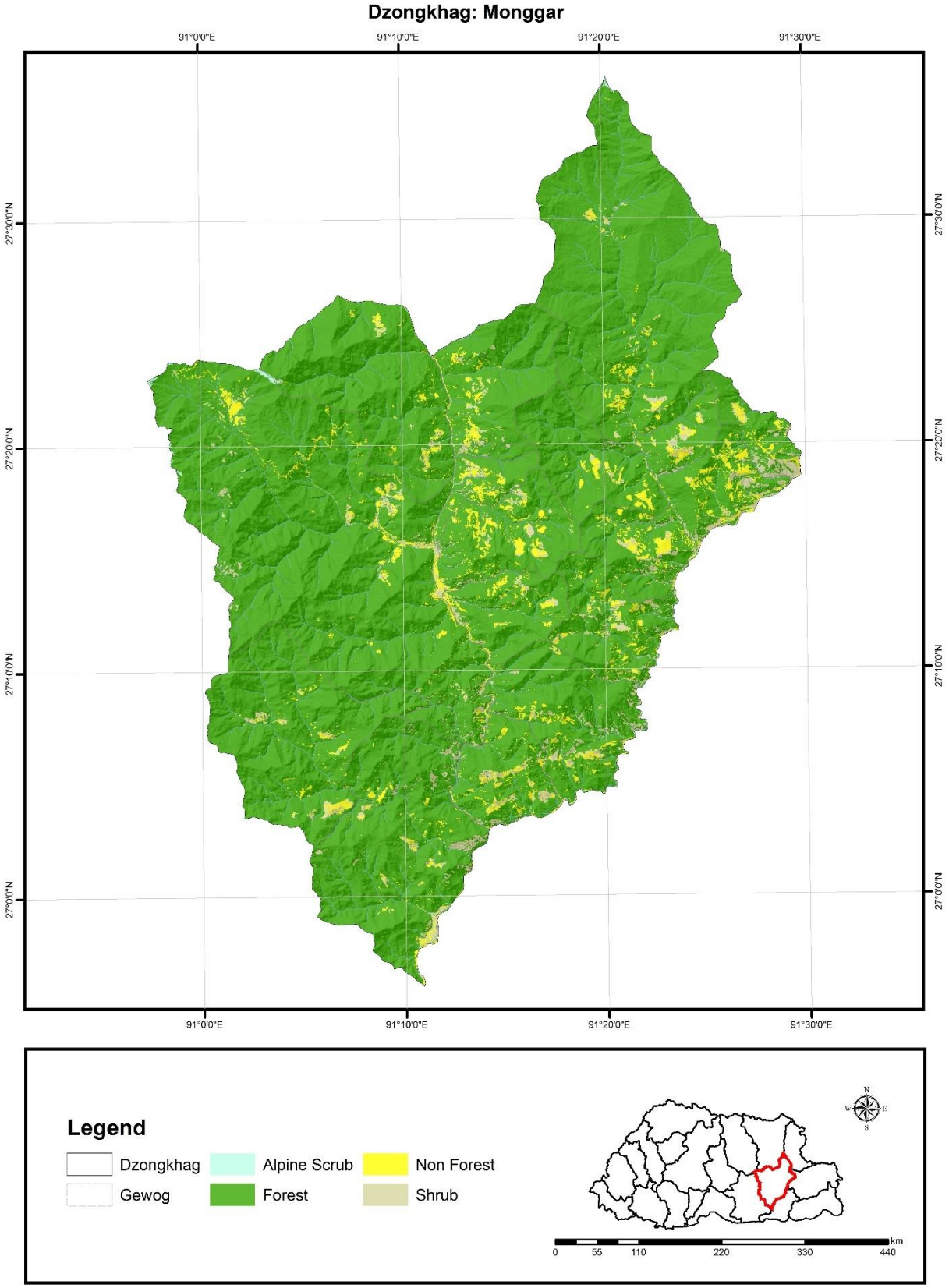



Dzongkhag: Lhuentse
90°50'0"E
91°0'0"E
91°10'0"E
91°20'0"E
91°30'0"E
28°0'0"N
27°50'0"N
27°40'0"N
27°30'0"N
Legend
Dzongkhag
Gewog
Alpine Scrub
Forest
Non Forest
Shrub
N
W
E
S
0
55
110
220
330
440
km

13. Mongar

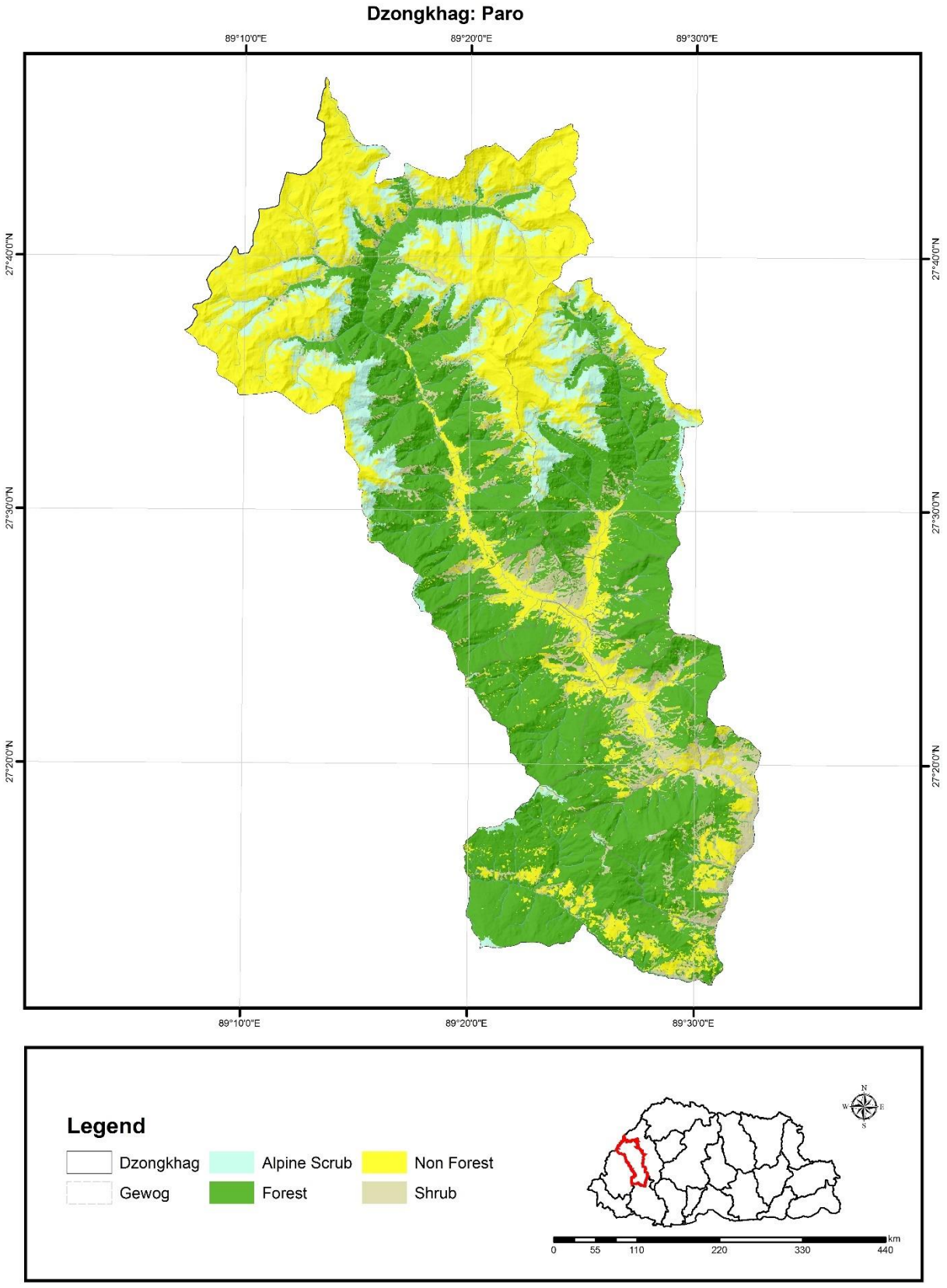
Class	Area (km²)	Area (Ha)	Percentage
Alpine Scrub	1.61	161.24	0.1%
Forest	1,759.84	175,984.46	91.4%
Non Forest	92.50	9,250.49	4.8%
Shrub	71.40	7,139.79	3.7%




Dzongkhag: Monggar
91°0'0"E
91°10'0"E
91°20'0"E
91°30'0"E
27°30'0"N
27°20'0"N
27°10'0"N
27°0'0"N
Legend
Dzongkhag
Gewog
Alpine Scrub
Forest
Non Forest
Shrub
N
W
E
S
0
55
110
220
330
440
km

