

Supplementary Materials

Characterization of the propagation of meteorological drought using the copula model

Haeun Jung^a, Jeongeun Won^a, Shinuk Kang^b, Sangdan Kim^{a,*}

^aDivision of Earth Environmental System Science (Major of Environmental Engineering), Pukyong National University, Busan 48513, Korea

^bK-water Research Institute, K-water, Daejeon 34045, Korea

*Corresponding author at: Division of Earth Environmental System Science (Major of Environmental Engineering), Pukyong National University, Busan 48513, Korea; skim@pknu.ac.kr

17 pages, 4 figures, 10 table

Figures

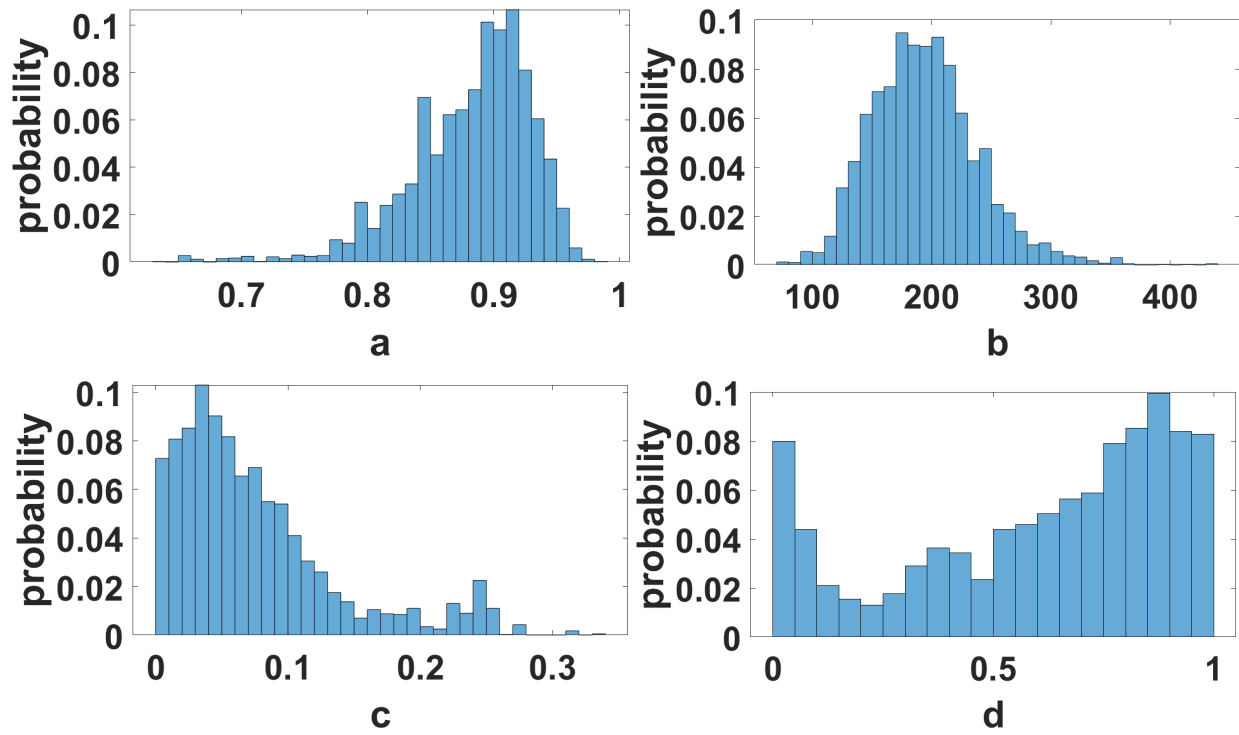


Figure S1. Posterior distribution of abcd model parameters (Andong Dam Basin).

