Supplementary Material: Mapping Deforestation and Forest Degradation Patterns in Western Himalaya, Pakistan. *Remote Sens.* 2016, *8*, 385

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Table S1. List of satellite data used.

Scene-D	1990s (Historic)	2000s (Medial)	2010 (Recent)	Sensor (H/M/R)
147-036	9 October 1989	16 September 1998	30 September 2009	TM/ETM/TM
148-035	29 June 1990	18 May 2001	4 August 2010	TM/ETM/TM
148-036	29 June 1990	16 July 1999	4 August 2009	TM/ETM/TM
149-034	15 October 1992	30 September 2001	27 August 2009	TM/ETM/TM
149-035	15 October 1992	30 September 2001	27 August 2009	TM/ETM/TM
149-036	15 October 1992	30 September 2001	27 August 2009	TM/ETM/TM
149-037	31 October 1992	30 September 2001	28 September 2009	TM/ETM/TM
150-034	26 July 1989	15 August 1999	19 September 2009	TM/ETM/TM
150-035	26 July 1989	16 September 1999	19 September 2009	TM/ETM/TM
150-036	20 September 1992	7 October 2001	19 September 2009	TM/ETM$^+$/TM
150-037	20 September 1992	11 Apr 2000	19 September 2009	TM/ETM/TM
151-034	27 September 1992	28 September 2001	10 September 2009	TM/ETM/TM
151-035	27 September 1992	27 October 2000	10 September 2009	TM/ETM$^+$/TM
151-036	27 September 1992	28 September 2001	10 September 2009	TM/ETM$^+$/TM
151-037	27 September 1992	11 October 2000	12 October 2009	TM/ETM$^+$/TM
151-038	27 September 1992	11 October 2000	12 October 2009	TM/ETM$^+$/TM
152-036	9 June 1990	5 October 2001	19 October 2009	TM/ETM/TM
152-037	9 June 1990	18 October 2000	20 November 2009	TM/ETM$^+$/TM
152-038	9 June 1990	17 November 1999	19 October 2010	TM/ETM$^+$/TM

S1: Summary of decision rule for improving land cover interpretation

To rectify the problems observed by the national experts we used conventional image indices and set the conditions and threshold values for each index. To begin with the classes that are more problematic and remove such features that may mix with other classes like shadow water and snow and pure shadow, therefore classifying water and snow first is better option to classify water we used Water Index and apply the condition

Water Index (WI) ≥ 150 (this may contain shadowed snow)

To remove shadowed snow one can use Elevation and slope together

Elevation ≥ 3000 and Slope ≥ 30 is snow

Another problem is with extracting high altitudes lakes which may probably mix with shadow snow

And to remove this thermal band is very useful because temperature of water and snow shows significant difference so the problematic high altitude wetlands can be extract by using thermal band and shape in Ecognition software and applying the mean to neighbor or difference to neighbor values of thermal band.

Thermal Band ≤ −10 degree Celsius is snow

Now apply the condition using Normalised Difference Snow Index (NDSI

NDSI ≥ 150 (may include shadow wetlands)

Once the snow and water is classified the remaining problematic class is shadow

Simply use the SI (Shadowed index)

SI ≥ 230 (pure dark areas) use another image or land cover to add classes in shadowed areas.

Now classify the forest using tassel cap indices both wet and greenness indices

Wetness Index > −4 and < 15 is dense forest which may include shadow and small portion of barren land shadow you are already classify and barren land can be removed by using greenness index

Greenness Index > −5 (will remove barren land)

Now classify the sparse forest using again tassel cap indices

Wetness Index > −20 and ≤ −4

Now remove the barren land using Greenness index hence this is a sparse forest decrease the threshold further to −10

Greenness Index < −10 is barren land

Sparse forest may include the agriculture fields which can be removed by using slope and shadow index (SI)

Slope < 20 and SI < 215 will extract the agriculture fields from sparse forest if any.

