# Supplementary Materials

# Predicting monthly runoff of the Upper Yangtze River based on the multiple Machine Learning models

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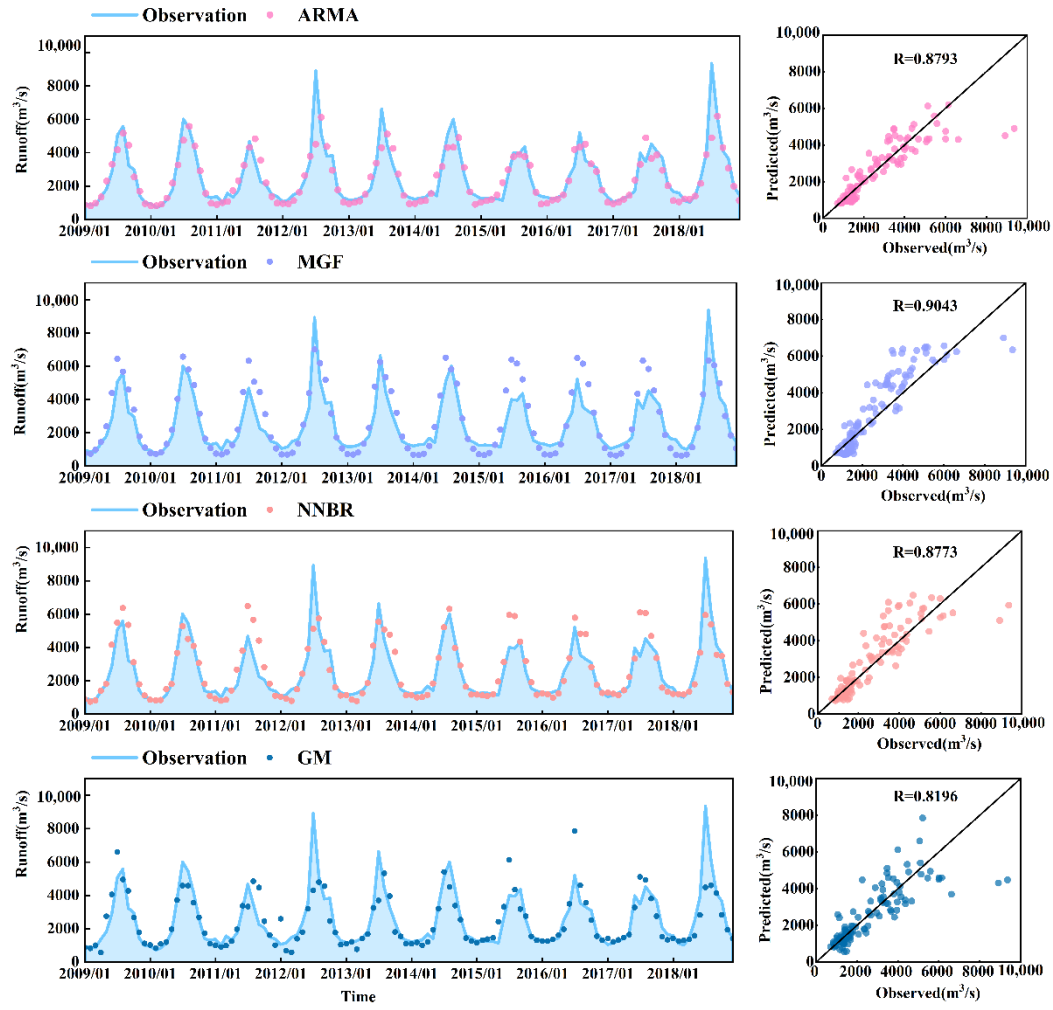
**Figure S1.** Observed runoff and simulated monthly runoff by univariate models for the Gaochang Station in the testing stage.