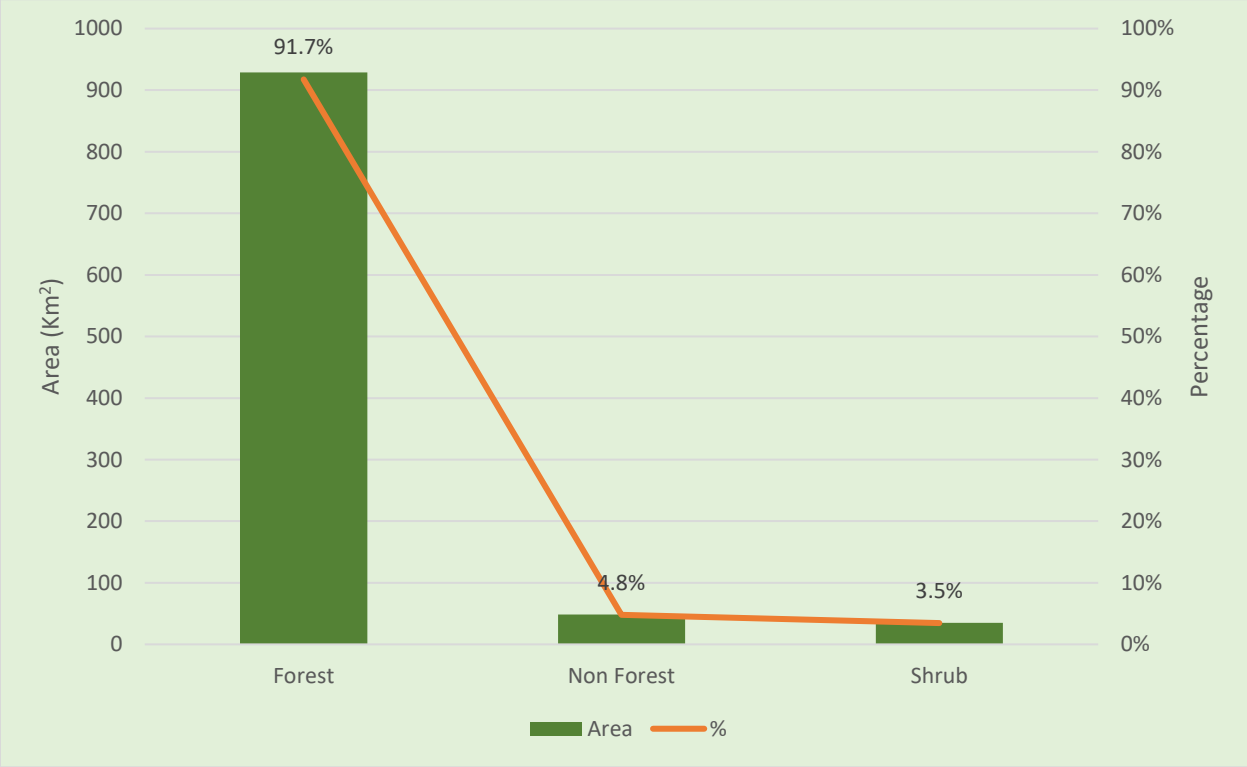
14. Paro

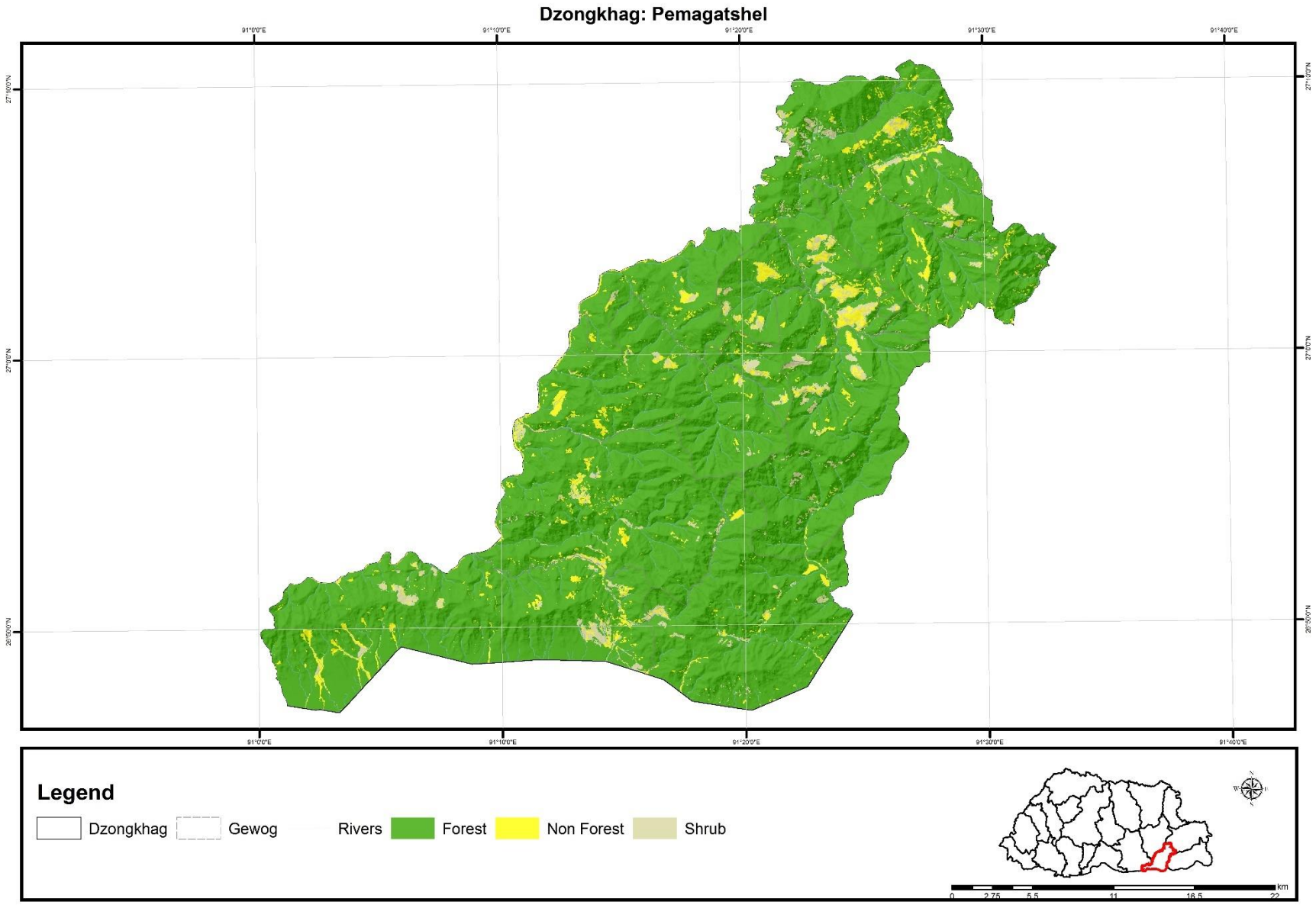
Class	Area (km²)	Area (Ha)	Percentage
Alpine Scrub	119.52	11,952.47	9.4%
Forest	646.42	64,641.80	50.7%
Non Forest	390.37	39,037.22	30.6%
Shrub	118.30	11,829.79	9.3%


Dzongkhag: Paro
89°10'0"E
89°20'0"E
89°30'0"E
27°40'0"N
27°30'0"N
27°20'0"N
Legend
Dzongkhag
Gewog
Alpine Scrub
Forest
Non Forest
Shrub
N
W
E
S
0
55
110
220
330
440
km

15. Pemagatshel

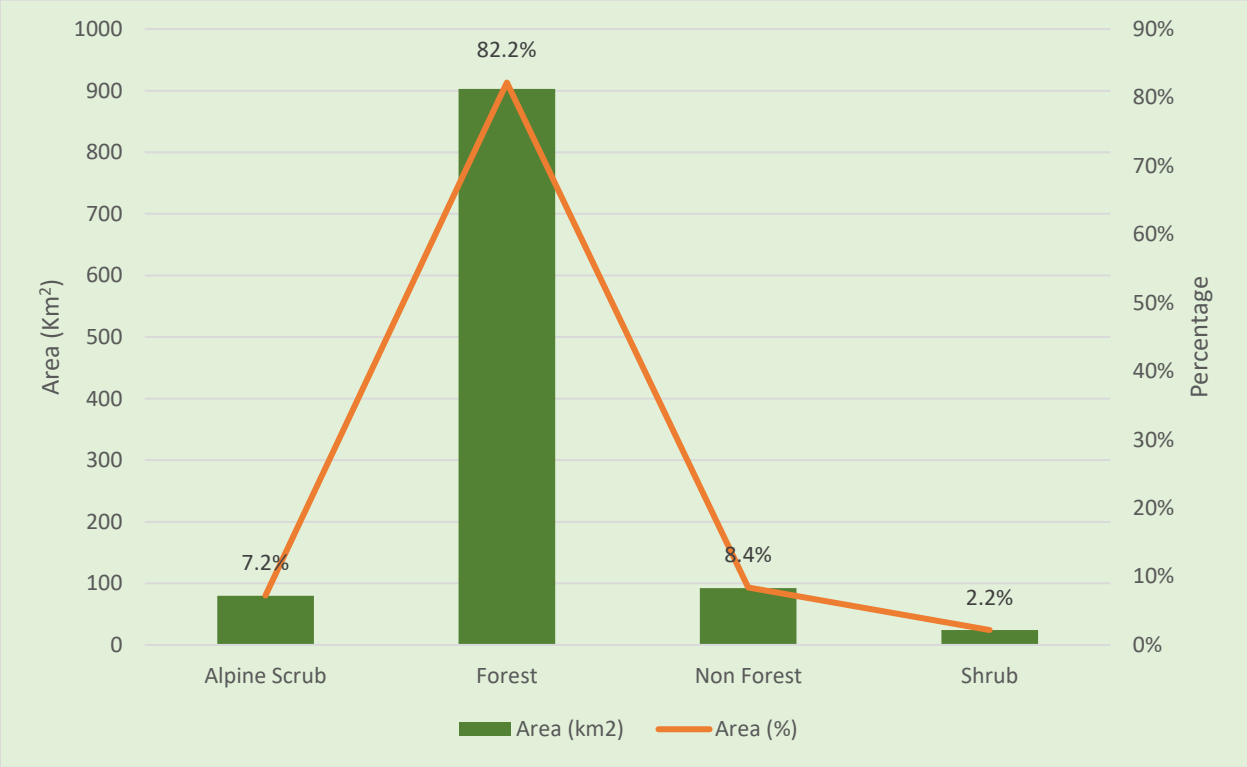
Class	Area (km²)	Area (Ha)	Percentage
Forest	928.60	92,859.73	91.7%
Non Forest	48.58	4,857.51	4.8%
Shrub	34.99	3,499.47	3.5%

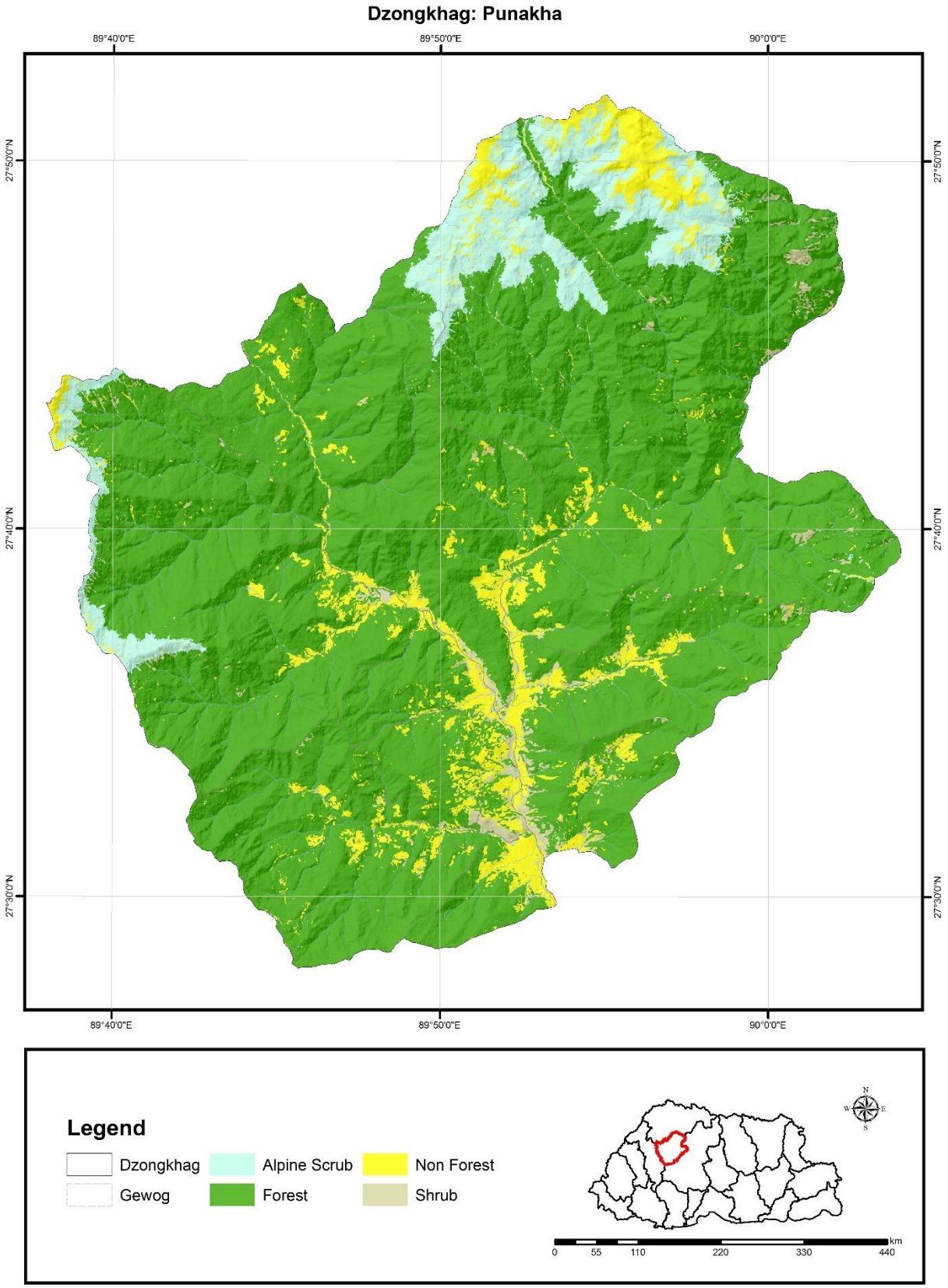



Dzongkhag: Pemagatshel
91°0'0"E
91°10'0"E
91°20'0"E
91°30'0"E
91°40'0"E
27°10'0"N
27°0'0"N
26°50'0"N
Legend
Dzongkhag
Gewog
Rivers
Forest
Non Forest
Shrub
km
0
2.75
5.5
11
16.5
22

16. Punakha

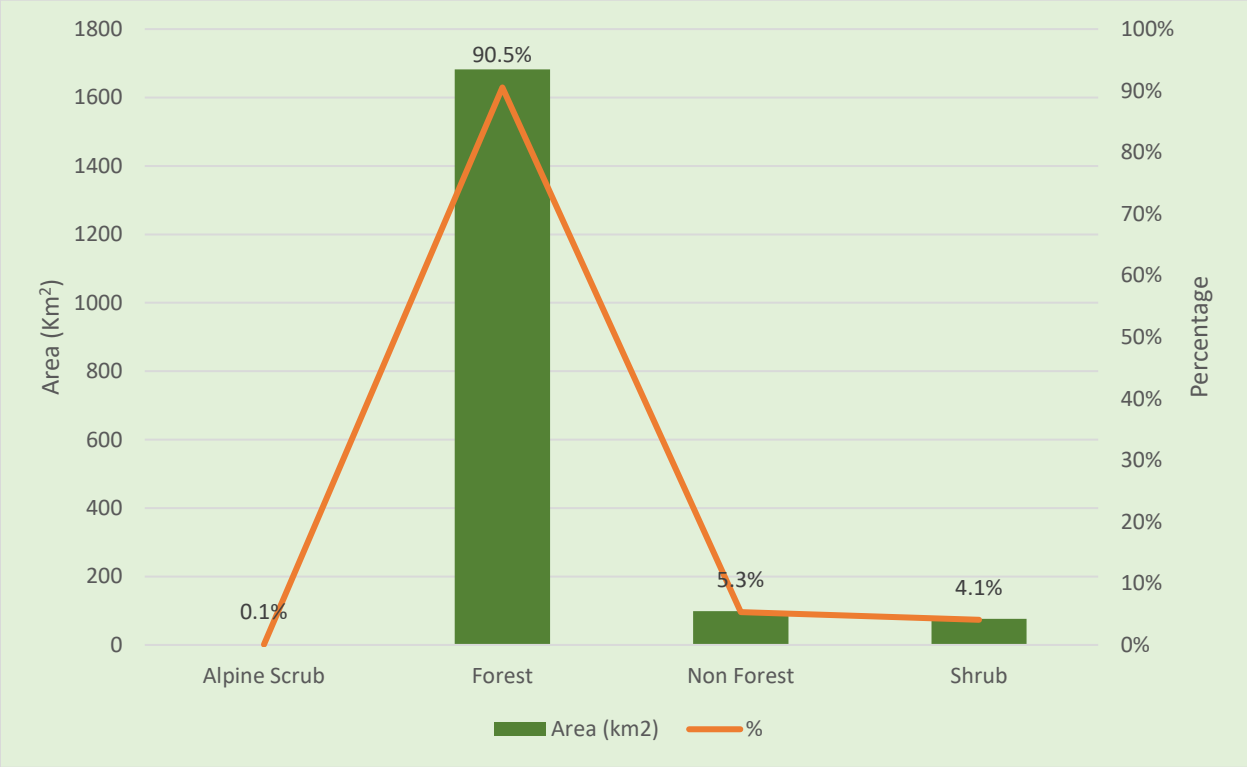
Class	Area (km²)	Area (Ha)	Percentage
Alpine Scrub	79.58	7,957.76	7.2%
Forest	903.09	90,309.45	82.2%
Non Forest	92.21	9,220.98	8.4%
Shrub	23.90	2,389.85	2.2%

