Forest Mapping

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Forest mapping and inventories are essential for countries worldwide, and remote sensing makes it possible on temporal and spatial scales, especially for countries with little to no forest inventories. Remote sensing data, irrespective of their type (active or passive sensing), provide valuable information on forest stands, their composition, and their comparison with field-based conventional studies, and land cover mapping using remote sensing methods is used widely worldwide. With time, remote sensing makes it possible to precisely map forest dispersion on landscapes by correlating forest properties with other factors and mapping the species-level distribution of forests using fine spectral resolution imageries. Remote sensing data types, including optical, point-cloud (e.g., LiDAR), RADAR (e.g., Synthetic Aperture Radar (SAR)), and hyperspectral, can be used effectively to map forest types. Furthermore, researchers have designed algorithms for robust time-series mapping for vegetation change detection and monitoring systems for forest attributes using multiple sources and techniques. Lechner et al. described six key reasons why remote sensing is becoming important in forest studies, including (1) remote sensing imagery allows wall-to-wall mapping by providing a synoptic view of the area observation, (2) temporal data available anywhere and anytime you need, (3) homogeneity in remote sensing data, eradicating the possibility of human-induced errors, (4) remotely sensed data integrity and interoperability, (5) cost-effective data availability, and (6) readily available remote sensing data products, reducing the need of expertise.

citations supervised image classification maximum likelihood classifier 18th constitutional amendment SAR REDD+ Forest Pakistan Billion tree

1. Articles Published in the Pre-2010 Period

1.1 Islamabad Capital Territory (ICT)

The first study by Siddiqui and Jamil [1] used principal component analysis (PCA), an unsupervised image classification technique, using a maximum likelihood algorithm to map the forest in Margala Hills possessing an area of 148 square kilometers (km^2), Islamabad. Their study incorporated SPOT XS, Landsat Multi-Spectral Scanner (MSS), and Landsat TM imageries to assess forest change between 1976–1987 and 1987–1990. This study classified forest class into dense and sparse forest subtypes and reported that forest area depleted between 1976 and 1987 but got an appraisal between 1978 and 1990. The second study by Malik and Husain [2] used pixel-based supervised classification for mapping forest in the same study area (126 km^2). They used SPOT multispectral (XS) and Landsat 5 Thematic Mapper (TM) sensor for mapping forest areas. Other than forest, they classified other classes, including agricultural land, settlements/urban, and sparse vegetation. Their study did not

mention the algorithm used for the classification, and they did not perform any accuracy assessment for the classified data. Their study calculated an annual forest decline rate of 0.6% between 1990–1998. Margala Hills lies in the north and northwest of ICT. Total forest cover extracted using GFW data (2019) was 102 km^2 in the entire ICT.

1.2. Mansehra District

Only one study in the pre-2010 period was performed in the Mansehra district of KP. Using unsupervised image classification, Lodhi et al. [3] mapped forest cover in Siran Valley, a part of the Mansehra district. They used a nonhierarchical clustering procedure known as ISODATA (Interactive Self Organizing Data Analysis) algorithm to produce a landcover map of Siran valley in former NWFP. Using Landsat MSS and TM satellite data, their study reported a decline in overall tropical, dry, deciduous forest decline between 1979–1993 (from 202.7 km^2 to 113.4 km^2). The forest cover in the whole of Mansehra district using GFW data was 1385 km^2 in 2019.

1.3. Thatta District

Only one study in the pre-2010 period was conducted in Keti Bunder, Thatta district of Sindh. This study was led by Saeed et al. [4] using a manual approach. They used band combination techniques to visually interpret dense, medium, sparse, and very sparse mangrove forests located in the study area. The decrypted image was then converted to a vector using an on-screen digitization approach. Using Landsat, Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) terra, and SPOT images for 1992, 2001, and 2007, they assessed that mangrove forests showed a declining trend from 1992–2001 (a net change of 19.38 km^2) while an increasing trend from 2001–2007. Using the GMW data set, a total of 34 km^2 of mangrove forest area was calculated in this coastal belt for 2019.

1.4. Kashmore District

The study by Siddiqui et al. [5] did not mention any image classification method. They worked on riverine forests in the Kashmore district of Sindh province using Landsat MSS and TM imageries for 1977, 1990, and 1998. This study evaluated that riverine forest declined at 8.78 km^2 per year (km^2/y) from 1977–1990 and 8.98 km^2/y from 1990–1998. The total forest cover extracted using the GFW data in this district was 34 km^2 for 2019.

1.5. Abbottabad District

The study was conducted by Abbas et al. [6] in Ayubia National Park (ANP), Abbottabad district of the former North Western Frontier Province (NWFP). Their study utilized object-based image analysis (OBIA) incorporating a supervised image classification method using high-resolution optical imagery of QuickBird. Using a neural network (NN) fuzzy classifier algorithm, they mapped forest subtypes, including conifer forest, conifer (shadowed) forest, and mixed forest in the complex topography of ANP. This study did not perform any forest change assessment but reported 29.56 km^2 of forest cover. This district's total forest cover area was 765 km^2, as calculated from the GFW data set.