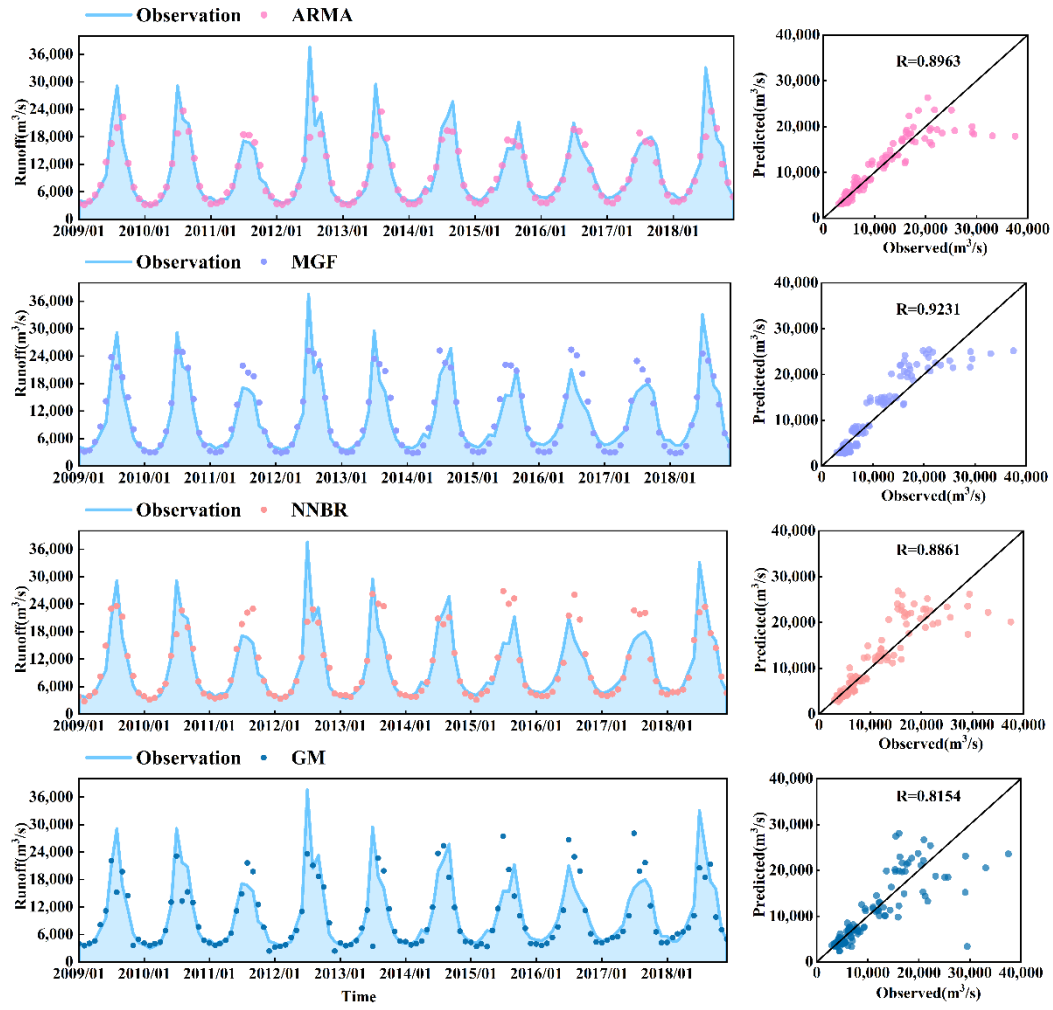
**Figure S2.** Observed runoff and simulated monthly runoff by univariate models for the Cuntan Station in the testing stage.