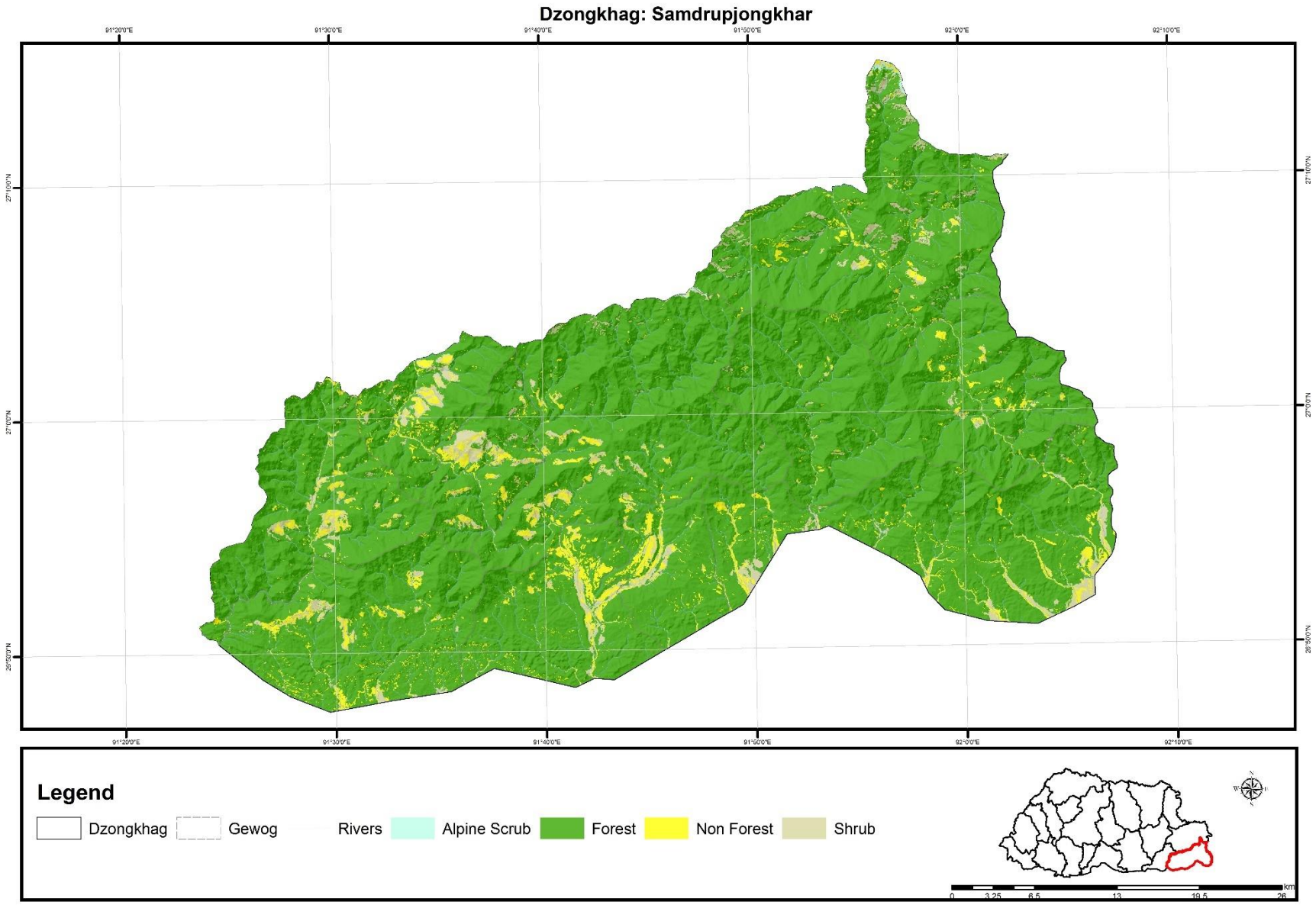



Dzongkhag: Punakha
89°40'0"E
89°50'0"E
90°0'0"E
27°50'0"N
27°40'0"N
27°30'0"N
Legend
Dzongkhag
Gewog
Alpine Scrub
Forest
Non Forest
Shrub
N
W
E
S
0
55
110
220
330
440
km

17. Samdrup Jongkhar

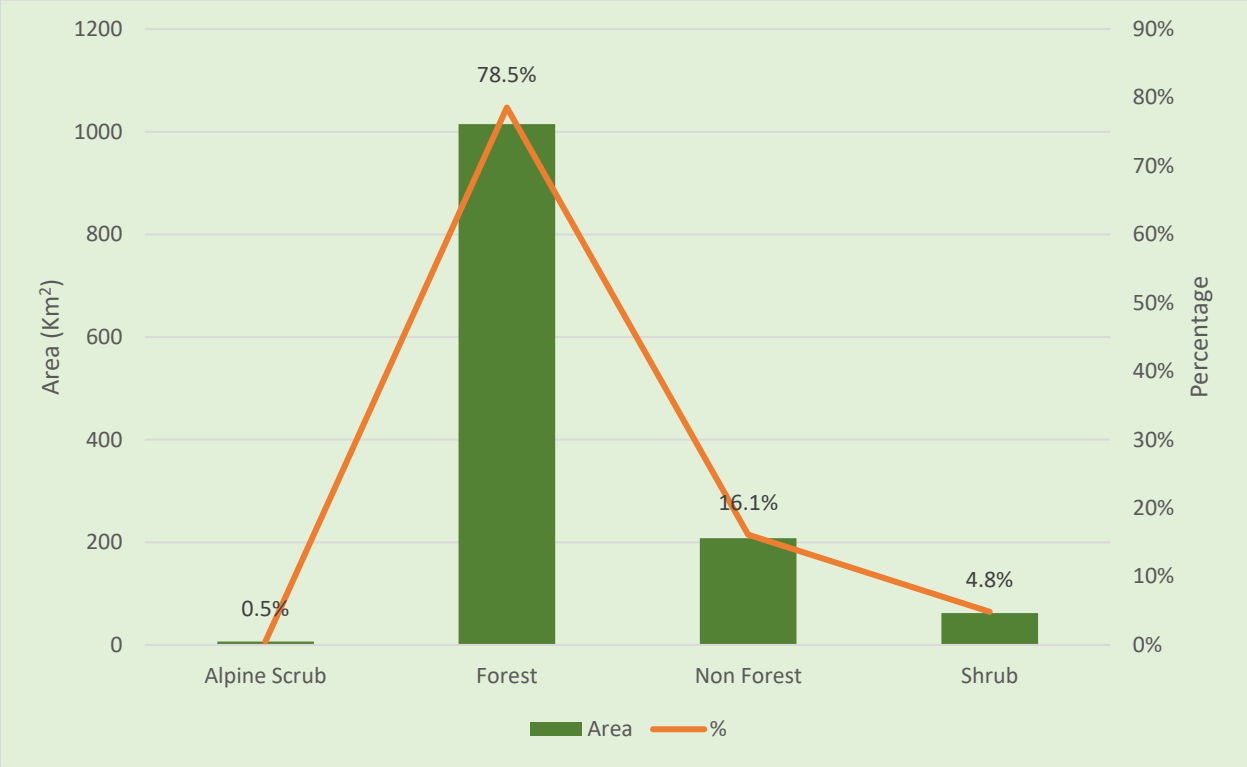
Class	Area (km²)	Area (Ha)	Percentage
Alpine Scrub	1.16	116.46	0.1%
Forest	1,682.67	16,8267.17	90.5%
Non Forest	98.95	9,894.59	5.3%
Shrub	76.03	7,603.27	4.1%

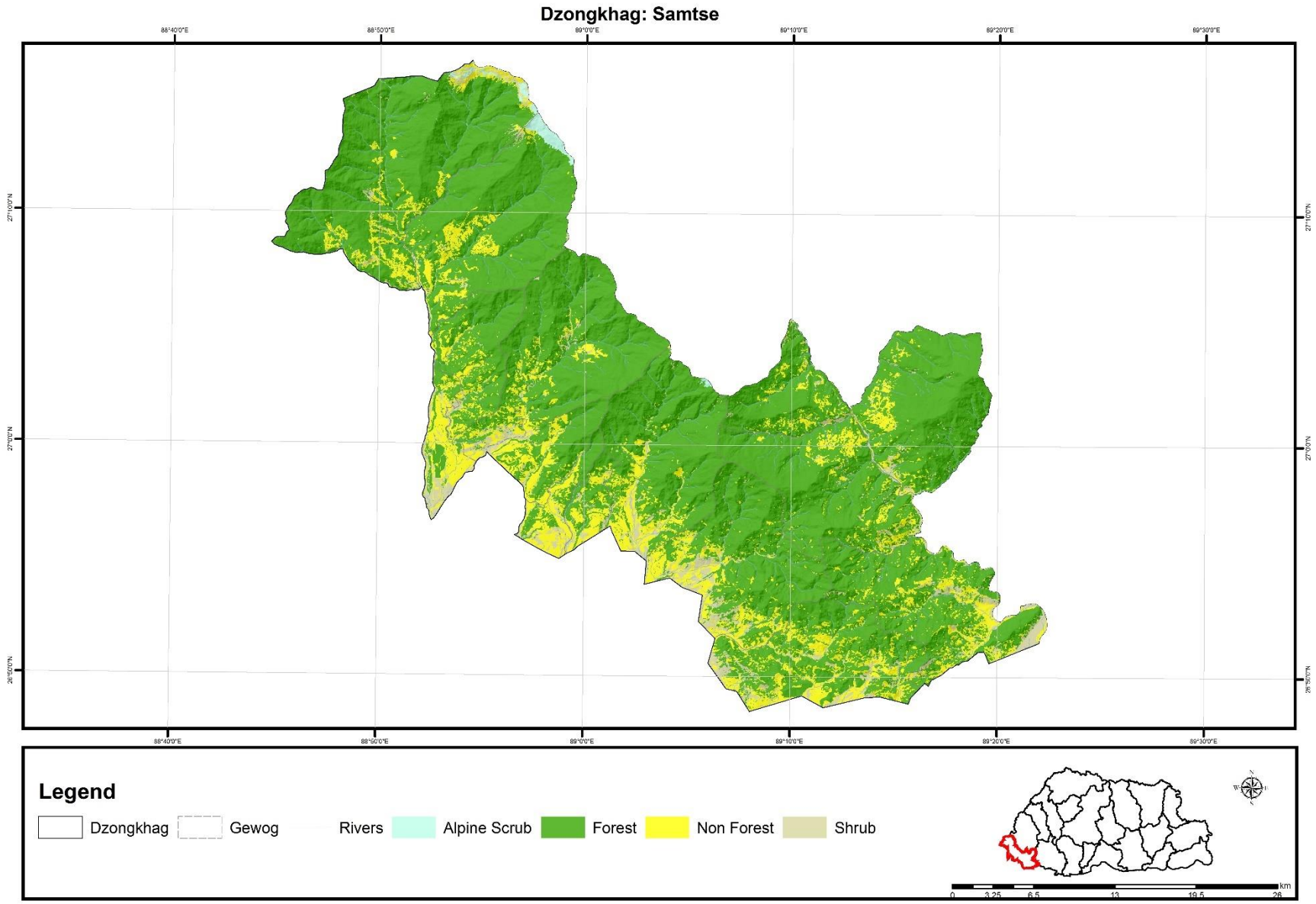



Dzongkhag: Samdrupjongkhar
91°20'0"E
91°30'0"E
91°40'0"E
91°50'0"E
92°0'0"E
92°10'0"E
27°10'0"N
27°0'0"N
26°50'0"N
Legend
Dzongkhag
Gewog
Rivers
Alpine Scrub
Forest
Non Forest
Shrub
0
3.25
6.5
13
19.5
26
km

