

Article

Land Use/Cover Classification of Large Conservation Areas Using **Ground-linked** High-resolution Unmanned Aerial Vehicle

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Appendix A. Supplementary Material

Table A1. An error matrix for ground-linked UAV-guided Sentinel-2 LULC Classification (RFC)

LULC Class	Grassland	Woodland	Shrubland	Bareland	Water	Riverine	Forest	Cultivation	Settlement	Mosaic	Total	User Accuracy
Grassland	358	4	6	2	3	2	0	1	2	1	379	0.94
Woodland	2	150	2	1	0	0	2	1	0	0	158	0.95
Shrubland	2	1	195	1	2	0	0	1	1	1	204	0.96
Bareland	1	0	1	49	1	0	0	1	2	0	55	0.89
Water	0	0	0	0	39	0	0	0	0	0	39	1.00
Riverine	0	1	0	0	0	32	2	0	0	1	36	0.89
Forest	0	1	1	2	0	1	28	0	0	0	33	0.85
Cultivation	2	0	1	0	0	0	0	27	0	0	30	0.90
Settlement	0	1	0	2	0	0	0	0	30	0	33	0.91
Mosaic	0	2	2	0	0	1	1	0	0	27	33	0.82
Total	365	160	208	57	45	36	33	31	35	30	1000	
Producer Accuracy	0.98	0.94	0.94	0.86	0.87	0.89	0.85	0.87	0.86	0.90		
Overall	Accuracy (%) =94		Kappa coefficient (k) = 0.92									

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Table A2. Error matrix for ground-linked UAV-guided Sentinel-2 LULC Classification (SVM)

LULC Class	Grassland	Woodland	Shrubland	Bareland	Water	Riverine	Forest	Cultivation	Settlement	Mosaic	Total	User Accuracy
Grassland	317	5	6	3	1	4	0	0	0	1	337	0.94
Woodland	1	84	2	9	1	0	2	4	0	2	105	0.80
Shrubland	2	2	180	3	0	3	0	0	8	0	198	0.91
Bareland	4	0	1	120	1	1	0	0	1	2	130	0.92
Water	0	0	0	0	55	0	0	0	0	0	55	1.00
Riverine	1	1	6	2	0	35	0	0	0	0	45	0.78
Forest	0	0	2	1	0	0	28	0	0	0	31	0.90
Cultivation	0	0	0	1	0	0	0	26	0	0	27	0.96
Settlement	0	0	0	0	0	0	0	0	36	0	36	1.00
Mosaic	0	5	0	1	1	0	2	0	0	27	36	0.75
Total	325	97	197	140	59	43	32	30	45	32	1000	
Producer Accuracy	0.98	0.87	0.91	0.86	0.93	0.81	0.88	0.87	0.80	0.84		
Overall	Accuracy (%) =91			Kappa coefficient (k) = 0.89								

Table A3. Error matrix for ground-linked UAV-guided Sentinel-2 LULC classification (MLC)

LULC class	Grassland	Woodland	Shrubland	Bareland	Water	Riverine	Forest	Cultivation	Settlement	Mosaic	Total	User Accuracy
Grassland	341	0	1	1	2	2	0	0	0	2	349	0.98
Woodland	0	60	3	4	1	2	0	1	0	1	72	0.83
Shrubland	2	2	116	5	0	2	0	0	4	1	132	0.88
Bareland	1	0	2	83	1	3	0	0	0	0	90	0.92
Water	1	0	0	0	51	0	0	0	0	3	55	0.93
Riverine	2	2	3	0	0	60	5	4	0	0	76	0.79
Forest	0	0	1	0	2	0	44	2	0	0	49	0.90
Cultivation	4	1	1	2	2	2	0	57	1	0	70	0.81
Settlement	0	0	0	0	2	1	0	0	48	3	54	0.89
Mosaic	0	3	2	0	1	1	2	2	0	42	53	0.79
Total	351	68	129	95	62	73	51	66	53	52	1000	
Producer Accuracy	0.97	0.88	0.90	0.87	0.82	0.82	0.86	0.86	0.91	0.81		
Overall accuracy (%) = 90 Kappa coefficient (k) = 0.88												

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Table A4. An error matrix for unguided Sentinel-2 LULC classification using (RFC).