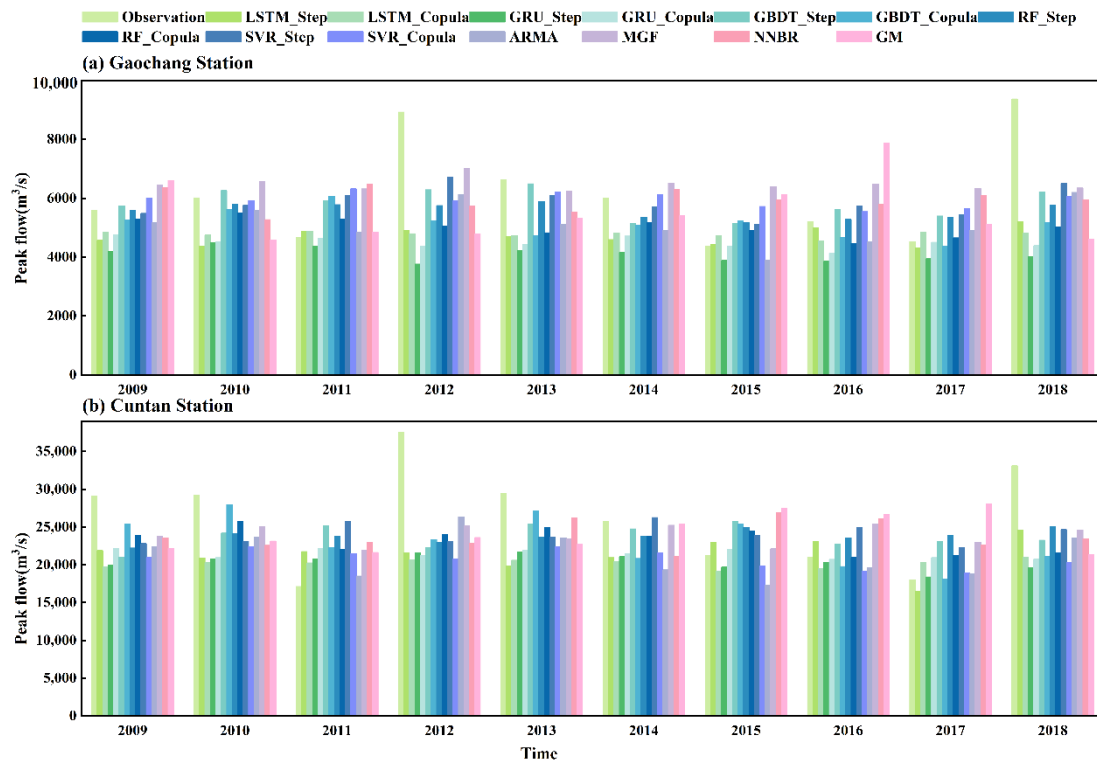
**Figure S3.** Annual peak flows of machine learning models and univariate models for the Gaochang Station and Cuntan Station in the testing stage.
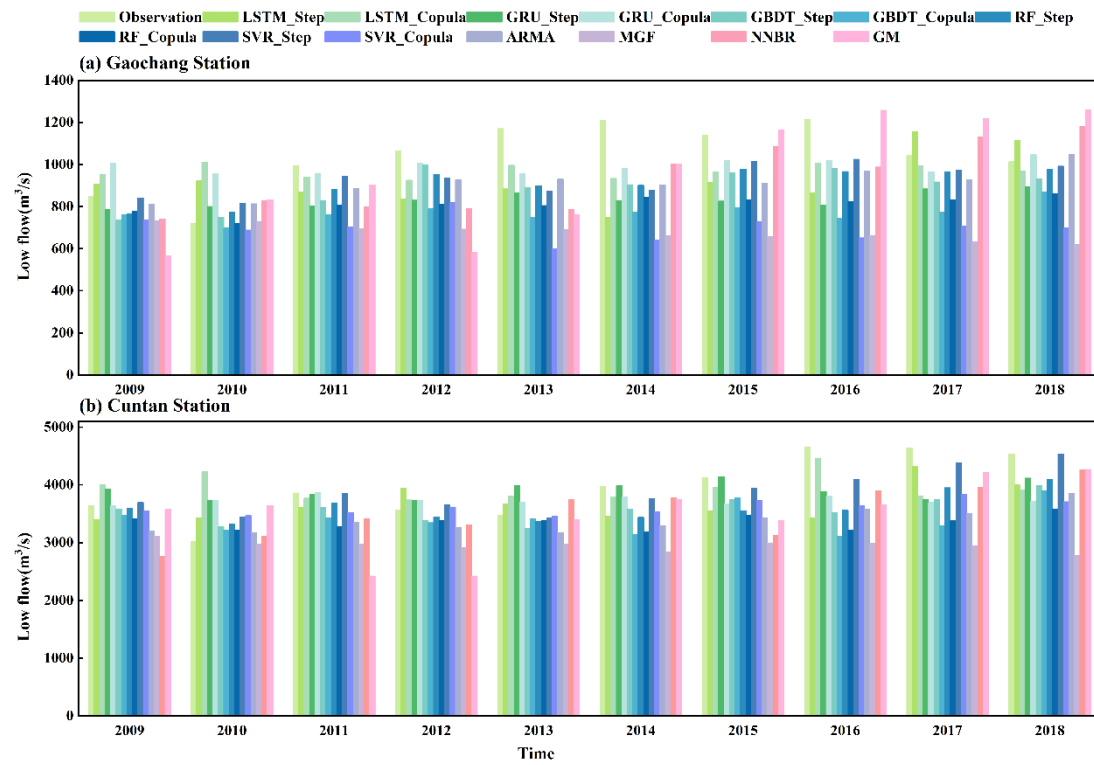
**Figure S4.** Annual low flows of machine learning models and univariate models for the Gaochang Station and Cuntan Station in the testing stage.
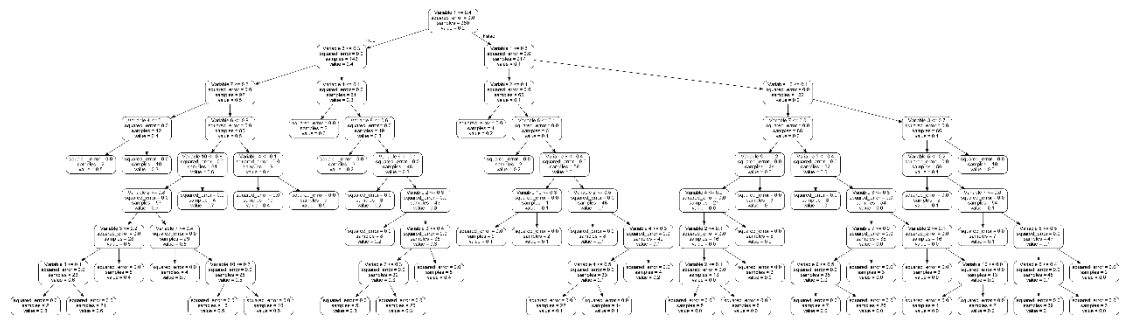
**Figure S5.** The decision tree visualizing plot in the RF_Step model at Cuntan Station.

**Table S1.** The candidate predictive variables for runoff forecasting models.

| Number | Variable's name |
|---|---|
| 1 | Northern Hemisphere Subtropical High Area Index |
| 2 | North African Subtropical High Area Index |
| 3 | North African-North Atlantic-North American Subtropical High Area Index |
| 4 | Indian Subtropical High Area Index |
| 5 | Western Pacific Subtropical High Area Index |
| 6 | Eastern Pacific Subtropical High Area Index |
| 7 | North American Subtropical High Area Index |
| 8 | Atlantic Subtropical High Area Index |
| 9 | South China Sea Subtropical High Area Index |
| 10 | North American-Atlantic Subtropical High Area Index |
| 11 | Pacific Subtropical High Area Index |
| 12 | Northern Hemisphere Subtropical High Intensity Index |
| 13 | North African Subtropical High Intensity Index |
| 14 | North African-North Atlantic-North American Subtropical High Intensity Index |
| 15 | Indian Subtropical High Intensity Index |
| 16 | Western Pacific Subtropical High Intensity Index |
| 17 | Eastern Pacific Subtropical High Intensity Index |
| 18 | North American Subtropical High Intensity Index |
| 19 | North Atlantic Subtropical High Intensity Index |
| 20 | South China Sea Subtropical High Intensity Index |
| 21 | North American-North Atlantic Subtropical High Intensity Index |
| 22 | Pacific Subtropical High Intensity Index |
| 23 | Northern Hemisphere Subtropical High Ridge Position Index |
