Forecasting of selected drought indices using selected models based on the theory of decision trees

Master Thesis

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Název práce

Forecasting of selected drought indices using selected models based on the theory of decision trees

Název anglicky

Forecasting of selected drought indices using selected models based on the theory of decision trees

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Cíle práce

The aim of thesis is to evaluate the temporal forecast of the selected drought indices using black box models based on the theory of decision trees.

Metodika

The methods are based on:

1. the preparation of dataset of drought indices
2. calibration and validation of random forest models on drought forecast
3. calibration and validation of models of extremely randomized trees on drought forecast
4. comparison of model results

Doporučený rozsah práce

standard

Klíčová slova

drought, forecast, random forest, extremely randomized trees

Doporučené zdroje informací

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Contents

Abstract

In this thesis several drought indices, like the Standardised Precipitation Index (SPI), the Standardised Precipitation Evaporation Index (SPEI), the Standardised Soil Moisture (SSI) and the Palmer Drought Severity indices were analyzed using tree-based ensemble methods: Random Forest model and Extremeely Randomized Trees model. Tested Extremeely Randomized Trees and Random Forest models used forecasting and predicting methods. Data were obtained from 27 meteorological stations located in different parts of the Czech Republic. Records from 01/01/1982 to 01/12/2015 period were used. The results of forecasted drought indices was explained by the values of performance estimators, such as Mean Average Error (MAE), Root Mean Square Error (RMSE), Nash–Sutcliffe model efficiency coefficient (NSE) and Kling-Gupta Efficiency (KGE).

Keywords: Drought, Drought Index, Decision Tree, Random Forest, Extra-Trees, Ensemble methods

Declaration

I declare that this submitted thesis “Forecasting of selected drought indices using selected models based on the theory of decision trees” has been composed entirely by myself, except where explicitly stated otherwise in the text.

Aigerim Otarbayeva

Prague, April 18th 2019

Dedication and Acknowledgements

I would like to thank my final thesis supervisor, doc. Ing. Petr Maca, Ph.D. who guided me in this process, for his patience, support and inspiration. I couldn't make it without his all round help.

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Chapter 1

Introduction

Drought is a period of inadequate or no rain fall over extended time creation soil moisture deficit and hydrological imbalances.

Drought indices can be described by following indices: PDSI (The Palmer Drought Severity Index), SPI (The Standardised Precipitation Index), SPEI (The Standardised Precipitation Evapotranspiration Index) and SSI (The Standardized Soil Moisture Index).

The SPI index is evaluated by precipitation data. The SPI index can be used for evaluation of hydrological and agricultural droughts.

The SPEI index is based on precipitation and potential evapotranspiration data. Potential evapotranspiration temperature are mostly gained from information about temperature data. The SPEI index is expressed by using differences between potential evapotranspiration and precipitation. Generally, it uses the same derivation as SPI index, but the differences is that instead of precipitation time series used for derivation SPI, the time series of differences above are used.

Before discuss what is drought, firstly, let's provide information about historical perspective how drought was varied over regions of the world during the last millennium.

Proxy data together with instrumental records have demonstrated that large-scale droughts have occurred many times during the past 1000 years over the world, including North America, Asia, Africa and Australia. Assumed that these megadroughts were generated by multi-decadal El-Nino sea surface temperature patterns in the tropical Pacific Ocean in the cases of the XIXth and XXth centuries, including the Dust Bowl drought of the 1930s when increased dust has influenced the drought. In some studies, a significant role of the Atlantic multi-decadal Oscillation is mentioned as prolonged drought cause over United States and Mexico. (Dai, 2011)

Historical records over East China have demonstrated that large-scale droughts occurred many times during the last 500 years. The severe droughts in East China were occurred in 1586 - 1589, 1638 - 1641, and 1965 - 1966, which were firstly developed in North China and then either expanded southward or move to the Yangtze River Valley and the northern part of the southeastern coastal area. Also is assumed that large volcanic eruptions might be responsible for severe droughts in East China. (Dai, 2011)

West Africa was impacted by severe Sahel droughts in the 1970s and 1980s, which has devastated the local population. Proxy data for African lake levels indicated dry and wet periods occurred in the early and late part of the XIXth century, respectively, over West and East Africa. These data showed that natural monsoon variations in West Africa are the main reason of severe droughts. Droughts are also resulted from a southward shift of the warmest SSTs and the associated inter-tropical convergence zone (ITCZ) in the tropical Atlantic, and the steady warming in the Indian Ocean. (Dai, 2011)

Europe faced the highest frequency of drought events in the period 1951 - 1970 in most of the regions. An exception is the drought's highest frequency in the period 1991 - 2010 in South - Western regions. Overall, the drought events have been longest and most severe in North- Eastern Europe in the period 1951–1970, in Central European regions in the period 1971–1990, and in Southern Europe (in particular in the Mediterranean area) in the period 1991–2010. (Spinoni et al., 2015)

Log-logistic distribution has been used for modelling of streamflow and precipitation in hydrology.

1.1 The aim of thesis

The aim of present thesis is to review the knowledge about the drought phenomenon, to give information about drought types and their influence on environment, economy and society. Besides, the comprehensive overview of drought indicators was provided, especially the Palmer drought severity index (PDSI), the standardized precipitation index (SPI), the standardized precipitation evapotranspiration index (SPEI) and the standardised soil moisture index (SSI) and their calculations. Furthermore drought events forecasting and prediction were described for 27 meteorological stations, located in Czech Republic, using Random Forest and Extremely Randomized Trees decision tree methods.

1.2 The thesis structure

In the first few chapters, the drought phenomenon and its impact are described, and the characteristics of drought indicators are depicted.

The chapter 3 describes various drought forecasting methods and looks more closely to Decision Tree methods like Random Tree and Extremely Randomized Trees.

In the second part of the thesis the description of given meteorological stations in the Czech Republic is presented and forecasting models using decision tree methods are generated.

In the end of the thesis, the results were discussed and conclusion was made.

Chapter 2

Drought phenomenon review

According to Dai (2011) drought is a repeating extreme climate event characterized by below-normal precipitation over a period of months to years. Drought can occur even in wet region, because drought is characterized as time interval drier than its local normal conditions. This happens because drought is characterized as rain free period relative to its local normal condition.

When region is suffering with drought its ecosystem and as a result its economy become vulnerable. The most vulnerable sector affected by drought we can call the agriculture sector, which makes up to 37,72% of the world land area. From 2000 till 2013 the total land used for agriculture reduced approximately 0,4% with large regional differences. (Azadi et al., 2018)

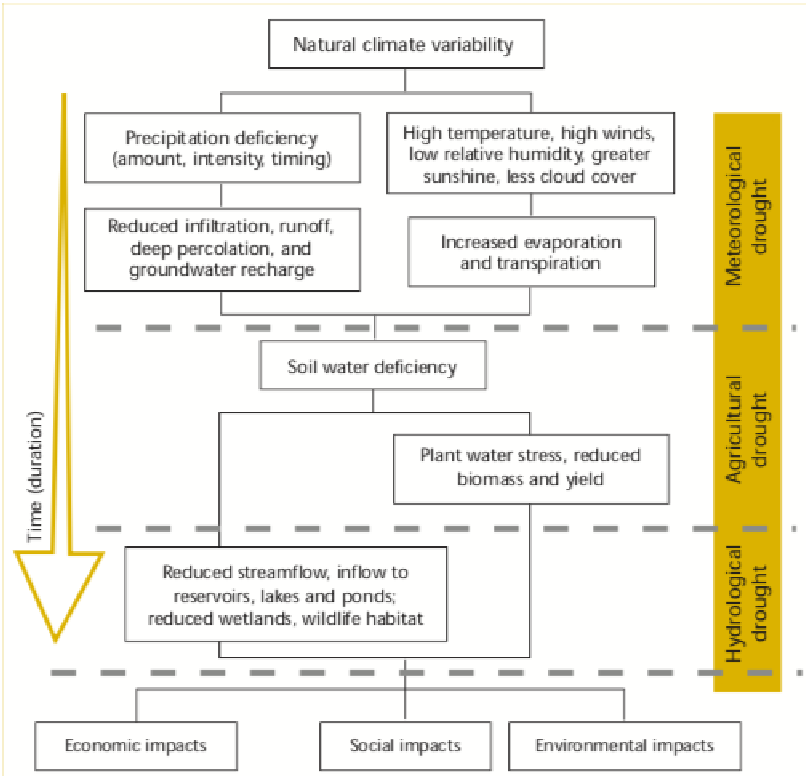
Headwaters and groundwater are influenced by drought, which can lead to water supply reduction, water quality deterioration, crop failure, loosen power generation, as well as affect on economic and social sides. (Riebsame et al., 1991)

Drought is the first among natural hazards on terms of the number of affected people, even if it differs in several ways. Firstly, it is difficult to determine the beginning and the end of drought and its impacts. That is why drought is often referred to as a creeping phenomenon. Secondly, drought doesn't have universal definition, and it is difficult to being defined. Thirdly, drought impacts expand over large geographical areas and are non-structural in comparison with other hazards. That is why it is more difficult to assess of impact and provision of relief actions. Fourthly, human activities can directly influence a drought by excessive irrigation, water overuse, deforestation and erosion. (Mishra and

Singh, 2010)

As demonstrated in Figure 2.1, a drought event depends on specific meteorological condition. Associated with precipitation deficiency and the increasing dry and warm weather, a meteorological drought develops. An agricultural drought might be occurred because of the precipitation deficiency and the high evapotranspiration, which reduces the soil water content. As long as the precipitation decreases and further has deficit in the catchment, stream flow feds by groundwater. Prolonged precipitation deficit can lead to depletion of groundwater reservoirs.

Figure 2.1: Impacts of drought (ISDR and WMO, 2004)



Since water from surface and groundwater reservoirs is often used for flood control, irrigation, recreation, hydro power, navigation or wildlife habitat, exceeding water demand results to socio-economic drought. Drought classification makes necessary better understand characteristics of drought and prevent drought impacts on time. (Stahl, Kirsten, 2001)

2.1 Drought classifications

As prescribed by Wilhite and Glantz (1985), each drought type can be characterised according to following criteria: intensity, duration and spatial distribution. Along with these criteria drought type depends on the human activities demands and by the vegetation on a region's water supplies.

Among three main criteria of drought, intensity can be determined as a key factor, since drought with short duration but with high intensity can cause greater damages. Sometime it is hard to determine the duration of drought, as well as its spatial distribution. It is worthy to note that there is a close affinity between drought classifications, because they have a significant impact on each other.

Based on source of water availability drought can be classified as:

- Meteorological drought;
- Hydrological drought;
- Agricultural drought;
- Socioeconomic drought.

2.1.1 Meteorological Drought

The first class of drought, meteorological drought, mainly indicates deficit rain of different rate and can lasts from months to years. Meteorological drought can lead to other types of droughts, such as agricultural and hydrological droughts. Meteorological drought is caused by continual anomalies in large scale atmospheric circulation patterns.

Precipitation is the main indicator for analysing meteorological drought. Monthly precipitation data have been used for analysing in some of the studies, other studies analyse drought duration and intensity in relation to cumulative precipitation shortages. (Mishra and Singh, 2010; Dai, 2011)

2.1.2 Hydrological Drought

Hydrological drought is related to a period when river streamflow and water storages in aquifers, lakes, or reservoirs fall below long-term mean levels. This drought class develops more slowly because it includes stored water that is depleted but not refilled. A lack of precipitation provokes agricultural and hydrological droughts, but other factors, such as intense but less frequent precipitation, poor water management, and erosion, can also cause or fade up these droughts.

Drought related regression analyses in streamflow to catchment properties depicted that geology is one of the main factors influencing hydrological drought (Dai, 2011; Mishra and Singh, 2010)

2.1.3 Agricultural Drought

Agricultural drought can be indicated as dry soils period that results from below-average precipitation, intense but less frequent rain events, or above-normal evaporation, all of which lead to reduced crop production and plant growth. For agricultural drought soil moisture content (not always measured) is often used. (Dai, 2011)

Soil moisture is used as an indicator of agricultural drought monitoring in different forms, such as soil moisture percentile and normalized soil moisture. (AghaKouchak, 2014) Also drought intensity can be represented by difference between vegetation water demand and available soil moisture. (Wilhite and Glantz, 1985)

Agricultural drought definition should correspond to crops' susceptibility at different vegetation development stage. Topsoil moisture deficit may prevent germination, leading to low yield per unit. A drought occurring in the later stage of crop plant can blast or deplete crop yields. (Economic and for Western Asia, 2005)

2.1.4 Socioeconomic Drought

Socioeconomic drought is related to the supply and requirement of some economic good with elements of meteorological, agricultural, and hydrological drought. Socioeconomic drought occurs, where the requirement for an economic good exceeds supply because of a weather-related shortfall in water supply. In 2004 the United Nations International Strategy for Disaster (UNISDR) and the World Meteorological Organisation (WMO) determined socioeconomic drought as a separate classification in their publication "Water and Disasters. Be informed and be prepared" in Geneva, Switzerland. It differs from drought types mentioned above because its existence depends on the time and space processes of supply and requirement to identify or classify droughts. Because of the natural variability of climate, water supply is sufficient in some years but unable to satisfy a demand in other years. In the majority of cases, the requirement for economic goods is increasing as a result of increasing population and consumption per capita. Supply may also increase because of improved production efficiency, technology, or the construction of reservoirs that increase surface water storage capacity. If both supply and requirement are increasing, the critical factor is the relative rate of change. (Economic and for Western Asia, 2005; ISDR and WMO, 2004; Wilhite and Glantz, 1985)

2.2 Drought Indices Description

In this chapter the types of indices and their characteristics are described. Before describing indices it is important to define meanings of drought indicators and indices and difference between them. Indicators are variables or parameters used to characterise drought conditions, for example: precipitation, temperature, streamflow, groundwater and reservoir levels, soil moisture and snowpack. Indices are variables or parameters used to numerically represented drought severity using hydro-meteorological inputs included indicators. The goal of indices is qualitative measuring of droughts on a given location for a given time period. Drought indices in combination with additional information on exposed assets and their vulnerability characteristics - are essential for tracking and anticipating drought-related impacts and outcomes. (Svoboda M. D. and (GWP), 2016)

We can distinguish three main methods for monitoring drought and determining early warning and assessment:

- using a single indicator or index;
- using multiple indicators or indices;

- using composite or hybrid indicators.

In the past, researchers used one indicator or index due to its the only availability or due to limited time to obtain data and compute derivative indices or other results. With time strong global interest and growth in the development of new indices based on various indicators has been appeared.

There are several drought indices widely used today around the world, but there is no single index that can be applied to all types of droughts, climate and sectors affected by droughts. Appropriate index should be used by many factors such as climate, space, time and severity levels.

In this thesis I will describe the Standardised Precipitation Index, the Standardised Precipitation Evapotranspiration Index, the Palmer Drought Severity Index and the Standardised Soil Moisture Index.

2.2.1 The Palmer Drought Severity Index (PDSI)

The Palmer Drought Severity Index is the most useful drought index which was developed by W. C. Palmer in 1965. The PDSI index uses monthly temperature and precipitation data together with moisture retention capacity to estimate relative dryness. The PDSI was mainly developed to estimate agricultural drought, but has also been used for determining other types of drought.

The Palmer method of drought evaluation is based on the use of two bucket-type layers of the soil horizon, with the lower horizon being saturated with water only while the upper horizon is saturated and the same applies to vapor.

The Palmer model also calculates the Palmer moisture anomaly index (Z index), which can detect agricultural drought, since it responds quickly to changes in soil moisture. (Lloyd-Hughes and Saunders, 2002)

The Palmer drought index is defined as a sum of the current moisture observation and of previous index value. The moisture observation can be find as

$d = P - \hat{P}$

where P is the total monthly precipitation; $\hat{P}$ is the water balance equation defined as

$\hat{P} = \bar{ET} + \bar{R} + \bar{RO} + \bar{L}$

where $\bar{ET}$ is the evapotranspiration; $\bar{R}$ is the soil water recharge; $\bar{RO}$ is the runoff; and $\bar{L}$ is the soil water loss. The over bars mean the average values for the given period taken over given calibration period.

The Palmer moisture anomaly index (Z index) can be defined as

$Z = K * d$

where K is a climate weighting factor, which is comparable with local significance in space and time.

And, finally, the PDSI for given i month is defined as

$PDSI_i = 0,897 PDSI_{i-1} + Z_i/3$

The PDSI values are divided into categories, ranging from extremely dry to extremely wet. These are listed in Table 2.1. (Lloyd-Hughes and Saunders, 2002)

Table 2.1: Severity Classification, PDSI.