18. Samtse

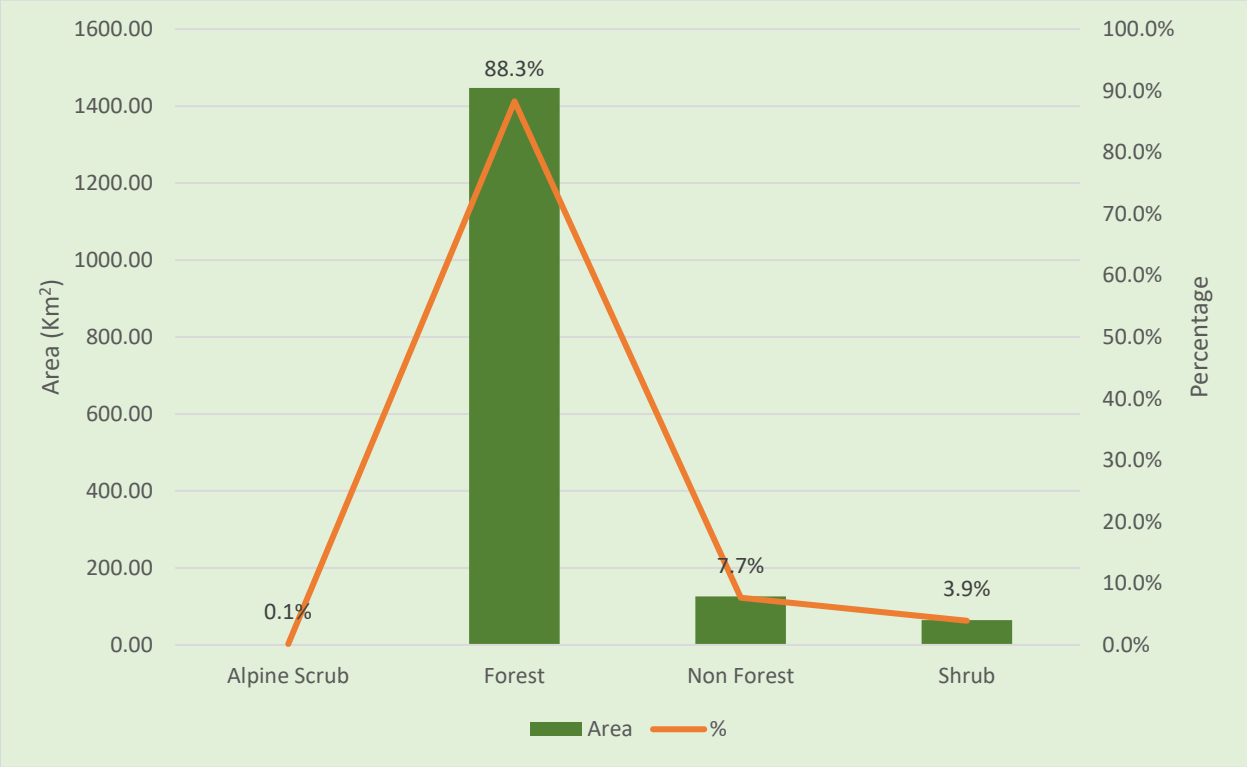
Class	Area (km²)	Area (Ha)	Percentage
Alpine Scrub	6.71	670.74	0.5%
Forest	1,014.95	101,494.52	78.5%
Non Forest	208.25	20,825.13	16.1%
Shrub	62.26	6,225.56	4.8%

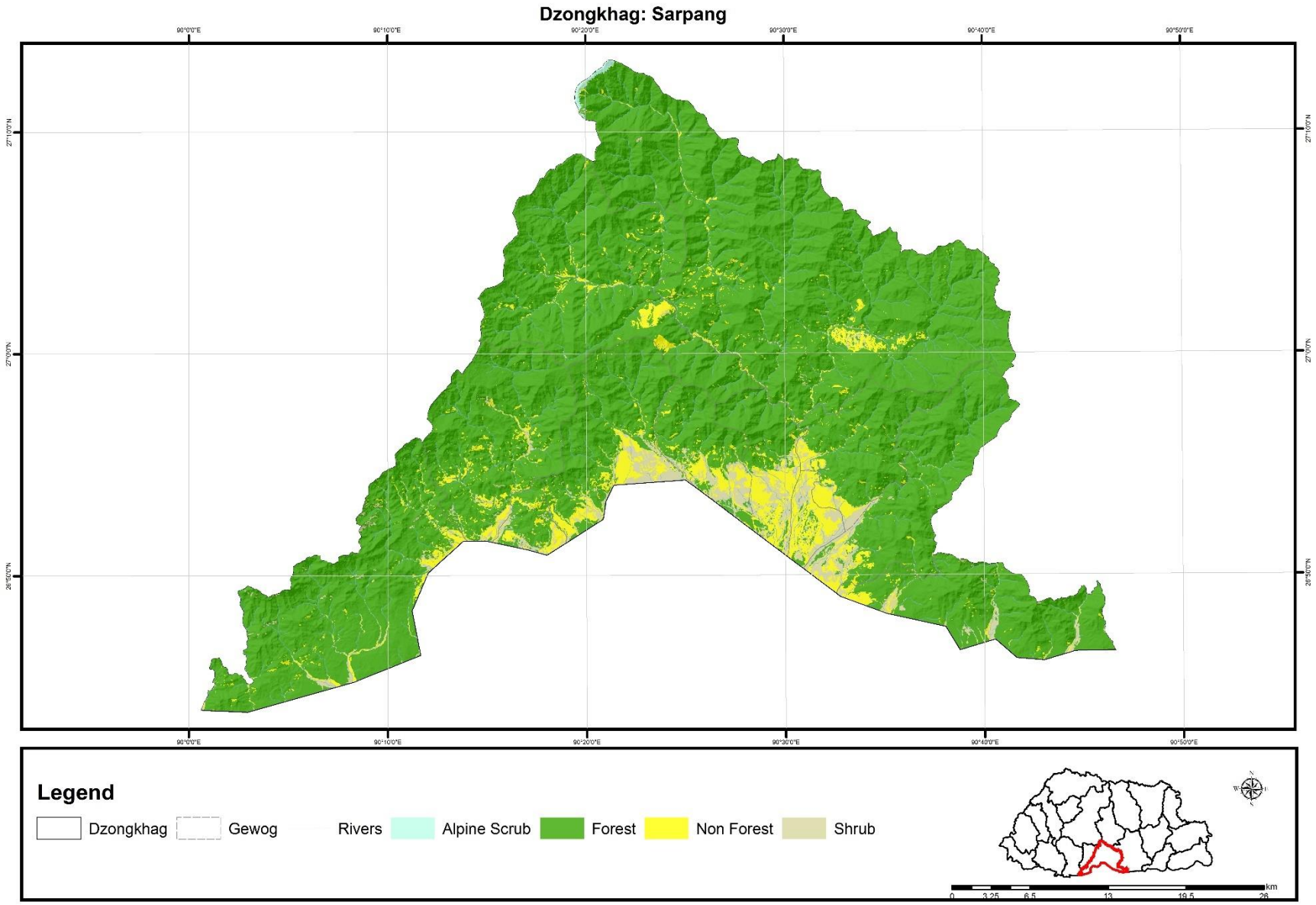



Dzongkhag: Samtse
88°40'0"E
88°50'0"E
89°0'0"E
89°10'0"E
89°20'0"E
89°30'0"E
27°10'0"N
27°0'0"N
26°50'0"N
Legend
Dzongkhag
Gewog
Rivers
Alpine Scrub
Forest
Non Forest
Shrub
km
0
3.25
6.5
13
19.5
26

19. Sarpang

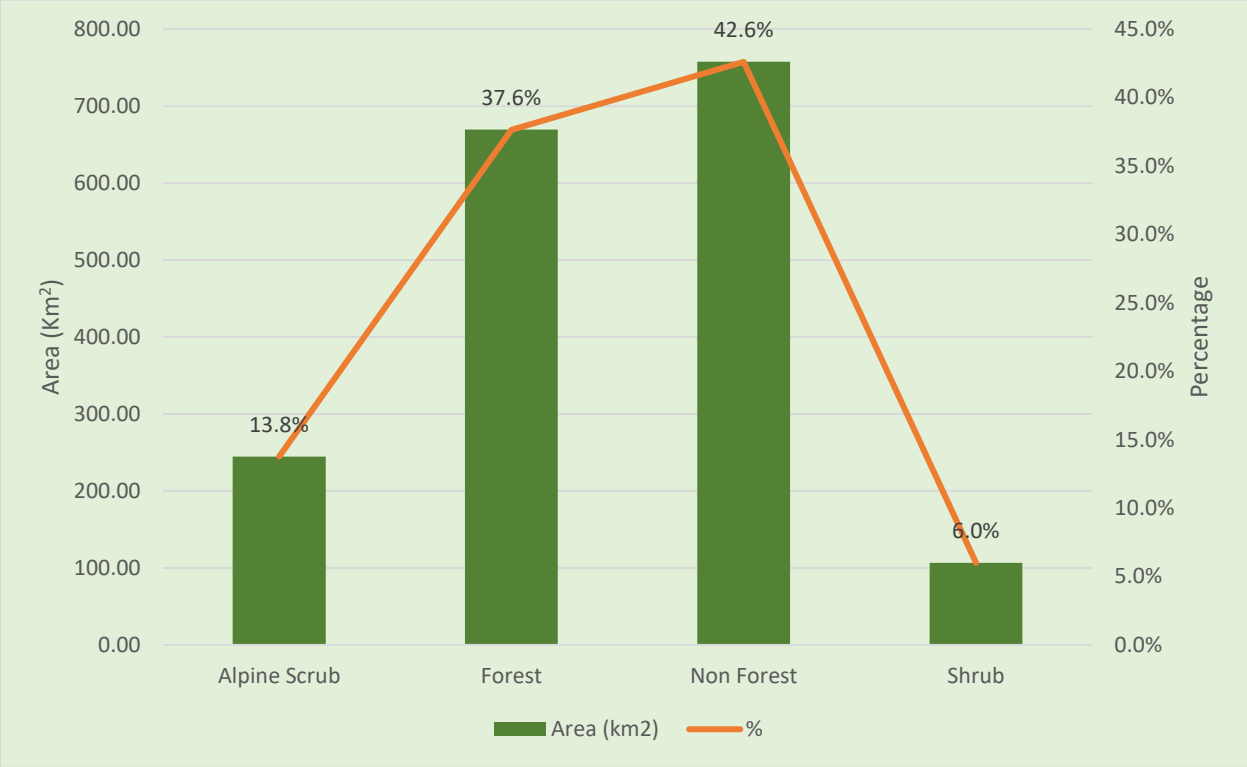
Class	Area (km²)	Area (Ha)	Percentage
Alpine Scrub	2.40	239.57	0.1%
Forest	1,446.84	144,684.17	88.3%
Non Forest	125.79	12,579.12	7.7%
Shrub	64.25	6,425.24	3.9%

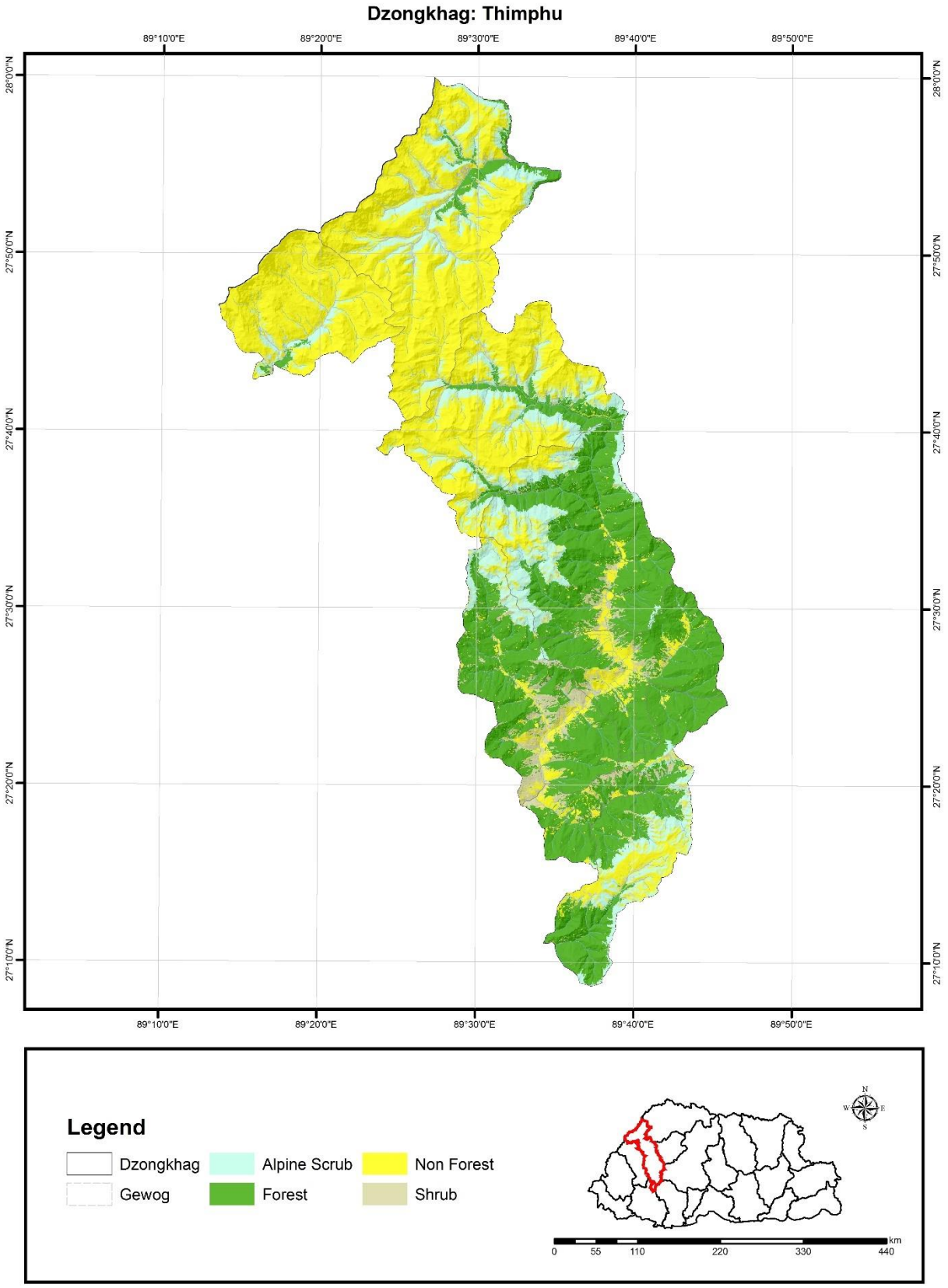



Dzongkhag: Sarpang
90°0'0"E
90°10'0"E
90°20'0"E
90°30'0"E
90°40'0"E
90°50'0"E
27°10'0"N
27°0'0"N
26°50'0"N
Legend
Dzongkhag
Gewog
Rivers
Alpine Scrub
Forest
Non Forest
Shrub
km
0
3.25
6.5
13
19.5
26