| 24 | North African Subtropical High Ridge Position Index |
| 25 | North African-North Atlantic-North American Subtropical High Ridge Position Index |
| 26 | Indian Subtropical High Ridge Position Index |
| 27 | Western Pacific Subtropical High Ridge Position Index |
| 28 | Eastern Pacific Subtropical High Ridge Position Index |
| 29 | North American Subtropical High Ridge Position Index |
| 30 | Atlantic Sub Tropical High Ridge Position Index |
| 31 | South China Sea Subtropical High Ridge Position Index |
| 32 | North American-North Atlantic Subtropical High Ridge Position Index |
| 33 | Pacific Subtropical High Ridge Position Index |
| 34 | Northern Hemisphere Subtropical High Northern Boundary Position Index |
| 35 | North African Subtropical High Northern Boundary Position Index |
| 36 | North African-North Atlantic-North American Subtropical High Northern Boundary Position Index |
| 37 | Indian Subtropical High Northern Boundary Position Index |
| 38 | Western Pacific Subtropical High Northern Boundary Position Index |
| 39 | Eastern Pacific Subtropical High Northern Boundary Position Index |
| 40 | North American Subtropical High Northern Boundary Position Index |
| 41 | Atlantic Subtropical High Northern Boundary Position Index |
| 42 | South China Sea Subtropical High Northern Boundary Position Index |

| Number | Variable's name |
|--------|-----------------|
| 43 | North American-Atlantic Subtropical High Northern Boundary Position Index |
| 44 | Pacific Subtropical High Northern Boundary Position Index |
| 45 | Western Pacific Sub Tropical High Western Ridge Point Index |
| 46 | Asia Polar Vortex Area Index |
| 47 | Pacific Polar Vortex Area Index |
| 48 | North American Polar Vortex Area Index |
| 49 | Atlantic-European Polar Vortex Area Index |
| 50 | Northern Hemisphere Polar Vortex Area Index |
| 51 | Asia Polar Vortex Intensity Index |
| 52 | Pacific Polar Vortex Intensity Index |
