

Unveiling China's Forest Soil properties: High-Resolution, Multi-Depth Mapping of Soil Bulk Density and pH Using Machine Learning Methods

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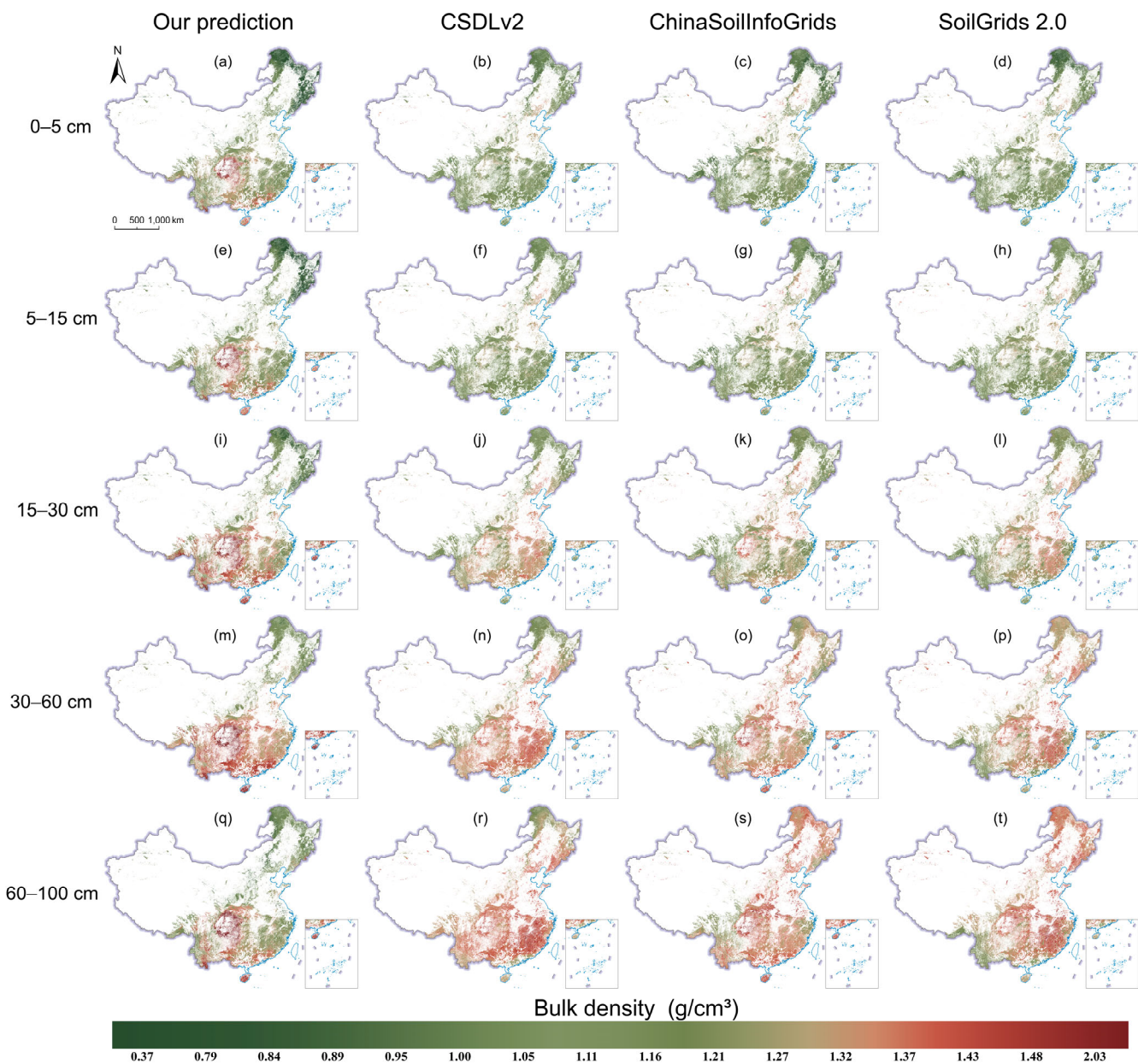