2. Articles Published in the Post-2010 Period

Around 90% (67) papers reviewed in this study were published in the post-2010 period. Most of these papers (59) used the supervised image classification method for classifying the satellite imageries to extract land use and land cover of the study areas. One study used the calibration of active remotely sensed data from the remaining studies, two studies used unsupervised image classification method, and three studies used the manual classification method, while two studies did not mention any method in their papers. Geographically, most of the studies (10) were conducted in ICT, seven in Swat district, five in Abbottabad district, five in Dir district, four each in Chitral and Thatta districts, two each in Mansehra, Rawalpindi, Gilgit, and Shaheed Benazirabad districts, three in the provinces of KP, GB, and AJK, three national-level studies on mangrove sites of Pakistan, and the remaining studies were performed in the remaining districts (one in each district).

2.1. Abbottabad District

A total of five studies were conducted in the Abbottabad district of KP (the former NWFP). The forest cover extracted from the GFW data set, for the year 2019, in this district was 765 km^2.

The first study (post-2010) on the urban forest assessment was conducted by Raza et al. [7] in the part of Abbottabad district (1967 km^2 area) of the former NWFP using Landsat TM, Enhanced Thematic Mapper (ETM), and ETM+ satellite imageries for 1998, 2005, and 2009. The maximum likelihood algorithm was used through the supervised image classification method to assess landcover classes of settlement, vegetation, water, forest, and bare land. Overall forest change from 1998–2009 was positive in this study, i.e., 11.943–14.77%. A subsequent study by Khan et al. [8] used SPOT-5 to assess urban forests in the Abbottabad district (4600 km^2 area) of KP for 2014. This study used the supervised image classification method to compare the MDC algorithm and parallel-piped classifier algorithms. This study did not report forest cover stats. Gul et al. [9] conducted another study in the Abbottabad district (4999 km^2 area) of KP to map urban forests using SPOT-5 data. They used two different classifiers, the NN classifier and Support Vector Machine (SVM) classifier, in OBIA to compare the classification results. This study also did not report forest stats. The study by Nisa et al. [10] used Landsat 5 data to map urban forests in a part of Abbottabad district (1756 km^2), KP. They used a pixel-based supervised image classification method to classify 2000 and 2009 Landsat images and reported that overall forest area decreased from 211.5 km^2 in 2000 to 195.9 km^2 in 2009. The last study in this district was led by Ullah et al. [11] and aimed to assess alpine forest distribution and change assessment in a part of Abbottabad district (1967 km^2), KP, using Landsat 5 TM, Landsat 7 ETM+, and Landsat 8 Operational Land Imager (OLI)/Thermal Infrared Sensor (TIRS). They used the non-parametric image classification technique of SVM through the supervised image classification method to classify images of 1987, 2002, and 2017. This study assessed a positive change in the forest area of 2.90% between 1987–2017, in contrast to the previous research by Nisa et al. [10], who assessed a decrease in the forest in the same study area between 2000–2009. As per the GFW data, the total forest cover they assessed for 2017 was 730 km^2, which increased to 765 km^2.

2.2. Chitral District

A total of four studies were conducted in the Chitral district of KP (former NWFP). The forest cover extracted from the GFW data set, for the year 2019, in this district was 247 km^2.

The first post-2010 study focused on mapping the dry temperate forest of Chitral tehsil (5818 km^2) of Chitral district in the former NWFP by Shehzad et al. [12]. They achieved their objectives using the Landsat TM satellite data for 1992, 2000, and 2009. Using a pixel-based supervised image classification method, the study found that the deforestation rate increased from 0.14% per annum during 1992–2000 to 0.54% per annum during 2000–2009, with 3759 ha forest lost over the 17 years. This study reported 37.6 km^2 forest loss during this period. Zeb et al. [13] published the subsequent paper on the Kalasha valleys (456 km^2) of Chitral district, KP, using Landsat imagery for 2003 and 2015. They used supervised image classification incorporating a maximum likelihood algorithm and indicated a decline in forest area without mentioning the statistics. Similarly, the following paper, again by Zeb et al. [14], was performed in the same study (456 km^2) area using Landsat MSS, Landsat TM, Landsat ETM+, and Landsat OLI satellite imageries for 1973, 1993, and 2015 to map the dry, temperate, coniferous forests. This study also used the pixel-based supervised image classification method to report an overall decline in the forest area between 1993–2015 with a reduced rate of 0.6% and 0.9% per year in different valleys of the study area without mentioning the actual forest cover statistics. The third paper, by the same author Zeb [15], attempted to map the dry, temperate, conifer forests, deciduous forests, and oak scrub forests of the study area of Chitral district (14,850 km^2), KP. Using Landsat images and applying the supervised image classification method, this study mapped dense and sparse forests between 1973, 1993, and 2015. The author reported an annual rate of change of −0.43% between 1973–1993 and −0.82% between 1993–2015, with an overall rate of change of forest of −0.63% between 1973–2015. This study reported forest cover of 689 km^2 in 2015, compared to a very low estimated forest cover of 247 km^2 through GFW for 2019.