| 53 | North American Polar Vortex Intensity Index |
| 54 | Atlantic-European Polar Vortex Intensity Index |
| 55 | Northern Hemisphere Polar Vortex Intensity Index |
| 56 | Northern Hemisphere Polar Vortex Central Longitude Index |
| 57 | Northern Hemisphere Polar Vortex Central Latitude Index |
| 58 | Northern Hemisphere Polar Vortex Central Intensity Index |
| 59 | Eurasian Zonal Circulation Index |
| 60 | Eurasian Meridional Circulation Index |
| 61 | Asian Zonal Circulation Index |
| 62 | Asian Meridional Circulation Index |
| 63 | East Asian Trough Position Index |
| 64 | East Asian Trough Intensity Index |
| 65 | Tibet Plateau Region 1 Index |
| 66 | Tibet Plateau Region-2 Index |
| 67 | India-Burma Trough Intensity Index |
| 68 | Arctic Oscillation, AO |
| 69 | Antarctic Oscillation, AAO |
| 70 | North Atlantic Oscillation , NAO |
| 71 | Pacific/ North American Pattern , PNA |
| 72 | East Atlantic Pattern, EA |
| 73 | West Pacific Pattern , WP |
| 74 | North Pacific Pattern , NP |
| 75 | East Atlantic-West Russia Pattern , EA/WR |
| 76 | Tropical-Northern Hemisphere Pattern, TNH |
| 77 | Polar-Eurasia Pattern , POL |
| 78 | Scandinavia Pattern , SCA |
| 79 | Pacific Transition Pattern, PT |
| 80 | 30hPa zonal wind Index |
| 81 | 50 hPa zonal wind Index |
| 82 | Mid-Eastern Pacific 200mb Zonal Wind Index |
| 83 | West Pacific 850mb Trade Wind Index |
| 84 | Central Pacific 850mb Trade Wind Index |
| 85 | East Pacific 850mb Trade Wind Index |

| Number | Variable's name |
|---|---|
| 86 | Atlantic-European Circulation W Pattern Index |
| 87 | Atlantic-European Circulation C Pattern Index |
| 88 | Atlantic-European Circulation E Pattern Index |
| 89 | NINO 1+2 SSTA Index |
| 90 | NINO 3 SSTA Index |
| 91 | NINO 4 SSTA Index |
| 92 | NINO 3.4 SSTA Index |
| 93 | NINO W SSTA Index |
| 94 | NINO C SSTA Index |
| 95 | NINO A SSTA Index |
| 96 | NINO B SSTA Index |
| 97 | NINO Z SSTA Index |