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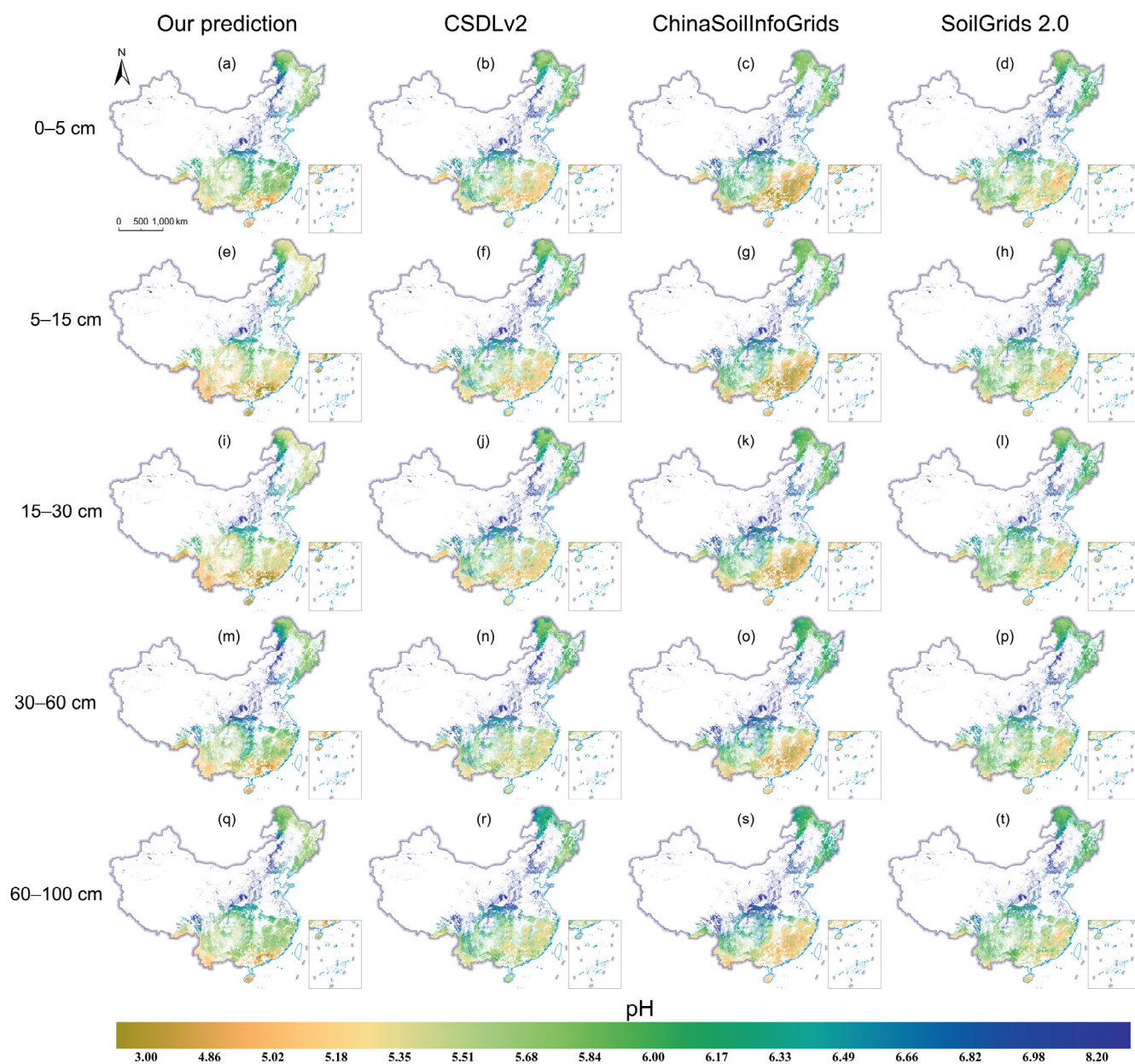
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S1 Supplementary Figures