2.3. Dir District

A total of five studies were conducted in the Dir (Lower and Upper) district of KP. The forest cover extracted from the GFW data set for 2019 was 257 km^2 for Lower Dir, 1019 km^2 for Upper Dir, and 1276 km^2 for both divisions of the Dir district.

The first study in this regard, by Sajjad et al. [16], used Landsat 5 data to map the coniferous forests mixed with the broadleaved forest in Barawal tehsil (391 km^2 area) of district Lower Dir, KP, using a pixel-based supervised image classification technique. They concluded that from 2000–2012, the forest area decreased by 12% (from 193.5 km^2 to 145.2 km^2) and the agriculture area increased by 7%. The study published by Munawar et al. [17] worked on mapping the temperate conifer forests using SPOT and MODIS satellite data in the district of Dir (Lower and Upper), KP, possessing a 4198 km^2 area. They obtained land cover from the Global Land Vegetation Monitoring (GVM) project and reported that in 2001 the forest change was −362 km^2 using SPOT and −587 km^2 ha using MODIS, while in 2012, it was 151 km^2 ha using SPOT and 416 km^2 ha using MODIS, showing a positive trend in the forest area. The following, conducted by Ullah et al. [18] in the Dir Kohistan (Part of Upper Dir) forest division (927 km^2 area), KP, used SPOT-5 imagery to spatially assess subtropical broadleaved oak forest temperate distribution coniferous forest, alpine, and subalpine forests. They used the pixel-based supervised image

classification method to classify images of 2004, 2007, 2010, and 2013 and found that the forest declined 6.4% from 2004 to 2013 with an annual rate of −0.6%. The forest cover reported for 2013 was 289.5 km^2. The study by Ullah et al. [19] used Landsat 8 OLI and SPOT-5 to map the subtropical oak forest and dry temperate coniferous forest using multiple non-parametric image classification techniques, including k-nearest neighbor (k-NN), SVM, random forest (RF), and NN in part of Dir Kohistan forest division (99 km^2 area), KP. This study reported an average forest cover of 43.4 km^2 using all image classification algorithms. The last study conducted in this district used a manual approach (digitization) for satellite image classification, conducted by Haq et al. [20]. They used land-use surveyed maps to estimate coniferous and alpine forests in the study area of Dir (Lower and Upper) valley, KP. They scanned the maps and digitized them for 1970 and 2014 and found that 17% of forests declined during this period. This study did not mention forest cover statistics.

2.4. Gilgit District

A total of two studies were conducted in the Gilgit district of GB. The forest cover extracted from the GFW data set, for the year 2019, in this district was 148 km^2. It is important to note that both of these studies were conducted in a part of this district, and none of the studies used the district as a whole.

The study by Khan et al. [21] in the Central Karakoram National Park (CKNP), GB (10,000 km^2 area), used high-resolution SPOT-5 satellite data to map the forest area for 2013. However, the study did not report any statistics on the land cover. In the paper by Imran and Din [22], they used Sentinel-2 satellite images to map the alpine, sub-alpine, and coniferous forests of Bagrote valley (4.4 km^2) in GB. This study utilized OBIA incorporating an NN classifier to map the landcover for 2016 in the study area. This study classified the images into the landcover classes of dense conifer, sparse conifer, agricultural land, linear/block plantations, sparse broadleaved, sparse mix, dense mix, and dense broadleaved. The study reported forest cover (including all types) as 0.28 km^2 (6.4% of the study area).

2.5. Islamabad Capital Territory (ICT)

A total of 10 studies were conducted in the federal area of ICT, which is the maximum number of studies in a single district. The forest cover extracted from the GFW data set, for the year 2019, in this district was 102 km^2.

Among the twin studies by Butt et al. [23], the first study used Landsat 5 TM data to spatially assess the conifer forest and dry, semi-evergreen forest in the Rawal watershed (274.4 km^2 area) near ICT. They evaluated a decrease in forest area from 1992–2012 using maximum likelihood in the supervised image classification method with an annual rate of –6.6%. This study reported a forest cover of 122.9 km^2 in this watershed. The second study, by Butt et al. [24], used Landsat 5 TM and SPOT data sets to evaluate landcover in the Simly watershed (164 km^2 area) near ICT using the supervised image classification method. They reported that vegetation (mixed forest) in 1992 was 113.2 km^2, decreasing to 70.1 km^2 in 2012, with a −26% change. The following study by Hassan et al. [25] used Landsat 5 TM and SPOT-5 imageries for 1992 and 2012 to map forest change in ICT (907 km^2 area). Using a pixel-based supervised image classification method, their study evaluated that the forest area in Islamabad declined from 121.4 km^2 in 1992 to 61.4 km^2 ha in 2012, with an annual rate of change of –2.47%. In contrast, the