| 98 | Tropical Northern Atlantic SST Index |
| 99 | Tropical Southern Atlantic SST Index |
| 100 | Western Hemisphere Warm Pool Index |
| 101 | Indian Ocean Warm Pool Area Index |
| 102 | Indian Ocean Warm Pool Strength Index |
| 103 | Western Pacific Warm Pool Area Index |
| 104 | Western Pacific Warm Pool Strength index |
| 105 | Atlantic Multi-decadal Oscillation Index |
| 106 | Oyashio Current SST Index |
| 107 | West Wind Drift Current SST Index |
| 108 | Kuroshio Current SST Index |
| 109 | ENSO Modoki Index |
| 110 | Nino Eastern Pacific index |
| 111 | Nino Central Pacific index |
| 112 | Indian Ocean Basin-Wide Index |
| 113 | Tropic Indian Ocean Dipole Index |
| 114 | South Indian Ocean Dipole Index |
| 115 | Cold Air Activity Index |
| 116 | Western North Pacific Typhoon number |
| 117 | Number of Landing Typhoon on China |
| 118 | Total Sunspot Number Index |
| 119 | Southern Oscillation Index |
| 120 | Tropical Pacific Outgoing Long Wave Radiation Index |
| 121 | Multivariate ENSO Index |
| 122 | Pacific Decadal Oscillation Index |
| 123 | Atlantic Meridional Mode SST Index |
| 124 | Quasi-Biennial Oscillation Index |
| 125 | Globally Integrated Angular Momentum Index |
| 126 | Solar Flux Index |
| 127 | Equatorial Pacific 130°E-80°W Upper 300m temperature averaged anomaly index |
| 128 | Equatorial Pacific 160°E-80°W Upper 300m temperature Average anomaly index |

| Number | Variable's name |
| --- | --- |
| 129 | Equatorial Pacific 180$^{\circ}$ -100$^{\circ}$ W Upper 300m temperature Average anomaly index |
| 130 | North Atlantic Triple index |
| 131 | Runoff |
| 132 | Air Pressure |
| 133 | Average Temperature |
| 134 | Maximum Temperature |
| 135 | Minimum Temperature |
| 136 | Relative Humidity |
| 137 | Monthly Precipitation |
| 138 | Wind Speed |
| 139 | Daylight Hours |

**Table S2.** Statistical metrics of 1-month-ahead runoff forecasting results of AI models for the Gaochang Station and Cuntan Station.