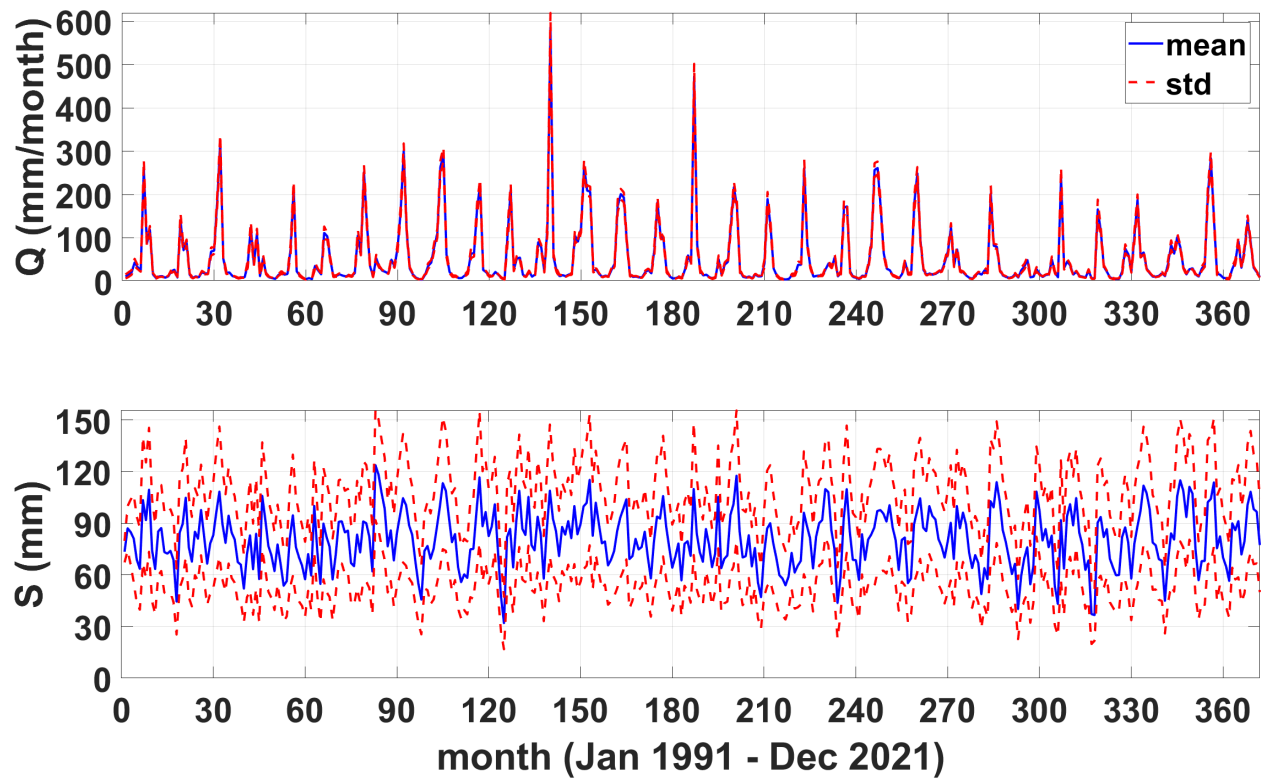


Figure S2. Simulated monthly runoff ensembles from posterior distribution of parameters (Andong Dam Basin).