PDSI value	**Class**
$PDSI \geq 4,00$	Extremely wet
$3,00 \leq PDSI < 4,00$	Very wet
$2,00 \leq PDSI < 3,00$	Moderate wet
$1,00 \leq PDSI < 2,00$	Slightly wet
$0,5 \leq PDSI < 1,00$	Incipient wet spell
$-0,5 \leq PDSI < 0,5$	Near normal
$-0,5 \leq PDSI < -1,00$	Incipient dry spell
$-1,00 \leq PDSI < -2,00$	Mild drought
$-2,00 \leq PDSI < -3,00$	Moderate drought
$-3,00 \leq PDSI < -4,00$	Severe drought
$PDSI \leq -4,00$	Extreme drought

2.2.1.1 Limitation of Palmer Drought Severity Index

The most substantial limitations of the PDSI include:

- all precipitation is treated as rain so the other precipitation types are not counted, which can lead to questionable trust of real-time winter PDSI values;
- the PDSI doesn't monitor well mountainous areas, especially since a majority of precipitation in these regions falls as snowfall during the winter, thus can slowly respond to developing drought conditions;
- an index's timescale makes the PDSI better suited for characterising agriculturally related impacts rather than longer- term hydrological impacts;
- the natural lag between precipitation and runoff is not considered and no runoff occurs in the model until the water capacity of the surface and subsurface soil layers are full, leading to an underestimation of runoff;

All these limitations result in developing of new drought monitoring indices, such as Standardised Precipitation Index, or SPI.

2.2.2 The Standardized Precipitation Index (SPI)

The Standardized Precipitation index was developed in 1992 at Colorado State University by McKee et al. and firstly presented at the 8th Conference on Applied Climatology in January 1993.

In 2009, World Meteorological Organisation recommended SPI for widespread use in countries wanting to track meteorological drought. (Hayes et al., 2011)

Calculation of the SPI for a specific time period and location requires long-term monthly precipitation data for 30 years or more. (Hayes, MJ and Svoboda, MD and Wilhite, DA and Vanyarkho, OV, 1999)

For the SPI calculation a monthly precipitation data set of at least 30 years is prepared for a given period of months. A set of time scale is determined, which could be equal

Table 2.2: Drought Severity Classification, SPI.

	Index value	Class
Non-Drought	$SPI \geq 2,00$	Extremely wet
	$1,50 \leq SPI < 2,00$	Very wet
	$1,00 \leq SPI < 1,50$	Moderate wet
	$-1,00 \leq SPI < 1,00$	Near normal
Drought	$-1,50 \leq SPI < -1,00$	Moderate drought
	$-2,00 \leq SPI < -1,50$	Severe drought
	$SPI < -2,00$	Extremely drought

to 3, 6, 12, 24, or 48 months. That means a new month value is determined from the previous months. The precipitation data set is fitted to the Gamma function to define the relationship of probability to precipitation, which then transformed into a normal distribution. Positive SPI values demonstrate greater than median precipitation and negative values indicate inverse condition. Since the SPI is normalized, so wetter and drier climates are represented in the same way.

The SPI can be defined as:

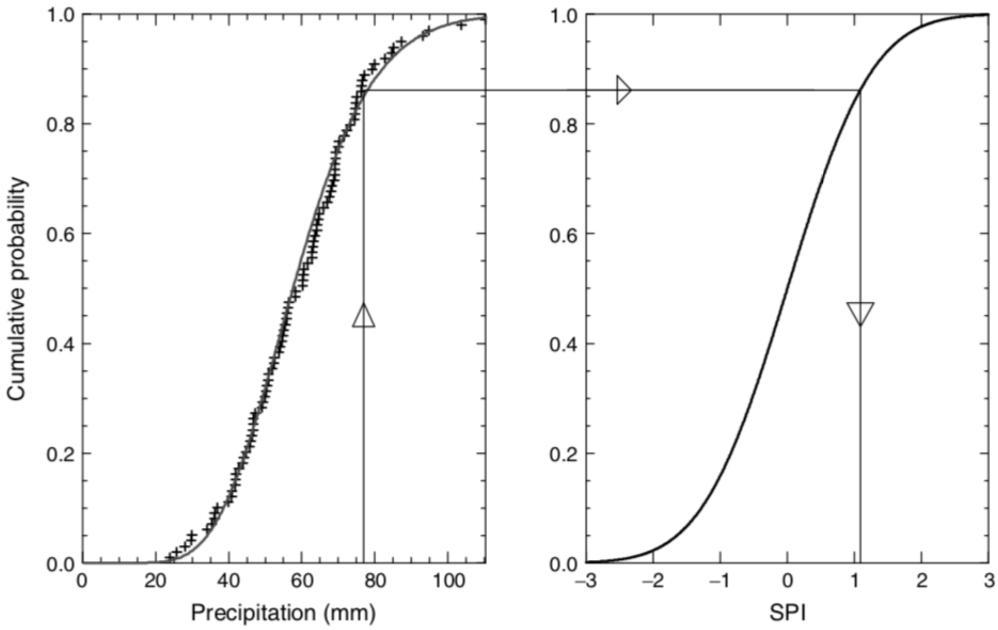
$SPI = (x_{ij} - x_{im})/\delta$

where x_{ij} is the total rainfall for given period (mm) in ith station and j observation; x_{im} is the average rainfall for given period; δ is the standard deviation.

The SPI has an intensity scale in which both, positive and negative values, are presented. They are corresponded to dry and wet events (Table 2.2). Drought is signified when SPI result become continuously negative and reach value of -1 and is considering ongoing until SPI obtain 0 value.

In Figure 2.2 the SPI determination is shown. It consists of 2 panels: first one shows the empirical cumulative probability distribution of precipitation, the second one demonstrates a graph of standard normal cumulative probability. The example given in figure used data for a 3 month average December–January–February (DJF) of precipitation over the south east of England for the period 1901–1999. (Lloyd-Hughes and Saunders, 2002)

Figure 2.2: Transformation from a fitted Gamma function to the normal distribution. (Lloyd-Hughes and Saunders, 2002)



2.2.2.1 Limitation of the Standardised Precipitation Index

The main weakness of the SPI is the precipitation as the only input. Using of the SPI is insufficient when considering with the temperature component, which is important to the overall water balance and water use of a region. The other limitation of SPI is that index can lead to misuse of the output when calculated for short periods of record, or on data that contain many missing values. (Hayes et al., 2011)

2.2.3 The Standardized Precipitation Evapotranspiration Index (SPEI)

The Standardized Precipitation Evapotranspiration Index (SPEI) was developed by Vicente-Serrano et al. at the Instituto Pirenaico de Ecologia in Zaragoza, Spain.

The SPEI is based on SPI, but also includes a temperature data, giving possibility to index to consider temperature effect on drought development using basic water balance calculation. It is making SPEI an ideal index when looking at the impact of climate change in model output under various future scenarios. The SPEI, as well as the SPI, has an intensity scale in which both, positive and negative values, are presented corresponding to wet and dry events. (Svoboda M. D. and (GWP), 2016)

Table 2.3: Drought Severity Classification, SPEI. (Nam et al., 2015)

SPEI value	**Class**
$SPEI \geq 2,00$	Extremely wet (humid)
$1,50 \leq SPEI < 2,00$	Severe wet
$1,00 \leq SPEI < 1,50$	Moderate wet
$0,50 \leq SPEI < 1,00$	Slightly wet
$-0,50 \leq SPEI < 0,50$	Near normal
$-1,00 \leq SPEI < -0,50$	Mild dry
$-1,50 \leq SPEI < -1,00$	Moderate dry
$-2,00 \leq SPEI < -1,50$	Severe dry
$SPEI \leq -2,00$	Extreme dry (drought)

The SPEI is based on the SPI calculation procedure. The SPEI use monthly differences between precipitation and potential evapotranspiration (PET). It is uses Thornthwaite (1948) method that is calculated at different time scales and requires only mean monthly temperature. Following this method, the monthly PET (mm) is defined by

$PET = 16K(\frac{10T}{I})^m$

where T is a mean monthly temperature; I is a heat index, which is found as the sum of 12 monthly index values i; K is a correction coefficient computed as a function of the latitude and month; m is a coefficient depending in I .

Index value i is defined using formula

$i = (\frac{T}{5})^{1,514}$

The correction coefficient K can be computed as

$K = (\frac{N}{12})(\frac{NDM}{30})$

where NDM is the number of days in month and N is the maximum number of sun hours, which is calculated using

$N = (\frac{24}{\pi})\varpi_s$

where ϖ_s is the hourly angle of sun rising. ϖ_s can be calculate as following

$$\varpi_s = arccos(-tan\varphi tan\delta)$$

where φ is the latitude in radians and δ is the solar declination in radians.

δ is calculated using

$$\delta = 0,4093sen(\frac{2\pi J}{365} - 1,405)$$

where J is the average Julian day of the month.

After calculating the PET, it is possible to calculate difference between the precipitation P and PET for the month i using

$$D_i = P_i - PET_i$$

For the SPI calculation at different time scales a probability distribution of the gamma family is used. Even though two-parameters distribution is using for calculation the SPI such as gamma distribution, a three-parameter distribution is needed to calculate the SPEI, which can take values in range $\gamma < x < \infty$, where γ is the parameter of origin of the distribution, therefore x can have negative values. The three-parameter distribution for the SPEI calculation are Pearson III, Log-normal, General Extreme Value, Log-logistic. (Vicente-Serrano et al., 2010)

L-moments ratio diagrams are analogous to conventional central moments, but they are able to characterize a wider range of distribution function and are most robust in a relation to outliers in the data.

2.2.4 Standardized Soil Moisture Index (SSI)

The standardized soil moisture index (SSI) is based on soil moisture only and is defined as the standard deviations obtained from the long-term normal conditions at a given location and timescale. Specifically, the SSI is computed by fitting a non-parametric probability distribution function to historical soil moisture records and then transforming it into a normal distribution with a mean of zero and standard deviation of one, as it depicted in Figure 2.3. Negative standard normal values indicate dry conditions and positive values indicate wet conditions. (Carrao et al., 2013)

Table 2.4: Drought Severity Classification, SSI. (Carrao et al., 2013)

SSI value	**Class**
$SSI > 2,00$	|Extremely wet
$1,50 < SSI \leq 2,00$	Severe wet
$1,00 < SSI \leq 1,50$	Moderate wet
$-1,00 < SSI \leq 1,00$	Near normal
$-1,50 < SSI \leq -1,00$	Moderate dry
$-2,00 < SSI \leq -1,50$	Severe dry
$SSI \leq -2,00$	Extreme dry

The SSI can be estimated for various timescales since uses soil moisture average amount. The SSI calculation is similar to the Empirical Standardized Precipitation Index (ESPI) and consists of three steps:

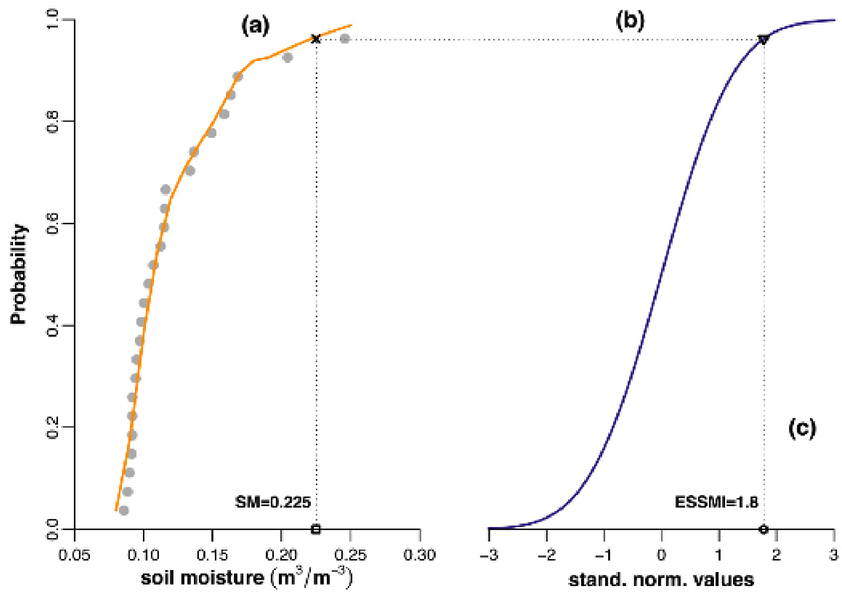
1. the Probability Density Function (PDF) is fitted to the long term record of the Essential Climate Variable Soil Moisture (ECV SM) observations, where t is an average timescale (1-, 3-, 6-, or 12-months), and n is years.

2. the Empirical Cumulative Density Function (ECDF) of averaged ECV SM observations is calculated.

3. the non-exceedance probability is transformed to the standard normal variable (mean=0 and variance=1) and the SSI value is found.

In Figure 2.3 the SSI drought index computation process is demonstarted. The example is taken from Carrao et al. (2016). The orange curve on the left represents the ECDF related to the PDF fitted by means of ECV SM observations collected in the long-term period (gray filled circles). The blue curve on the right represents the standard normal cumulative distribution function (CDF). The non-exceedance probability is estimated in Step (a), transformed to the standard normal variable Z in Step (b), and the SSI value is found in Step (c).

Figure 2.3: SSI drought index computation process (Carrao et al., 2016)



2.2.5 Comparison of drought indicators

Several comparisons, like Guttman's in 1998 and Hayes's et al. in 1999, were made since Standardized Precipitation Index was released. These comparisons were concluded that SPI has advantages of statistical consistency and able to characterize both impacts, short-term and long-term, through different time scales precipitation anomalies. Nowadays, the SPI is the most used standardized meteorological drought index. Its advantages are simplicity, results calculated in normalized values and computation possibility in different time scales. Also, because of its probabilistic property, the SPI better monitors drought risk analysis, than PDSI. (Guttman, 1998; Cancelliere et al., 2007) Disadvantage of the SPI is that only precipitation data are needed , although other meteorological variables might be important too. Also due to the SPI has standardised nature, it is not capable of identifying regions that may be more subjected to drought than others. (Van Loon, 2015)

Before the SPI releasing the PDSI was widely used drought index. It measures deviation of moisture balance using a simple water balance model. But despite of worldwide application, the PDSI has set of limitations. Firstly, the calculation procedure is complex, spatially variant and difficult to interpret. Secondly, it doesn't include snow accumulation and soil moisture control during evapotranspiration. Finally, since the PDSI drought index was calibrated for the USA, it should be re-calibrated for using in other regions. (Van Loon, 2015)

At this time in Europe, the most used drought indices are the SPI and the SPEI. Since the SPI takes as a basis precipitation data it is applied in almost every region in Europe. While as the SPEI is based on the difference of precipitation and potential evapotranspiration data, it is applied particularly in regions where these data are available, for example Iberian Peninsula.

The PDSI has been successfully applied in drought studies in Europe as well, although its require many variables for calculation. (Spinoni et al., 2015)

Chapter 3

Drought Forecasting methods

In these latter days, interest in drought planning has been heightened at all levels. One of the reasons of that interest are great expenses in economical, social and environmental fields caused by drought impacts. People can reduce drought impacts by planning ahead methods for mitigation drought impact risk. (Monacelli et al., 2005)

Hydrological measurements and real-time meteorological observations together with historical observations become an input data for drought forecasting methods in a specific area. Recently machine learning methods have also been applied for drought forecast.

Drought forecasting can be done applying physical, conceptual or data-driven approaches. Data-driven approach doesn't required large number variables as inputs, therefore is widely used in hydrological forecasting. These models also have rapid design time. In contrast with physical and conceptual models, data-driven models can be used for real-time forecasting. (Belayneh and Adamowski, 2012)

The most widely used over past two decades drought-forecasting tools are Artificial neural networks (ANN), that remind the structure of biological neural networks. The advantage of using ANNs is using of black box modelling technique, there is no need to assign the physical processes between the inputs and outputs. Multilayer perceptron (MLP), the type of ANN, has been used in several studies and usually been optimised with a back propagation algorithm. However, ANN are terminated to manage nonstationarities in the data, as well as a weakness shared by multiple linear regression (MLR) and autoregressive integrated moving average (ARIMA) models. (Belayneh and Adamowski, 2012)

Limitation with non stationary data led to hybrid models development, where non stationary data is pretreat and, then, run through a forecasting method to cope with the nonlinearity. Wavelet analysis is an effective mathematical tool to deal with non stationary data and has been widely applied to several hydrological studies. This improves the ability of Wavelet-neural network conjunction model (WN) forecast a model effectively by capturing useful information on various resolution levels. (Kim and Valdes, 2003)

Along with ANN and WN models one of the effective forecasting method is Support Vector Regression (SVR) model, which was invented by Vladimir Vapnik in 1995. SVR model can be applied for both, classification and regression problems. SVR model follows the structural risk minimisation principle, therefore generalisation error decreased. However, it takes longer computation than neural network. (Belayneh and Adamowski, 2013)

In the present thesis I will use the machine learning models like Decision Tree, Random Forest and Extremely Randomised Trees to effectively forecast all given drought indices. In the following sections the results for the best results for 27 basins will be presented.