forest cover in the same area was extracted as 102 km^2 using a global forest data set. Following this, Mannan et al. [26] used Landsat 5 TM, Landsat 7 ETM, and Landsat 8 OLI to assess forest change of subtropical, broad-leaved evergreen and subtropical Chir Pine forests in Margallah Hills National Park (MHNP), Islamabad, from 1990 to 2017, possessing an area of 174 km^2. Using the maximum likelihood classifier in the supervised image classification method, they reported that dense forests decreased by 11.14% (with a rate of −0.41% per year) and open forests increased by 4.28% (with a rate of 0.15% per year). The research conducted by Batool and Javaid [27] used Landsat 7 ETM+ and Landsat 8 OLI to map forest change between 2000–2018 in MHNP (571 km^2), Islamabad. Using the maximum likelihood algorithm in the supervised image classification method, they reported a net change of –13% from 2000–2018, a loss of 651.48 km^2 of forest area. The paper by Waseem and Khayyam [28] used Landsat 5 and Landsat 8 satellite data to map the forest area of ICT (907 km^2). They used the supervised image classification method to report that the study area faced a 22% reduction in the vegetative (forest) cover area between 1992 and 2017, with a high, 51%, reduction between 2008 and 2017. The study by Khan et al. [29] focused on the impact of land use and land cover changes on the urban heat island in Islamabad (906 km^2) using a machine learning RF algorithm. They used Landsat 5 TM and Landsat 8 OLI images to map Islamabad's subtropical broadleaves and pine forests for 1993 and 2018. They assessed a net change in the forest area of −1.4% between 1993–2018. The forest cover reported for 2018 was 266.8 km^2. Gilani et al. [30] worked on urban landscape ecology dynamics of Islamabad (906 km^2) over four decades (1976–2016) using Landsat 3 MSS, Landsat 5 TM, Landsat 7 ETM+, and Landsat 8 OLI satellite images. They mapped the tropical forest cover of Islamabad using the supervised image classification method and reported that the annual rate of change of tree cover >40% canopy between 1976–2016 was −0.81%. The reported 132.3 km^2 area for tree cover >40% canopy. Subsequently, Shah et al. [31] used Landsat MSS, Landsat TM, Landsat ETM+, and Landsat OLI sensors' data to spatially assess thick and mixed forest land distribution in Islamabad (906 km^2) for 1979, 1989, 1999, 2009, and 2019. Using the supervised image classification method, their study indicated that 81.3 km^2 of forest area declined from 1979 to 2019. This study reported forest cover of 93.4 km^2 for 2019 in contrast to 102 km^2 of forest cover extracted from the global data set for the same year, 2019. The last study on ICT (906 km^2) by Shah and Nizami [32] used OBIA for the same years using the same satellite data as in their previous research. This study also indicated the same 81.3 km^2 deforestation between 1979–2019.

2.6. Mansehra District

A total of two studies were conducted in the Mansehra district of KP. The forest cover extracted from the GFW data set, for the year 2019, in this district was 1385 km^2. It is important to note that both of these studies were conducted in a part of this district, and none of the studies used the district as a whole.

The first study, by Amjad et al. [33], used Landsat 5 and Landsat 8 satellite imageries to map the tropical forest of Mansehra district (4,296 km^2 area), KP, for 1998, 2008, and 2017. Using the pixel-based image classification method, they reported that the forest in the study area increased from 1998 to 2008 and had a huge decrease from 1998 to 2017. This study reported 668 km^2 forest cover in 2008 compared to 194 km^2 in 2017. The second study, by Ullah et al. [34], used Landsat 5 TM, Landsat 7 ETM+, and Landsat 8 OLI data to map the land cover of a study area within Mansehra and Battagram districts (1802 km^2 area) of KP. The forest cover for the Battagram district

extracted through the GFW data set was 462 km^2. The study used a supervised image classification method incorporating non-parametric image classification techniques (SVM and Andreson classification scheme level 1). This study reported vegetation (forest) cover in 1990 to be 1017.66 km^2, in 2002 to be 933.25 km^2, and in 2017 to be 841.89km^2, with a net change of -9.88% between 1990–2017.

2.7. Rawalpindi District

A total of two studies were conducted in the Rawalpindi district of Punjab. The forest cover extracted from the GFW data set, for the year 2019, in this district was 712 km^2.

Shahzad et al. [35] explored the trend of the Himalayan subtropical pine forests using SPOT-5 high-resolution optical imagery from 2005–2011 in the Murree galliat area (468 km^2 area), Rawalpindi district, Punjab. They used the standard NN technique in OBIA through supervised image classification to assess forest conversions in the state-owned and community/private forests. The results showed a decrease of about 5 km^2 of 'closed-canopy *Pinus wallichiana*' forest from 2005–2011 in the state-managed area, whereas a reduction of about 2 km^2 in the community/private forest was observed. The following study, by Mannan et al. [36], utilized Landsat 5 TM and Landsat 8 OLI satellite images to explore the sub-tropical and moist temperate forests in the foothills of the Himalayan mountains (622 km^2 area), Rawalpindi district, Punjab. Using a pixel-based maximum likelihood algorithm in supervised image classification, they reported that the annual rate of forest change between 1998–2008 was −0.09%, which increased to −0.32% between 2008–2018. This study reported 392.3 km^2 forest cover in the study area, and the projected forest cover for 2018 was 405.5 km^2.

