Supplementary Materials

Supplementary Figures S1–S7

Supplementary Tables S1–S2

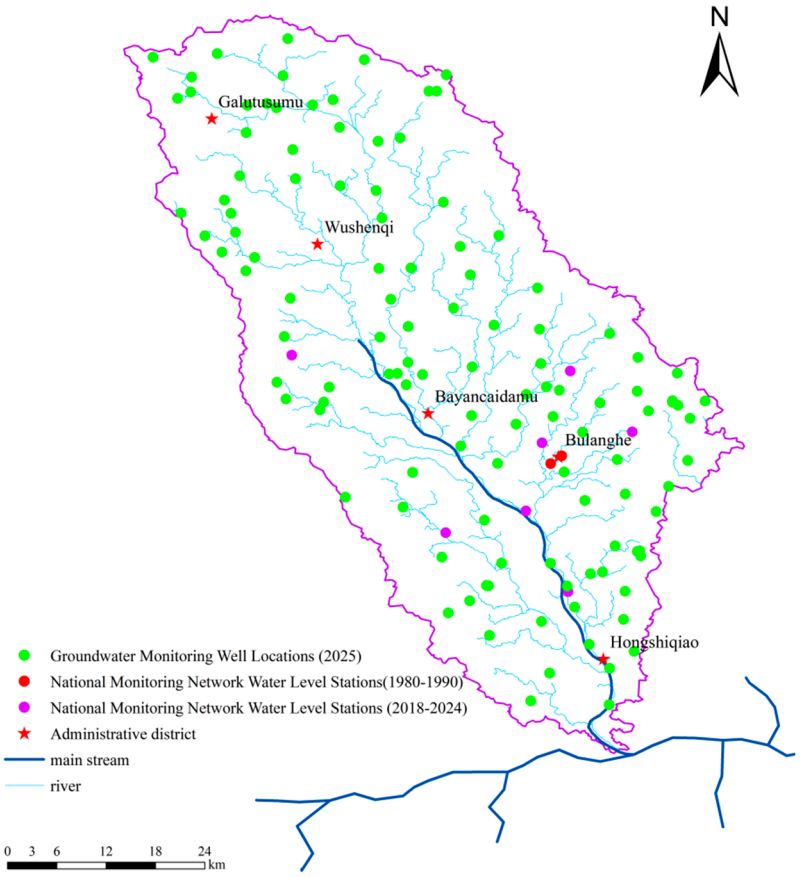


Figure S1. Groundwater monitoring sites for the Hai Liutu River Basin in 2025 and national monitoring network sites.

Note: Due to the different observation scales between field-based and satellite-derived groundwater storage data (2000–2022), as well as the limited availability of long-term continuous monitoring records, the groundwater observation data from 2014 to 2025 were selected for analysis in this study.

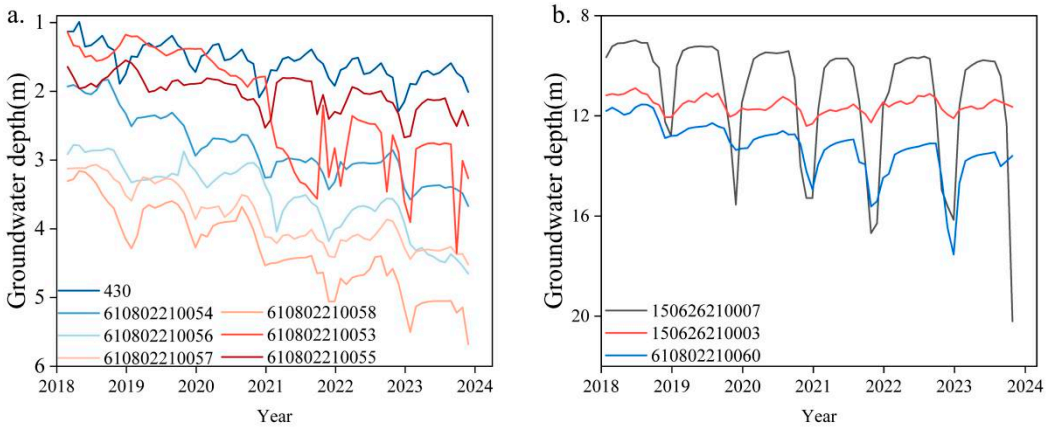


Figure S2. Groundwater change trends based on point-scale observation data, including in-situ monitoring sites and national monitoring stations. a. groundwater depth < 6m; b, groundwater depth > 6m (8 - 20 m).