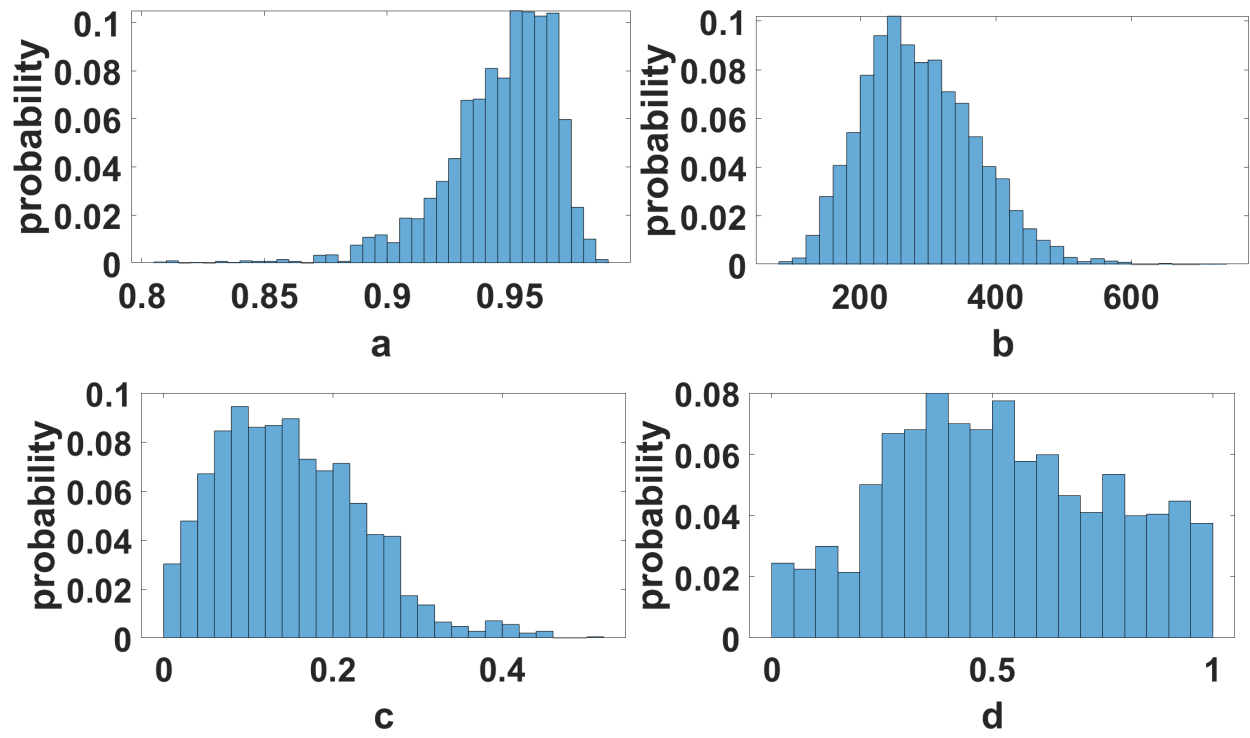


Figure S3. Posterior distribution of abcd model parameters (Hapcheon Dam Basin).

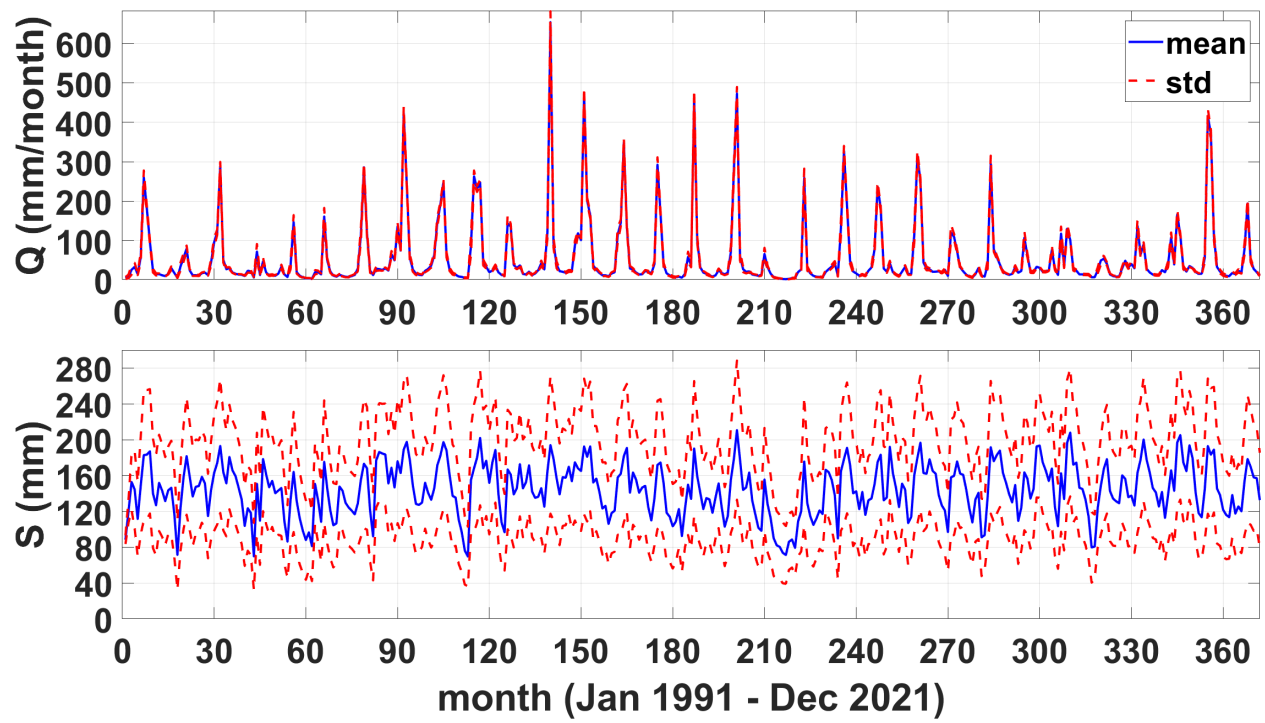


Figure S4. Simulated monthly runoff ensembles from posterior distribution of parameters (Hapcheon Dam Basin).