3.1 Decision Trees

In this section the general information about Decision Tree methods is provided.

Linear regression is the widely method of modeling the relationship between dependent variable and one or more independent variables. Sometimes it is possible to combine some of the interactions, but the amount of parameters can get large and stronger nonlinearities are going to be trouble. As a variant to nonlinear regression can be used partitioning the space into smaller regions, where the interactions are more manageable. These regions could be partitioned again until we get region of the space ordinary for fitting simple models to them. This process is called *recursive partition*.

Decision tree is a modeling approach used for visual and explicit representation of model estimation. Decision trees use the tree for representing the recursive partition. We start to ask a sequence of questions from *the root node* of the tree and end with the *[*terminal nodes], or *[*leaves]. The interior nodes are labeled with questions and the branches are labeled by the answers. Next questions we ask depend on the answers to previous questions. Independent variables could be continuous, discrete or categorical etc. (Minka, 2006)

The decision trees are easy to interpret, that is a big advantage. On the other hand, that decision tree could be over fit with noisy data as a tree gets deeper. For handling over fitting of tree we can use pruning, the method of limiting tree depth.

In statistical approaches like artificial neural network (ANN) it is difficult to represent function as a rule understood by people. On the other hand, in decision tree the rules can be written in an “if - then” format, which can be observed to check the results’ significance. (Sattari et al., 2012)

Decision tree can be divided into two groups: regression tree and classification tree. These types of trees predict continuous dependent variables and categorical predictor variables, respectively.

3.2 Random forest regression tree models

The Random Forest was developed by Breiman in 2001 and represents a non-parametric technique based on flexible decision tree algorithm. This technique is an extension of classification and regression trees (CART), which produces many classification trees to improve model prediction and designed to predict continuous variables of Y. Continuous variable is predicted by performing recursive partitioning on the training data. (Pham et al., 2017)

During the Random Forest modeling randomized set of variables splits the tree to nodes. The goal of model building process is to find the average outcome of all the trees. To run the Random Forest model the number of variables used in each model building process (mtry) and the number of trees to be built in the forest (ntree) are necessary to be known. There is no exact procedure how many variables and trees should be use, the main principle is that in order to minimize the generalization error, the mentioned parameters should be optimized. (Rahmati et al., 2016)

Each tree in Random Forest model is generated by bootstrap samples, leaving about one-third of the overall sample for validation, using the out-of-bag (OOB) error. According to Breiman (2001), out-of-bag error is the proportion of out-of-bag samples that were incorrectly classified. The main advantages of this method are:

a no over fitting occurs;

b individual trees are low correlated since the diversity of the forest is increased through the usage of a limited number of variables;

c higher prediction performance;

d low bias and low variance due to averaging over a large number of trees;

e robust error estimates using the out-of-bag data. (Wiesmeier et al., 2011)

Regression trees are constructed using a recursive partitioning (RP) algorithm, which looks as follows (Torgo et al., 1999):

Input: A set of n datapoints,$(< x_i, y_i >), i = 1,...,n$

Output: A regression tree

if *termination criterion* **then**

  Create Leaf Node and assign it a Constant Value;

  Return Leaf Node;

else

  Find Best Splitting Test s*;

  Create Node t with s*;

  Left_branch(t) = RecursivePartitioningAlgorithm($< x_i , y_i > : x_i \rightarrow s*$);

  Right_branch(t) = RecursivePartitioningAlgorithm($< x_i , y_i > : x_i \not\rightarrow s*$);

  Return Node t;

end

The algorithm has three main components:

- the splitting rule;
- termination criterion;
- terminal node assigning rule.

The main disadvantage can be the fact that since Random Forest model is a “black box” model it can be very demanding in terms of time and computer resources. (Prasad et al., 2006)

A detailed mathematical description of Random Forest can be found in Breiman (2001). The goal of Random Forest is to measure the correlation between independent variables and a dependent variable to assign the weight value for each variable. In this thesis, the drought indices like SPI, SPEI, PDSI, scPDSI and SSI as dependent variable and independent variables, respectively.

3.3 Extremely Randomized Tree

Extremely Randomized Trees (Extra-Trees) is a non parametric tree-based regression method proposed by Geurts in 2006 and is a totally randomized tree-based ensemble method that randomly selects both the input variables and the splitting values considered in creating a node during building a tree, and create a forest of trees to compensate for the randomization, via averaging of the constituent tree outcomes. Extra-Trees can be characterized as method that (a) is computationally efficient; (b) mitigates the poor generalization property and tendency to over fitting of traditional standalone decision trees (e.g. CART); and, (c) allows to infer the relative importance of the input variables, which might help in the ex-post physical interpretation of the model. (Galelli and Castelletti, 2013)

Extra-Trees model building is characterized by three parameters: M- number of trees in the ensemble, K - number of random splits, and n_{min} - number of samples required for splitting a node.

Increasing of M parameter reduces the variance of model, but needs more efforts for computation, therefore the appropriate M value will depend on compromise between computational requirements and model accuracy.

The parameter K may be chosen in the interval $[1, ..., n]$, where n is the number of variables. The smaller parameter K is, the stronger the randomization of the trees and the weaker the dependence of their structure on the output values in training data set. In the extreme case, for K equal to 1, the splits (cut-directions and cut-points) are chosen in a totally independent way of the output variable and totally randomized trees are built. On the other extreme case, when K equal to n, the cut-direction selection is not randomized anymore, and the randomization effect acts only through the choice of cut-points.

The last parameter of the Extra-Trees method is the n_{min}. Larger values of n_{min} lead to smaller trees with higher bias and smaller variance, and, inversely, lower values of n_{min} lead to grown trees, which may be over fitted. The optimal value of n_{min} depends on principle on the level of noise in the training data set. Even if noisy should be refined, the results illustrate that the noisier the output, the higher the optimal value of n_{min}, which leads to the method robustness to high noise conditions. (Galelli and Castelletti, 2013)

In Extra - Trees nodes are split according to the following sequence: K random splits are randomly chosen and, for each split, a random cut-point is chosen; the cut-point which is mostly reduce the variance splits the node. The termination test that determines when to stop partitioning a node is based on the number of instances within the node. When this number is smaller than a user-defined value n_{min}, the algorithm stops partitioning a node and a leaf is created. (Geurts et al., 2006) Value is finally assigned to each leaf, obtained as the average of values associated to the inputs getting in that leaf. The computation produced by the M trees are finally aggregated by arithmetic average.

The rationale behind the approach is that the use of the original training data set (instead of a bootstrap or bagging) is motivated to minimize bias, while the combined use of randomization and ensemble averaging is aimed at reducing the variance of the model output. (Geurts et al., 2006) Thus, final model doesn't require the post processing methods, such as pruning or smoothing.

In this thesis, I study the prediction efficiency of extremely randomized trees (Extra-Trees), related to its explanation ability, accuracy and computational efficiency.

3.4 Models for prediction and forecasting

In this section forecasting and prediction methods will be characterized. Also I will describe the main differences between these two methods.

Forecasting and prediction are both characterize more or less the same concept, that fortells the future based on past and present data.

Prediction model is used to predict future outcome, usually at a specific point in time.. Prediction can also be applied to events that have already happened.

Forecasting is the process of analysing and interpreting a future events, which takes the past and the present datasets into account. Forecasting would be a subset of prediction. There are two methods of forecasting including quantitative and qualitative:

- Qualitative methos is based on expert judgment rather than numerical figures. Qualitative method can be used when past data are not available. This method includes Delphi method, consumer surveys and expert opinion.
- Quantitative forecasting models are used to forecast future data as a function of past data. This method uses time series analysis, extrapolation, econometric analysis and regression analysis. In this thesis the autoregressive model for forecasting was used.

The main differences between prediction and forecasting models could be assigned as:

1. Accuracy.

   A Forecast is more accurate compared to a prediction. This is because forecasts are derived by analyzing a set of past data, which probability of being wrong are minimal. On the other hand, a prediction can be right or wrong due to selected data for prediction.

2. Application.

   Forecasts are only applicable in the field where there is a lot of information about the subject matter. while, prediction can be applied anywhere as long as there is an expected future outcome.

In the flowcharts given below prediction and forecasting models are depicted. In 3.1 the prediction model is shown. On the left side of flowchart drought indices as inputs in a range $DI_i[t,...t-LAG]$ are taken. Then, dataset is training using Random Forest and Extra-Trees models, and output consider all drought indices $DI_j[t]$ is predicted.

Figure 3.1: Flow chart of prediction model.

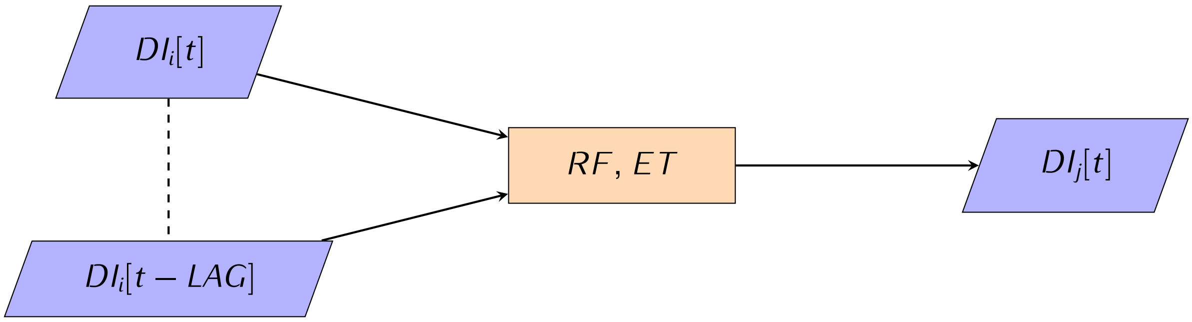
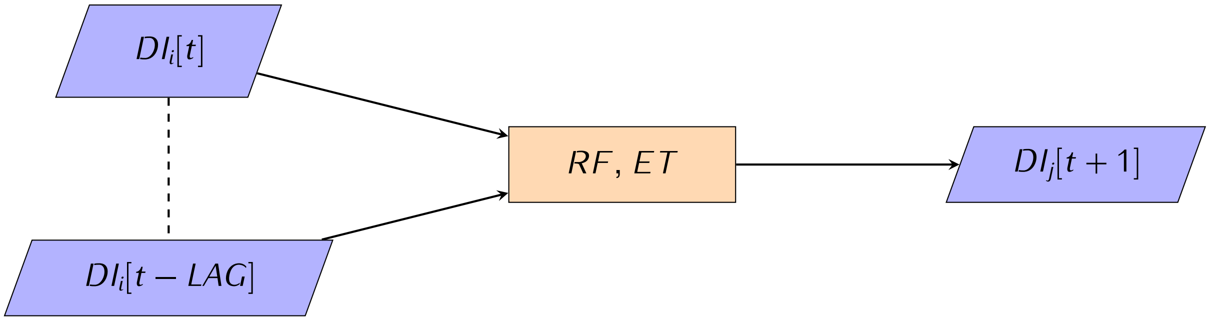


Figure 3.2: Flow chart of prediction model.



In the next flowchart 3.2 the forecasting model is plotted. The main different on this type of model, as previously noted, is the predicted output $DI_j[t + 1]$, which means the future event forecasting.

Chapter 4

Data

4.1 Basin description

In my thesis I have obtained dataset from 27 meteorological stations, located in different parts of Czech Republic. The table 4.1 shows the description of these basins. Also, in table 4.2 are shown long term average values of meteorological variables, like Precipitation, Temperature and Evapotranspiration. The period mentioned in thesis is from 01/01/1982 to 01/12/2015.

The climatic data used in this Thesis derived from Czech Hydrometeorological Institute. Variables used for drought indices computation are monthly precipitation and average temperature and evapotranspiration for the period January 1982 - December 2015, located over the territory of Czech Republic.

Table 4.1: Dataset used for prediction drought indices.

Identifier	Name	Name of station	Area, (km^2)	Number of Hydrological Sequence
0170	Metuje	Maršov nad Metují	94.68	1-01-03-0130-0-00-40
0180	Metuje	Hronov	248.59	1-01-03-0310-0-00-40
0250	Divoká Orlice	Nekoř	182.49	1-02-01-0110-2-00-70
0580	Novohradka	Úhřetice	458.91	1-03-03-1020-0-00-70
0660	Doubrava	Žleby	381.84	1-03-05-0450-0-00-30
0840	Jizera	Vilémov	146.17	1-05-01-0110-0-00-60
0850	Jizerka	Dolní Štìpanice	44.08	1-05-01-0220-0-00-70
0900	Kamenice	Bohuňovsko-Jesenný	179.10	1-05-01-0740-0-00-60
0910	Jizera	Železný Brod	791.26	1-05-02-0010-0-00-50
1020	Jizera	Tuřice	2158.34	1-05-03-0150-0-00-60
1350	Vydra	Modrava	2189.80	1-08-01-0130-0-00-30
1430	Volynka	Němětice	383.36	1-08-02-0410-0-00-30
1510	Otava	Písek	2913.70	1-08-03-1010-0-00-70
1790	Radbuza	Staňkov	701.51	1-10-02-0680-0-00-20
1980	Berounka	Beroun	8286.23	1-11-04-0560-0-00-30
2110	Teplá	Cihelny	262.57	1-13-02-0210-1-00-60
2400	Labe	Děčín	51120.34	1-14-04-0010-0-00-70
2940	Odra	Bohumín	4663.74	2-03-02-0110-0-00-30
3450	Morava	Raškov	349.79	4-10-01-0450-0-00-60
3511	Desná	Šumperk	240.63	4-10-01-0850-0-00-50
3540	Moravská Sázava	Lupěné	445.21	4-10-02-0420-0-00-70
3550	Morava	Moravičany	1561.19	4-10-02-0650-0-00-70
4215	Morava	Strážnice	9144.83	4-13-02-0340-0-00-30
4410	Svratka	Borovnice	127.97	4-15-01-0070-0-00-70
4530	Křetínka	VD Letovice	126.59	4-15-02-0340-2-00-30
4540	Svitava	Letovice	423.78	4-15-02-0350-0-00-30
4650	Jihlava	Dvorce	307.35	4-16-01-0270-0-00-50

Table 4.2: Long term average value of meteorolocical variables

	DBC	precipitation	temperature	evapotranspiration
1	0170	64.86	6.95	33.82
2	0180	63.96	7.12	33.78
3	0250	84.87	6.41	34.32
4	0580	58.08	8.37	35.73
5	0660	60.40	8.29	35.74
6	0840	108.84	5.05	33.44
7	0850	99.58	5.39	32.29
8	0900	97.97	6.00	33.25
9	0910	87.97	6.46	33.23
10	1020	57.88	8.56	33.32
11	1350	101.53	4.69	38.98
12	1430	63.30	7.12	35.72
13	1510	63.10	7.50	35.10
14	1790	57.69	8.30	33.60
15	1980	52.17	8.14	33.44
16	2110	60.01	6.91	33.55
17	2400	55.91	8.13	33.85
18	2940	65.52	7.71	36.77
19	3450	79.67	6.11	34.63
20	3511	78.60	5.89	33.63
21	3540	64.52	7.46	34.22
22	3550	68.20	7.04	33.81
23	4215	58.86	8.20	34.94
24	4410	67.11	6.83	39.50
25	4530	54.65	7.42	34.52
26	4540	54.10	7.59	33.95
27	4650	57.29	7.37	34.74

4.2 Time series of drought indices

The time series models are commonly used in hydrology and explaining the severity of drought events. Using time series models a time series of a drought quantifying parameter can be used for drought forecasting, depending upon the previous observations. (Mishra and Singh, 2010) Mostly drought indices are presented in a form of time series.

In this thesis time series of all five drought indices for every meteorological station are shown in Figures 4.1 - 4.9. They are the Standardized Precipitation Index (SPI), the Standardised Precipitation Evapotranspiration Index (SPEI), the Palmer Drought Severity Index (PDSI), the self-calibrated Palmer Drought Severity Index (scPDSI) and the Standardized Soil Moisture Index (SSI).