20. Thimphu

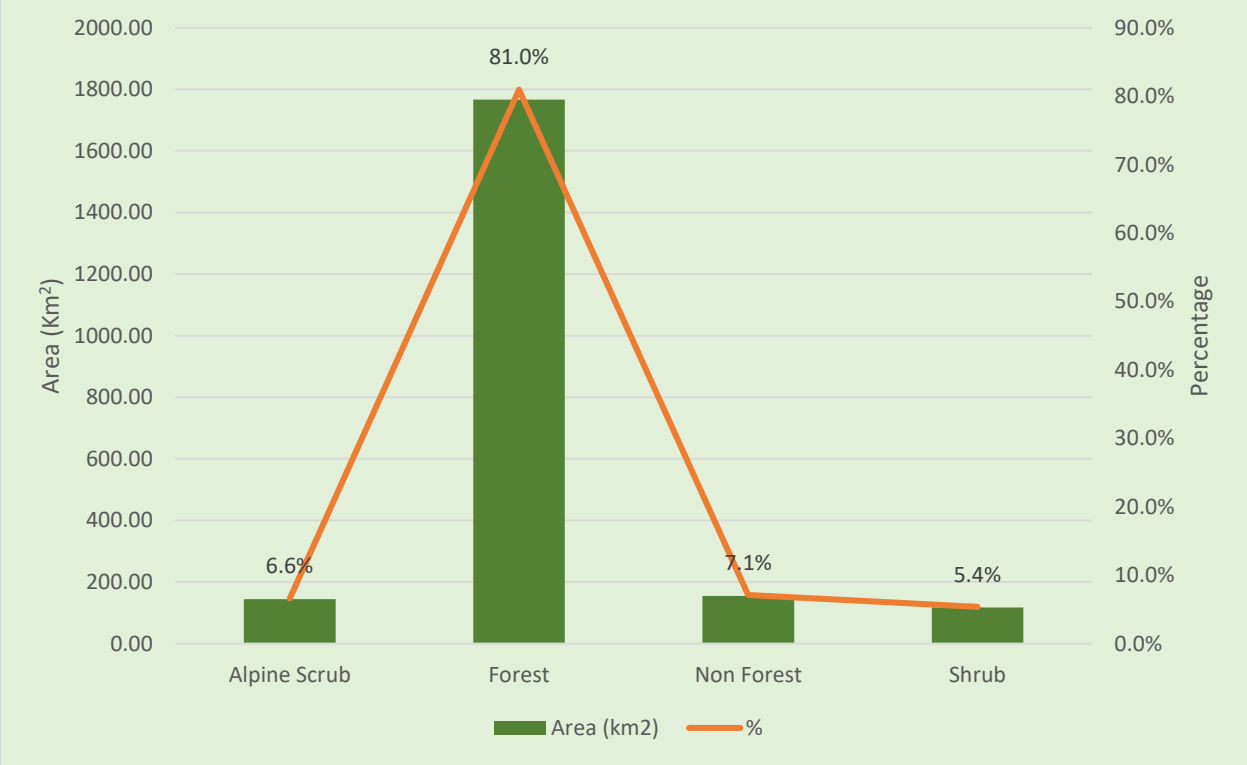
Class	Area (km²)	Area (Ha)	Percentage
Alpine Scrub	244.67	24,466.59	13.8%
Forest	669.33	66,932.51	37.6%
Non Forest	757.75	75,774.89	42.6%
Shrub	106.67	10,666.74	6.0%

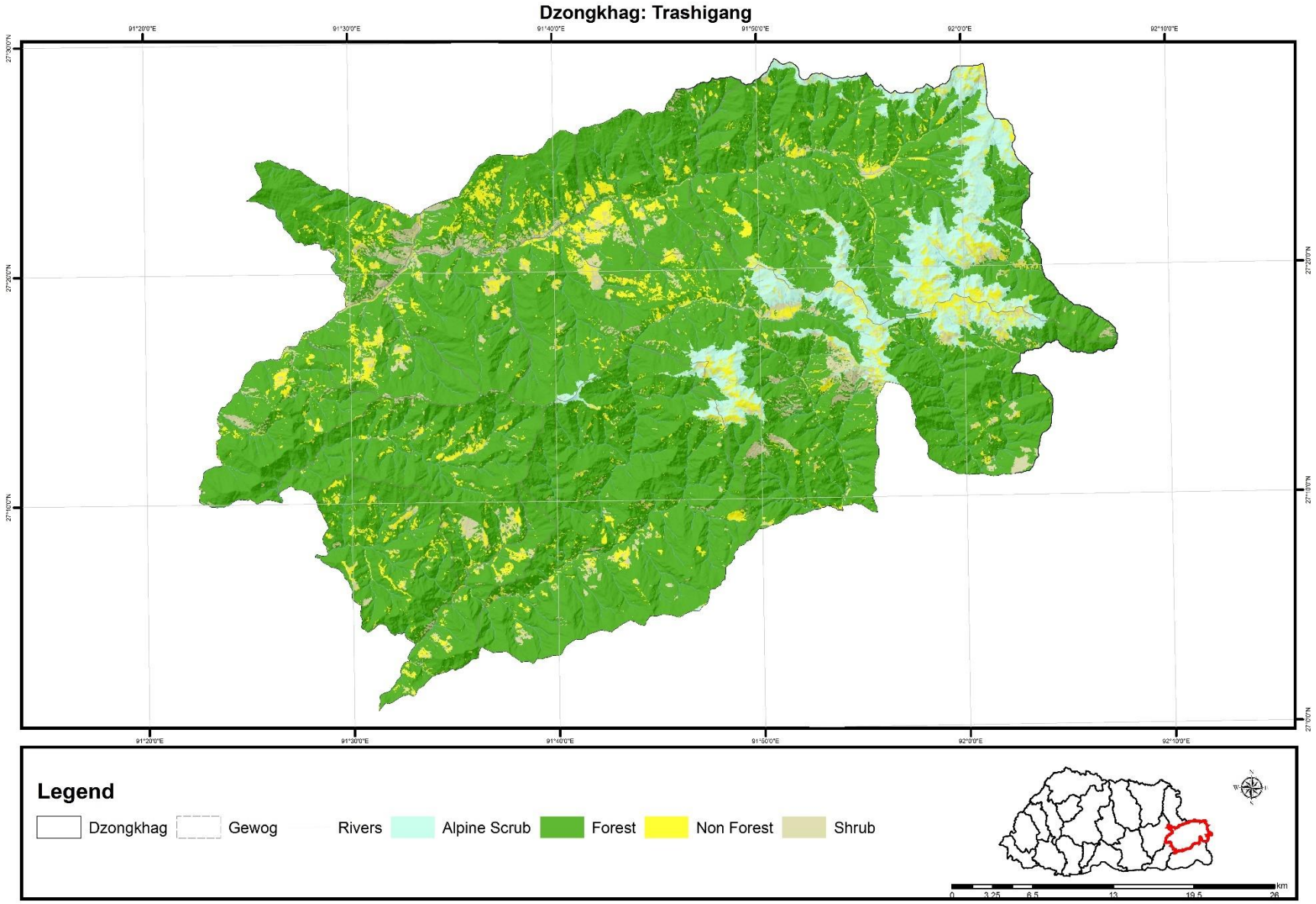



Dzongkhag: Thimphu
89°10'0"E
89°20'0"E
89°30'0"E
89°40'0"E
89°50'0"E
28°0'0"N
27°50'0"N
27°40'0"N
27°30'0"N
27°20'0"N
27°10'0"N
Legend
Dzongkhag
Gewog
Alpine Scrub
Forest
Non Forest
Shrub
N
W
E
S
0
55
110
220
330
440
km

21. Trashigang

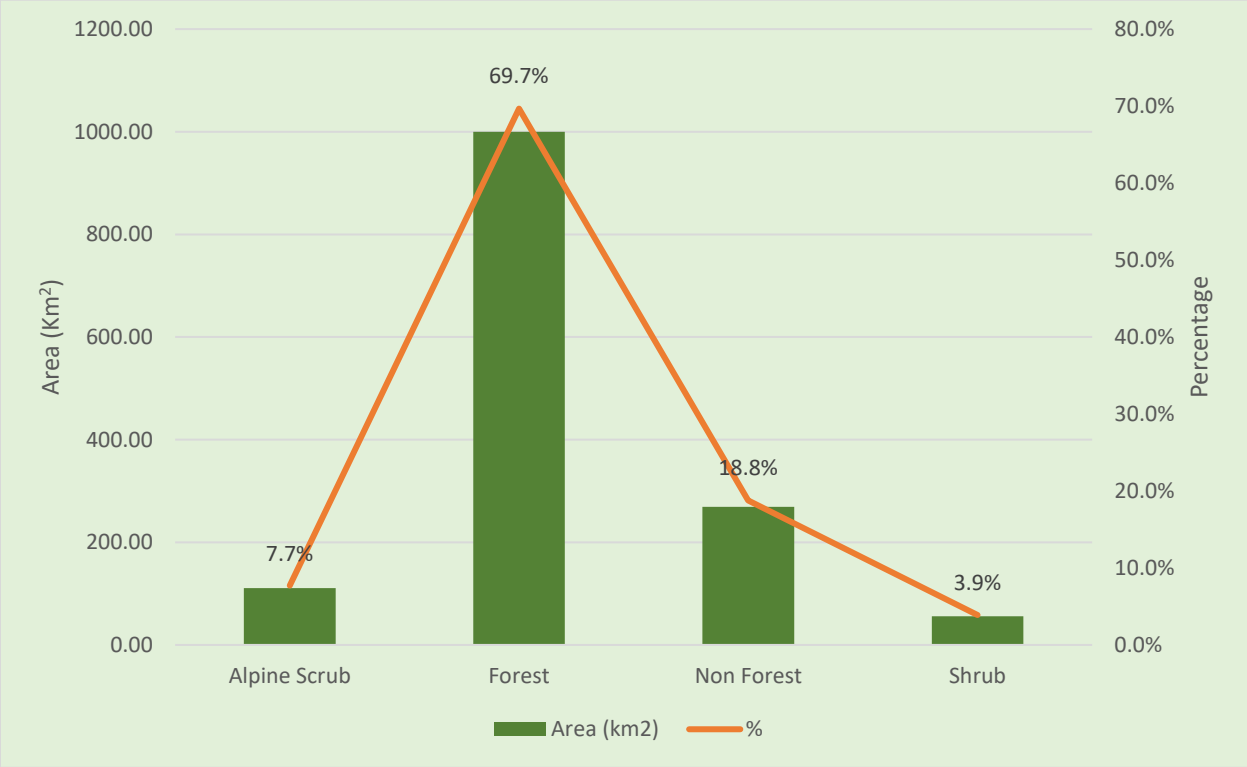
Class	Area (km²)	Area (Ha)	Percentage
Alpine Scrub	143.99	14,398.99	6.6%
Forest	1,766.87	176,686.66	81.0%
Non Forest	154.56	15,455.80	7.1%
Shrub	117.12	11,711.83	5.4%