2.8. Shaheed Benazirabad District

A total of two studies were conducted in the Shaheed Benazirabad district of Sindh. The forest cover extracted from the GFW data set, for the year 2019, in this district was 11 km^2. Siyal et al. [37] conducted a study in the Pai forest (20 km^2 area), located in the Shaheed Benazirabad district of Sindh, using Landsat TM, ETM, and OLI satellite imageries. They used supervised image classification to map dense and sparse forests for 1987, 1992, 2000, 2010, 2013, and 2014. They observed that the total forest cover of the study area increased about 24% from 1992 to 2010 and about 6% from 2010 to 2014. The study reported 16.4 km^2 of total forest cover in 2014. The second study in this district, by Shafique et al. [38], evaluated Landsat 8 OLI/TIRS to map the Pai forest (19 km^2) in district Shaheed Benazirabad, Sindh. Using unsupervised image classification indexes of Normalized Difference Vegetation Index (NDVI) and Enhanced Vegetation Index (EVI), they reported that forest carbon stock declined between 2018–2020. However, this study did not report statistics of forest cover found in the study area.

2.9. Swat District

A total of seven studies were conducted in the Swat district of KP. The forest cover extracted from the GFW data set, for the year 2019, in this district was 939 km^2. The first post-2010 study in this district (5037 km^2) used the manual method for image classification, published by Qasim et al. [39]. This study aimed to map conifer forests of Swat district, the former NWFP, using aerial photographs and satellite imageries. The forest area was digitized

through visual interpretation, and they found a significant decrease in forest area from 1968–2007. The study reported a total of 56.5 km^2 of forest cover in three selected zones of this district. The work on coniferous forest mapping by Qasim et al. [40] in this district (5037 km^2 area) used a manual digitization approach using aerial photographs and satellite imageries for 1968, 1990, and 2007. They divided the study area into different zones, A, B, and C. In zone C, 75.1% of the forest area was converted to rangeland in 40 years, whereas this happened to 37.8% of the area in zone A. Afforestation also occurred in the study area but was negligible compared to deforestation. The subsequent study was conducted by Qamer et al. [41], who used Landsat 5 TM, Landsat 7 Enhanced Thematic Mapper Plus (ETM+), and SPOT-5 High-Resolution Visible (HRV) imageries to temporally map the western Himalayan subalpine conifer and subtropical pine forests in Swat and Shangla districts of the former NWFP. The forest cover in the Shangla district was 539 km^2, as calculated through the GFW data set. Using a pixel-based image classification method, they mapped dense and open forest in the study area for 2001 and 2009 and found an average annual gross deforestation rate of 0.82%. This study reported an overall forest area of 1572.82 km^2 for 2009 compared to 1478 km^2 forest cover (for 2019) extracted from the GFW data set for both districts. The study by Ali et al. [42] used Landsat imagery to estimate the spatial distribution of tropical deciduous to the alpine forest in the Swat valley (5337 km^2 area), KP. They assessed forest change between 1992–2011 and reported a 13.42% decrease in the dense forest, while open forest increased from 926 km^2 in 1992 to 116.7 km^2 ha in 2011. A subsequent study by Ahmad et al. [43] mapped coniferous forest change in Kumrat valley (346 km^2 area), district Swat, KP, using Landsat 5 TM and Landsat 8 OLI satellite data. They used the supervised image classification method to state a net loss of 6.3 km^2 (with a rate of 0.29 km^2 per year) from 1994–2016. Ahmad et al. [44] used Landsat 8 OLI to map *Cedrus Deodara* forest, *Pinus Wallichiana* forest, *Abies pindrow*, and mixed coniferous forest in the Kumrat valley (346 km^2 area), district Swat, KP. They used a maximum likelihood classifier in the supervised image classification method and mapped dense and open forests for 2016. This study reported a total of 176.9 km^2 of forest cover in the study area for 2016. The last study in this district, by Talib et al. [45], used Landsat TM, Landsat ETM+, and Landsat OLI/TIRS to map the forests of Swat valley (5392 km^2 area). The study reported that the forest area decreased from 1473.1 km^2 in 2000 to 1235.40 km^2 in 2005 to 1167.093 km^2 in 2010 to 1086.05 km^2 in 2015. In contrast to this, the forest cover extracted through the GFW data set was 939 km^2 for 2019.