Figure 4.1: Time series for Maršov nad Metují, Hronov and Nekoř meteorological basins

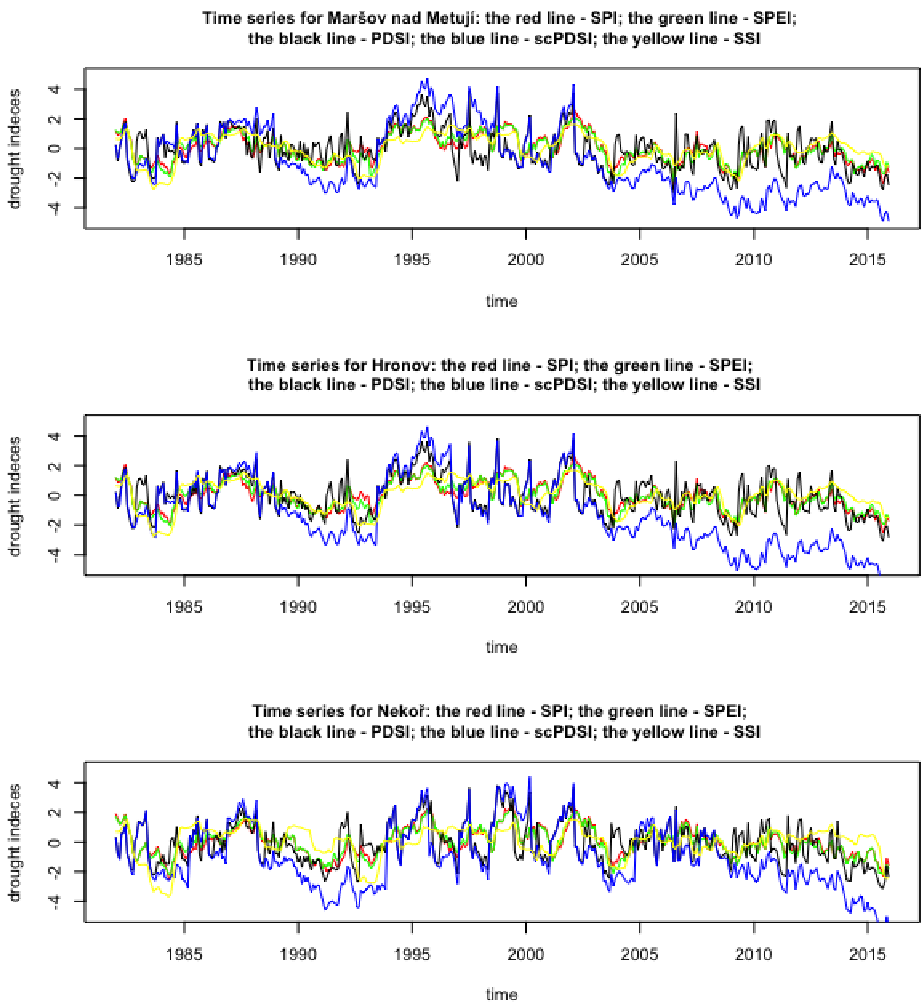


Figure 4.2: Time series for Úhřetice, Žleby and Vilémov meteorological basins

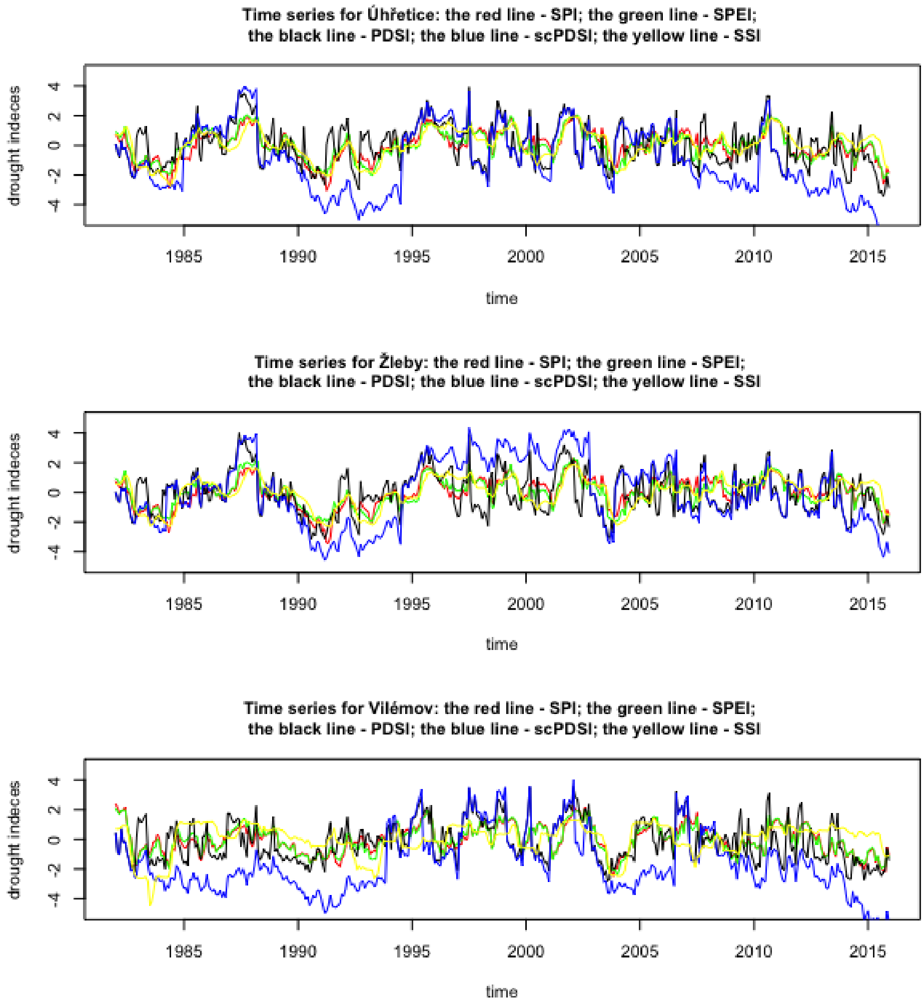


Figure 4.3: Time series for Dolní Štìpanice, Bohuňovsko-Jesenný and Železný Brod meteorological basins

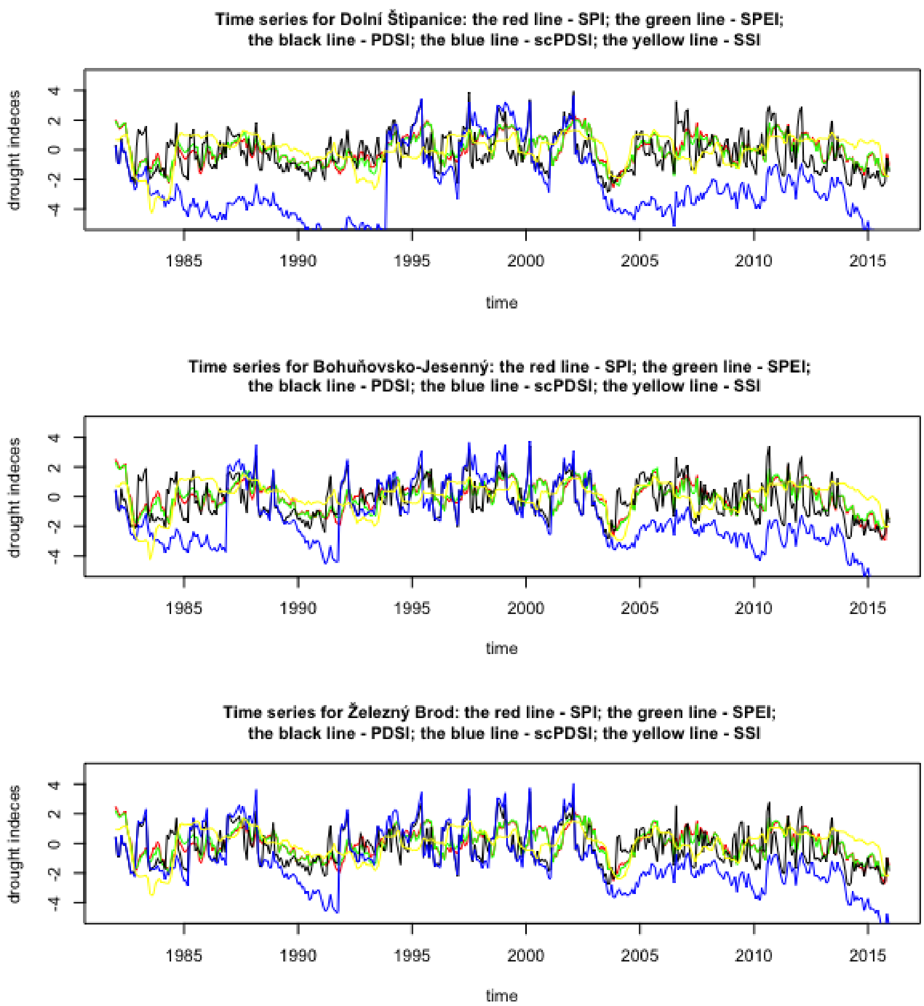


Figure 4.4: Time series for Dolní Tuřice, Modrava and Němětice meteorological basins

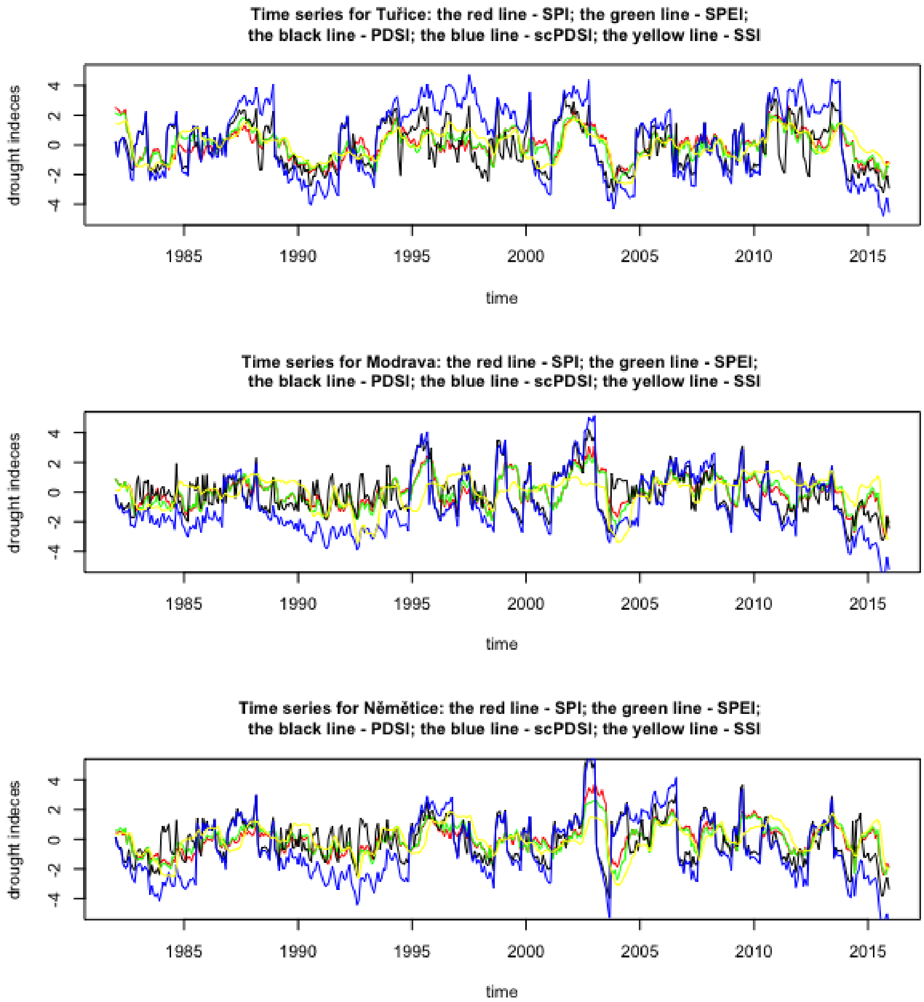


Figure 4.5: Time series for Dolní Písek, Staňkov and Beroun meteorological basins