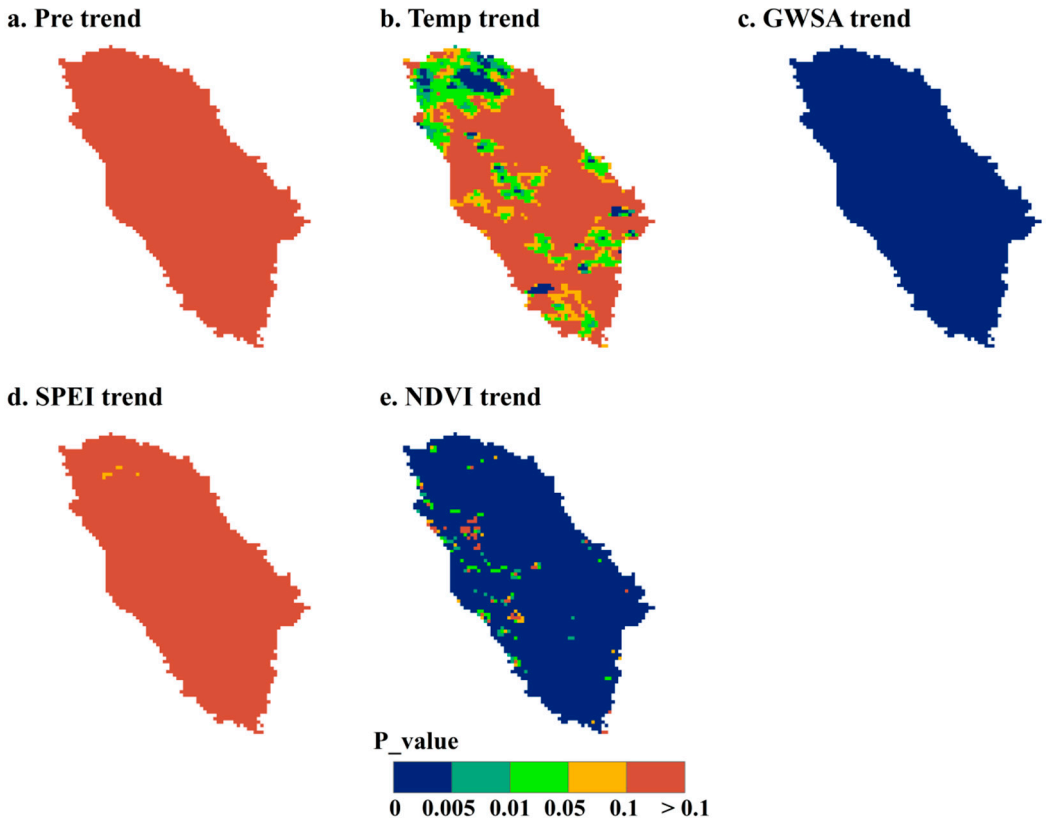


Figure S3. Trend analysis with Mann-Kendall (MK) test significance (p-values), classified into five levels, with significance levels classified as $p < 0.005$, $p < 0.01$, $p < 0.05$, $p < 0.1$ and $p > 0.1$ (not significant).