20 **Figure S1. Bulk density prediction (g/cm³) maps:** rows show five soil depths (0–5, 5–15, 15–30, 30–60, and 60–100 cm) and columns show four datasets (Our prediction, CSDLv2, ChinaSoilInfoGrids, and SoilGrids2.0). Publisher’s remark: please note that the above figure contains disputed territories.



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Figure S2. pH prediction maps: rows show five soil depths (0–5, 5–15, 15–30, 30–60, and 60–100 cm) and columns show four datasets (Our prediction, CSDLv2, ChinaSoilInfoGrids, and SoilGrids2.0). Publisher's remark: please note that the above figure contains disputed territories.

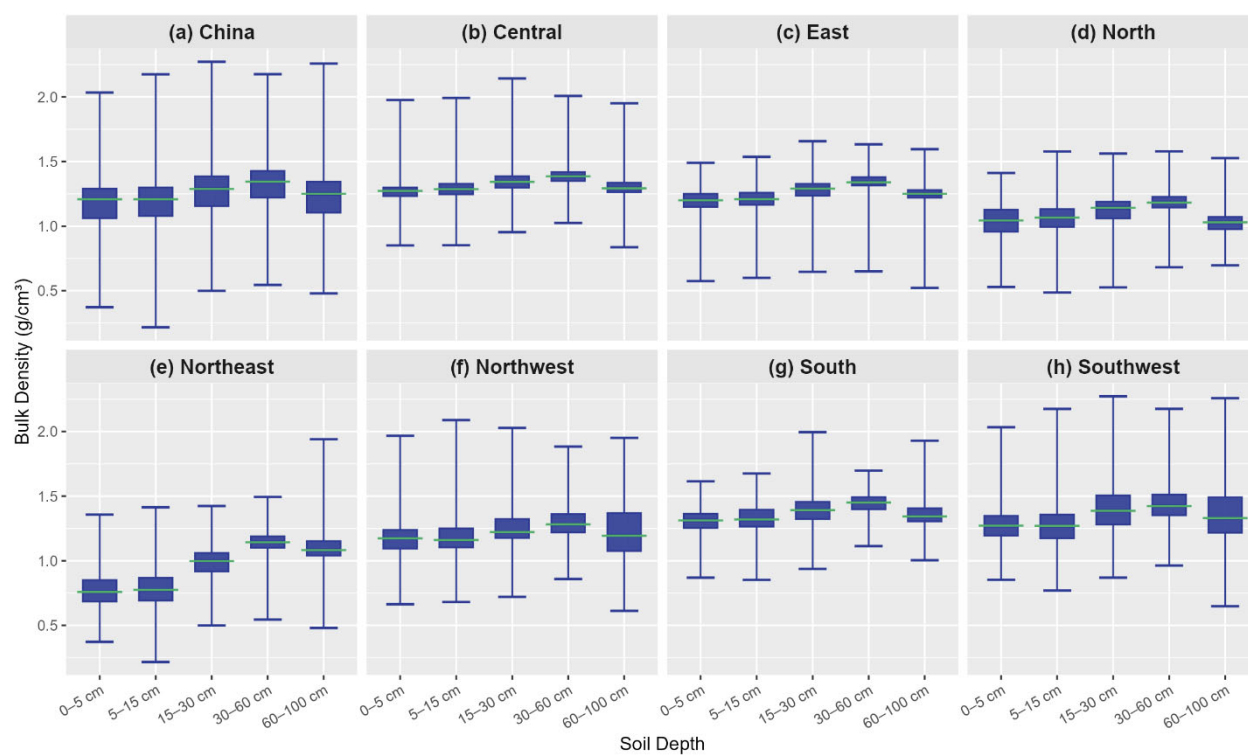


Figure S3. Statistical distribution of soil BD across five depths in (a) China and seven geographical regions: (b) Central, (c) East, (d) North, (e) Northeast, (f) Northwest, (g) South, (h) Southwest.