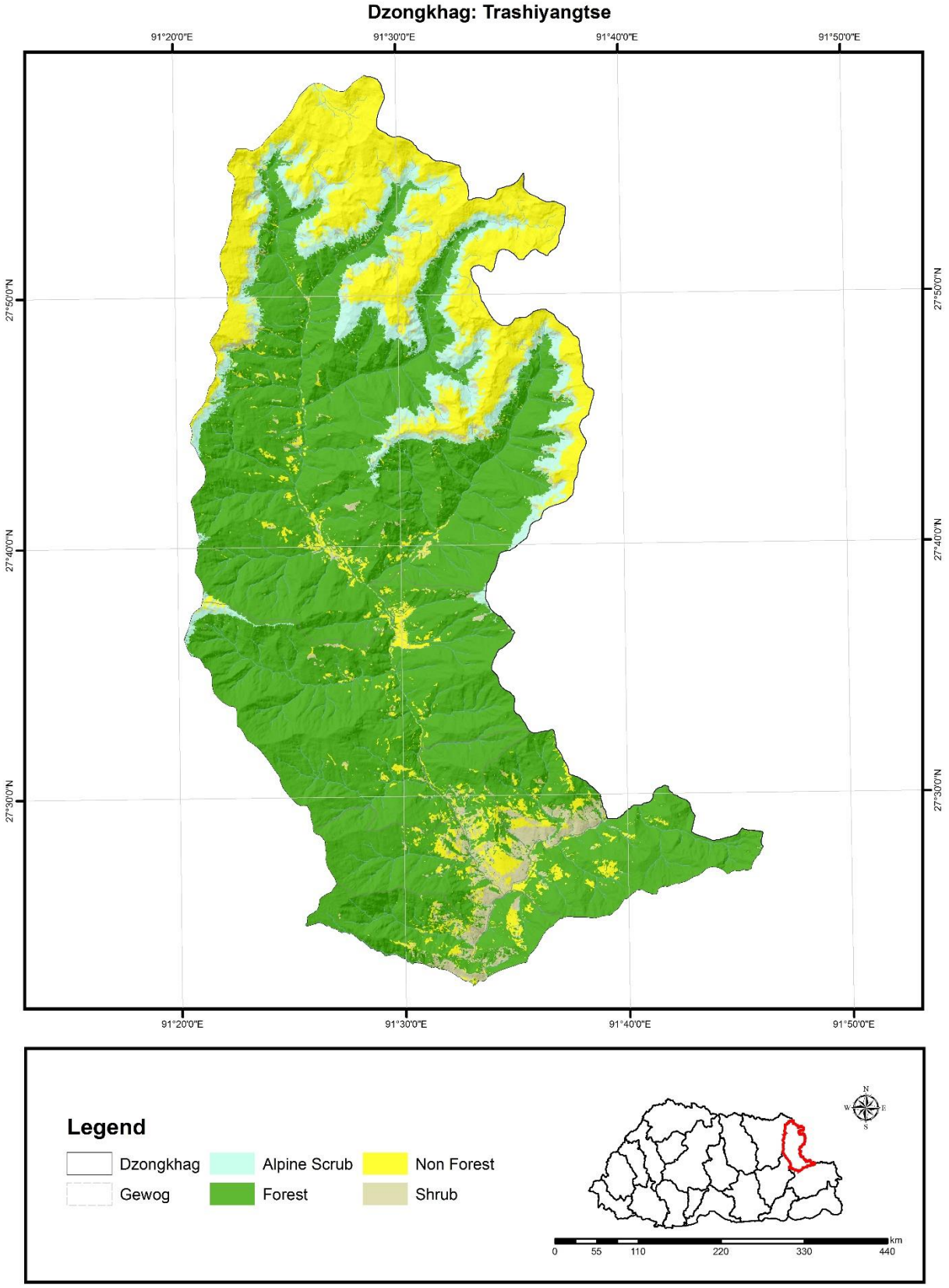



Dzongkhag: Trashigang
91°20'0"E
91°30'0"E
91°40'0"E
91°50'0"E
92°0'0"E
92°10'0"E
27°30'0"N
27°20'0"N
27°10'0"N
27°0'0"N
Legend
Dzongkhag
Gewog
Rivers
Alpine Scrub
Forest
Non Forest
Shrub
0
3.25
6.5
13
19.5
26
km

22. Trashi Yangtse

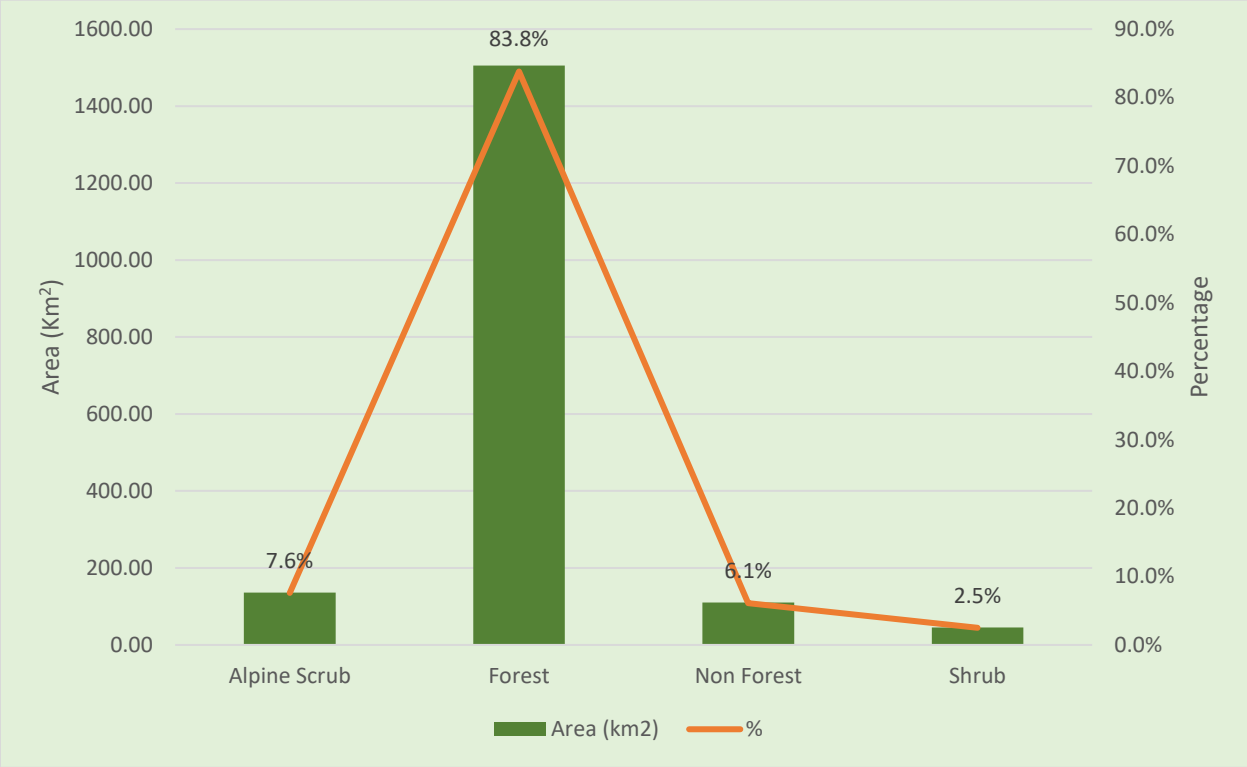
Class	Area (km²)	Area (Ha)	Percentage
Alpine Scrub	110.42	11,041.61	7.7%
Forest	999.73	99,973.46	69.7%
Non Forest	269.09	26,909.47	18.8%
Shrub	55.72	5,571.78	3.9%

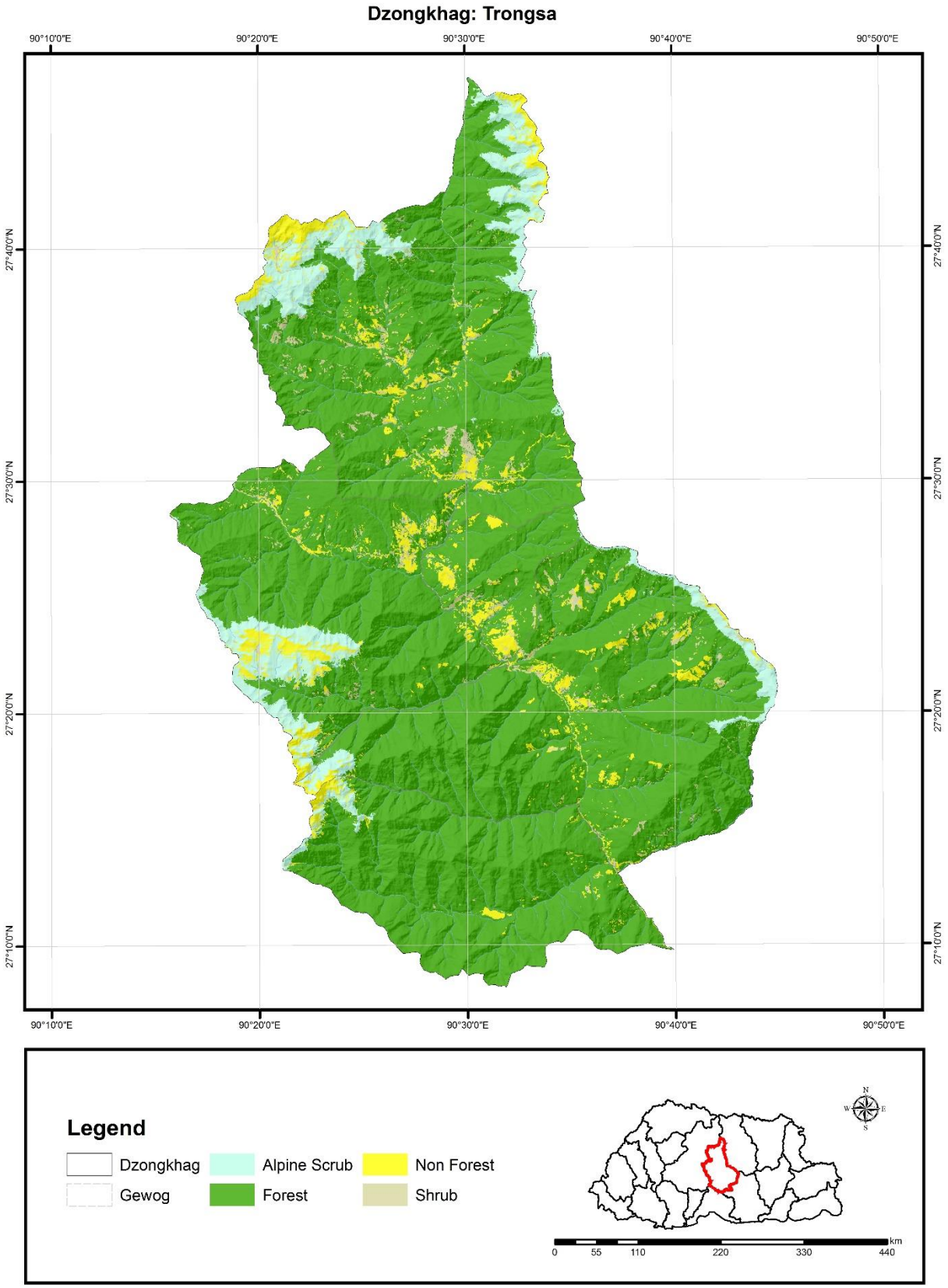



Dzongkhag: Trashiyangtse
91°20'0"E
91°30'0"E
91°40'0"E
91°50'0"E
27°50'0"N
27°40'0"N
27°30'0"N
Legend
Dzongkhag
Gewog
Alpine Scrub
Forest
Non Forest
Shrub
N
W
E
S
0
55
110
220
330
440
km

23. Trongsa

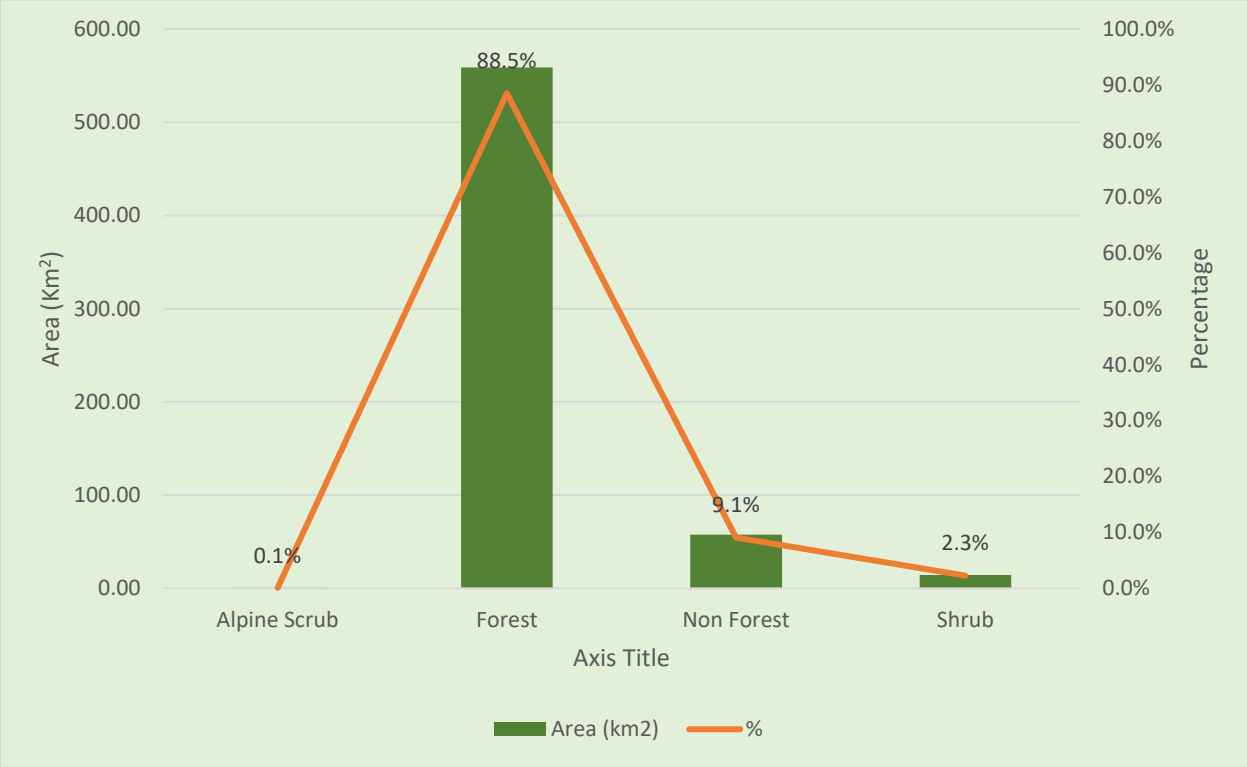
Class	Area (km²)	Area (Ha)	Percentage
Alpine Scrub	136.22	13,622.35	7.6%
Forest	1,505.17	150,517.32	83.8%
Non Forest	109.79	10,979.49	6.1%
Shrub	44.88	4,488.29	2.5%