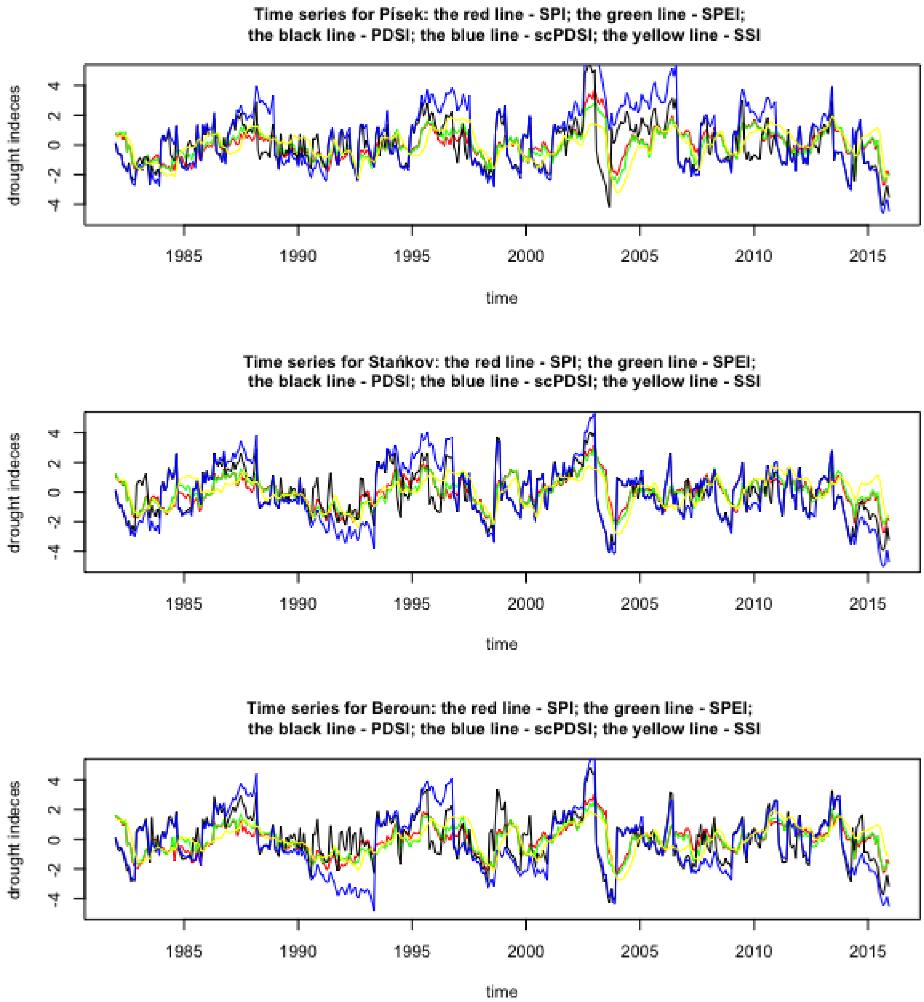


Figure 4.6: Time series for Cihelny, Děčín and Bohumín meteorological basins

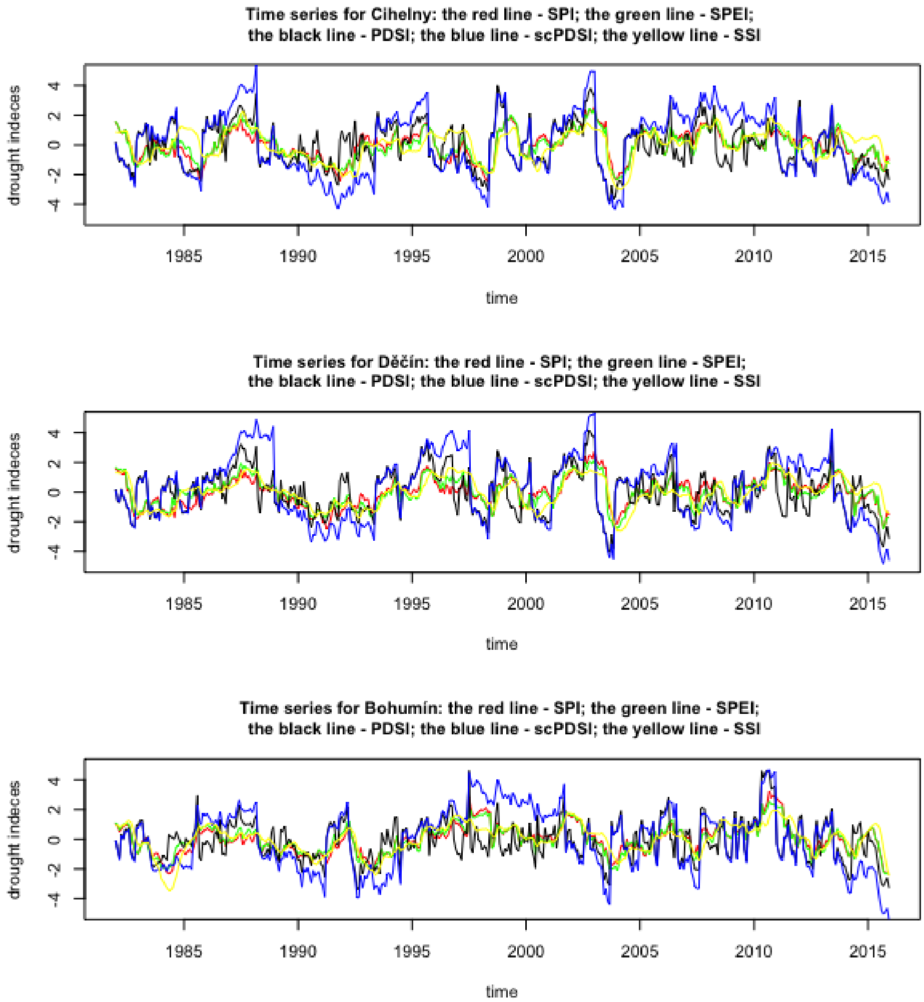


Figure 4.7: Time series for Raškov, Šumperk and Lupěné meteorological basins

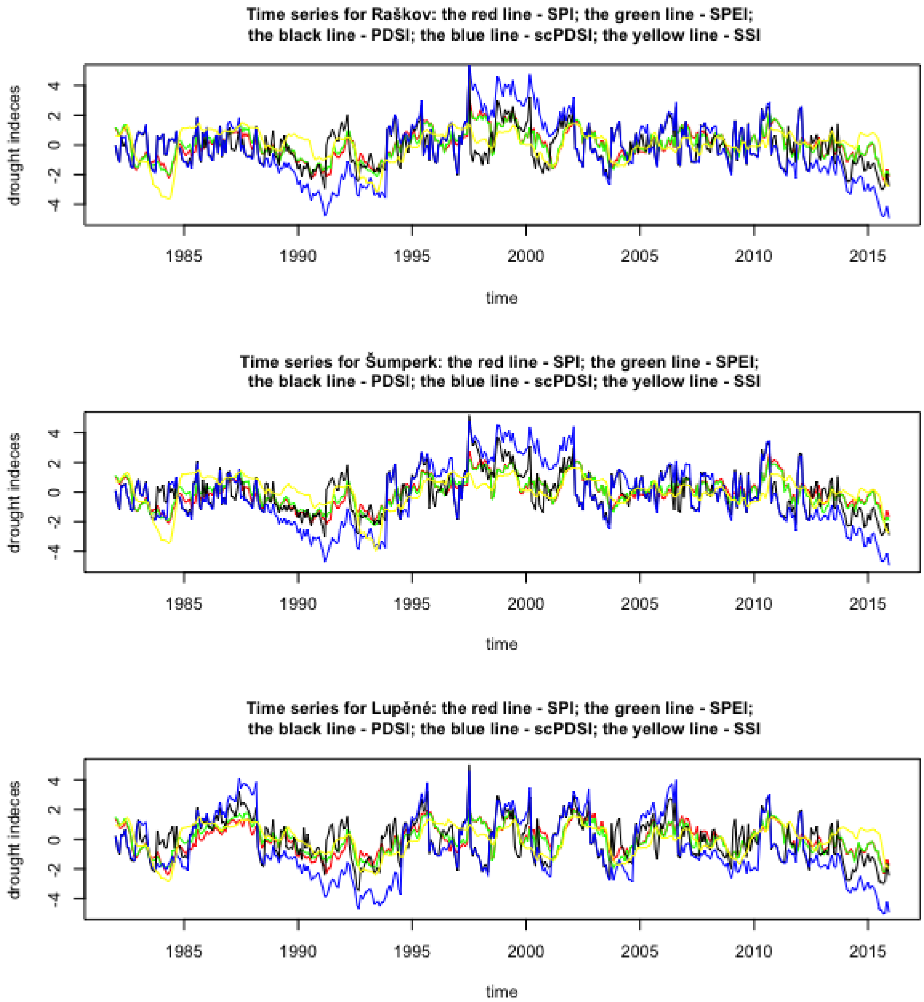
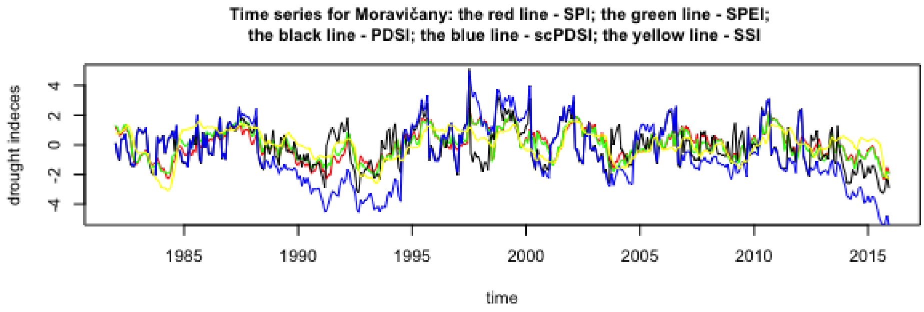
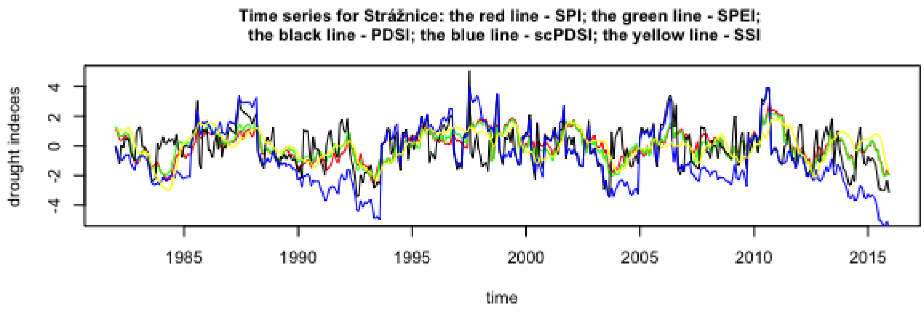


Figure 4.8: Time series for Moravičany, Strážnice and Borovnice meteorological basins





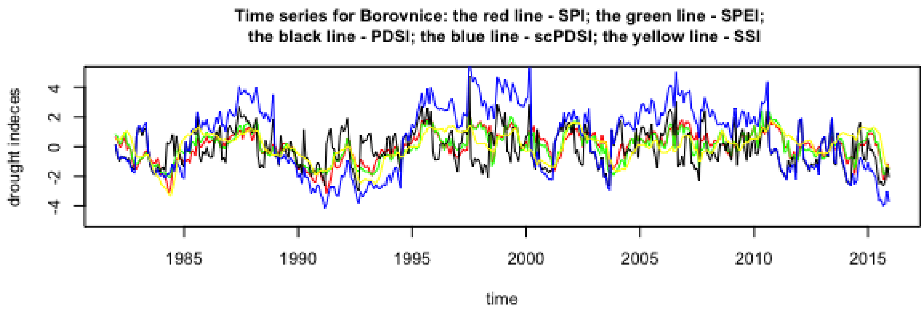
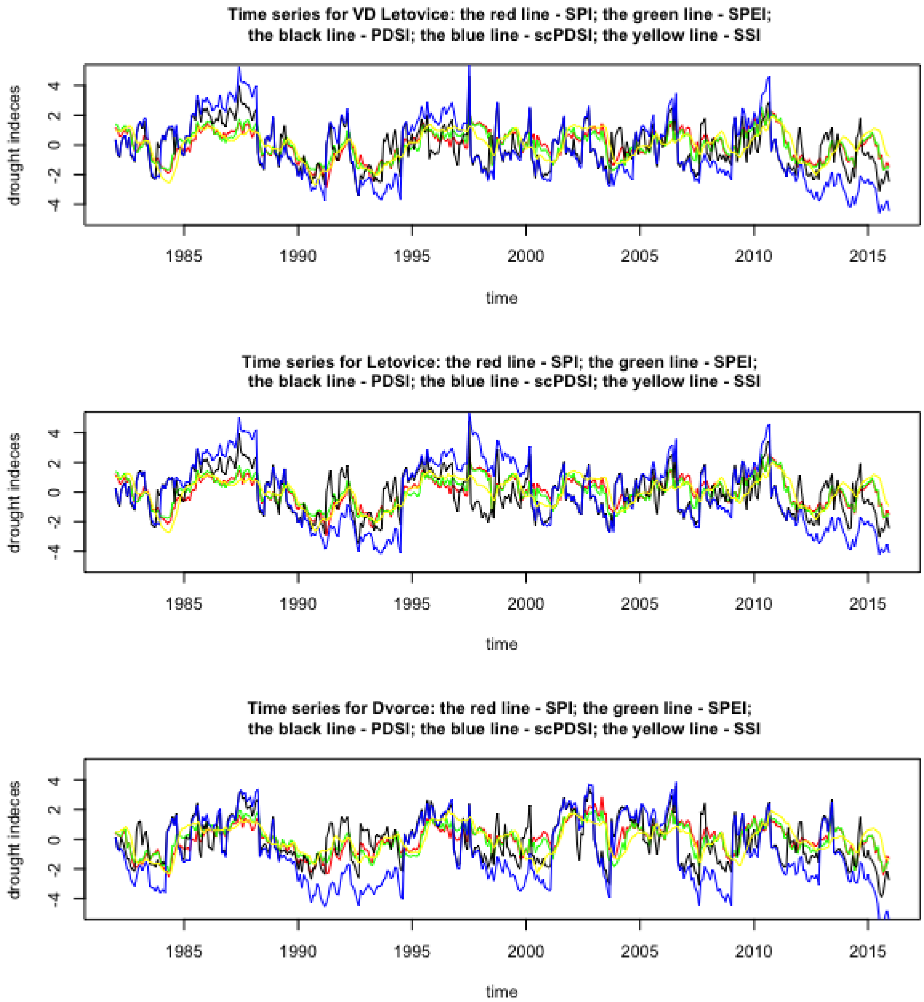


Figure 4.9: Time series for VD Letovice, Letovice and Dvorce meteorological basins



Chapter 5

Results

The results of the thesis are organized as follows. First, tables of the relationships between drought indices are analyzed. Then, the following models were tested:

Random Forest prediction models , which are providing the prediction of drought indices based on the other drought indices values;

Random Forest forecasting models , which are providing the forecasting of drought indices based on the other drought indices values;

Extra-Trees prediction models , which are providing the prediction of drought indices based on the other drought indices values;

Extra-Trees forecasting models , which are providing the forecasting of drought indices based on the other drought indices values;

5.1 Relationship between drought indices

The relationships between drought indices derived from the station-observed metrics data on an average annual basis are shown in Tables below.

The strongest correlation in Random Forest prediction (Tables 5.1-5.4) for model evaluation metrics in calibration are found between SPI and SPEI and SPEI and SPI (MAE = 0.10, RMSE = 0.13, NSE = 0.98, KGE = 0.92 and 0.93, respectively). Also we can maintain strong relationship between SSI and SPEI (MAE = 0.16, RMSE = 0.21, NSE = 0.95, KGE = 0.84). The worst relationships in calibration are defined between SPI and scPDSI (MAE = 0.50, RMSE = 0.61) and SSI and PDSI (NSE = 0.88, KGE = 0.66). The best relationship in validation is SPI-SPEI (MAE = 0.23, RMSE = 0.28, NSE = 0.85, KGE = 0.74). The weakest relationship is between SSI and scPDSI (MAE = 2.35, RMSE = 2.73, NSE = -3.75, KGE = 0.03).

Table 5.1: Relation between drought indices in Random Forest prediction for Mean Average Error (MAE)

	Calibration					Validation				
	SPI	SPEI	PDSI	scPDSI	SSI	SPI	SPEI	PDSI	scPDSI	SSI
SPI	-	0.10	0.38	0.50	0.20	-	0.23	1.13	1.75	0.59
SPEI	0.10	-	0.37	0.49	0.16	0.25	-	1.11	1.68	0.56
PDSI	0.18	0.18	-	0.37	0.23	0.46	0.45	-	1.02	0.88
scPDSI	0.17	0.17	0.22	-	0.22	0.53	0.52	0.75	-	0.91
SSI	0.18	0.16	0.38	0.45	-	0.73	0.69	1.37	2.35	-

Table 5.2: Relation between drought indices in Random Forest prediction for Root Mean Square Error (RMSE)

	Calibration					Validation				
	SPI	SPEI	PDSI	scPDSI	SSI	SPI	SPEI	PDSI	scPDSI	SSI
SPI	-	0.13	0.45	0.61	0.27	-	0.28	1.31	1.99	0.70
SPEI	0.13	-	0.45	0.60	0.20	0.33	-	1.28	1.92	0.66
PDSI	0.23	0.22	-	0.50	0.30	0.57	0.56	-	1.20	1.05
scPDSI	0.22	0.21	0.29	-	0.29	0.65	0.65	0.94	-	1.09
SSI	0.24	0.21	0.48	0.58	-	0.89	0.83	1.59	2.73	-

Regarding Random Forest forecasting model (Tables 5.5 - 5.8), the strongest relationship in calibration is SPEI-SPI (MAE = 0.16, RMSE = 0.21, NSE = 0.95, KGE = 0.84). The relationships between SPI-SPEI, scPDSI-SPEI are also significant (MAE = 0.17, RMSE = 0.22, NSE = 0.95, KGE = 0.84 and 0.83, respectively). The weakest relationships are SPI-scPDSI, SPEI-scPDSI and SPI-PDSI, SPEI-PDSI. The best relationship among all in validation is SPI-SPEI, but generally can't be defined as good (MAE = 0.42, RMSE = 0.53,

Table 5.3: Relation between drought indices in Random Forest prediction for Nash–Sutcliffe model efficiency coefficient (NSE)

	Calibration					Validation				
	SPI	SPEI	PDSI	scPDSI	SSI	SPI	SPEI	PDSI	scPDSI	SSI
SPI	-	0.98	0.89	0.91	0.93	-	0.85	-0.00	-1.35	-0.37
SPEI	0.98	-	0.89	0.92	0.96	0.81	-	0.05	-1.19	-0.27
PDSI	0.94	0.95	-	0.94	0.91	0.43	0.46	-	-0.16	-1.86
scPDSI	0.95	0.95	0.95	-	0.92	0.20	0.24	0.44	-	-1.90
SSI	0.94	0.95	0.88	0.92	-	-0.44	-0.31	-0.48	-3.75	-

Table 5.4: Relation between drought indices in Random Forest prediction for Kling-Gupta Efficiency (KGE)

	Calibration					Validation				
	SPI	SPEI	PDSI	scPDSI	SSI	SPI	SPEI	PDSI	scPDSI	SSI
SPI	-	0.92	0.68	0.75	0.79	-	0.74	0.08	0.16	0.31
SPEI	0.93	-	0.69	0.76	0.86	0.67	-	0.09	0.16	0.47
PDSI	0.80	0.81	-	0.82	0.74	0.40	0.42	-	0.48	0.13
scPDSI	0.82	0.83	0.82	-	0.76	0.36	0.30	0.32	-	0.05
SSI	0.80	0.84	0.66	0.77	-	0.10	0.17	0.01	0.03	-

NSE = 0.53, KGE = 0.38). As in previous model evaluation, the weakest relationship in validation is SSI-scPDSI (MAE = 2.46, RMSE = 2.86, NSE = -3.75, KGE = 0.03).

In Extra-Trees prediction model (Tables 5.9 - 5.12), the strongest relationship in calibration can be found between SPI-SPEI, SPEI-SPI, scPDSI-SPI, scPDSI-SPEI, and the weakest are SPI-scPDSI and SPEI-scPDSI. In validation the relationship is not so strong like in calibration. From the given value the best is between SPI and SPEI (MAE = 0.42, RMSE = 0.53, NSE = 0.52, KGE = 0.21). THe weakest validation relationship is defind between SSI and scPDSI and scPDSI and SSI.

Finally, the strongest relationships in calibration in Extra-Trees forecasting models (Tables 5.13 - 5.16), as well as previously, are between SPI and SPEI and SPEI and SPI (MAE = 0.08, RMSE = 0.10, NSE = 0.99, KGE = 0.95 and 0.96, resepctively). Also good results are shown between other inputs, which forecasted the other drought indices. Relatively

Table 5.5: Relation between drought indices in Random Forest Forecasting for Mean Average Error (MAE)

	Calibration					Validation				
	SPI	SPEI	PDSI	scPDSI	SSI	SPI	SPEI	PDSI	scPDSI	SSI
SPI	-	0.17	0.43	0.55	0.21	-	0.42	1.35	1.98	0.57
SPEI	0.16	-	0.43	0.55	0.16	0.43	-	1.32	1.89	0.55
PDSI	0.19	0.19	-	0.49	0.23	0.49	0.47	-	1.34	0.87
scPDSI	0.18	0.17	0.36	-	0.22	0.53	0.52	1.10	-	0.89
SSI	0.20	0.19	0.39	0.47	-	0.78	0.74	1.45	2.46	-

Table 5.6: Relation between drought indices in Random Forest Forecasting for Root Mean Square Error (RMSE)

	Calibration					Validation				
	SPI	SPEI	PDSI	scPDSI	SSI	SPI	SPEI	PDSI	scPDSI	SSI
SPI	-	0.22	0.53	0.67	0.27	-	0.53	1.56	2.24	0.68
SPEI	0.21	-	0.53	0.67	0.21	0.55	-	1.52	2.16	0.64
PDSI	0.24	0.24	-	0.61	0.30	0.60	0.58	-	1.56	1.04
scPDSI	0.22	0.22	0.46	-	0.28	0.66	0.66	1.35	-	1.07
SSI	0.26	0.24	0.49	0.60	-	0.96	0.92	1.70	2.86	-

to validation, the best values are shown also between SPI-SPEI and SPEI-SPI, and the worst - between SSI and scPDSI (MAE = 2.36, RMSE = 2.74, NSE = -3.77, KGE = -0.80).