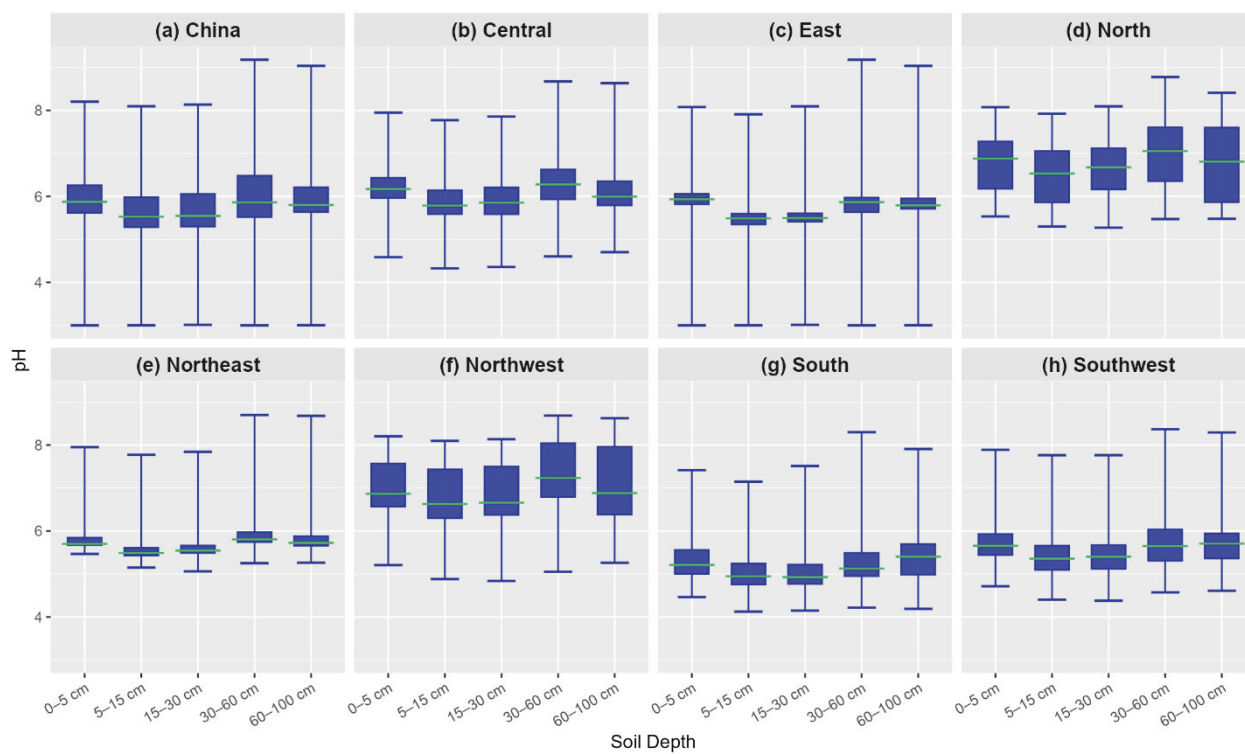


Figure S4. Statistical distribution of soil pH across five depths in (a) China and seven geographical regions: (b) Central, (c) East, (d) North, (e) Northeast, (f) Northwest, (g) South, (h) Southwest.