Table S1. Propagation probability of hydrological drought under various severities of meteorological drought at Andong Dam Basin (case 1).

| Seasons | Conditions for SPI | Hydrological drought probability | | | |
|---------|-----------------------|----------------------------------|------------------------------|------------------------------|------------------------------|
| | | SRI \leq -0.5 (0.30854) | SRI \leq -1.0 (0.15866) | SRI \leq -1.5 (0.06681) | SRI \leq -2.0 (0.02275) |
| Spring | SPI \leq -0.5 | 0.60310 | 0.36813 | 0.17726 | 0.06621 |
| | SPI \leq -1.0 | 0.71591 | 0.48298 | 0.25800 | 0.10593 |
| | SPI \leq -1.5 | 0.81865 | 0.61271 | 0.36956 | 0.17183 |
| | SPI \leq -2.0 | 0.89799 | 0.73871 | 0.50458 | 0.27002 |
| Summer | SPI \leq -0.5 | 0.68387 | 0.40204 | 0.17966 | 0.06260 |
| | SPI \leq -1.0 | 0.78185 | 0.51081 | 0.24516 | 0.08829 |
| | SPI \leq -1.5 | 0.82974 | 0.58220 | 0.29863 | 0.11164 |
| | SPI \leq -2.0 | 0.84897 | 0.61571 | 0.32785 | 0.12558 |
| Fall | SPI \leq -0.5 | 0.57655 | 0.33892 | 0.15749 | 0.05754 |
| | SPI \leq -1.0 | 0.65909 | 0.42224 | 0.21320 | 0.08350 |
| | SPI \leq -1.5 | 0.72736 | 0.50632 | 0.28161 | 0.12115 |
| | SPI \leq -2.0 | 0.78035 | 0.58233 | 0.35577 | 0.17004 |
| Winter | SPI \leq -0.5 | 0.57810 | 0.33998 | 0.15800 | 0.05772 |
| | SPI \leq -1.0 | 0.66116 | 0.42403 | 0.21424 | 0.08393 |
| | SPI \leq -1.5 | 0.72971 | 0.50878 | 0.28336 | 0.12201 |
| | SPI \leq -2.0 | 0.78278 | 0.58528 | 0.35828 | 0.17152 |

Table S2. Propagation probability of hydrological drought under various severities of meteorological drought at Andong Dam Basin (case 2).

| Seasons | Conditions for SPI | Hydrological drought probability | | | |
|---------|--------------------|----------------------------------|------------------------------|------------------------------|------------------------------|
| | | SRI \leq -0.5 (0.30854) | SRI \leq -1.0 (0.15866) | SRI \leq -1.5 (0.06681) | SRI \leq -2.0 (0.02275) |
| Spring | SPI \leq -0.5 | 0.60263 | 0.36781 | 0.17711 | 0.06617 |
| | SPI \leq -1.0 | 0.71527 | 0.48240 | 0.25766 | 0.10579 |
| | SPI \leq -1.5 | 0.81796 | 0.61189 | 0.36892 | 0.17150 |
| | SPI \leq -2.0 | 0.89738 | 0.73776 | 0.50362 | 0.26937 |
| Summer | SPI \leq -0.5 | 0.72565 | 0.42791 | 0.19027 | 0.06607 |
| | SPI \leq -1.0 | 0.83215 | 0.55929 | 0.27094 | 0.09770 |
| | SPI \leq -1.5 | 0.87874 | 0.64343 | 0.33943 | 0.12840 |
| | SPI \leq -2.0 | 0.89609 | 0.68132 | 0.37706 | 0.14738 |
| Fall | SPI \leq -0.5 | 0.66407 | 0.38949 | 0.17430 | 0.06081 |
| | SPI \leq -1.0 | 0.75744 | 0.48874 | 0.23345 | 0.08398 |
| | SPI \leq -1.5 | 0.80499 | 0.55440 | 0.28095 | 0.10448 |
| | SPI \leq -2.0 | 0.82466 | 0.58568 | 0.30681 | 0.11653 |
| Winter | SPI \leq -0.5 | 0.57345 | 0.33680 | 0.15648 | 0.05718 |
| | SPI \leq -1.0 | 0.65497 | 0.41870 | 0.21115 | 0.08266 |
| | SPI \leq -1.5 | 0.72267 | 0.50143 | 0.27814 | 0.11946 |
| | SPI \leq -2.0 | 0.77549 | 0.57646 | 0.35080 | 0.16712 |