| Station | Method | Training | | | | Testing | | | |
|---------|--------|----------|------|-----|---|---------|------|-----|---|
| | | MAPE (%) | RMSE (m³/s) | NSE | R | MAPE (%) | RMSE (m³/s) | NSE | R |
| Gaochang | LSTM_Step | 19.403 | 792.094 | 0.835 | 0.949 | 18.230 | 729.330 | 0.770 | 0.923 |
| | LSTM_Copula | 21.121 | 808.111 | 0.828 | 0.941 | 17.624 | 691.492 | 0.783 | 0.937 |
| | GRU_Step | 17.580 | 802.057 | 0.829 | 0.931 | 19.716 | 816.700 | 0.721 | 0.911 |
| | GRU_Copula | 22.294 | 850.196 | 0.810 | 0.937 | 16.685 | 737.825 | 0.766 | 0.932 |
| | GBDT_Step | 0.000 | 0.000 | 1.000 | 1.000 | 19.713 | 731.833 | 0.705 | 0.934 |
| | GBDT_Copula | 0.000 | 0.000 | 1.000 | 1.000 | 22.162 | 773.929 | 0.702 | 0.907 |
| | RF_Step | 11.075 | 490.953 | 0.932 | 0.969 | 18.353 | 708.891 | 0.714 | 0.937 |
| | RF_Copula | 6.485 | 281.765 | 0.977 | 0.990 | 20.610 | 738.703 | 0.738 | 0.919 |
| | SVR_Step | 13.628 | 647.024 | 0.883 | 0.944 | 21.487 | 802.021 | 0.638 | 0.931 |
| | SVR_Copula | 15.818 | 714.062 | 0.858 | 0.934 | 26.266 | 844.106 | 0.577 | 0.931 |
| Cuntan | LSTM_Step | 15.719 | 3058.171 | 0.859 | 0.955 | 14.907 | 3101.704 | 0.778 | 0.940 |
| | LSTM_Copula | 20.718 | 3458.816 | 0.819 | 0.934 | 14.441 | 2782.648 | 0.835 | 0.960 |
| | GRU_Step | 19.562 | 3215.930 | 0.842 | 0.938 | 14.445 | 2860.145 | 0.826 | 0.950 |
| | GRU_Copula | 18.389 | 3163.134 | 0.847 | 0.937 | 15.407 | 2954.973 | 0.803 | 0.954 |
| | GBDT_Step | 0.640 | 64.080 | 1.000 | 1.000 | 16.211 | 2962.934 | 0.752 | 0.953 |
| | GBDT_Copula | 0.148 | 14.824 | 1.000 | 1.000 | 17.261 | 2799.659 | 0.780 | 0.953 |
| | RF_Step | 10.770 | 2107.181 | 0.930 | 0.969 | 15.688 | 2824.587 | 0.760 | 0.961 |
| | RF_Copula | 6.062 | 1121.299 | 0.980 | 0.991 | 16.734 | 2616.354 | 0.811 | 0.962 |
| | SVR_Step | 11.833 | 2556.120 | 0.896 | 0.950 | 13.982 | 2823.656 | 0.783 | 0.957 |
| | SVR_Copula | 16.262 | 3311.167 | 0.828 | 0.919 | 15.517 | 2928.979 | 0.816 | 0.946 |

**Table S3.** Statistical metrics of 1-month-ahead runoff forecasting results of univariate models for the Gaochang Station and Cuntan Station.

| Station | Method | Training | | | | Testing | | | |
|---------|--------|----------|------|-----|---|---------|------|-----|---|
| | | MAPE (%) | RMSE (m³/s) | NSE | R | MAPE (%) | RMSE (m³/s) | NSE | R |
| Gaochang | ARMA | 13.309 | 640.431 | 0.885 | 0.946 | 17.473 | 715.578 | 0.774 | 0.900 |
| | MGF | 17.919 | 692.055 | 0.864 | 0.964 | 27.786 | 866.840 | 0.517 | 0.949 |
| | NNBR | 16.525 | 787.161 | 0.820 | 0.923 | 19.637 | 789.312 | 0.633 | 0.939 |
| | GM | 18.773 | 843.042 | 0.755 | 0.907 | 20.667 | 886.644 | 0.618 | 0.888 |
| Cuntan | ARMA | 13.912 | 2846.220 | 0.871 | 0.939 | 14.387 | 2844.681 | 0.835 | 0.928 |
| | MGF | 14.941 | 3061.850 | 0.832 | 0.963 | 20.654 | 2847.211 | 0.772 | 0.959 |
| | NNBR | 15.755 | 3068.175 | 0.837 | 0.927 | 16.890 | 3303.493 | 0.682 | 0.944 |
| | GM | 18.604 | 3674.002 | 0.742 | 0.901 | 19.230 | 4067.540 | 0.561 | 0.879 |