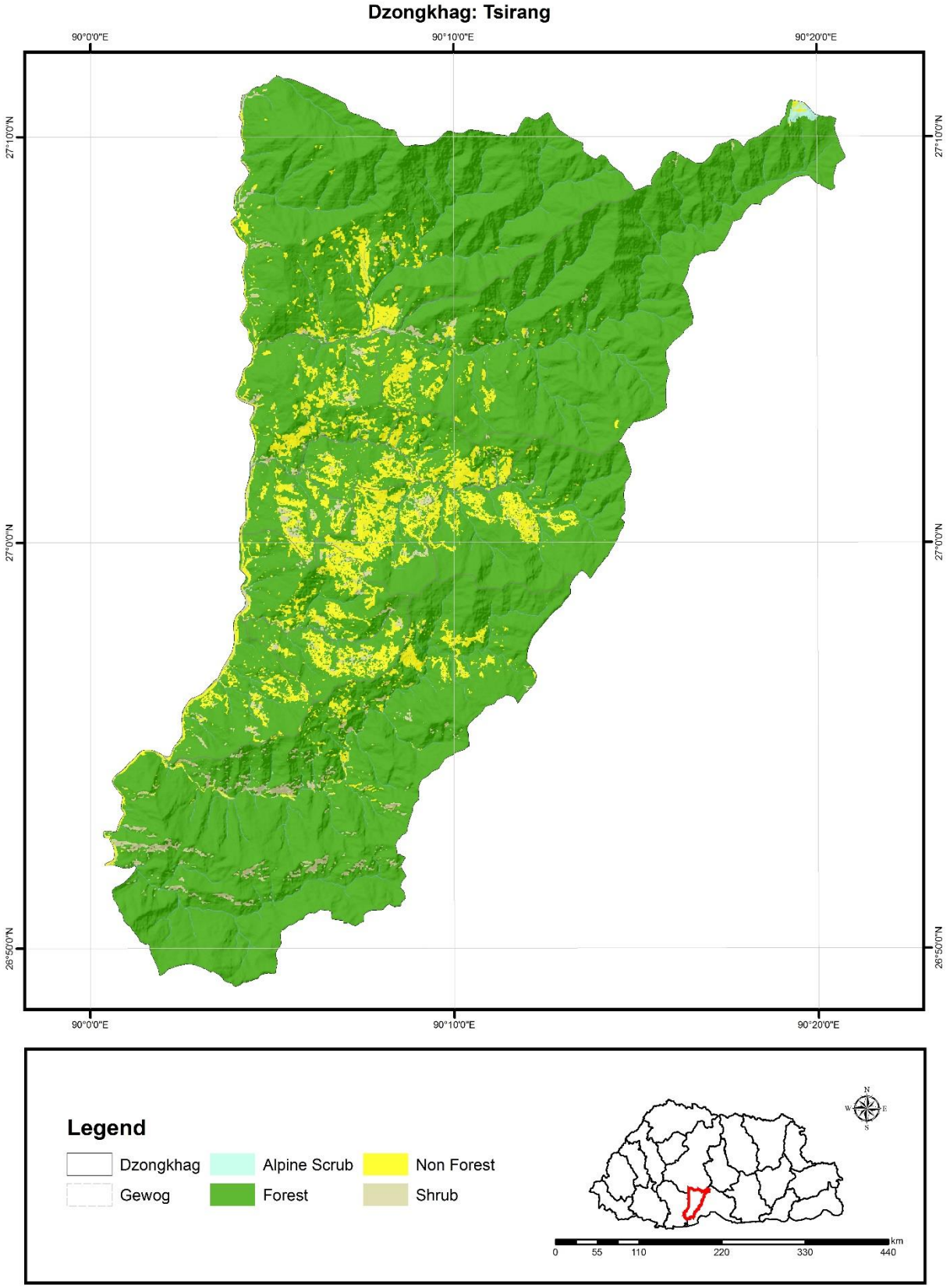



Dzongkhag: Trongsa
90°10'0"E
90°20'0"E
90°30'0"E
90°40'0"E
90°50'0"E
27°40'0"N
27°30'0"N
27°20'0"N
27°10'0"N
Legend
Dzongkhag
Gewog
Alpine Scrub
Forest
Non Forest
Shrub
N
W
E
S
0
55
110
220
330
440
km

24. Tsirang

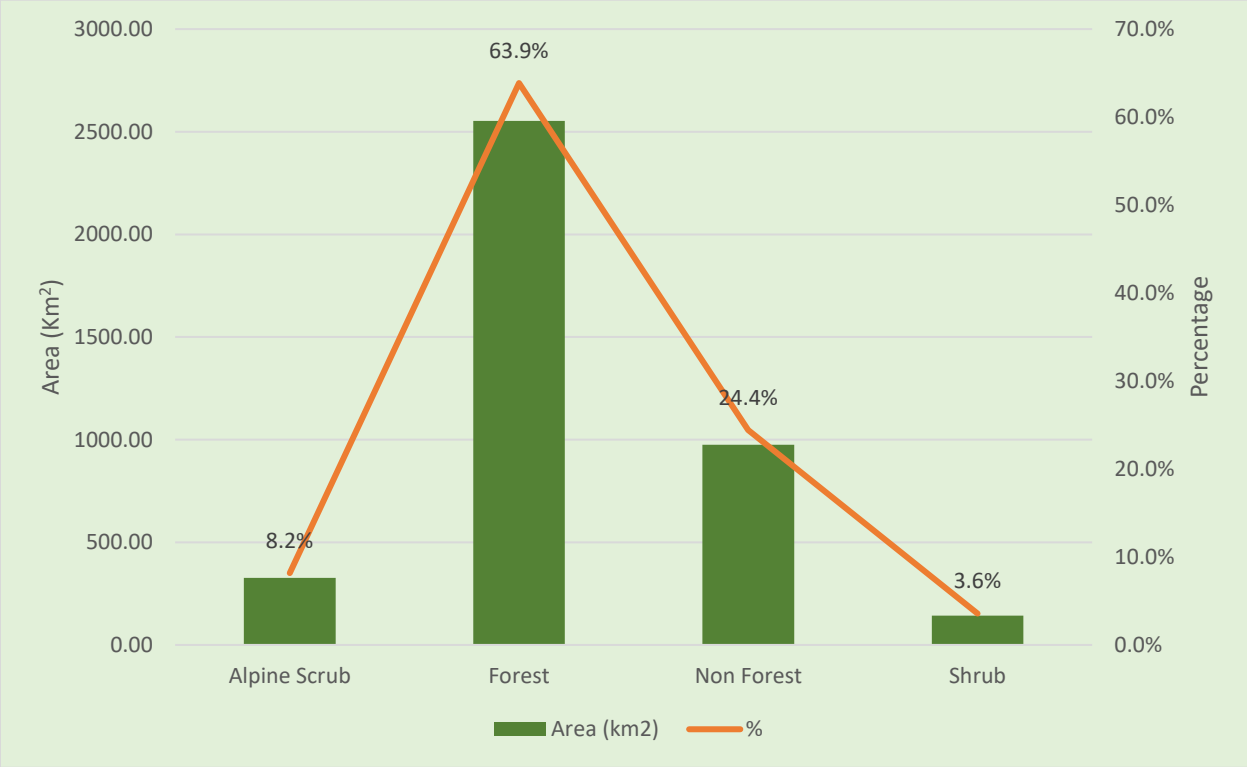
Class	Area (km²)	Area (Ha)	Percentage
Alpine Scrub	0.63	62.73	0.1%
Forest	559.00	55,900.05	88.5%
Non Forest	57.51	5,751.03	9.1%
Shrub	14.49	1,449.46	2.3%

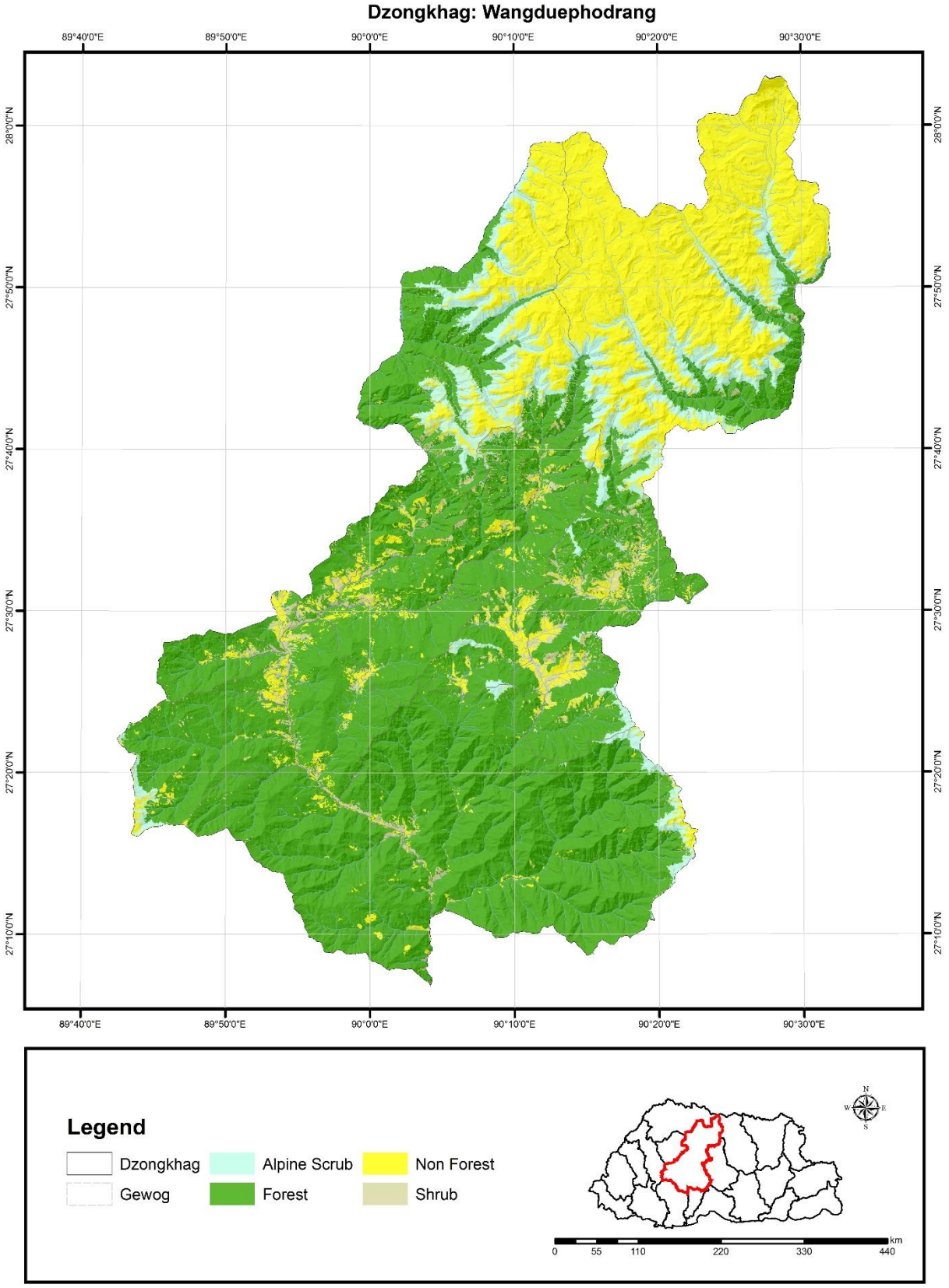



Dzongkhag: Tsirang
90°0'0"E
90°10'0"E
90°20'0"E
27°10'0"N
27°0'0"N
26°50'0"N
Legend
Dzongkhag
Gewog
Alpine Scrub
Forest
Non Forest
Shrub
N
W
E
S
0
55
110
220
330
440
km