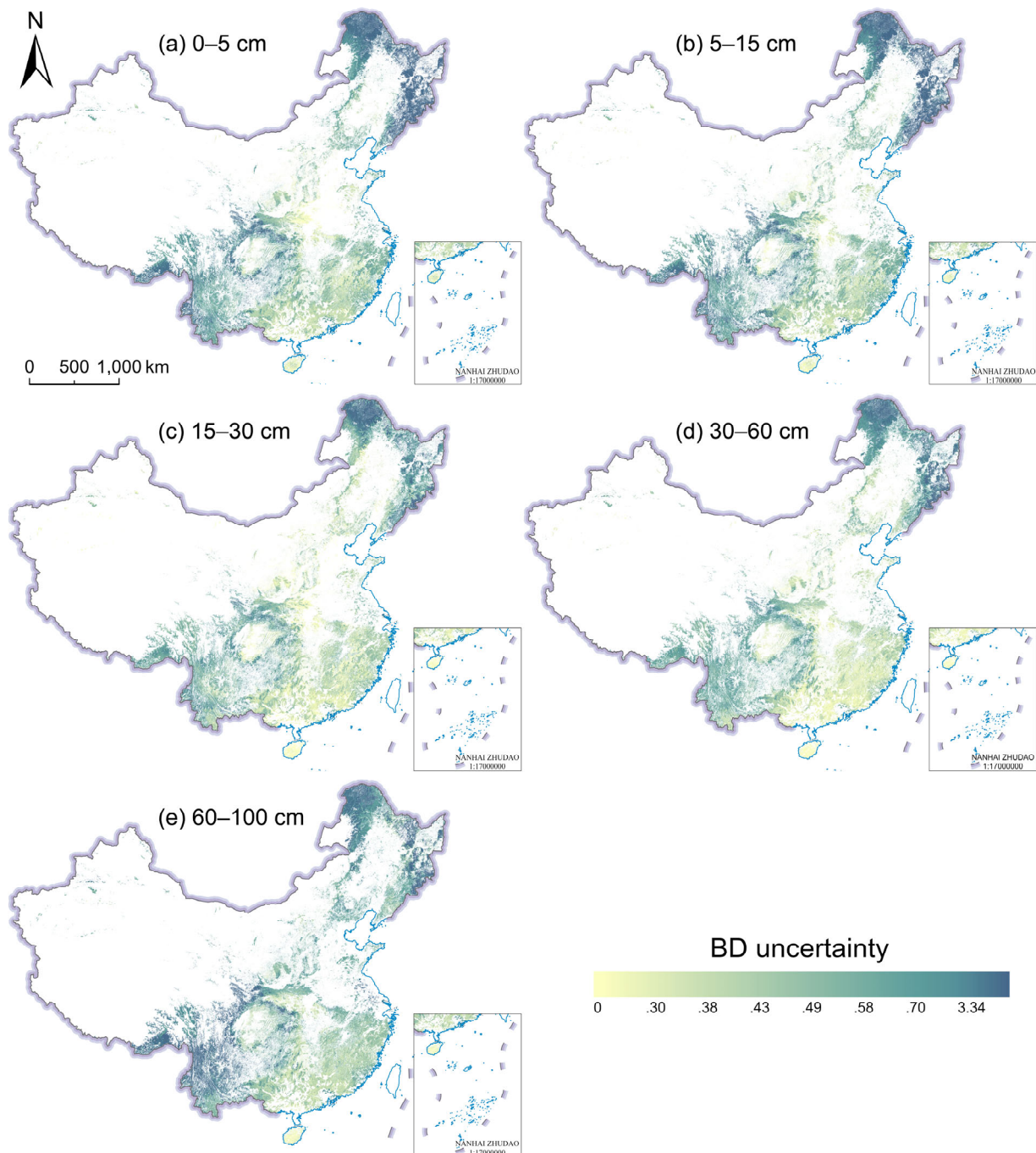
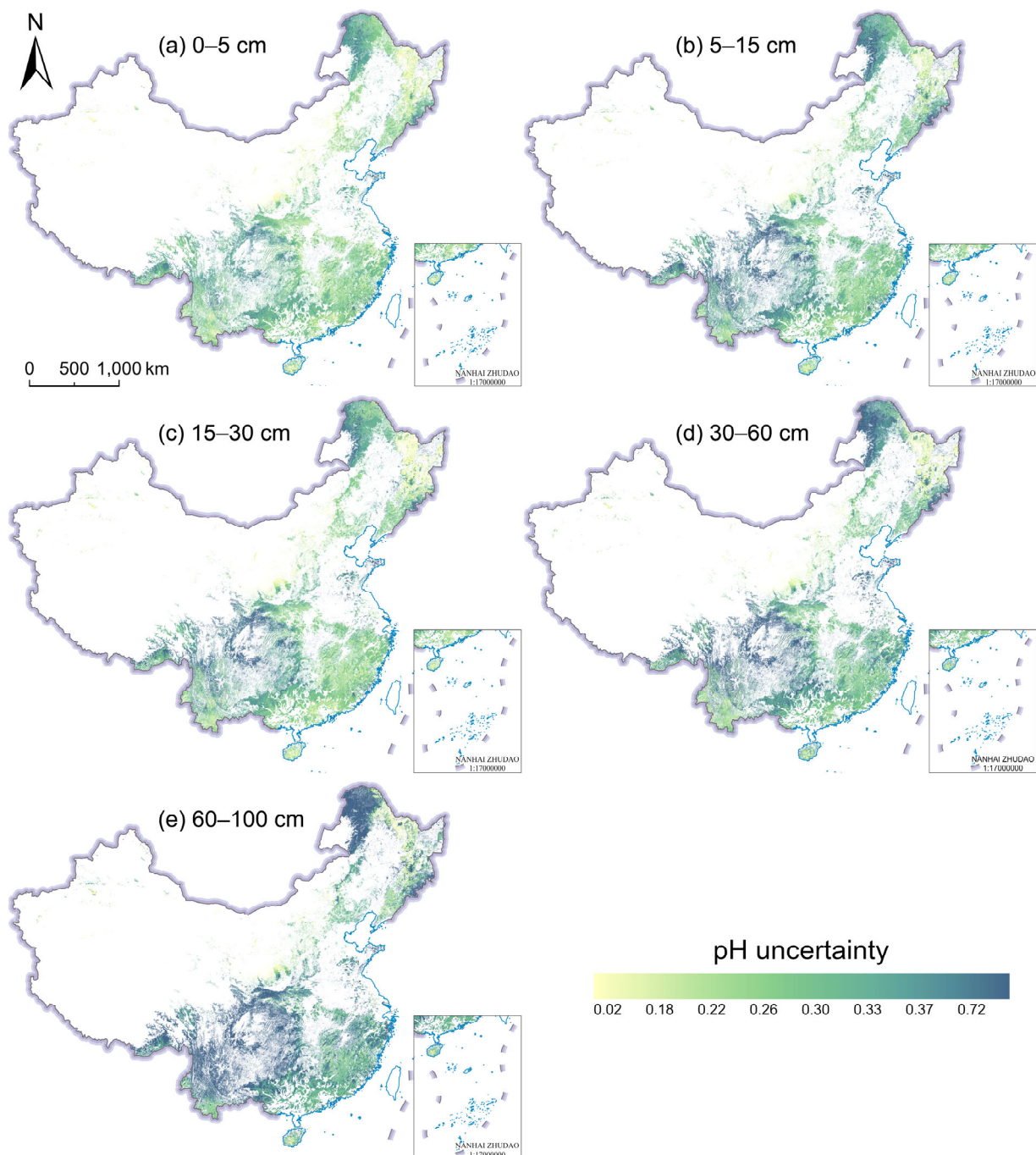