2.10. Thatta District

A total of four studies were conducted in the Thatta district of Sindh. The forest cover (riverine and mangrove forests) extracted from the GFW (2019), and GMW (2016) data sets in this district was 964.9 km^2. The first study on mangrove forest cover assessment was led by [46] in the Indus delta (1010 km^2 area), district Thatta, Sindh. Along with Landsat TM, they were the first in Pakistan to use Landsat 8 OLI satellite data for forest cover assessment. They incorporated a supervised classification method combined with a manual digitization method to delineate mangroves, mudflats, vegetation/crop, algae, sand, and water for 2009 and 2014. The results showed that the total area of mangrove cover was 946.52 km^2 using supervised image classification and 960.83 km^2 using manual digitization in 2009, while it was 1010.11 km^2 using supervised image classification, and 1082.71km^2 using manual digitization in 2014, clearly indicating an increase in mangrove forests. The second study, by Qasim et al. [47], in district Thatta (17,361 km^2 area), Sindh, used Landsat imagery to map the riverine/mangrove forest by

applying a maximum likelihood algorithm in supervised image classification. Their study evaluated that the forest area declined from 1527.6 km^2 in 1990 to 1293.1 km^2 in 2010 to 1022.2 km^2 in 2014. The paper by Rehman and Kazmi [48] attempted to map mangrove forests in the Indus delta (11,962 km^2 area), district Thatta, Sindh, using Landsat 7 ETM+ and Landsat 8 OLI satellite images. They used the supervised image classification method to map dense and regular mangroves for 2000 and 2014. Their study assessed an annual decrease rate of dense forests of −0.93 km^2 and regular mangroves' yearly increase rate of 23.21 km^2 from 2000–2014. The total mangrove forest cover in this study was 953.2 km^2 for 2014. The last study in this district (942 km^2 area) by Abbasi et al. [49] used Landsat 3 MSS and Landsat 5 TM satellite imageries to map the Thatta river's riverine forest in the Indus river basin, Sindh. Using the supervised image classification method, they mapped the riverine forests for 1979, 1992, 1998, 2000, 2006, 2009, and 2010 and observed an enormous net change in the forest area of −89.07% between 1979–2010.

2.11. Khyber Pakhtunkhwa (KP), Gilgit-Baltistan (GB), and Azad Jammu and Kashmir (AJK)

A total of three studies were conducted collectively in three administrative areas of Pakistan, including KP, GB, and AJK. The forest cover extracted from the GFW data set, for the year 2019, in this study area was 15,103 km^2. Qamer et al. [50] conducted the first regional-level study, including the province of KP and the administrative units of GB and AJK (182,600 km^2 area) using Landsat TM and ETM satellite imageries for 1990, 2000, and 2010. The study evaluated that the overall annual forest cover rate of change was –0.38% for the entire area from 1990 to 2010 (KP −0.42%, GB −0.31%, and AJK −0.13%). The total forest cover in this entire region was 21,521 km^2 for 2010. The second such study, published by Munawar and Udelhoven [51], used MODIS to map the evergreen coniferous forest, including some deciduous broad-leaved forests, for 2000–2018 in KP, GB, and Kashmir (183,000 km^2 area) regions. However, the study does mention that it used pixel-based classification, but without reporting the method, and it also did not mention the forest change statistics. The following study, by Khan et al. [52], used Landsat 5 and Landsat 8 remotely sensed images to map the alpine forests existing in the northern part of Pakistan (GB, KP, and AJK), possessing an area of 85,435.4 km^2. They used a maximum likelihood classifier to map the forests for 2000, 2010, and 2020. This study mainly aimed to find the impact of land use and land cover changes on snow leopards' habitat. An unfavorable change of 1777.20 km^2 (−32%) was observed in the forest woodland between 2000–2020. The study reported a forest cover of 6649.8 km^2 for 2020.

2.12. Coastal Mangrove Sites of Pakistan

The coastal mangrove sites of Pakistan consist of five locations, including Indus Delta and Sandspit in Sindh, and Miani Hor (Sonmiani Bay), Kalmat Khor, and Jiwani (Gwadar Bay) in Balochistan. The total mangrove forest cover assessed through the GMW data set collectively in these sites was 680 km^2 in 2016. The first national-scale study, by Abbas et al. [53], used NN and rule-based methods in OBIA to map mangrove forests using ALOS AVNIR-2 for 2009. The total mangrove forest cover for all these sites was 981.3 km^2 in this study. The following study was done by Abbas et al. [54], who used a NN fuzzy classifier through OBIA to map the mangrove forest belt located at the coastal belt (1580 km^2 study area) of Pakistan. Advanced Land Observation Satellite's (ALOS) Advanced Visible

and Near Infrared Radiometer type 2 (AVNIR-2) sensor high-resolution data were used for 2008–2009. The total mangrove forest cover for all these sites was 924.1 km^2 in this study. The latest study by Gilani et al. [55], mapped national-level mangroves in Pakistan, including various sites (9538 km^2 area) for 1990, 1995, 2000, 2005, 2010, 2015, and 2020. Processing and classification of Landsat 5 TM, Landsat 7 ETM+, and Landsat 8 OLI satellite images reported a national-scale increase in a mangrove from 477.22 km^2 in 1990 to 1463.59 km^2 in 2020 with an annual rate of change of 3.74%.