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LULC class	Grassland	Woodland	Shrubland	Bareland	Water	Riverine	Forest	Cultivation	Settlement	Mosaic	Total	User Accuracy
Grassland	484	4	10	4	3	0	0	5	6	3	521	0.93
Woodland	2	81	8	1	0	0	1	1	0	2	96	0.84
Shrubland	2	1	70	1	2	0	0	1	1	3	81	0.86
Bareland	0	0	1	61	1	0	0	1	2	0	66	0.92
Water	0	0	0	1	42	0	0	0	0	0	43	0.98
Riverine	0	8	0	0	0	33	2	0	0	1	41	0.75
Forest	0	1	0	0	0	1	46	0	0	0	48	0.96
Cultivation	2	0	1	0	0	0	0	32	0	0	35	0.91
Settlement	0	1	0	5	2	0	0	0	28	0	36	0.78
Mosaic	0	2	2	0	0	0	1	0	0	27	33	0.82
Total	490	98	92	73	50	34	50	40	37	36	1000	
Producer Accuracy	0.99	0.83	0.76	0.84	0.84	0.88	0.92	0.80	0.76	0.75		
Overall accuracy (%) = 90				Kappa coefficient (k) = 0.87								

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Table A5. Error matrix for unguided Sentinel-2 LULC classification (SVM)

LULC Class	Grassland	Woodland	Shrubland	Bareland	Water	Riverine	Forest	Cultivation	Settlement	Mosaic	Total	User Accuracy
Grassland	325	0	1	1	3	3	0	0	1	1	335	0.97
Woodland	0	79	5	4	1	5	4	1	0	2	101	0.78
Shrubland	2	2	84	5	0	2	2	1	4	1	103	0.82
Bareland	1	0	2	83	1	2	0	0	2	1	92	0.90
Water	1	0	0	3	48	0	0	0	1	3	56	0.86
Riverine	2	4	3	0	0	65	3	0	0	0	77	0.84
Forest	0	2	1	0	0	0	52	0	0	3	58	0.90
Cultivation	9	0	1	5	0	0	0	61	1	0	77	0.79
Settlement	0	0	1	6	0	0	0	1	32	2	42	0.76
Mosaic	0	5	4	0	0	0	2	4	0	44	59	0.75
Total	340	92	102	107	53	77	63	68	41	57	1000	
Producer Accuracy	0.96	0.86	0.82	0.78	0.91	0.84	0.83	0.90	0.78	0.77		
Overall	Accuracy (%) =87		Kappa coefficient (k) =0.85									

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Table A6. Error matrix for unguided Sentinel-2 LULC classification (MLC)

LULC Class	Grassland	Woodland	Shrubland	Bareland	Water	Riverine	Forest	Cultivation	Settlement	Mosaic	Total	User Accuracy
Grassland	206	1	9	17	2	0	0	3	2	3	243	0.85
Woodland	4	82	6	0	0	4	3	0	1	6	106	0.77
Shrubland	2	12	115	7	1	4	4	2	4	2	153	0.75
Bareland	8	2	2	107	1	0	0	9	5	0	134	0.80
Water	1	0	0	4	53	0	0	0	3	0	61	0.87
Riverine	0	6	2	2	0	45	1	0	0	4	60	0.75
Forest	0	2	0	1	5	3	45	0	0	2	58	0.78
Cultivation	2	3	2	1	0	0	0	48	1	0	57	0.84
Settlement	1	0	2	2	8	0	0	0	50	0	63	0.79
Mosaic	0	2	6	0	0	5	0	1	1	50	65	0.77
Total	224	110	144	141	70	61	53	63	67	67	1000	
Producer Accuracy	0.92	0.75	0.80	0.76	0.76	0.74	0.85	0.76	0.75	0.75		
Overall	Accuracy (%) =80		Kappa coefficient (k) = 0.77									