Table 5.7: Relation between drought indices in Random Forest Forecasting for Nash–Sutcliffe model efficiency coefficient (NSE)

	Calibration					Validation				
	SPI	SPEI	PDSI	scPDSI	SSI	SPI	SPEI	PDSI	scPDSI	SSI
SPI	-	0.95	0.85	0.89	0.93	-	0.53	-0.39	-1.72	-0.08
SPEI	0.95	-	0.85	0.90	0.96	0.49	-	-0.33	-1.53	-0.00
PDSI	0.94	0.94	-	0.91	0.91	0.38	0.43	-	-0.53	-1.35
scPDSI	0.94	0.95	0.89	-	0.93	0.22	0.26	-0.07	-	-1.43
SSI	0.93	0.94	0.87	0.91	-	-0.62	-0.49	-0.65	-3.75	-

Table 5.8: Relation between drought indices in Random Forest Forecasting for Kling-Gupta Efficiency (KGE)

	Calibration					Validation				
	SPI	SPEI	PDSI	scPDSI	SSI	SPI	SPEI	PDSI	scPDSI	SSI
SPI	-	0.84	0.62	0.71	0.78	-	0.38	0.02	0.10	0.33
SPEI	0.84	-	0.62	0.72	0.85	0.33	-	0.01	0.11	0.47
PDSI	0.78	0.79	-	0.75	0.74	0.34	0.37	-	0.29	0.15
scPDSI	0.82	0.83	0.69	-	0.77	0.33	0.28	0.06	-	0.07
SSI	0.77	0.80	0.65	0.75	-	0.04	0.08	0.01	0.03	-

Table 5.9: Relation between drought indices in Extra-Trees prediction for Mean Average Error (MAE)

	Calibration					Validation				
	SPI	SPEI	PDSI	scPDSI	SSI	SPI	SPEI	PDSI	scPDSI	SSI
SPI	-	0.13	0.31	0.40	0.15	-	0.42	1.34	1.97	0.56
SPEI	0.13	-	0.31	0.40	0.12	0.44	-	1.32	1.91	0.54
PDSI	0.14	0.14	-	0.37	0.18	0.48	0.47	-	1.34	0.83
scPDSI	0.13	0.13	0.27	-	0.16	0.53	0.52	1.11	-	0.87
SSI	0.15	0.14	0.30	0.34	-	0.77	0.73	1.45	2.45	-

Table 5.10: Relation between drought indices in Extra-Trees prediction for Root Mean Square Error (RMSE)

	Calibration					Validation				
	SPI	SPEI	PDSI	scPDSI	SSI	SPI	SPEI	PDSI	scPDSI	SSI
SPI	-	0.17	0.39	0.49	0.20	-	0.53	1.55	2.23	0.66
SPEI	0.17	-	0.38	0.48	0.16	0.56	-	1.52	2.17	0.63
PDSI	0.18	0.18	-	0.46	0.23	0.59	0.58	-	1.55	0.99
scPDSI	0.17	0.16	0.34	-	0.21	0.66	0.65	1.35	-	1.05
SSI	0.20	0.18	0.38	0.44	-	0.95	0.90	1.70	2.86	-

Table 5.11: Relation between drought indices in Extra-Trees prediction for Nash–Sutcliffe model efficiency coefficient (NSE)

	Calibration					Validation				
	SPI	SPEI	PDSI	scPDSI	SSI	SPI	SPEI	PDSI	scPDSI	SSI
SPI	-	0.97	0.92	0.94	0.96	-	0.52	-0.37	-1.75	-0.02
SPEI	0.97	-	0.92	0.94	0.98	0.47	-	-0.32	-1.63	0.05
PDSI	0.97	0.97	-	0.95	0.95	0.40	0.44	-	-0.49	-1.14
scPDSI	0.97	0.97	0.94	-	0.96	0.21	0.27	-0.07	-	-1.34
SSI	0.96	0.96	0.93	0.95	-	-0.59	-0.42	-0.65	-3.73	-

Table 5.12: Relation between drought indices in Extra-Trees prediction for Kling-Gupta Efficiency (KGE)

	Calibration					Validation				
	SPI	SPEI	PDSI	scPDSI	SSI	SPI	SPEI	PDSI	scPDSI	SSI
SPI	-	0.91	0.76	0.83	0.88	-	0.21	-0.53	-0.34	-17.80
SPEI	0.92	-	0.76	0.83	0.92	0.33	-	-0.42	-0.21	-18.80
PDSI	0.88	0.89	-	0.85	0.84	-0.23	-0.04	-	0.34	-30.60
scPDSI	0.90	0.91	0.82	-	0.87	-0.28	-0.06	-0.07	-	-34.57
SSI	0.88	0.89	0.79	0.85	-	-0.93	-0.83	-0.53	-0.79	-

Table 5.13: Relation between drought indices in Extra-Trees Forecasting for Mean Average Error (MAE)

	Calibration					Validation				
	SPI	SPEI	PDSI	scPDSI	SSI	SPI	SPEI	PDSI	scPDSI	SSI
SPI	-	0.08	0.27	0.37	0.15	-	0.23	1.14	1.75	0.58
SPEI	0.08	-	0.27	0.36	0.12	0.26	-	1.12	1.71	0.56
PDSI	0.13	0.13	-	0.29	0.18	0.46	0.45	-	1.02	0.85
scPDSI	0.13	0.13	0.16	-	0.16	0.52	0.52	0.73	-0	0.89
SSI	0.14	0.13	0.29	0.33	-	0.72	0.67	1.37	2.36	-

Table 5.14: Relation between drought indices in Extra-Trees Forecasting for Root Mean Square Error (RMSE)

	Calibration					Validation				
	SPI	SPEI	PDSI	scPDSI	SSI	SPI	SPEI	PDSI	scPDSI	SSI
SPI	-	0.10	0.33	0.44	0.20	-	0.28	1.30	1.99	0.68
SPEI	0.10	-	0.33	0.43	0.15	0.33	-	1.28	1.94	0.64
PDSI	0.17	0.16	-	0.37	0.23	0.57	0.55	-	1.19	1.01
scPDSI	0.16	0.16	0.22	-	0.21	0.65	0.65	0.91	-	1.07
SSI	0.18	0.16	0.36	0.43	-	0.87	0.81	1.59	2.74	-

Table 5.15: Relation between drought indices in Extra-Trees Forecasting for Nash–Sutcliffe model efficiency coefficient (NSE)

	Calibration					Validation				
	SPI	SPEI	PDSI	scPDSI	SSI	SPI	SPEI	PDSI	scPDSI	SSI
SPI	-	0.99	0.94	0.95	0.96	-	0.85	0.01	-1.40	-0.29
SPEI	0.99	-	0.94	0.96	0.98	0.81	-	0.05	-1.29	-0.20
PDSI	0.97	0.97	-	0.97	0.95	0.44	0.46	-	-0.12	-1.61
scPDSI	0.97	0.97	0.98	-	0.96	0.20	0.25	0.48	-	-1.81
SSI	0.97	0.97	0.93	0.96	-	-0.39	-0.23	-0.48	-3.77	-

Table 5.16: Relation between drought indices in Extra-Trees Forecasting for Kling-Gupta Efficiency (KGE)

	Calibration					Validation				
	SPI	SPEI	PDSI	scPDSI	SSI	SPI	SPEI	PDSI	scPDSI	SSI
SPI	-	0.95	0.81	0.85	0.89	-	0.10	-0.23	-0.29	-2.86
SPEI	0.96	-	0.81	0.86	0.93	0.58	-	-0.10	-0.11	-3.32
PDSI	0.89	0.90	-	0.89	0.84	-0.68	-0.88	-	0.54	-5.64
scPDSI	0.90	0.91	0.90	-	0.87	-1.00	-0.37	0.38	-	-6.10
SSI	0.89	0.91	0.80	0.86	-	-1.42	-1.82	-0.45	-0.80	-

5.2 Random Forest and Extra-Trees implementation

For the purpose of my thesis, I have used two types of models, Random Forest and Extra-Trees. For training and creating regression models the R packages "randomForest" and "extraTrees" were used.

On the training dataset same model with different hyper parameters or different models can be trained. Training observations may differ slightly while sampling; however, overall population remains the same. Outputs in models are combined by the average since regression modeling.

I have divided training data into two parts, calibration and validation, in the ratio 85:15. As was mentioned in Moriasi et al. (2007), calibration can be characterized as the process of model parameters estimation by comparing model output under given conditions with observed data for the same conditions. In turn, model validation is the process of model's running using input parameters determined during the calibration.

Then, the Random Forest model with default parameters was created, with "mtry" equals to 4 and "ntree" equals to 500. According to Random Forest package description:

- ntree: Number of trees to grow. This should not be set to too small a number, to ensure that every input row gets predicted at least a few times.
- mtry: Number of variables randomly sampled as candidates at each split. Note that the default values are different for classification ($sqrt(p)$ where p is number of variables in x) and regression ($p/3$).

Regarding Extra-Trees model, the default parameters are ntree equals to 500 and nodesize equals to 5. According to Extra Trees package description:

- ntree: the number of trees (default 500).
- nodesize: the size of leaves of the tree (default is 5 for regression and 1 for classification).

After creation of models I have evaluated them via model's accuracy measuring metrics.

5.3 The performance of Random Forest and Extra-Trees

For evaluating the performance the following metrics were applied: Mean Absolute Error (MAE), Root mean squared error (RMSE), Nash-Sutcliffe Efficiency (NSE) and Kling-Gupta Efficiency (KGE). For that evaluation the "hydroGOF" package in R was used.

Mean Absolute Error (MAE) measures the average magnitude of the errors in a set of predictions, without considering their direction. The equation of MAE is following:

$MAE = \frac{1}{N}\sum_{i=1}^{N}(|Q_{obs}(i) - Q_{sim}(i)|)$

where Q_{sim} is simulated value;
Q_{obs} is the observation;
N is a total amount of observations.

Root mean squared error (RMSE) is the standard deviation of the residuals. RMSE can be defined as:

$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(Q_{obs}(i) - Q_{sim}(i))^2}$

Nash-Sutcliffe Efficiency (NSE) is used to measure the predictive power of hydrological models. It is defined as:

$NSE = 1 - \frac{\sum_{t=1}^{T}(Q_m^t - Q_o^t)^2}{\sum_{t=1}^{T}(Q_o^t - \overline{Q_o})^2}$

Kling-Gupta Efficiency (KGE) provides decomposition of the Nash-Sutcliffe efficiency and can be calculates as follows:

$KGE = 1 - ED$

with

$ED = \sqrt{(r-1)^2 + (\alpha-1)^2 = (\beta-1)^2}$

where ED is the Euclidian distance from the ideal point;
β is the bias.

Below in Table 5.17 the ranges of model metrics are depicted.

Table 5.17: MAE, RMSE, NSE and KGE ranges

Criteria	Range	Best
MAE	$[0; \infty]$	0
RMSE	$[0; \infty]$	0
NSE	$[-\infty; 1]$	1
KGE	$[-\infty; 1]$	1

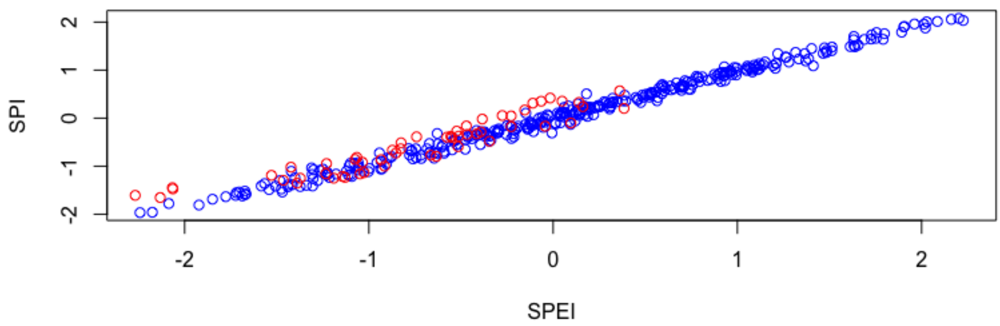
5.4 Analysis of models‘ performance

For the purpose of this section I have used 27 basins with time-lag equals to 12. Tables below describe models' metrics for all basins for calibration and validation.

As it can be seen below, for Random Forest prediction model the best performance show models based on the SPI and the SPEI inputs. They both can accurately predict the SPI, the SPEI and the SSI drought indices. Inversely, the PDSI and the scPDSI indices can't be predicted well.

In Figure 5.1 determined the SPEI index based on the SPI inputs using Random Forest prediction model

Figure 5.1: Best model using Random Forest prediction model, Nekoř

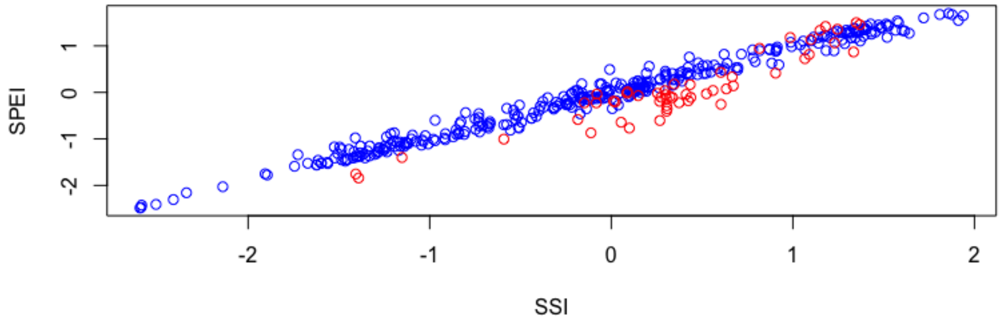


Random Forest forecasting model displays that the SSI, the SPI and the SPEI indices are forecasted via almost each drought indices' inputs. In turn, the PDSI and the scPDSI forecasted models show good result in calibration, but not good results in validation.

The best model using Random Forest forecasting model is shown below in Figure 5.2

with the SPI inputs and defined SSI outputs.

Figure 5.2: Best model using Random Forest forecasting model, Děčín



Concerning to Extra-Trees prediction models the best results are shown based on the SPI, the SPEI and the PDSI inputs. The scPDSI and the SSI inputs demonstrate good results in calibration and not well results in validation.

And the last, Extra-Trees forecasting models displayed the same results as Extra-Trees prediction models. The highest coefficients of detemination are found in models based on the SPI, the SPEI and the PDSI inputs. They forecast the SPI, the SPEI, the SSI and the PDSI indices.

Below the best models created using Extra-Trees prediction and forecasting models, respectively, can be found.

Figure 5.3: Best model using Extra-Trees prediction model, Tuřice

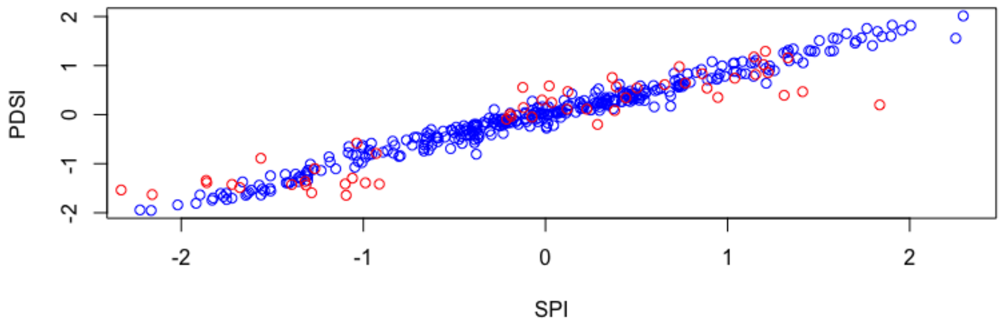
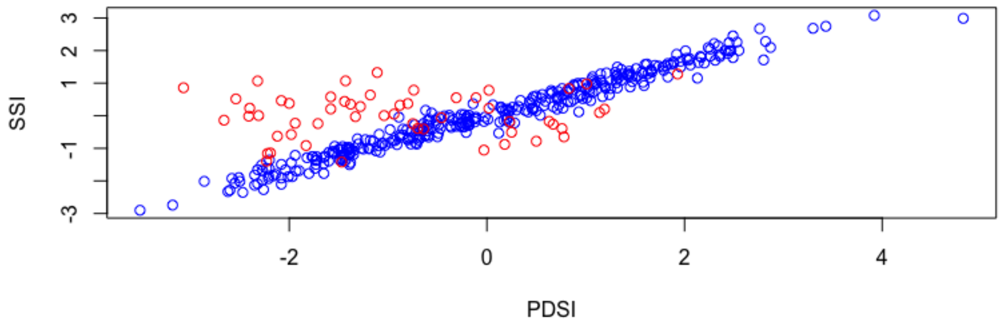


Figure 5.4: Best model using Extra-Trees forecasting model, Letovice



Altogether, we can see that Extra-Trees models give more accurate and faster results. It is determined by the fact of splitting data methods and computational speed.