Agriculture fields can be classified using SAVI or TSAVI and slope

SAVI ≥ 180 and TSAVI > 180 and slope < 20 will give you the cropped agriculture fields from the remaining unclassified data

Use the NDVI threshold to separate the grasses shrubs from fallow fields

NDVI ≥ 150 is grasses

Remaining pixels under slope < 20 are fallow fields rest is barren land

Finally you have to sub classify forest categories into Conifer, Mix and Broadleaf. Where use of Modified Non-Linear vegetation Index (MNLI) is very helpful which categories the different tones of the vegetation which behaves different in infrared region

MNLI ≤ 60 is Conifer forest

MNLI > 60 and ≤ 80 is Mix Forest

MNLI > 80 is broadleaf forest

Elevation to separate out broadleaf forest which lower in elevation approximately

Shadow index < 1000 is also very helpful to categories the forest into sub classes

Note: Threshold values may differ slightly from image to image depending upon the image quality or rectification method.

Table S2. Land cover change matrix for 1990–2000 for Khyber Pakhtunkhwa.

	DCF	SCF	DMF	SMF	DBF	SBF	GS	AG	P	AC	AF	BSR	SGI	W	Total 1990
DCF	543,111	10,275					21,288			16	2	340		4	567,035
SCF		320,291					9294	2		33	13	900	1	3	330,536
DMF			316,535	1765			8354	1		42	9	1337	1	101	328,145
SMF			1684	156,945			4153			11	2	353			163,148
DBF					83,581	714	2505			150	288	1376	1	1369	89,985
SBF						152,513	1682			69	3	798		282	155,347
GS			70		465	1800	1,674,586	24	41	51,579	11,326	212,414	7095	6991	1,974,390
AG								46,730	2	13	6	1055	2710	1	50,518
P							11	1	38	3	2	3			58
AC			3		14	39	17,248	10	66	907,130	397,078	145,412	134	3378	1,470,512
AF					1	5	988		7	44,812	165,915	42,815	6	382	254,930
BSR			67		181	591	226,598	15,853	304	68,698	183,098	3,344,805	159,282	22,132	4,021,609
SGI							13,544	15,349		14	10	154,497	504,225	165	687,802
W					91	130	3048	13	1	1627	2508	15,738	663	49,768	73,587
Total 2000	543,111	330,566	318,359	158,710	84,333	155,792	1,983,299	77,983	459	1,074,197	760,260	3,921,843	674,118	84,576	10,167,602

Table S3. Land cover change matrix for 2000–2010 Khyber Pakhtunkhwa.

KPK	DCF	SCF	DMF	SMF	DBF	SBF	GS	AG	P	AC	AF	BSR	SGI	W	Total 2000
DCF	**499,617**	16,266					23,651			25		3552			543,111
SCF		**317,868**					7997			17		4682		1	330,565
DMF			**307,654**	5461			3510			30		1698		5	318,358
SMF			185	**153,793**			2620			10		2100			158,708
DBF			0		**81,896**	627	1032			30		743		4	84,332
SBF			0		50	**150,115**	3550			103	10	1961		4	155,793
GS			245		139	102	**1,955,798**		1	4802	11	21,939	27	235	1,983,299
AG							2	**76,826**		3		526	623	3	77,983
P							6		**399**	16	6	31			458
AC			9		14	7	53,274	7	38	**932,341**	60,778	27,290	1	438	1,074,197
AF			2		1	9	25,240	3	4	415,570	**217,637**	101,414		380	760,260
BSR			21		27	156	29,099	321	6	81,919	14,294	**3,702,185**	81,632	12,182	3,921,842
SGI			1			1	10,638	7784		62	11	336,073	**318,792**	758	674,120
W			1340		135	4308	6231	2		3723	3014	22,165	49	**43,609**	84,576
Total 2010	499,617	334,134	309,457	159,254	82,262	155,325	2,122,648	84,943	448	1,438,651	295,761	4,226,359	401,124	57,619	10,167,602

Table S4. Land cover change matrix for 1990–2000 for Gilgit-Baltistan.