Figure S5. Uncertainty maps of predicted BD at 0–5 cm (a), 5–15 cm (b), 15–30 cm (c), 30–60 cm (d) and 60–100cm (e) depths.
 Publisher's remark: please note that the above figure contains disputed territories.



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Figure S6. Uncertainty maps of predicted pH at 0–5 cm (a), 5–15 cm (b), 15–30 cm (c), 30–60 cm (d) and 60–100cm (e) depths.
 Publisher's remark: please note that the above figure contains disputed territories.

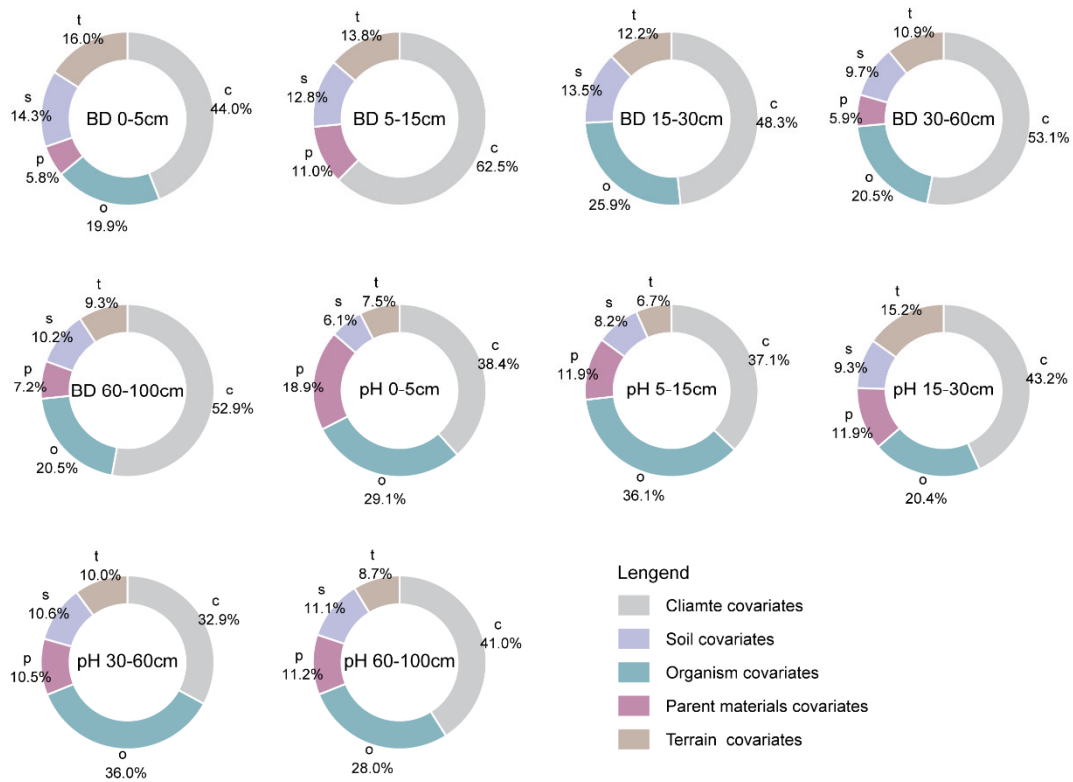


Figure S7. Proportional Contribution of FRFS-Selected Variable Categories to BD and pH across five depth intervals.