The remain tables are located in Appendix in the end of the Thesis.

Table 5.18: The calibration and validation results for Random Forest prediction model of SPEI forecast based on SPI inputs

Basin	Calibration				Validation			
	MAE	RMSE	NSE	KGE	MAE	RMSE	NSE	KGE
0170	0.09	0.12	0.98	0.93	0.20	0.24	0.85	0.84
0180	0.09	0.12	0.98	0.93	0.19	0.22	0.87	0.84
0250	**0.08**	**0.10**	**0.99**	**0.94**	0.22	0.27	0.82	0.73
0580	0.11	0.14	0.98	0.92	0.22	0.28	0.84	0.70
0660	0.12	0.15	0.98	0.91	0.26	0.31	0.83	0.65
0840	0.08	0.11	0.99	0.94	0.20	0.25	0.92	0.85
0850	0.08	0.11	0.99	0.94	**0.15**	**0.20**	0.94	**0.88**
0900	0.09	0.11	0.98	0.93	0.18	0.24	**0.95**	0.85
0910	0.10	0.12	0.98	0.92	0.20	0.27	0.92	0.82
1020	0.12	0.15	0.97	0.90	0.24	0.32	0.91	0.79
1350	0.09	0.11	0.99	0.94	0.23	0.32	0.87	0.76
1430	0.09	0.12	0.99	0.94	0.21	0.32	0.90	0.70
1510	0.10	0.12	0.98	0.93	0.27	0.35	0.87	0.67
1790	0.11	0.14	0.98	0.92	0.24	0.28	0.89	0.74
1980	0.10	0.13	0.98	0.92	0.31	0.36	0.83	0.70
2110	0.10	0.12	0.98	0.93	0.19	0.25	0.89	0.70
2400	0.12	0.15	0.98	0.90	0.33	0.41	0.80	0.68
2940	0.09	0.11	0.99	0.94	0.16	0.22	0.93	0.80
3450	0.08	0.11	0.99	0.94	0.17	0.21	0.88	0.75
3511	0.09	0.11	0.99	0.94	0.33	0.39	0.56	0.55
3540	0.12	0.15	0.98	0.91	0.25	0.30	0.74	0.62
3550	0.11	0.13	0.98	0.92	0.28	0.32	0.73	0.63
4215	0.11	0.14	0.98	0.91	0.19	0.25	0.89	0.73
4410	0.12	0.15	0.98	0.91	0.29	0.32	0.79	0.57
4530	0.11	0.14	0.98	0.91	0.18	0.22	0.90	0.84
4540	0.11	0.14	0.98	0.92	0.20	0.24	0.89	0.82
4650	0.11	0.15	0.98	0.91	0.26	0.32	0.83	0.65

Table 5.19: The calibration and validation results for Random Forest prediction model of SSI forecast based on SPEI inputs

Basin	Calibration				Validation			
	MAE	RMSE	NSE	KGE	MAE	RMSE	NSE	KGE
0170	0.14	0.18	0.97	0.89	0.63	0.68	-0.82	0.81
0180	0.14	0.18	0.97	0.89	0.71	0.76	-1.02	0.68
0250	0.22	0.29	0.93	0.78	0.98	1.16	-1.72	0.31
0580	**0.10**	**0.13**	**0.98**	**0.94**	0.47	0.53	0.06	0.68
0660	0.11	0.14	0.98	0.93	0.42	0.49	0.27	0.34
0840	0.30	0.38	0.88	0.67	1.00	1.11	-5.54	0.06
0850	0.24	0.31	0.92	0.75	0.73	0.87	-1.36	0.21
0900	0.23	0.31	0.92	0.75	0.89	1.02	-1.13	0.39
0910	0.22	0.29	0.92	0.76	0.79	0.89	-0.68	0.36
1020	0.11	0.15	0.98	0.90	0.39	0.46	0.68	0.76
1350	0.22	0.29	0.93	0.77	0.74	0.88	-0.03	0.26
1430	0.13	0.17	0.97	0.89	0.41	0.47	0.73	0.57
1510	0.13	0.16	0.97	0.90	0.48	0.55	0.53	0.49
1790	0.14	0.18	0.97	0.88	0.54	0.68	0.04	0.33
1980	0.10	0.13	0.98	0.93	0.44	0.52	0.10	0.59
2110	0.16	0.21	0.96	0.86	0.50	0.59	0.09	0.07
2400	0.10	0.13	0.98	0.93	0.36	0.42	0.44	0.74
2940	**0.10**	**0.13**	**0.98**	**0.94**	**0.23**	**0.30**	**0.86**	0.70
3450	0.21	0.26	0.94	0.81	0.44	0.52	0.45	0.34
3511	0.20	0.24	0.95	0.83	0.28	0.37	0.71	0.57
3540	0.15	0.20	0.96	0.88	0.82	0.91	-1.21	0.17
3550	0.17	0.21	0.96	0.86	0.64	0.72	-0.40	0.36
4215	0.13	0.16	0.97	0.91	0.49	0.56	0.62	0.56
4410	0.16	0.20	0.96	0.87	0.60	0.75	-0.40	0.11
4530	0.12	0.15	0.98	0.92	0.38	0.50	0.71	0.79
4540	0.11	0.14	0.98	0.92	0.35	0.43	0.76	**0.86**
4650	0.14	0.18	0.97	0.90	0.53	0.59	-0.16	0.51

Table 5.20: The calibration and validation results for Random Forest model of SSI forecast based on SPEI inputs

Basin	Calibration				Validation			
	MAE	RMSE	NSE	KGE	MAE	RMSE	NSE	KGE
0170	0.14	0.19	0.97	0.88	0.61	0.68	-0.62	0.78
0180	0.15	0.20	0.96	0.87	0.68	0.73	-0.68	0.68
0250	0.22	0.29	0.93	0.77	0.94	1.13	-1.07	0.27
0580	**0.11**	**0.14**	**0.98**	**0.93**	0.45	0.50	0.25	0.75
0660	0.12	0.15	0.98	0.92	0.38	0.46	0.43	0.42
0840	0.29	0.38	0.88	0.67	0.93	1.03	-3.65	0.03
0850	0.25	0.32	0.91	0.73	0.71	0.85	-0.73	0.20
0900	0.24	0.31	0.91	0.74	0.79	0.90	-0.39	0.41
0910	0.22	0.30	0.92	0.75	0.74	0.84	-0.21	0.34
1020	0.12	0.16	0.97	0.89	0.42	0.48	0.67	0.75
1350	0.23	0.31	0.92	0.75	0.77	0.91	0.13	0.18
1430	0.14	0.17	0.97	0.89	0.39	0.47	0.75	0.57
1510	0.13	0.17	0.97	0.89	0.50	0.56	0.59	0.48
1790	0.15	0.19	0.96	0.87	0.51	0.67	0.19	0.34
1980	0.11	0.14	0.98	0.92	0.45	0.51	0.26	0.61
2110	0.16	0.21	0.96	0.85	0.47	0.58	0.15	0.09
2400	**0.10**	**0.14**	**0.98**	**0.92**	0.38	0.44	0.48	0.74
2940	0.12	0.15	0.98	0.93	**0.26**	**0.33**	**0.85**	**0.66**
3450	0.22	0.27	0.94	0.80	0.42	0.51	0.60	0.39
3511	0.20	0.24	0.95	0.83	0.31	0.39	0.73	0.57
3540	0.16	0.21	0.96	0.86	0.77	0.87	-0.69	0.28
3550	0.18	0.22	0.95	0.85	0.59	0.70	-0.05	0.42
4215	0.13	0.16	0.97	0.90	0.49	0.57	0.63	0.56
4410	0.17	0.21	0.96	0.86	0.59	0.75	-0.22	0.12
4530	0.12	0.15	0.98	0.91	0.38	0.48	0.73	0.79
4540	0.12	0.15	0.98	0.92	0.34	0.41	0.78	0.86
4650	0.15	0.19	0.97	0.88	0.49	0.56	0.00	0.53

Table 5.21: The calibration and validation results for Random Forest model of scPDSI forecast based on scPDSI inputs

Basin	Calibration				Validation			
	MAE	RMSE	NSE	KGE	MAE	RMSE	NSE	KGE
0170	0.23	0.33	0.98	0.93	**0.37**	**0.47**	0.65	0.67
0180	0.25	0.35	0.97	0.91	0.56	0.72	0.34	0.37
0250	0.27	0.40	0.96	0.87	0.83	1.06	0.33	0.47
0580	0.25	0.37	0.97	0.90	0.71	0.94	0.46	0.56
0660	0.24	0.35	0.97	0.91	0.67	0.89	0.68	0.50
0840	0.25	0.37	0.96	0.91	0.74	0.91	0.67	0.67
0850	**0.22**	**0.34**	**0.98**	**0.96**	0.54	0.65	0.83	0.80
0900	0.24	0.37	0.96	0.91	1.62	2.45	-1.57	0.12
0910	0.24	0.36	0.96	0.89	0.89	1.39	0.02	0.16
1020	0.31	0.44	0.96	0.88	0.85	1.05	**0.89**	0.71
1350	0.27	0.39	0.96	0.87	0.94	1.21	0.66	0.51
1430	0.28	0.42	0.96	0.87	0.95	1.38	0.54	0.40
1510	0.29	0.42	0.96	0.88	1.04	1.50	0.38	0.18
1790	0.30	0.42	0.95	0.85	0.98	1.39	0.44	0.28
1980	0.22	0.35	0.97	0.90	0.73	1.05	0.71	0.49
2110	0.25	0.39	0.97	0.89	0.59	0.87	0.67	0.54
2400	0.24	0.36	0.97	0.90	0.81	1.18	0.74	0.53
2940	0.27	0.40	0.96	0.86	0.96	1.39	0.39	0.27
3450	0.29	0.41	0.96	0.85	0.64	0.86	0.66	0.56
3511	0.29	0.40	0.96	0.87	0.69	0.90	0.62	0.53
3540	0.25	0.36	0.97	0.90	0.57	0.75	0.75	0.66
3550	0.28	0.40	0.96	0.87	0.68	0.89	0.72	0.61
4215	0.25	0.38	0.96	0.88	0.63	0.91	0.56	0.56
4410	0.26	0.38	0.97	0.92	0.77	0.98	0.49	0.35
4530	0.29	0.41	0.96	0.86	0.85	1.05	-0.59	0.11
4540	0.26	0.38	0.97	0.90	0.49	0.57	0.48	0.49
4650	0.29	0.42	0.96	0.88	0.83	1.25	0.53	0.40

Table 5.22: The calibration and validation results for Extra-Trees prediction model of SPI forecast based on PDSI inputs

Basin	Calibration				Validation			
	MAE	RMSE	NSE	KGE	MAE	RMSE	NSE	KGE
0170	0.13	0.17	0.97	0.88	0.40	0.51	0.44	0.41
0180	0.14	0.18	0.96	0.87	0.42	0.53	0.42	0.42
0250	**0.12**	**0.15**	**0.98**	**0.91**	0.41	0.50	0.40	0.69
0580	0.14	0.18	0.97	0.88	0.40	0.48	0.46	0.65
0660	0.14	0.18	0.97	0.89	0.46	0.60	0.30	-2.22
0840	0.14	0.18	0.96	0.88	0.54	0.66	0.52	0.58
0850	0.14	0.17	0.97	0.89	0.41	0.51	0.62	0.02
0900	0.12	0.16	0.97	0.89	0.55	0.69	0.67	0.54
0910	0.14	0.17	0.96	0.87	0.48	0.62	0.64	0.55
1020	0.13	0.17	0.97	0.89	0.37	0.55	**0.77**	0.22
1350	0.14	0.18	0.97	0.88	0.58	0.74	0.36	0.26
1430	0.13	0.17	0.97	0.90	0.56	0.67	0.52	-0.22
1510	0.13	0.18	0.97	0.89	0.61	0.73	0.45	-2.46
1790	0.15	0.18	0.97	0.89	0.43	0.53	0.68	0.02
1980	0.15	0.19	0.96	0.88	0.59	0.69	0.40	-1.62
2110	0.14	0.18	0.97	0.90	0.56	0.65	0.15	-0.94
2400	0.15	0.19	0.96	0.88	0.52	0.63	0.53	-6.99
2940	0.14	0.18	0.97	0.88	0.49	0.62	0.39	0.51
3450	0.14	0.19	0.96	0.87	0.44	0.54	0.36	0.62
3511	0.13	0.17	0.97	0.90	0.48	0.61	-0.20	0.13
3540	0.15	0.18	0.97	0.88	0.39	0.49	0.33	0.50
3550	0.16	0.20	0.96	0.86	0.43	0.51	0.37	0.61
4215	0.15	0.19	0.96	0.86	0.48	0.59	0.28	0.49
4410	0.16	0.20	0.96	0.86	0.60	0.72	-0.06	-0.33
4530	0.16	0.20	0.96	0.86	0.46	0.55	0.23	0.48
4540	0.15	0.19	0.96	0.87	0.47	0.55	0.29	0.45
4650	0.17	0.20	0.96	0.87	0.44	0.56	0.45	0.45

Chapter 6

Discussion

There are lots of articles oriented to drought phenomenon and methods to characterize it, as well as ways to find the easiest and more robust calculation methods. The review of drought modeling concepts was published by Mishra and Singh (2011), where different methodologies were described which include drought forecasting, probability based modeling, spatio-temporal analysis and many others.

The article can be emphasized is Belayneh and Adamowski (2013), where artificial neural networks (ANNs), support vector regression (SVR), and coupled wavelet neural network (WA-ANN) were explored. The SPI index was used for forecasting. Resuts indicated WA-ANN models were the most accurate models for forecasting 3-month SPI and 6-month SPI values over lead times of 1 and 3 months in the Awash River Basin in Ethiopia.

The other scientific work of Belayneh et al. (2014) forecasted the long-term SPI (SPI 12 and SPI 24) using stochastic model (ARIMA) and compared to artificial neural networks (ANNs), and support vector regression (SVR). In addition to these three model types, wavelet transforms were used to pre-process the inputs for ANN and SVR models to form WA-ANN and WA-SVR models. This was the first time when WA-SVR models have been explored and tested for long-term SPI forecasting. And again, as in a previous study WA-ANN demonstrated better results in the same basin.

In my thesis five types of drought indices (the SPI, the SPEI, the SSI, the PDSI, the scPDSI) were defined using two methods of decision tree models, such as Random Forest and Extra-Trees. The same drought indices were taken as predictors and two model methods, prediction and forecasting, were implemented.

When comparing the result of Random Forest and Extra-Trees models, the second type seem faster since instead of computing the locally optimal split combination (for the Random Forest) for each feature under consideration, a random value is selected for the split (for the Extra-Trees). This leads to more diversified trees and less splitters to evaluate when training an extremly random forest.

The related study of evaluation drought via Extra-Trees model was previousy made by Galelli and Castelletti (2013). The evaluation of Extra-Trees was performed against other tree-based methods (CART and M5) and parametric data-driven approaches (ANNs and multiple linear regression). Results demonstrated that Extra-Trees perform comparatively well to the best of M5 method, while outperforming the other approaches in terms of computational requirement when adopted on large datasets.

In thesis, achieved resuts showed that the SPI and the SPEI indices were defined precisely by all indices' inputs. This is related to parameters which are necessary for characterizing them contained in input indices, like precipitation and evapotranspiration data. The results of predicting and forecasting of the SSI index are the second best since they were defined using the statistical stabdardization approach, the SPEI and the SSI inputs both, in prediction and forecasting.

The results of other indices (the PDSI and the scPDSI) were partially good. They showed good values of model performance indices in Random Forest prediction model using the same inputs. In Random Forest forecasting model, only the scPDSI was forecasted well by the same input data. In contrary, in Extra-Trees prediction models the scPDSI predicted the same index, and in Extra-Trees forecasting models both indices were defined by the same inputs. We obtained these results since evaluations of the PDSI and the scPDSI require more input parameters from predictors.

The next studies should be oriented on changing the number of taken into consideration lag-time for creating prediction and forecasting and comparing the results. Also, given indices could be evaluated using other drought forecasting methods, such as Artificial Neural Network (ANN), probability models, hybrid model or via remotely sensed data, as shown in Choi et al. (2013) and in Rhee and Im (2017).