GB	DCF	SCF	DMF	SMF	DBF	GS	AG	P	AC	AF	BSR	SGI	W	Total 1990
DCF	**44,248**	688				257				1	32			45,226
SCF		**81,570**				745			6	12	34			82,367
DMF			**27,414**	20		42	5		1	2	6			27,489
SMF			447	**10,275**		64	23		3	3	13	1		10,828
DBF					2									2
GS						**823,296**	3	2261	809	23	10,326	694	26	837,438
AG						0	**334,719**	7240	92	32	10,632	1238	42	353,995
P						47	307	**5698**	29	7	28	3	7	6126
AC						1104	31	47	43,583	31,696	3307	41	236	80,045
AF						26	30	4	3822	33,897	947	10	117	38,852
BSR						107,637	79,159	3490	2467	3,736	2,098,023	124,369	8463	2,427,343
SGI						52,917	162,801	7393	37	15	987,653	1,750,315	1742	2,962,873
W						218	302	132	131	363	4547	709	**13,231**	19,632
Total 2000	44,248	82,258	27,861	10,296	2	986,354	577,378	26,263	50,979	69,787	3,115,546	1,877,379	23,864	6,892,215

Table S5. Land cover change matrix for 2000–2010 for Gilgit-Baltistan.

GB	DCF	SCF	DMF	SMF	DBF	GS	AG	P	AC	AF	BSR	SGI	W	Total 2000
DCF	41,800	1315				966					167			44,248
SCF		78,139				1,986			12		2103		18	82,258
DMF			26,188	678		844					150			27,860
SMF				10,110		115			1		69		1	10,295
DBF					2									2
GS						985,419	1	57	32		554	155	136	986,354
AG						3	574,465	181	39	4	227	2398	62	577,378
P						530	1192	24,432	36		49	8	16	26,263
AC						2708	40	7	41,054	1971	5059	13	127	50,979
AF						5596	54	13	37,807	11,682	14,254	18	364	69,787
BSR			2			21,793	9948	82	2028	369	2,774,749	298,714	7862	3,115,546
SGI						1991	17,995	12	18	3	224,566	1,632,271	524	1,877,379
W						50	49	2	166	41	2647	532	20,376	23,864
Total 2010	41,800	79,454	26,189	10,788	2	1,022,002	603,743	24,785	81,193	14,069	3,024,594	1,934,108	29,485	6,892,214

Table S6. Land cover change matrix for 1990–2000 for AJK.

AJK	DCF	SCF	DMF	SMF	DBF	SBF	GS	AG	AC	AF	BSR	SGI	W	Total 1990
DCF	169,521	1335					265		16	3	9			171,149
SCF		111,251					912		47	7	83		1	112,300
DMF			89,488	391			754		42	14	43			90,731
SMF			309	27,702			136		3	1	14			28,165
DBF					30,670	544	360		35	150	141		2	31,902
SBF					1	25,235	31		3	25	26			25,320
GS			10		14	25	232,932		17,207	3464	10,834	18	137	264,641
AG								3534	1	2	193	8		3738
AC			1		11	13	17,538		166,966	50,816	8524	4	141	244,013
AF					1	1	37	3	4568	3567	709	2	13	8902
BSR			4		146	177	15,841	4709	8929	15,682	47,382	1185	686	94,742
SGI							9934	4329	48	280	37,894	33,377	299	86,161
W					82	66	4885	1	1819	1056	11,303	27	6488	25,728
Total 2000	169,521	112,585	89,812	28,093	30,926	26,061	283,624	12,577	199,687	75,066	117,154	34,621	7766	1,187,494

Table S7. Land cover change matrix for 2000–2010 for AJK.