Table S3. Propagation probability of hydrological drought under various severities of meteorological drought at Andong Dam Basin (case 3).

| Seasons | Conditions for SPI | Hydrological drought probability | | | |
|---------|-----------------------|----------------------------------|------------------------------|------------------------------|------------------------------|
| | | SRI \leq -0.5 (0.30854) | SRI \leq -1.0 (0.15866) | SRI \leq -1.5 (0.06681) | SRI \leq -2.0 (0.02275) |
| Spring | SPI \leq -0.5 | 0.63172 | 0.36872 | 0.16520 | 0.05771 |
| | SPI \leq -1.0 | 0.71705 | 0.45375 | 0.21498 | 0.07716 |
| | SPI \leq -1.5 | 0.76297 | 0.51054 | 0.25396 | 0.09366 |
| | SPI \leq -2.0 | 0.78272 | 0.53809 | 0.27503 | 0.10315 |
| Summer | SPI \leq -0.5 | 0.74750 | 0.44098 | 0.19536 | 0.06769 |
| | SPI \leq -1.0 | 0.85758 | 0.58585 | 0.28507 | 0.10279 |
| | SPI \leq -1.5 | 0.90223 | 0.67699 | 0.36306 | 0.13825 |
| | SPI \leq -2.0 | 0.91806 | 0.71682 | 0.40598 | 0.16063 |
| Fall | SPI \leq -0.5 | 0.64742 | 0.37883 | 0.16967 | 0.05924 |
| | SPI \leq -1.0 | 0.73672 | 0.47057 | 0.22385 | 0.08044 |
| | SPI \leq -1.5 | 0.78359 | 0.53159 | 0.26678 | 0.09878 |
| | SPI \leq -2.0 | 0.80339 | 0.56096 | 0.29008 | 0.10945 |
| Winter | SPI \leq -0.5 | 0.64173 | 0.37517 | 0.16806 | 0.05869 |
| | SPI \leq -1.0 | 0.72960 | 0.46444 | 0.22061 | 0.07924 |
| | SPI \leq -1.5 | 0.77616 | 0.52391 | 0.26207 | 0.09690 |
| | SPI \leq -2.0 | 0.79596 | 0.55262 | 0.28454 | 0.10712 |

Table S4. Propagation probability of hydrological drought under various severities of meteorological drought at Andong Dam Basin (case 4).

| Seasons | Conditions for SPI | Hydrological drought probability | | | |
|---------|--------------------|----------------------------------|------------------------------|------------------------------|------------------------------|
| | | SRI \leq -0.5 (0.30854) | SRI \leq -1.0 (0.15866) | SRI \leq -1.5 (0.06681) | SRI \leq -2.0 (0.02275) |
| Spring | SPI \leq -0.5 | 0.64342 | 0.37626 | 0.16854 | 0.05885 |
| | SPI \leq -1.0 | 0.73172 | 0.46626 | 0.22157 | 0.07960 |
| | SPI \leq -1.5 | 0.77837 | 0.52619 | 0.26347 | 0.09745 |
| | SPI \leq -2.0 | 0.79818 | 0.55509 | 0.28618 | 0.10781 |
| Summer | SPI \leq -0.5 | 0.75297 | 0.44420 | 0.19657 | 0.06808 |
| | SPI \leq -1.0 | 0.86383 | 0.59265 | 0.28869 | 0.10408 |
| | SPI \leq -1.5 | 0.90784 | 0.68558 | 0.36928 | 0.14086 |
| | SPI \leq -2.0 | 0.92324 | 0.72584 | 0.41363 | 0.16420 |
| Fall | SPI \leq -0.5 | 0.66488 | 0.39001 | 0.17453 | 0.06088 |
| | SPI \leq -1.0 | 0.75845 | 0.48964 | 0.23393 | 0.08416 |
| | SPI \leq -1.5 | 0.80603 | 0.55553 | 0.28166 | 0.10476 |
| | SPI \leq -2.0 | 0.82568 | 0.58690 | 0.30765 | 0.11689 |
| Winter | SPI \leq -0.5 | 0.60693 | 0.35263 | 0.15799 | 0.05523 |
| | SPI \leq -1.0 | 0.68575 | 0.42774 | 0.20133 | 0.07210 |
| | SPI \leq -1.5 | 0.72965 | 0.47811 | 0.23464 | 0.08600 |
| | SPI \leq -2.0 | 0.74901 | 0.50281 | 0.25255 | 0.09388 |