S2 Supplementary Tables

Table S1 Reference and comparison datasets for environmental covariates.

Name	Abbreviation	Scale/resolution	Soil-forming factor ^{a)}	Type ^{b)}
Digital Elevation Model	DEM	30m	t	Q
Slope	Slope	30m	t	Q
Aspect	Aspect	30m	t	Q
Plan curvature	PlanCur	30m	t	Q
Profile curvature	ProCur	30m	t	Q
topographic wetness index	TWI	30m	t	Q
Soil Surface Roughness	SSR	30m	t	Q
Elevation Relief Ratio	ERR	30m	t	Q
Local Position Index	LPI	30m	t	Q
Geomorphological Types Map	Geomor	1:2.5 M	t	C
Soil type	Soil	1:1 M	s	C
Clay	Clay	1:1 M	s	Q
Silt	Silt	1:1 M	s	Q
Sand	Sand	1:1 M	s	Q
Additive Log-Ratio of Sand to Clay	ALR1	1:1 M	s	Q
Additive Log-Ratio of Silt to Clay	ALR2	1:1 M	s	Q
Mean Annual Soil Moisture Content Index	SMCI_A	1km	s	Q
Growing Season Soil Moisture Content Index	SMCI_GS	1km	s	Q
Parent Material	PM	10m	p	Q
Clay Mineral Ratio	CMR	10m	p	Q
Geological map	Geol	1:2.5 M	p	C
Depth to Bedrock	DTB	100m	p	Q
Forest type	FT	1:2.5 M	o	C
Mean Annual Normalized Difference Vegetation Index	NDVI_A	250m	o	Q
Growing Season Normalized Difference Vegetation Index	NDVI_GS	250m	o	Q
Monthly Maximum Normalized Difference Vegetation Index	NDVI_MAX	250m	o	Q
Mean Annual Leaf Area Index	LAI_A	500m	o	Q
Growing Season Leaf Area Index	LAI_GS	500m	o	Q
Net Primary Productivity	NPP	500m	o	Q
Mean Annual Temperature	TEM_A	1km	c	Q
Mean Growing Season Temperature	TEM_GS	1km	c	Q
Monthly Maximum Temperature	TEM_MAX	1km	c	Q
Monthly Minimum Temperature	TEM_MIN	1km	c	Q
Mean Annual Precipitation	PRE_A	1km	c	Q
Growing Season Precipitation	PRE_GS	1km	c	Q
Mean Annual Evapotranspiration	PET_A	1km	c	Q
Growing Season Evapotranspiration	PET_GS	1km	c	Q
Mean Annual Solar Radiation	SR_A	5km	c	Q
Growing Season Solar Radiation	SR_GS	5km	c	Q
Mean Annual Normalized Difference Water Index	NDWI_A	250m	c	Q
Growing Season Normalized Difference Water Index	NDWI_GS	250m	c	Q

Note: a) t: topography; p: parent material; o: organisms; s: soil; c: climate. b) Q: quantitative; C: categorical.

Property	Depth (cm)	mtry	node.size	num.trees
BD	0–5	4	9	1163
	5–15	3	4	1421
	15–30	2	4	788
	30–60	2	4	1179
	60–100	9	3	947
pH	0–5	7	9	941
	5–15	5	11	607
	15–30	13	6	828
	30–60	9	9	252
	60–100	3	5	509

Table S3 Summary statistics of the BD (g/cm³) and pH..

Property	Depth (cm)	Minimum	25%	Mean	Median	75%	Maximum	STD
BD	0–5	0.372	1.062	1.157	1.208	1.291	2.034	0.213
	5–15	0.217	1.078	1.165	1.208	1.299	2.175	0.218
	15–30	0.499	1.155	1.267	1.288	1.386	2.272	0.189
	30–60	0.545	1.221	1.336	1.344	1.427	2.176	0.152
	60–100	0.479	1.104	1.251	1.250	1.343	2.258	0.199
pH	0–5	3.000	5.618	5.997	5.874	6.260	8.204	0.654
	5–15	3.002	5.285	5.697	5.528	5.981	8.097	0.685
	15–30	3.012	5.297	5.731	5.545	6.055	8.136	0.710
	30–60	3.000	5.518	6.056	5.862	6.482	9.179	0.814
	60–100	3.004	5.634	6.013	5.800	6.210	9.036	0.755

Table S4 FRFS–Selected Environmental Covariates for Soil BD and pH at Five Depth Intervals. Refer to Table 1 for the abbreviations and units of the soil properties interested.