AJK	DCF	SCF	DMF	SMF	DBF	SBF	GS	AG	AC	AF	BSR	SGI	W	Total 2000
DCF	167,689	1509					280		10		23		11	169,521
SCF		111,463					612		113		387		11	112,585
DMF			86,905	2287			379		82		158			89,811
SMF			2	27,563			245		104	2	174		3	28,093
DBF					30,167	47	159		90	3	373		87	30,926
SBF					1	25,520	111		39	2	330		57	26,061
GS			190		135	42	247,646		14,003	99	17,090	72	4348	283,624
AG								10,443	21		2087	26		12,577
AC			13		20	51	3057		181,066	10,637	3406		1438	199,687
AF			0		10	11	635	5	41,972	29,350	2414	2	668	75,066
BSR			73		141	49	11,583	1493	5487	1021	80,034	7450	9824	117,154
SGI					1		285	182	28	0	8443	25,667	14	34,621
W					1		99	1	145	13	1164	121	6,222	7765
Total 2010	167,689	112,971	87,182	29,850	30,478	25,720	265,091	12,124	243,158	41,127	116,083	33,338	22,681	1,187,492

S2: Comparison with other studies in the area

Following are the results on the comparison with previous studies [1,2].

Table S8. Comparison of current assessment with global assessment [1].

	Current Study		Hansen *et al.* 2013	
Province	Forest cover 2000	Deforestation (2000–2010)	Forest cover 2000	Deforestation (2000–2010)
AJK	456,997	3107	462,293	666
Gilgit—Baltistan	164,664	6431	135,895	157
Kyber Pakhtunkhwa	1,590,867	50,818	1,166,674	8642
Total	2,212,528	60,356	1,764,862	9465

Table S9. Comparison of current assessment with previous national assessment [2]—Khyber Pakhtunkhwa (KP) including FATA.

	Land Cover FSMP (1990)			Land Cover Current Study (1990)		
Simplified Class Name	**Class Name**	**Area (ha)**	**Area %**	**Class Name**	**Area (ha)**	**Area %**
	Dense Coniferous Forest	75,000	0.74	Dense Coniferous Forest	567,035	5.58
	Sparse Coniferous Forest	865,000	8.51	Sparse Coniferous Forest	330,536	3.25
Coniferous Forest	Sub Total	940,000	9.24	Sub Total	897,571	8.83
				Close Mix Forest	328,145	3.23
				Sparse Mix Forest	163,148	1.60
	Scrub	539,000	5.3	Dense Broadleaved Forest	163,148	1.60
	Riverain dense	2000	0.02	Sparse Broadleaved Forest	89,985	0.89
	Riverain Sparse	11,000	0.11			
	Farmland trees	70,000	0.69			
	Linear planting	2000	0.02			
	Misc. planting	120,000	1.18			
Broadleaved Forest	Sub Total	744,000	7.32	Sub Total	253,132	2.49
Forest Total		**1,684,000**	**16.56**		**1,641,997**	**16.15**
	Alpine	269,000	2.65	Peatlands	59	0.00
Alpine Pasture				Alpine Grasses	50,518	0.50
	Sub Total	269,000	2.65	Sub Total	50,576	0.50
	Non-degraded	519,000	5.1	Grasses/Shrubs	1,974,390	19.42
Grasses/Shrubs	Degraded	4,106,000	40.37			
	Sub Total	4,625,000	45.48	Sub Total	1,974,390	19.42
Agriculture	Agriculture	1,546,000	15.2	Agriculture	1,725,442	16.97
Vegetation (other than Forest) Total		**6,440,000**	**63.32**		**3,750,409**	**36.89**
Baren Land/Urban Areas	URBAN/Unclassify			Bare Soil/Rocks	4,021,609	39.55
	Above 3650 m	1,792,000	17.62			
	Below 3650 m	52,000	0.51			
	Rock, gravel	138,000	1.36			
	Sub Total	1,982,000	19.49	Sub Total	4,021,609	39.55
Snow/Galciers	Snow/glacier			Snow/Glaciers/Ice	687,803	6.76
Water Bodies	Riverbed	48,000	0.47	Waterbodies	73,587	0.72
	Lake	1000	0.01			
	Dam, reservoir	15,000	0.15			
	Sub Total	64,000	0.63	Sub Total	73,587	0.72
Non Vegetation Total		**2,046,000**	**20.12**		**4,782,999**	**47.04**
Grand Total		10,170,000	100		10,175,404	100

Table S10. Comparison of current assessment with previous national assessment [2]—Gilgit-Baltistan (GB).