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Table A7. Comparative proportional coverage (%) of LULC classes derived from ground-linked UAV-guided and unguided Sentinel-2 LULC classification approaches

Accuracy	Classification Approach	RFC	SVM	MLC
OA (%)	UAV-guided Sentinel-2	94	91	90
	Un-guided Sentinel-2	90	87	80
Kappa (k)	UAV-Guided Sentinel-2	0.92	0.89	0.88
	Un-guided Sentinel-2	0.87	0.85	0.77
LULC Class	Classification Approach	(%)	(%)	(%)
Grassland	UAV-guided Sentinel-2	55.20	30.34	34.16
	Unguided Sentinel-2	43.33	32.34	25.65
Shrubland	UAV-guided Sentinel-2	4.69	19.17	12.18
	Unguided Sentinel-2	27.37	20.13	13.87
Woodland	UAV-guided Sentinel-2	7.59	10.94	11.19
	Unguided Sentinel-2	1.68	4.03	4.43
Bareland	UAV-guided Sentinel-2	3.96	3.26	3.03
	Unguided Sentinel-2	6.02	10.79	7.11
Water	UAV-guided Sentinel-2	24.28	20.00	20.34
	Unguided Sentinel-2	15.34	18.14	17.49
Riverine	UAVguided Sentinel-2	0.18	3.68	2.24
	Unguided Sentinel-2	0.05	0.55	1.69
Forest	UAV-guided Sentinel-2	1.44	1.15	0.72
	Unguided Sentinel-2	0.98	1.16	1.06
Cultivation	UAV-guided Sentinel-2	1.60	3.82	5.91
	Unguided Sentinel-2	3.30	8.18	11.41
Settlement	UAVguided Sentinel-2	0.01	0.02	0.65
	Unguided Sentinel-2	0.03	2.23	10.52
Mosaic	UAV-guided Sentinel-2	1.05	3.23	5.50
	Unguided Sentinel-2	1.90	6.85	10.85

Table A8. Agreement test between the ground-linked UAV-guided Sentinel-2 and unguided Sentinel-2 classification approaches (RFC)

LULC Class	Pixel Counts				Matched Pixels	Proportion of matched unguided Sentinel-2 pixels (%)	Agreement Ratio for total pixels-AR ₂ (%)	Unmatched Pixels	
	A _o	%	B _o	%	A _o B _o	$AR_1 = \left(\frac{A_o B_o}{B_o} \right) \times 100$	$AR_2 = \left(\frac{A_o B_o}{\sum A_o} \right) \times 100$	A ₁	B ₁
Grassland	60,221	56.25	33,403	31.20	25,216	75.5	23.55	35,005	8,187
Shrubland	5,820	5.44	18,980	17.73	2,121	11.2	1.98	3,699	16,859
Woodland	16,782	15.67	5,786	5.40	1,516	26.2	1.42	15,266	4,270
Bareland	6,611	6.17	9,174	8.57	2,927	31.9	2.73	3,684	6,247
Water	799	0.75	29	0.03	16	55.2	0.01	783	13
Riverine	2,920	2.73	684	0.64	226	33.0	0.21	2,694	458
Forest	4,783	4.47	3,368	3.15	2,823	83.8	2.64	1,960	545
Cultivation	3,454	3.23	25,550	23.86	2,269	8.9	2.12	1,185	23,281
Settlement	193	0.18	520	0.49	2	0.4	0.00	191	518
Mosaic	5,483	5.12	9,574	8.94	3,480	36.3	3.25	2,003	6,094
Total	107,066		107,068		40,596		37.92	66,470	66,472