Property	Depth (cm)	Environmental covariates	N
BD	0–5	PRE_A, NDWI_A, NPP, Elevation, PET_A, Soil, PET_GS, Geomor, ALR2, NDVI_MAX, SR_GS, DTB, NDVI_GS	13
	5–15	PRE_A, PET_A, SR_GS, Elevation, Soil, DTB, NDWI_GS	7
	15–30	PRE_A, NPP, Soil, PET_A, Elevation, SR_GS, LAI_A	7
	30–60	PRE_A, NDWI_A, NPP, PET_A, Elevation, Soil, SR_GS, LAI_GS, DTB	9
	60–100	PRE_A, NDWI_A, NPP, PET_A, Soil, Elevation, SR_GS, DTB, LAI_GS	9
pH	0–5	NDWI_A, NPP, PRE_A, LAI_A, PET_A, CMR, Elevation, PM, Soil, NDVI_MAX, DTB, SR_GS, FT	13
	5–15	NPP, NDWI_A, LAI_A, PRE_A, NDVI_MAX, Elevation, PM, PET_A, DTB, Soil, SR_GS, Silt	12
	15–30	PRE_A, NDWI_A, NPP, Elevation, PET_A, NDVI_MAX, Geomor, Soil, DTB, PM, SR_GS, Silt	12
	30–60	NDWI_A, PRE_A, NPP, LAI_A, NDVI_A, NDVI_MAX, PET_A, Elevation, PM, DTB, SR_GS, Geomor, Soil, ALR2, Silt, FT	16
	60–100	NDWI_A, NPP, PRE_A, LAI_A, NDWI_GS, PET_A, NDVI_MAX, DTB, Soil, PM, ALR2, Elevation, SR_GS, NDVI_GS, Geomor	15

Table S5 Predictive performance of soil property predictions, CSDLv2, and ChinaSoilInfoGrids.

Validation	Depth (cm)	Our predictions			CSDLv2			ChinaSoilInfoGrids		
		MEC	RMSE	ME	MEC	RMSE	ME	MEC	RMSE	ME
10-fold CV	BD									
	0–5	0.782	0.090	0.000	0.620	0.120	0.000	0.483	0.147	-0.002
	5–15	0.815	0.084	0.000	0.630	0.110	0.000	0.479	0.138	-0.002
	15–30	0.828	0.081	-0.000	0.600	0.110	-0.000	0.457	0.132	-0.002
	30–60	0.874	0.079	-0.000	0.550	0.120	-0.000	0.403	0.128	-0.002
	60–100	0.889	0.087	0.000	0.570	0.120	-0.000	0.303	0.126	-0.003
	pH									
	0–5	0.844	0.215	-0.000	0.690	0.700	0.000	0.711	0.791	0.001
	5–15	0.834	0.254	0.000	0.700	0.680	0.000	0.724	0.724	0.003
	15–30	0.854	0.214	0.000	0.700	0.680	0.000	0.74	0.74	0.002
	30–60	0.854	0.256	0.001	0.680	0.700	-0.000	0.737	0.737	0.004
	60–100	0.868	0.238	0.001	0.680	0.700	0.000	0.736	0.736	0.006
IV	BD									
	0–5	0.598	0.164	-0.010	0.021	0.309	0.036	0.080	0.293	0.020
	5–15	0.611	0.181	-0.017	0.061	0.276	0.001	0.119	0.268	0.016
	15–30	0.657	0.155	0.006	0.108	0.258	0.007	0.172	0.249	0.013
	30–60	0.614	0.166	0.005	0.131	0.338	-0.126	0.013	0.316	-0.111
	60–100	0.656	0.166	-0.019	0.021	0.309	0.036	0.080	0.293	0.020
	pH									
	0–5	0.705	0.432	-0.003	0.660	0.637	-0.081	0.636	0.659	0.104
	5–15	0.726	0.480	-0.001	0.618	0.733	-0.333	0.676	0.675	-0.233
	15–30	0.742	0.448	-0.007	0.697	0.740	-0.073	0.728	0.701	0.041
	30–60	0.760	0.515	-0.002	0.653	0.778	-0.163	0.723	0.695	-0.118
	60–100	0.812	0.492	0.014	0.660	0.637	-0.081	0.636	0.659	0.104