	Land Cover FSMP (1990)			Land Cover Current Study (1990)		
Simplified Class Name	**Class name**	**Area (ha)**	**Area (%)**	**Class name**	**Area (ha)**	**Area (%)**
	Dense Coniferous Forest	46,000	0.65	Dense Coniferous Forest	45,226	0.66
	Sparse Coniferous Forest	614,000	8.72	Sparse Coniferous Forest	82,367	1.20
Coniferous Forest	Sub Total	660,000	9.38	Sub Total	127,593	1.85
				Close Mix Forest	27,489	0.40
				Sparse Mix Forest	10,828	0.16
Broadleaved Forest	Farmland trees	6000	0.09	Dense Broadleaved Forest	2	0.00
Forest Total		**666,000**	**9.46**		**165,912**	**2.41**
Alpine Pasture	Alpine	705,000	10.01	Peatlands	6126	0.09
				Alpine Grasses	353,995	5.14
	Sub Total	705,000	10.01	Sub Total	360,121	5.23
Grasses/Shrubs	Degraded	896,000	12.73	Grasses/Shrubs	837,438	12.09
Agriculture		48,000	0.68	Agriculture (cropp+fallow)	118,896	1.73
Vegetation (other than Forest) Total		**1,649,000**	**23.42**		**1,316,455**	**19.04**
Baren Land/Urban Areas	URBAN/Unclassify			Bare Soil/Rocks	2,427,343	35.22
	Above 3650 m	3,161,000	44.9			
	Below 3650 m	1,536,000	21.82			
	Sub Total	4,697,000	66.72	Sub Total	2,427,343	35.22
Snow/Glaciers	Snow/glacier	27,000	0.38	Snow/Glaciers/Ice	2,962,873	42.99
Water Bodies	Lake	1000	0.01	Water bodies	19,632	0.28
Non Vegetation Total		**4,725,000**	**67.12**		**5,409,848**	**78.49**
Grand Total		**7,040,000**	**100**		**6,892,215**	**100**

Table S11. Comparison of current assessment with previous national assessment [2]—Azad Jammu and Kashmir (AJK).

	Land Cover FSMP (1990)			Land Cover Current Study (1990)		
Simplified Class Name	**Class Name**	**Area (ha)**	**Area %**	**Class Name**	**Area (ha)**	**Area %**
	Dense Coniferous Forest	17,000	1.28	Dense Coniferous Forest	171,149	14.41
	Sparse Coniferous Forest	224,000	16.84	Sparse Coniferous Forest	112,300	9.46
Coniferous Forest	Sub Total	241,000	18.12	Sub Total	283,449	23.87
				Close Mix Forest	90,731	7.64
				Sparse Mix Forest	28,165	2.37
	Scrub	16,000	1.2	Dense Broadleaved Forest	31,902	2.69
	Riverain dense	1000	0.08	Sparse Broadleaved Forest	25,320	2.13
	Farmland trees	7000	0.53			
	Misc. planting	10,000	0.75			
Broadleaved Forest	Sub Total	34,000	2.56	Sub Total	57,222	4.82
Forest Total		**275,000**	**20.68**		**459,567**	**38.70**
Alpine Pasture	Alpine	79,000	5.94	Alpine Grasses	3738	0.31
Grasses/Shrubs	Degraded	731,000	54.96	Grasses/Shrubs	264,641	22.29
Agriculture	Agriculture	42,000	3.16	Agriculture	252,915	21.30
Vegetation (other than Forest) Total		**852,000**	**64.06**		**521,295**	**43.90**

Baren Land/Urban Areas	URBAN/Unclassify					
	Above 3650 m	184,000	13.83	Bare Soil/Rocks	94,742	7.98
Snow/Galciers				Snow/Glaciers/Ice	86,161	7.26
Water Bodies	Dam, reservoir	19,000	1.43	Waterbodies	25,728	2.17
Non Vegetation Total		**203,000**	**15.26**		**206,632**	**17.40**
Grand Total		1,330,000	100		1,187,494	100

References

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2. Government of Pakistan. *Forestry Sector Master Plan*; Ministry of Food and Agriculture: Islamabad, Pakistan, 1992.