2.13. Other Districts

The remaining 18 studies were performed in different districts of Pakistan. The study by Abbasi et al. [56] in the forest divisions of the districts of Sukkur and Shikarpur (1997 km^2 area), Sindh, used Landsat MSS and TM satellite images to generate landcover maps of riverine forests for 1979, 1992, 1998, 2000, 2006, and 2009. Their study examined a considerable decline, 85%, of riverine forests from 1979–2009. Forest cover in 1979 was observed as 22.67% of the total study area, while in 2009, it was 5.97% (119.2 km^2). The total forest cover of both districts was calculated as 12 km^2 using the GFW data set (2019). The study by Iqbal and Khan [57] in the Muzaffarabad district of AJK (740 km^2 area) used Landsat TM satellite data to map subtropical, evergreen, dry, broad-leaved forests, subtropical Chir pine forests, and temperate broad-leaved forests for 1998 and 2009 using the pixel-based supervised image classification method. The classification results revealed that, from 1998 to 2009, over a period of about 11 years, forest cover and low vegetation decreased at the annual rate of 2.70% and 2.60%, respectively. This study reported a forest cover of 155.5 km^2 for 2009 compared to 724 km^2 calculated through the GFW data set (2019). Batool et al. [58] used Landsat ETM data to map forest cover in the Thak valley (Diamir District), KP. Using supervised image classification, the forest change assessment in the study area (213 km^2) was performed for 1989, 1999, and 2009, where forest decreased from 85.83 km^2 in 1989 to 34.4 km^2 in 2009. The total forest area in the entire district was calculated as 570 km^2 using the GFW data set for 2019. Among all the reviewed papers in this review, only one study, conducted by Baig et al. [59], used active remotely sensed data. Using a calibration technique, they mapped an irrigated forest plantation (47 km^2 area) in the Sahiwal district, Punjab, through SAR ALOS-2 PALSAR (the Phased Array type L-band Synthetic Aperture Radar). Along with this, they used WorldView-3 imagery to verify their results. They mapped various forest tree species, including Shisham (*Dalbergia sissoo*), Sufeda (*Eucalyptus camaldulensis*), Toot or Mulberry (*Morus alba*), and Simal (*Bombax ceiba*) in pure and mixed forms with naturally grown Mesquite (*Prosopis juliflora*). The total forest area in the entire district was calculated as 3 km^2 using the GFW data set for 2019. Younis and Ammar [60] mapped the forest area in Besham watershed (which lies within Buner and Mansehra districts), KP, using Landsat 5 TM satellite data from 2000–2010 with an area of 6812 km^2. This study reported a net loss of 17% (3.88 km^2) from 2000–2010 in the forest area. This study reported forest cover of 1892.6 km^2 for 2010 compared to 1849 km^2 forest cover in both of these districts (Buner and Mansehra) through the GFW data set for 2019. The following study, led by Rashid and Iqbal [61], used Landsat 4–5 TM, Landsat 7 ETM, and Landsat 8 OLI to map conifer and pine forests along the Karakoram Highway (N-35), through KP, to GB (4,200 km^2 area). The study used imageries of 1990, 2000, 2010, and 2016 and reported a 26% decrease in the forest cover during this period. The total forest cover of KP and GB combined was 11,042 km^{2,} as per the GFW data set for 2019. The following study, by Khan et al. [62], used Landsat 5, Landsat 7, and Landsat 8 images for 1996, 2003, and 2016 to map the urban forest in Peshawar district (1257