25. Wangdue Phodrang

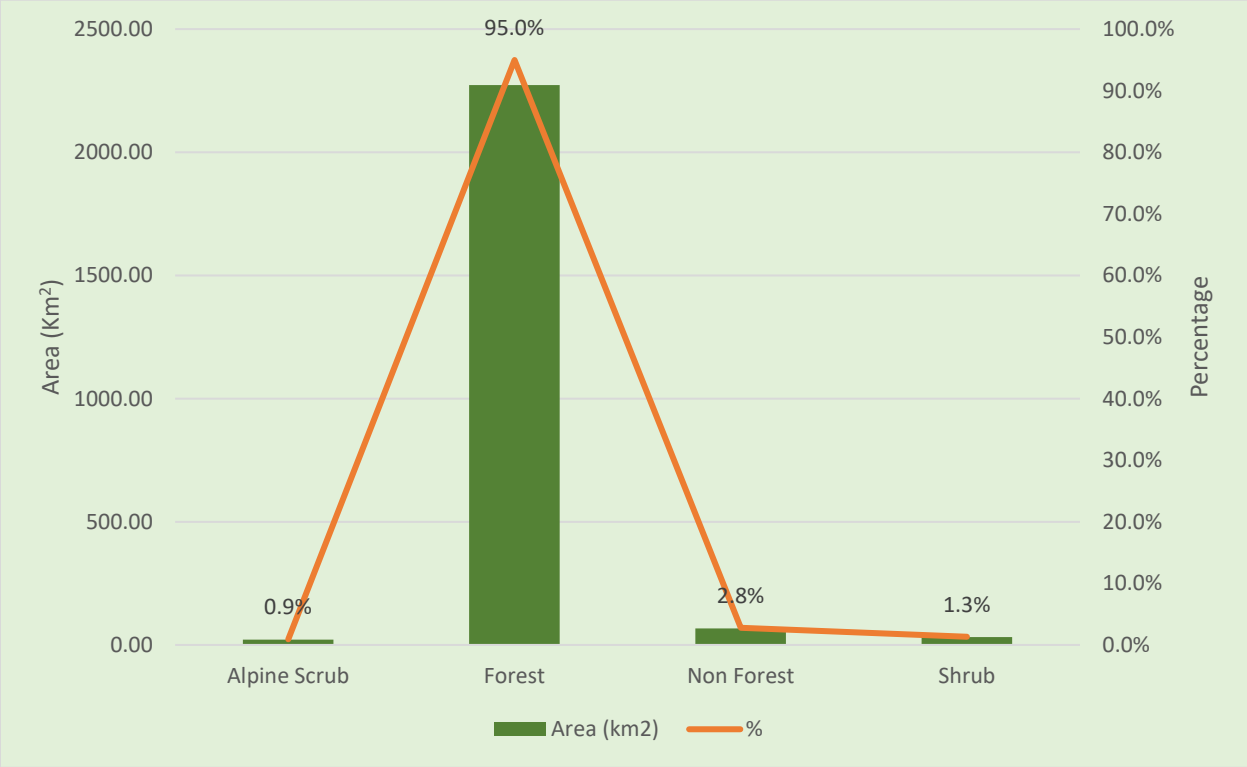
Class	Area (km²)	Area (Ha)	Percentage
Alpine Scrub	326.14	32,613.74	8.2%
Forest	2,552.32	255,231.54	63.9%
Non Forest	975.55	97,554.57	24.4%
Shrub	142.41	14,241.03	3.6%

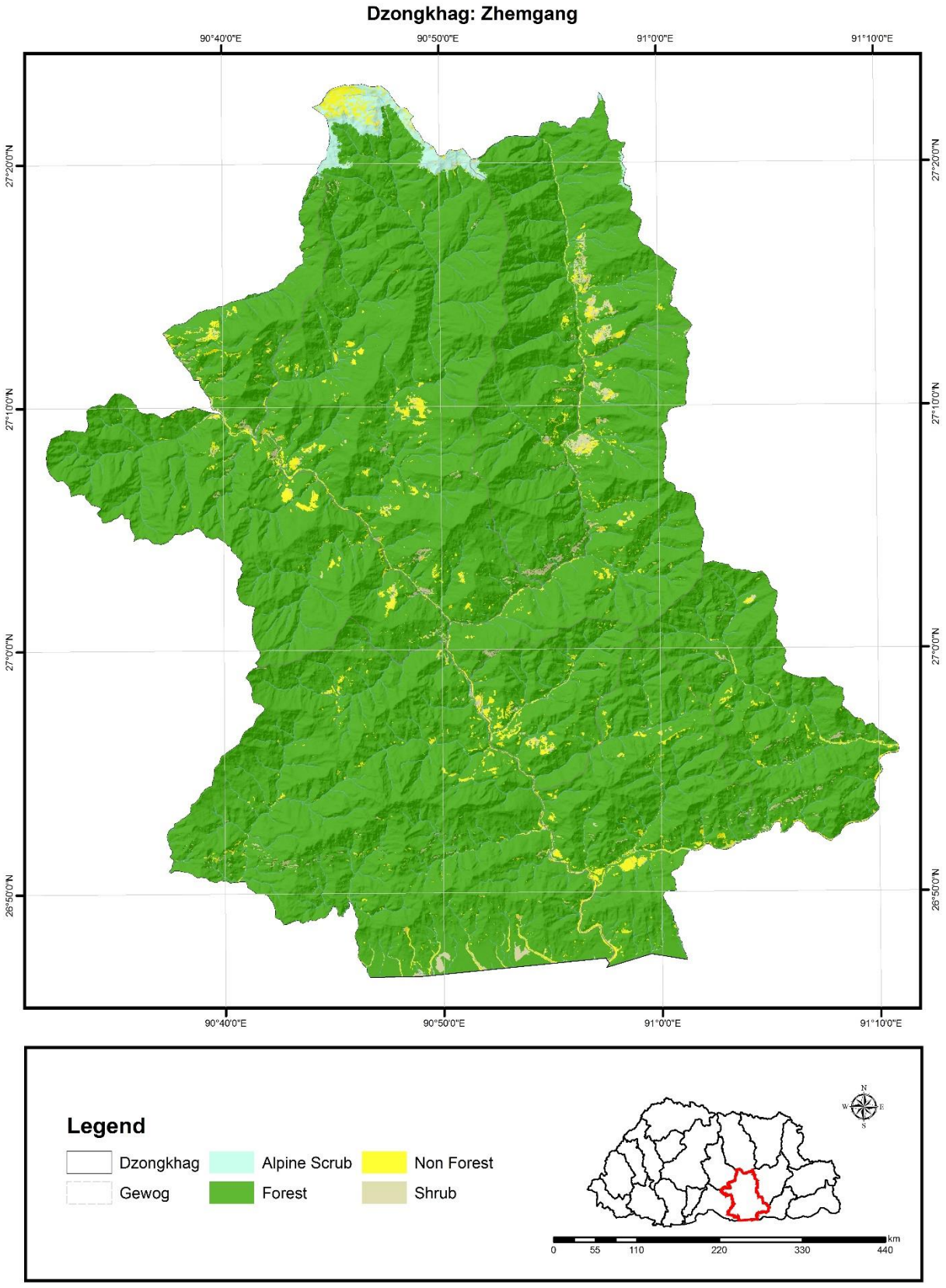



Dzongkhag: Wangduephodrang
89°40'0"E
89°50'0"E
90°0'0"E
90°10'0"E
90°20'0"E
90°30'0"E
28°0'0"N
27°50'0"N
27°40'0"N
27°30'0"N
27°20'0"N
27°10'0"N
Legend
Dzongkhag
Gewog
Alpine Scrub
Forest
Non Forest
Shrub
N
W
E
S
0
55
110
220
330
440
km

26. Zhemgang

Class	Area (km²)	Area (Ha)	Percentage
Alpine Scrub	21.86	2,185.58	0.9%
Forest	2,272.99	227,298.68	95.0%
Non Forest	66.72	6,672.21	2.8%
Shrub	31.52	3,152.00	1.3%




Dzongkhag: Zhemgang
90°40'0"E
90°50'0"E
91°0'0"E
91°10'0"E
27°20'0"N
27°10'0"N
27°0'0"N
26°50'0"N
Legend
Dzongkhag
Gewog
Alpine Scrub
Forest
Non Forest
Shrub
N
W
E
S
0
55
110
220
330
440
km

27. Comparison with Land Use Land Cover 2016

Dzonkhag	Forest Cover 2022		LULC 2016	
	Area (km²)	Percentage	Area (km²)	Percentage
Bumthang	1,354.23	50.3	1,393.57	51.8
Chhukha	1,643.02	88.3	1,661.51	89.3
Dagana	1,483.19	86.9	1,520.86	89.1
Gasa	536.71	17.3	608.53	19.6
Haa	1,244.85	66	1,257.72	66.7
Lhuentse	1,777.6	62.8	1,834.21	64.8
Mongar	1,759.84	91.4	1,758.87	91.4
Paro	646.42	50.7	662.83	52
Pemagatshel	928.6	91.7	919.27	90.8
Punakha	903.09	82.2	918.95	83.6
Samdrup Jongkhar	1,682.67	90.5	1,686.9	90.8
Samtse	1,014.95	78.5	1,052.03	81.4
Sarpang	1,446.84	88.3	1,468.52	89.6
Thimphu	669.33	37.6	712.14	40
Trashigang	1,766.87	81	1,727.58	79.2
Trashi Yangtse	999.73	69.7	1004	70
Trongsa	1,505.17	83.8	1,537.25	85.6
Tsirang	559	88.5	552.65	87.5
Wangdue Phodrang	2,552.32	63.9	2,640.62	66.1
Zhemgang	2,272.99	95	2,253.61	94.2
Total	**26,747.41**	**69.7**	**27,171.62**	**70.8**

Over all there was a slight decrease in the forest cover between 2016 (FRMD, 2017) and 2022. The total forest area decreased from 27,171.62 km^2 (70.8%) to 26,747.41km2 (69.7%). In absolute figure, approximately 424.21 km2 (1%) of forest area has decreased over the period of 6 years.

Among the Dzongkhags, Zhemgang has the highest cover both in 2016 (FRMD, 2017) and 2022 with 2,253.61 km2 (94.2%) and 2,272.99 km2 (95%) respectively. Similarly, Gasa has the lowest cover in both years, with 608.53 km2 (19.6%) in 2016 (FRMD, 2017) and 536.71 km2 (17.3%) in 2022.

Some of the dzongkhags where forest cover has marginally decreased over the period of 6 years are Wangduephodrang, Samtse, Trongsa, Thimphu, Paro and Dagana.

While some areas experienced a slight decrease in forest cover, others remained relatively stable or showed slight increases. Overall, there was a slight decline in forest cover percentage for the entire region.

28. Constraint and limitation

Mapping forest cover in the mountainous country like Bhutan using Landsat comes with certain constraints and limitation. One of the primary limitations is the spatial resolution of Landsat 8, which is not fine enough to capture the small-scale variation in forest cover accurately. At the national level, where large scale forest cover pattern is assessed, the 30m spatial resolution provides a reasonable estimation of overall forest cover. However, as the spatial resolution decreases to dzongkhag and gewog levels, the limitation of spatial resolution becomes more pronounced. It becomes increasingly challenging to identify and map smaller forest patches, boundary and change in land use accurately. Therefore, the accuracy of the map will decrease as one zooms to dzongkhag and gewog level.

Another significant constraint is the mountainous topography. The steep slopes and complex terrain of Bhutan can result in shadows, variations in illumination, and perspective distortion in satellite imageries. These factors make it difficult to differentiate between forest and non-forest area accurately. Such challenges posed by the topography can lead to misclassification and reduced accuracy in mapping forest cover.

Cloud coverage is another constraint when using the satellite image. Bhutan's mountainous region often experience persistent could cover, which can impede the acquisition of could-free satellite images. Limited availability of could-free image hampers the temporal coverage required for comprehensive forest cover mapping. Satellite image with less cloud cover is available only during winter

months. In winter months many trees' species shed their leaves and the absence of foliage can affect the spectral response and hinder the ability to accurately classify and map forest cover. Furthermore, the winter months may not capture the full extent of the forest cover due to seasonal variation. In mountainous region like Bhutan, certain forested area might be covered with snow during the winter, which can obscure the underlying vegetation and limit the visibility of forest cover. This can lead to underestimation or misclassification of forested areas, particularly in higher elevation where snow cover is more permanent.

29. Conclusion

Forest cover mapping of Bhutan using the Landsat 8 imagery and Random Forest algorithm in eCognition has provided valuable insight into the distribution and extent of forest cover across the landscape. The results indicate that the country's forest cover accounts for 69.7 % of the total geographical land, representing decrease of 1% compared to the previous assessment conducted in 2016 (FRMD, 2017).

Along with the forest cover, other types of woody land, such as alpine scrub and shrubs, were also identified and mapped. These types of land make up 10.3% of the overall geographical area and account for 6.6% and 3.7%, respectively.

The findings provide crucial information for understating the current state of forest cover in Bhutan. The 1% decrease of forest cover compared to 2016 assessment (FRMD, 2017) raises concern about potential deforestation or changes in land use practices.

With the map accuracy of 90%, it demonstrates the reliability and effectiveness of the Random Forest algorithm for classifying the forest cover in Bhutan. However, it is also important to acknowledge the limitation associated with the use of remote sensing technology and those related to the spatial resolution of Landsat 8 imagery.

Overall, the map provides valuable information for decision-making process to land management and biodiversity conservation in Bhutan. The results contribute to a better understanding of the distribution and changes in forest cover, highlighting the need for continued monitoring of forest cover of Bhutan.

30. References

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