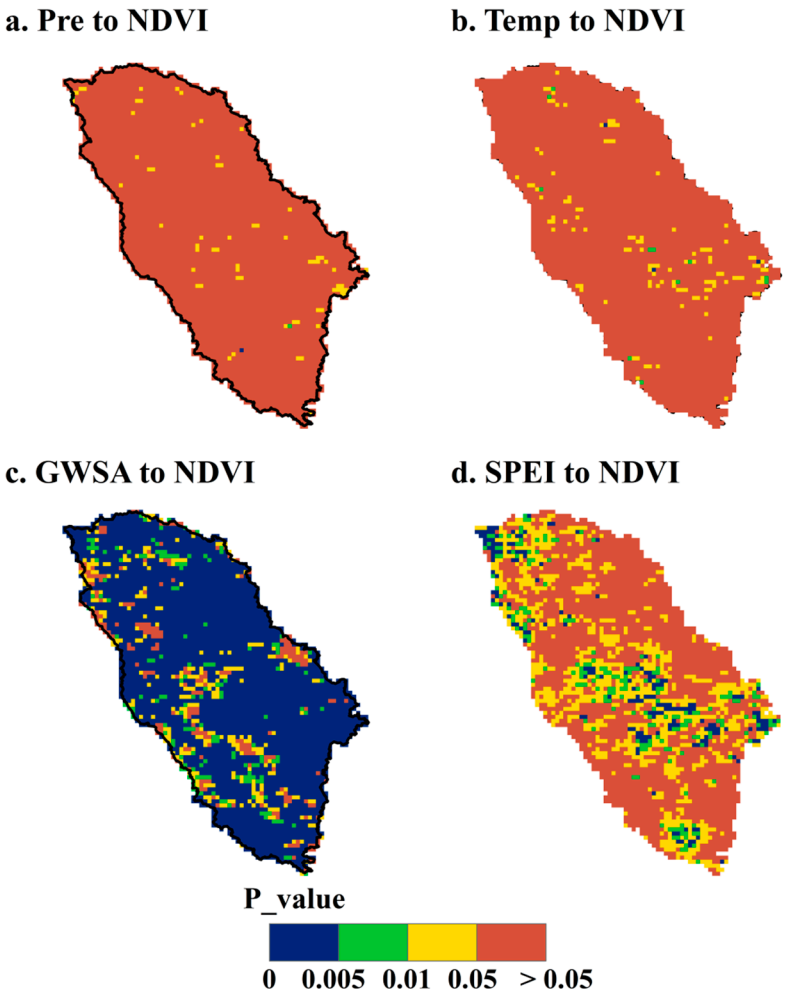


Figure S4. Spatial distribution of partial correlation coefficients between NDVI and driving factors, with significance levels (p-values) classified as $p < 0.005$ (highly significant), $p < 0.01$(moderately significant), $p < 0.05$ (significant), and $p > 0.05$ (not significant).