Table S5. Propagation probability of hydrological drought under various severities of meteorological drought at Andong Dam Basin (case 5).

| Seasons | Conditions for SPI | Hydrological drought probability | | | |
|---------|-----------------------|----------------------------------|------------------------------|------------------------------|------------------------------|
| | | SRI \leq -0.5 (0.30854) | SRI \leq -1.0 (0.15866) | SRI \leq -1.5 (0.06681) | SRI \leq -2.0 (0.02275) |
| Spring | SPI \leq -0.5 | 0.65889 | 0.38619 | 0.17288 | 0.06033 |
| | SPI \leq -1.0 | 0.75102 | 0.48306 | 0.23044 | 0.08287 |
| | SPI \leq -1.5 | 0.79840 | 0.54726 | 0.27648 | 0.10268 |
| | SPI \leq -2.0 | 0.81813 | 0.57795 | 0.30152 | 0.11428 |
| Summer | SPI \leq -0.5 | 0.73368 | 0.45295 | 0.20878 | 0.07323 |
| | SPI \leq -1.0 | 0.88086 | 0.64796 | 0.35074 | 0.13566 |
| | SPI \leq -1.5 | 0.96421 | 0.83294 | 0.56059 | 0.26473 |
| | SPI \leq -2.0 | 0.99317 | 0.94608 | 0.77738 | 0.47541 |
| Fall | SPI \leq -0.5 | 0.67406 | 0.39584 | 0.17703 | 0.06172 |
| | SPI \leq -1.0 | 0.76979 | 0.49981 | 0.23932 | 0.08614 |
| | SPI \leq -1.5 | 0.81759 | 0.56834 | 0.28975 | 0.10804 |
| | SPI \leq -2.0 | 0.83707 | 0.60075 | 0.31726 | 0.12101 |
| Winter | SPI \leq -0.5 | 0.57994 | 0.33499 | 0.14995 | 0.05243 |
| | SPI \leq -1.0 | 0.65146 | 0.40013 | 0.18692 | 0.06676 |
| | SPI \leq -1.5 | 0.69253 | 0.44391 | 0.21481 | 0.07822 |
| | SPI \leq -2.0 | 0.71106 | 0.46555 | 0.22968 | 0.08460 |

Table S6. Propagation probability of hydrological drought under various severities of meteorological drought at Hapcheon Dam Basin (case 1).

| Seasons | Conditions for SPI | Hydrological drought probability | | | |
|---------|--------------------|----------------------------------|------------------------------|------------------------------|------------------------------|
| | | SRI \leq -0.5 (0.30854) | SRI \leq -1.0 (0.15866) | SRI \leq -1.5 (0.06681) | SRI \leq -2.0 (0.02275) |
| Spring | SPI \leq -0.5 | 0.66217 | 0.42645 | 0.20417 | 0.07280 |
| | SPI \leq -1.0 | 0.82932 | 0.63534 | 0.35799 | 0.13814 |
| | SPI \leq -1.5 | 0.94295 | 0.85017 | 0.62435 | 0.29937 |
| | SPI \leq -2.0 | 0.98735 | 0.96335 | 0.87912 | 0.62098 |
| Summer | SPI \leq -0.5 | 0.66999 | 0.39326 | 0.17593 | 0.06135 |
| | SPI \leq -1.0 | 0.76477 | 0.49529 | 0.23692 | 0.08526 |
| | SPI \leq -1.5 | 0.81249 | 0.56264 | 0.28614 | 0.10658 |
| | SPI \leq -2.0 | 0.83205 | 0.59459 | 0.31297 | 0.11917 |
| Fall | SPI \leq -0.5 | 0.73368 | 0.43275 | 0.19218 | 0.06669 |
| | SPI \leq -1.0 | 0.84158 | 0.56894 | 0.27607 | 0.09955 |
| | SPI \leq -1.5 | 0.88756 | 0.65563 | 0.34790 | 0.13192 |
| | SPI \leq -2.0 | 0.90440 | 0.69426 | 0.38740 | 0.15208 |
| Winter | SPI \leq -0.5 | 0.64944 | 0.38013 | 0.17024 | 0.05943 |
| | SPI \leq -1.0 | 0.73925 | 0.47276 | 0.22500 | 0.08087 |
| | SPI \leq -1.5 | 0.78622 | 0.53434 | 0.26847 | 0.09946 |
| | SPI \leq -2.0 | 0.80601 | 0.56394 | 0.29207 | 0.11028 |