km^2 area), Pakistan. This study used the supervised image classification method to report vegetation (including forest) increase from 1996 to 2003 and then decrease from 2003 to 2016. An overall vegetation decrease of 21.90% was described between 2003 to 2016. The total forest area in the entire district was calculated as 9 km^2 using the GFW data set for 2019. The study by Urooj and Ahmad [63] incorporated Landsat 5 TM, Landsat 7 ETM+, and Landsat 8 OLI to map the dry, subtropical thistle and scrub forests in and around the surroundings of Mangla Dam (3053 km^2 area) in the Mirpur district of AJK. Using the supervised image classification method, they mapped the land cover of 1992, 2002, and 2013 and reported that deforestation occurred with a net change of 547.45 km^2 from 1992 to 2013. The total forest area in the entire district was calculated as 63 km^2 using the GFW data set for 2019. The study by Khan et al. [64] used Landsat TM, Landsat ETM+, and Landsat OLI satellite data sets to map temperate forests in Sudhnuti district (471 km^2 area), AJK. They extracted vegetation fractions (forest, non-forest area) using Linear Spectral Mixture Analysis (LSMA), a supervised image classification approach, for 1989, 1993, 1999, 2005, 2010, 2015, and 2018. As a result, they reported that the forest area declined between 1989–1993 and 1993–1999; it increased between 1999–2005, 2005–2010, 2010–2015, and 2015–2018. This study reported approximately 203 km^2 of forest cover for 2018 compared to 297 km^2 for 2019, as calculated through the GFW data set. The subsequent study by Mahmoudi et al. [65], used Moderate Resolution Imaging Spectroradiometer (MODIS) data to map regional mixed forests of Balochistan and the eastern Iran region (769,824 km^2 area). Using MODIS land cover type product (MCD12Q1) on a yearly basis, this study reported that the forest area increased between 2001–2013. The total forest area in the entire province of Balochistan was calculated as 18 km^2 using the GFW data set for 2019. The following research, by Ali et al. [66], used SPOT-5 satellite imagery to map Subalpine, dry temperate, moist temperate, oak, subtropical broad-leaved, subtropical pine, and dry tropical thorn forests of KP (11,336 km^2 area) using OBIA. The total forest area in the entire province of KP was calculated as 10,123 km^2 using the GFW data set for 2019. The following study by Saddique et al. [67] used Landsat TM, Landsat ETM+, and Landsat OLI to map the evergreen and deciduous forests in the river Jhelum basin (Mangal Dam watershed), AJK (33,397 km^2 area). Using a machine-learning algorithm (RF) in supervised image classification, they reported that the forest area showed a positive difference of 2806.87 km^2 between 2001–2009 and 2009–2018. This study reported a forest cover of 12,118 km^2 for the entire watershed for 2018. The total forest area in the entire AJK region was calculated as 4061 km^2 using the GFW data set for 2019. The following study, conducted by Hussain et al. [68], used Landsat TM and Landsat OLI satellite imagery in the urban forest (3650 km^2 area) of Multan district, Punjab. They mapped the study area for two cropping seasons of *Rabi* and *Kharif*. They reported that the forest area gained a negative change of –41 km^2 from 1988–2017 during the *Rabi* season and –48.6 km^2 for the same period during the *Kharif* season. This study reported a forest cover area of 53 km^2 compared to 59 km^2 extracted through the GFW data set for 2019. Another research work by Hussain et al. [69] for mapping urban forest in Lodhran district, Punjab, used Landsat 4–5 TM, Landsat 7 ETM+, and Landsat 8 OLI satellite images for 1977, 1987, 1997, 2007, and 2017. Using a maximum likelihood classifier in the supervised image classification, they reported that the vegetation (forest) area increased from 87.9% (of the total study area) in 1987 to 90.8% in 2017. The total forest area in the entire district was calculated as only 1 km^2 using the GFW data set for 2019. That the subsequent study used the supervised image classification method was published by Khan et al. [70], who used Landsat 7 and Landsat 8 satellite images to map the Himalayan moist temperate and sub-alpine temperate forests' AGB of Battagram (1507 km^2 area), KP, for 2000

and 2015. Their study indicated a –16.88% loss in the forests of the study area with an annual deforestation rate of 2.51%. This study reported a forest cover area of 450.8 km^2 in 2015 compared to 462 km^2 extracted through the GFW data set for 2019. Ali and Nayyar [71] used Landsat 8 OLI satellite imagery to assess mangrove forests located in the Karachi region's coastal belt (2030 km^2 area) for 2017 using the unsupervised image classification method. They used pixel-based spectral indexes, including NDVI, Normalized Difference Moisture Index (NDMI), Ratio Vegetation Index (RVI), EVI, Combined Mangrove Recognition Index (CMRI), and Soil Adjusted Vegetation Index (SAVI) to delineate mangrove and non-mangrove land covers. This study reported a mangrove forest cover area of 228.6 km^2 in 2017 compared to 34 km^2 extracted through the GMW data set for 2019. The difference in the areas is because mangroves do not have an exact boundary. The paper by Haq et al. [72] used Landsat 3 MSS, Landsat 7 ETM+, and Sentinel 2A satellite images to map dense Deodar and Pine forest, *Juniperus Communis* (juniper), *Pinus Wallichiana* (blue pine), *Abies Webbiana* (silver fir), *Aesculus Indica* (bankhor), Pinus species, *Cedrus Deodara* (deodar), *Abies Pindrow* (palunder), *Pinus Gerardiana* (chalghoza), and *Juglans Regia* (walnut) in the Palas valley in Kohistan district (7492 km^2 area), KP. Using the maximum likelihood classification technique in the supervised image classification method, this study reported that the forest cover declined between 1980–2017, with a change of −12.23%. This study reported a forest cover area of 198.6 km^2 in 2017. The forest cover of the entire Kohistan district, extracted through the GFW data set, was 1304 km^2. The last reviewed study, performed by Zafar et al. [73], used MODIS data to map the coniferous, broad-leaved, and mixed forests in GB (68,601 km^2 area) using a pixel-based supervised image classification method. This study reported that a substantial increase in the forest was observed between 2008–2017 yearly. This study reported an overall forest cover in the study area as 0.081% of the total area, while the GFW data set showed 919 km^2 of forest cover in the entire GB for 2019.

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