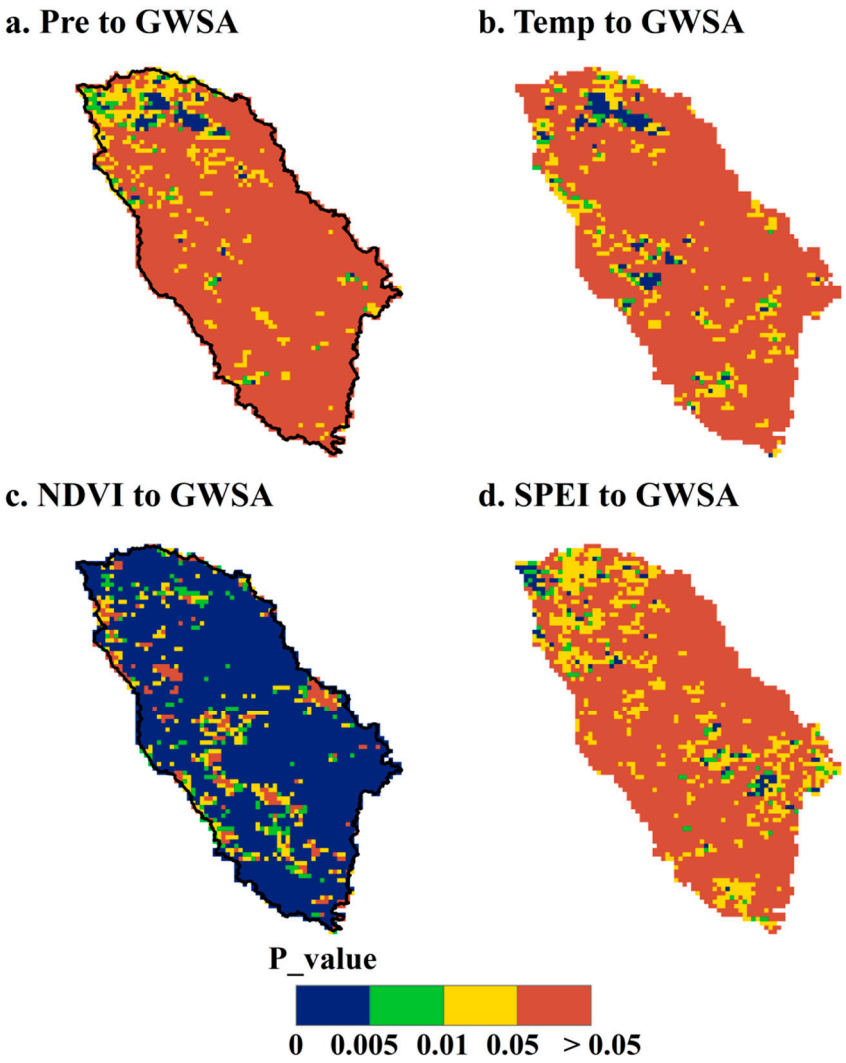


Figure S5. Spatial distribution of partial correlation coefficients between GWSI and driving factors, with significance levels (p-values) classified as $p < 0.005$ (highly significant), $p < 0.01$(moderately significant), $p < 0.05$ (significant), and $p > 0.05$ (not significant).

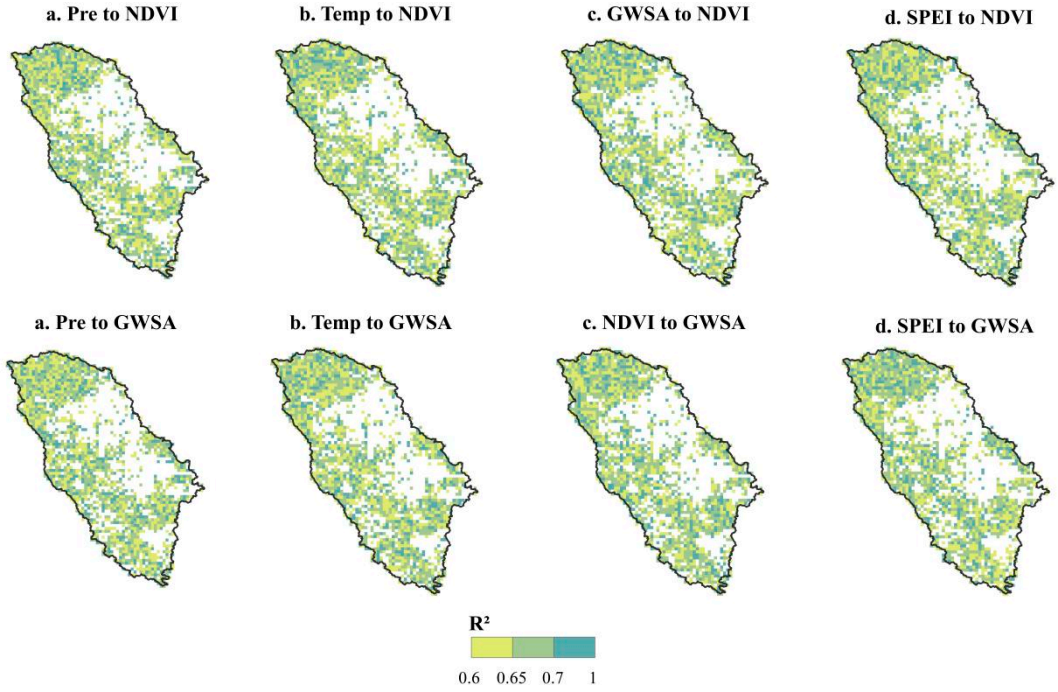


Figure S6. Spatial distribution of Random Forest model validation accuracy (R^2).