Table S7. Propagation probability of hydrological drought under various severities of meteorological drought at Hapcheon Dam Basin (case 2).

| Seasons | Conditions for SPI | Hydrological drought probability | | | |
|---------|-----------------------|----------------------------------|------------------------------|------------------------------|------------------------------|
| | | SRI \leq -0.5 (0.30854) | SRI \leq -1.0 (0.15866) | SRI \leq -1.5 (0.06681) | SRI \leq -2.0 (0.02275) |
| Spring | SPI \leq -0.5 | 0.69984 | 0.44867 | 0.20956 | 0.07337 |
| | SPI \leq -1.0 | 0.87253 | 0.68199 | 0.37788 | 0.14089 |
| | SPI \leq -1.5 | 0.96784 | 0.89740 | 0.67601 | 0.31468 |
| | SPI \leq -2.0 | 0.99498 | 0.98251 | 0.92409 | 0.67461 |
| Summer | SPI \leq -0.5 | 0.78131 | 0.46033 | 0.20244 | 0.06988 |
| | SPI \leq -1.0 | 0.89521 | 0.62898 | 0.30792 | 0.11088 |
| | SPI \leq -1.5 | 0.93491 | 0.73126 | 0.40367 | 0.15539 |
| | SPI \leq -2.0 | 0.94770 | 0.77323 | 0.45632 | 0.18456 |
| Fall | SPI \leq -0.5 | 0.71115 | 0.41904 | 0.18671 | 0.06492 |
| | SPI \leq -1.0 | 0.81491 | 0.54214 | 0.26181 | 0.09438 |
| | SPI \leq -1.5 | 0.86228 | 0.62176 | 0.32467 | 0.12230 |
| | SPI \leq -2.0 | 0.88045 | 0.65820 | 0.35916 | 0.13934 |
| Winter | SPI \leq -0.5 | 0.70851 | 0.41741 | 0.18604 | 0.06470 |
| | SPI \leq -1.0 | 0.81174 | 0.53905 | 0.26017 | 0.09378 |
| | SPI \leq -1.5 | 0.85921 | 0.61786 | 0.32205 | 0.12123 |
| | SPI \leq -2.0 | 0.87751 | 0.65402 | 0.35599 | 0.13794 |

Table S8. Propagation probability of hydrological drought under various severities of meteorological drought at Hapcheon Dam Basin (case 3).

| Seasons | Conditions for SPI | Hydrological drought probability | | | |
|---------|--------------------|----------------------------------|------------------------------|------------------------------|------------------------------|
| | | SRI \leq -0.5 (0.30854) | SRI \leq -1.0 (0.15866) | SRI \leq -1.5 (0.06681) | SRI \leq -2.0 (0.02275) |
| Spring | SPI \leq -0.5 | 0.61720 | 0.39728 | 0.19502 | 0.07144 |
| | SPI \leq -1.0 | 0.77260 | 0.57747 | 0.32951 | 0.13257 |
| | SPI \leq -1.5 | 0.90067 | 0.78252 | 0.55790 | 0.27525 |
| | SPI \leq -2.0 | 0.96884 | 0.92450 | 0.80830 | 0.55015 |
| Summer | SPI \leq -0.5 | 0.78730 | 0.46362 | 0.20357 | 0.07022 |
| | SPI \leq -1.0 | 0.90160 | 0.63692 | 0.31209 | 0.11233 |
| | SPI \leq -1.5 | 0.94016 | 0.74117 | 0.41146 | 0.15872 |
| | SPI \leq -2.0 | 0.95233 | 0.78338 | 0.46608 | 0.18933 |
| Fall | SPI \leq -0.5 | 0.66649 | 0.39103 | 0.17497 | 0.06103 |
| | SPI \leq -1.0 | 0.76044 | 0.49141 | 0.23486 | 0.08450 |
| | SPI \leq -1.5 | 0.80806 | 0.55776 | 0.28306 | 0.10533 |
| | SPI \leq -2.0 | 0.82769 | 0.58931 | 0.30931 | 0.11760 |
| Winter | SPI \leq -0.5 | 0.71273 | 0.45572 | 0.21097 | 0.07348 |
| | SPI \leq -1.0 | 0.88624 | 0.69753 | 0.38380 | 0.14151 |
| | SPI \leq -1.5 | 0.97432 | 0.91145 | 0.69283 | 0.31894 |
| | SPI \leq -2.0 | 0.99650 | 0.98689 | 0.93659 | 0.69184 |

Table S9. Propagation probability of hydrological drought under various severities of meteorological drought at Hapcheon Dam Basin (case 4).

| Seasons | Conditions for SPI | Hydrological drought probability | | | |
|---------|-----------------------|----------------------------------|------------------------------|------------------------------|------------------------------|
| | | SRI \leq -0.5 (0.30854) | SRI \leq -1.0 (0.15866) | SRI \leq -1.5 (0.06681) | SRI \leq -2.0 (0.02275) |
| Spring | SPI \leq -0.5 | 0.54554 | 0.31763 | 0.14718 | 0.05384 |
| | SPI \leq -1.0 | 0.61770 | 0.38723 | 0.19290 | 0.07514 |
| | SPI \leq -1.5 | 0.67971 | 0.45811 | 0.24797 | 0.10479 |
| | SPI \leq -2.0 | 0.73015 | 0.52399 | 0.30773 | 0.14233 |
| Summer | SPI \leq -0.5 | 0.79309 | 0.46674 | 0.20463 | 0.07054 |
| | SPI \leq -1.0 | 0.90767 | 0.64467 | 0.31616 | 0.11374 |
| | SPI \leq -1.5 | 0.94505 | 0.75083 | 0.41919 | 0.16202 |
| | SPI \leq -2.0 | 0.95662 | 0.79320 | 0.47577 | 0.19412 |
| Fall | SPI \leq -0.5 | 0.65878 | 0.38612 | 0.17285 | 0.06032 |
| | SPI \leq -1.0 | 0.75088 | 0.48294 | 0.23038 | 0.08285 |
| | SPI \leq -1.5 | 0.79826 | 0.54711 | 0.27639 | 0.10264 |
| | SPI \leq -2.0 | 0.81799 | 0.57778 | 0.30141 | 0.11424 |
| Winter | SPI \leq -0.5 | 0.70746 | 0.45287 | 0.21042 | 0.07344 |
| | SPI \leq -1.0 | 0.88070 | 0.69120 | 0.38143 | 0.14127 |
| | SPI \leq -1.5 | 0.97179 | 0.90584 | 0.68600 | 0.31726 |
| | SPI \leq -2.0 | 0.99593 | 0.98521 | 0.93165 | 0.68486 |

Table S10. Propagation probability of hydrological drought under various severities of meteorological drought at Hapcheon Dam Basin (case 5).

| Seasons | Conditions for SPI | Hydrological drought probability | | | |
|---------|-----------------------|----------------------------------|------------------------------|------------------------------|------------------------------|
| | | SRI \leq -0.5 (0.30854) | SRI \leq -1.0 (0.15866) | SRI \leq -1.5 (0.06681) | SRI \leq -2.0 (0.02275) |
| Spring | SPI \leq -0.5 | 0.65524 | 0.38385 | 0.17186 | 0.05998 |
| | SPI \leq -1.0 | 0.74648 | 0.47907 | 0.22833 | 0.08210 |
| | SPI \leq -1.5 | 0.79372 | 0.54225 | 0.27336 | 0.10142 |
| | SPI \leq -2.0 | 0.81347 | 0.57252 | 0.29784 | 0.11272 |
| Summer | SPI \leq -0.5 | 0.79446 | 0.46747 | 0.20488 | 0.07061 |
| | SPI \leq -1.0 | 0.90909 | 0.64652 | 0.31713 | 0.11407 |
| | SPI \leq -1.5 | 0.94619 | 0.75314 | 0.42105 | 0.16281 |
| | SPI \leq -2.0 | 0.95761 | 0.79554 | 0.47812 | 0.19529 |
| Fall | SPI \leq -0.5 | 0.65202 | 0.38179 | 0.17096 | 0.05968 |
| | SPI \leq -1.0 | 0.74246 | 0.47556 | 0.22648 | 0.08141 |
| | SPI \leq -1.5 | 0.78955 | 0.53785 | 0.27064 | 0.10033 |
| | SPI \leq -2.0 | 0.80934 | 0.56774 | 0.29462 | 0.11136 |
| Winter | SPI \leq -0.5 | 0.70025 | 0.44890 | 0.20961 | 0.07337 |
| | SPI \leq -1.0 | 0.87297 | 0.68249 | 0.37808 | 0.14091 |
| | SPI \leq -1.5 | 0.96806 | 0.89787 | 0.67655 | 0.31483 |
| | SPI \leq -2.0 | 0.99503 | 0.98266 | 0.92451 | 0.67516 |