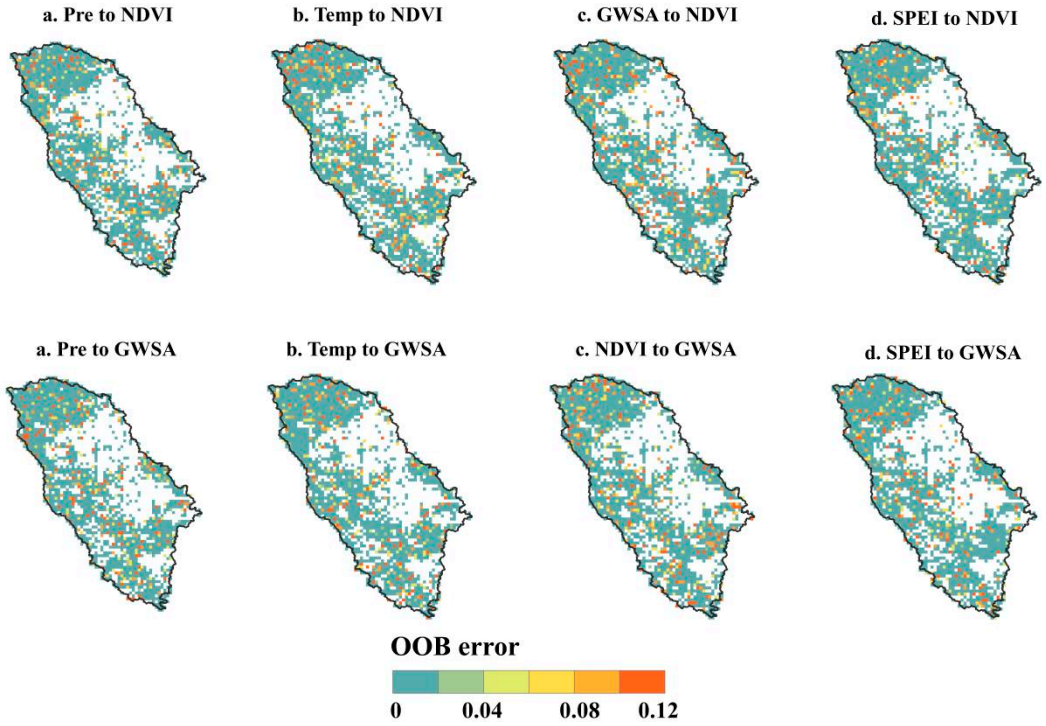


Figure S7. Spatial distribution of the Out-of-Bag (OOB) error in Random Forest model validation.

Table S1. Degree of Groundwater-Dependent Ecosystems in the Hailiutu River Basin Based on a Weighted Multi-Factor Comprehensive Index.

Evaluation Index	Very Low I	Low II	Medium III	High IV	Very High V	Notes
Groundwater Depth (m)	> 15 m	10 – 15 m	5 – 10 m	2 – 5 m	< 2 m	Classified based on groundwater depths, combined with vegetation- groundwater relationships
Soil Type	1	2	3	4	5	Based on sand and gravel content; soils classified by water-holding capacity from low to high
Vegetation Coverage (%)	<10%	10 – 30%	30 – 45%	45 – 60%	>60%	Graded according to standard vegetation coverage indicators
Evapotranspiration ET (mm/day)	<1.2	1.2 – 2.1	2.1 – 3.0	3.0 – 4.9	>4.9	Graded based on statistical characteristics of data using Natural Breaks method

Table S2. Information on long-term groundwater monitoring sites used in this study. (8 plots from 2014 to 2025).

	Observation ID	X-coordinate	Y-coordinate	Longitude	Latitude	Wellhead Elevation
1	610802210053	335730.1958	4231664.463	111.04	38.23	1100.91
2	610802210055	331897.4066	4241568.293	111	38.31	1112.22
3	430	333884.9578	4247932.398	111.02	38.35	1206.95
4	610802210054	324168.8681	4239071.264	110.92	38.32	1159.98
5	610802210056	333619.6003	4249791.915	111.02	38.32	1184.04
6	610802210057	336488.3982	4258472.271	111.05	38.44	1226.16
7	610802210058	342262.143	4250946.562	111.11	38.38	1219.87
8	150626210007	309948.7963	4260972.627	110.8	38.47	1304.686