Chapter 7

Conclusion

In recent years, a lot of studies were created to analyse the spatial patterns of drought risk and a big attention was given to solve this problem.

In the first part of this thesis I have described the drought, its ecological and economical impact to society and classifications of drought. Then, the drought indices such the Palmer Drought Severity Index, the Standardized Precipitation Index, the Standardized Precipitation Evapotranspiration Index and the Standardized Soil Moisture Index were described. They were developed to identify the drought phenomenon. First of them is The Standardized Precipitation Index, which is based on precipitation data and it is related to the description of meteorological drought. Second of them is The Standardized Precipitation Evapotranspiration Index, which is based on precipitation and potential evapotranspiration data and characterises meteorological nd agricultural drought. Also the Standardized Soil Moisture Index, which is the main indicator for agricultural drought monitoring, were described. And the last one, the Palmer Drought Severity Index based on on a 2-layer bucket-type water balance model and describes meteorological drought.

Then I have characterized the drought forecasting methods, specifically Random Forest and Extremely Randomized Tree methods and their procedure for drought prediction and forecasting using the drought indices as inputs for 27 meteorological basins located in the diffreent parts of the Czech Republic. Five drought indices – the SPI, the SPEI, the PDSI, the scPDSI and the SSI – have been used as the predictands. Models were based on data obtained from January 1982 to December 2015.

The tested results show that Extra-Trees models gave more accurate and faster results.

This is related to the internal structure of Extra-Trees model, which computes the locally optimal split combination differently than the Random Forest. This leads to more diversified trees and less splitters to evaluate when training an extremly random forest.

After evaluating the Random Forest and Extra-Trees models performance, the best results were shown for all given drought indices.

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Appendix A

Random Forest prediction results

Random Forest prediction models‘ performance based on drought indices inputs creating for 27 meteorological basins.

Table A.1: The calibration and validation results for Random Forest prediction model of SPI forecast based on SPI inputs

Basin	Calibration				Validation			
	MAE	RMSE	NSE	KGE	MAE	RMSE	NSE	KGE
0170	**0.04**	**0.06**	**1.00**	**0.97**	0.10	0.17	0.94	0.85
0180	0.04	0.07	1.00	0.96	0.10	0.18	0.93	0.84
0250	**0.04**	**0.06**	**1.00**	**0.97**	0.09	0.13	0.96	0.89
0580	0.04	0.07	1.00	0.97	0.12	0.21	0.89	0.76
0660	0.05	0.08	0.99	0.97	**0.08**	**0.13**	0.96	0.85
0840	0.04	0.07	0.99	0.96	0.14	0.19	0.96	0.86
0850	0.04	0.07	0.99	0.96	0.10	0.14	**0.97**	**0.89**
0900	0.04	0.06	0.99	0.96	0.19	0.31	0.93	0.78
0910	0.04	0.07	0.99	0.96	0.15	0.24	0.95	0.82
1020	0.04	0.07	0.99	0.96	0.14	0.23	0.96	0.85
1350	0.04	0.07	1.00	0.96	0.20	0.38	0.82	0.64
1430	0.04	0.07	0.99	0.96	0.14	0.29	0.90	0.73
1510	0.04	0.07	1.00	0.97	0.17	0.31	0.89	0.70
1790	0.04	0.07	1.00	0.97	0.13	0.24	0.93	0.77
1980	0.04	0.07	1.00	0.96	0.13	0.20	0.94	0.84
2110	0.04	0.07	1.00	0.97	0.10	0.15	0.95	0.87
2400	**0.04**	**0.06**	**1.00**	**0.97**	0.12	0.22	0.94	0.82
2940	0.05	0.08	0.99	0.96	0.12	0.19	0.93	0.79
3450	0.05	0.08	0.99	0.96	0.11	0.18	0.92	0.78
3511	0.04	0.07	1.00	0.97	0.10	0.14	0.94	0.82
3540	0.04	0.07	1.00	0.97	0.10	0.16	0.93	0.81
3550	0.04	0.07	0.99	0.96	0.10	0.16	0.93	0.81
4215	0.05	0.08	0.99	0.96	0.11	0.15	0.95	0.86
4410	0.05	0.08	0.99	0.96	0.12	0.19	0.92	0.77
4530	0.04	0.08	0.99	0.96	0.11	0.15	0.94	0.88
4540	0.04	0.08	0.99	0.96	0.10	0.15	0.94	0.87
4650	0.05	0.07	0.99	0.96	0.11	0.19	0.94	0.80

Table A.2: The calibration and validation results for Random Forest prediction model of SPEI forecast based on SPI inputs

Basin	Calibration				Validation			
	MAE	RMSE	NSE	KGE	MAE	RMSE	NSE	KGE
0170	0.09	0.12	0.98	0.93	0.20	0.24	0.85	0.84
0180	0.09	0.12	0.98	0.93	0.19	0.22	0.87	0.84
0250	**0.08**	**0.10**	**0.99**	**0.94**	0.22	0.27	0.82	0.73
0580	0.11	0.14	0.98	0.92	0.22	0.28	0.84	0.70
0660	0.12	0.15	0.98	0.91	0.26	0.31	0.83	0.65
0840	0.08	0.11	0.99	0.94	0.20	0.25	0.92	0.85
0850	0.08	0.11	0.99	0.94	**0.15**	**0.20**	0.94	**0.88**
0900	0.09	0.11	0.98	0.93	0.18	0.24	**0.95**	0.85
0910	0.10	0.12	0.98	0.92	0.20	0.27	0.92	0.82
1020	0.12	0.15	0.97	0.90	0.24	0.32	0.91	0.79
1350	0.09	0.11	0.99	0.94	0.23	0.32	0.87	0.76
1430	0.09	0.12	0.99	0.94	0.21	0.32	0.90	0.70
1510	0.10	0.12	0.98	0.93	0.27	0.35	0.87	0.67
1790	0.11	0.14	0.98	0.92	0.24	0.28	0.89	0.74
1980	0.10	0.13	0.98	0.92	0.31	0.36	0.83	0.70
2110	0.10	0.12	0.98	0.93	0.19	0.25	0.89	0.70
2400	0.12	0.15	0.98	0.90	0.33	0.41	0.80	0.68
2940	0.09	0.11	0.99	0.94	0.16	0.22	0.93	0.80
3450	0.08	0.11	0.99	0.94	0.17	0.21	0.88	0.75
3511	0.09	0.11	0.99	0.94	0.33	0.39	0.56	0.55
3540	0.12	0.15	0.98	0.91	0.25	0.30	0.74	0.62
3550	0.11	0.13	0.98	0.92	0.28	0.32	0.73	0.63
4215	0.11	0.14	0.98	0.91	0.19	0.25	0.89	0.73
4410	0.12	0.15	0.98	0.91	0.29	0.32	0.79	0.57
4530	0.11	0.14	0.98	0.91	0.18	0.22	0.90	0.84
4540	0.11	0.14	0.98	0.92	0.20	0.24	0.89	0.82
4650	0.11	0.15	0.98	0.91	0.26	0.32	0.83	0.65

Table A.3: The calibration and validation results for Random Forest prediction model of PDSI forecast based on SPI inputs

Basin	Calibration				Validation			
	MAE	RMSE	NSE	KGE	MAE	RMSE	NSE	KGE
0170	0.37	0.44	0.89	0.67	0.82	1.03	0.08	0.07
0180	0.36	0.45	0.89	0.68	0.99	1.23	-0.35	0.02
0250	0.36	0.44	0.89	0.68	0.96	1.10	0.18	0.17
0580	0.41	0.48	0.88	0.67	1.08	1.27	-0.00	0.07
0660	0.40	0.48	0.89	0.69	1.00	1.16	0.14	0.11
0840	0.34	0.42	0.90	0.70	1.16	1.33	0.05	0.08
0850	0.34	0.43	0.89	0.68	1.13	1.28	-0.02	0.09
0900	0.35	0.42	0.88	0.67	1.29	1.47	-0.19	0.03
0910	0.35	0.42	0.88	0.66	1.18	1.35	-0.19	0.03
1020	0.42	0.50	0.89	0.68	1.23	1.35	0.45	0.19
1350	0.34	0.41	**0.91**	0.71	1.24	1.49	-0.52	0.01
1430	0.38	0.45	0.90	0.70	1.22	1.49	-0.06	0.07
1510	0.39	0.47	0.90	0.70	1.23	1.50	-0.01	0.06
1790	0.36	0.43	**0.91**	0.72	1.26	1.45	0.11	0.09
1980	0.38	0.45	**0.91**	0.72	1.47	1.72	-0.02	0.03
2110	0.37	0.45	0.91	0.72	1.15	1.32	-0.10	0.08
2400	0.39	0.47	0.90	0.71	1.36	1.63	-0.26	0.04
2940	0.38	0.48	0.87	0.65	0.96	1.08	0.37	0.17
3450	0.35	0.43	0.88	0.66	1.06	1.20	0.10	0.11
3511	0.36	0.43	0.90	0.70	1.17	1.31	-0.14	0.08
3540	0.38	0.46	0.89	0.68	1.13	1.27	-0.04	0.09
3550	0.36	0.44	0.88	0.66	1.21	1.37	-0.06	0.12
4215	0.39	0.48	0.87	0.65	1.12	1.28	0.09	0.07
4410	0.36	0.43	0.88	0.66	1.09	1.25	-0.13	0.05
4530	0.41	0.49	0.88	0.67	1.00	1.10	0.14	0.12
4540	0.42	0.50	0.88	0.66	0.91	1.02	0.27	0.18
4650	0.42	0.51	0.88	0.67	1.19	1.36	0.02	0.06

Table A.4: The calibration and validation results for Random Forest prediction model of scPDSI forecast based on SPI inputs

Basin	Calibration				Validation			
	MAE	RMSE	NSE	KGE	MAE	RMSE	NSE	KGE
0170	0.51	0.63	0.92	0.76	1.46	1.73	-3.94	0.07
0180	0.50	0.63	0.91	0.76	2.16	2.32	-6.52	0.10
0250	0.48	0.57	0.92	0.76	1.69	1.81	-1.09	0.38
0580	0.56	0.64	0.91	0.74	1.50	1.80	-1.17	0.14
0660	0.55	0.64	0.92	0.75	1.79	2.07	-0.82	0.06
0840	0.43	0.56	0.92	0.81	1.39	1.63	-0.09	0.48
0850	0.58	0.76	0.90	0.82	1.23	1.46	0.12	0.52
0900	0.50	0.62	0.90	0.76	2.12	2.43	-1.67	0.15
0910	0.52	0.63	0.88	0.71	1.85	2.06	-1.28	0.23
1020	0.53	0.64	0.92	0.75	2.01	2.28	0.46	0.19
1350	0.44	0.53	0.92	0.77	1.47	1.73	0.26	0.16
1430	0.49	0.58	0.92	0.76	1.84	2.26	-0.33	0.08
1510	0.49	0.59	**0.93**	0.78	1.63	2.00	-0.20	0.06
1790	0.43	0.52	**0.93**	0.76	1.56	1.74	0.09	0.15
1980	0.47	0.56	0.92	0.75	1.99	2.29	-0.47	0.05
2110	0.48	0.60	**0.93**	0.77	1.62	1.88	-0.60	0.10
2400	0.48	0.60	0.92	0.75	1.93	2.33	-0.07	0.16
2940	0.46	0.58	0.92	0.74	1.81	2.11	-0.49	0.08
3450	0.47	0.55	0.92	0.74	1.74	1.88	-0.74	0.13
3511	0.47	0.56	0.92	0.76	2.02	2.14	-1.28	0.17
3540	0.51	0.61	0.91	0.74	1.50	1.67	-0.29	0.21
3550	0.52	0.62	0.90	0.72	1.78	1.97	-0.47	0.16
4215	0.47	0.56	0.91	0.76	1.51	1.80	-0.87	0.15
4410	0.47	0.62	0.92	0.79	2.16	2.49	-2.47	0.02
4530	0.58	0.68	0.89	0.67	1.96	2.14	-6.05	0.07
4540	0.50	0.61	0.92	0.75	2.01	2.16	-6.69	0.14
4650	0.59	0.71	0.89	0.72	1.42	1.64	0.12	0.19

Table A.5: The calibration and validation results for Random Forest prediction model of SSI forecast based on SPI inputs

Basin	Calibration				Validation			
	MAE	RMSE	NSE	KGE	MAE	RMSE	NSE	KGE
0170	0.19	0.26	0.94	0.81	0.76	0.83	-1.66	0.78
0180	0.19	0.26	0.94	0.81	0.78	0.85	-1.53	0.62
0250	0.25	0.33	0.91	0.72	0.78	1.00	-1.02	0.17
0580	0.13	0.18	0.97	0.89	0.53	0.66	-0.42	0.28
0660	0.16	0.22	0.96	0.86	0.39	0.47	0.34	0.24
0840	0.31	0.41	0.86	0.63	0.96	1.08	-5.24	0.06
0850	0.30	0.40	0.87	0.64	0.79	0.89	-1.43	0.07
0900	0.27	0.36	0.89	0.68	0.91	1.02	-1.15	0.19
0910	0.26	0.36	0.88	0.67	0.80	0.91	-0.74	0.18
1020	0.17	0.23	0.94	0.81	0.50	0.59	0.48	0.52
1350	0.28	0.37	0.88	0.67	0.93	1.08	-0.57	0.09
1430	0.19	0.24	0.94	0.81	0.36	0.44	0.76	0.55
1510	0.20	0.25	0.94	0.80	0.51	0.60	0.44	0.41
1790	0.19	0.25	0.94	0.81	0.63	0.76	-0.22	0.19
1980	0.14	0.18	0.97	0.87	0.38	0.50	0.16	0.48
2110	0.21	0.26	0.94	0.79	0.52	0.60	0.04	0.02
2400	0.17	0.23	0.95	0.83	0.37	0.49	0.26	0.57
2940	**0.13**	**0.16**	**0.98**	**0.90**	**0.24**	**0.31**	**0.85**	**0.72**
3450	0.25	0.32	0.91	0.74	0.53	0.62	0.20	0.16
3511	0.26	0.33	0.91	0.73	0.33	0.43	0.62	0.40
3540	0.23	0.28	0.93	0.77	0.67	0.82	-0.77	0.05
3550	0.24	0.29	0.92	0.76	0.56	0.66	-0.18	0.15
4215	0.17	0.21	0.96	0.85	0.59	0.66	0.48	0.25
4410	0.20	0.25	0.94	0.81	0.61	0.74	-0.36	0.02
4530	0.14	0.18	0.97	0.89	0.52	0.65	0.52	0.55
4540	0.13	0.16	0.97	0.90	0.48	0.59	0.54	0.58
4650	0.17	0.23	0.95	0.83	0.56	0.62	-0.28	0.10

Table A.6: The calibration and validation results for Random Forest prediction model of SPI forecast based on SPEI inputs

Basin	Calibration				Validation			
	MAE	RMSE	NSE	KGE	MAE	RMSE	NSE	KGE
0170	0.08	0.11	0.99	0.94	0.27	0.35	0.73	0.58
0180	0.09	0.11	0.99	0.94	0.27	0.33	0.77	0.65
0250	**0.08**	**0.10**	**0.99**	**0.95**	0.19	0.24	0.86	0.86
0580	0.12	0.16	0.97	0.91	0.26	0.36	0.70	0.54
0660	0.12	0.16	0.98	0.91	0.20	0.26	0.86	0.70
0840	0.08	0.11	0.99	0.93	0.21	0.26	0.92	0.77
0850	0.08	0.10	0.99	0.94	**0.18**	**0.23**	**0.93**	**0.77**
0900	0.08	0.10	0.99	0.94	0.29	0.40	0.89	0.70
0910	0.09	0.12	0.98	0.93	0.25	0.32	0.90	0.73
1020	0.11	0.14	0.98	0.91	0.34	0.42	0.87	0.68
1350	0.08	0.10	0.99	0.94	0.30	0.44	0.76	0.59
1430	0.09	0.12	0.99	0.94	0.25	0.38	0.83	0.64
1510	0.10	0.13	0.98	0.93	0.28	0.41	0.82	0.60
1790	0.10	0.13	0.98	0.93	0.30	0.42	0.79	0.59
1980	0.11	0.14	0.98	0.92	0.27	0.34	0.85	0.68
2110	0.10	0.13	0.98	0.93	0.18	0.24	0.89	0.81
2400	0.13	0.16	0.97	0.90	0.32	0.40	0.80	0.58
2940	0.09	0.11	0.99	0.94	0.23	0.31	0.83	0.63
3450	0.08	0.11	0.99	0.94	0.21	0.29	0.80	0.63
3511	0.09	0.11	0.99	0.94	0.25	0.31	0.68	0.77
3540	0.11	0.14	0.98	0.92	0.25	0.31	0.73	0.64
3550	0.10	0.13	0.98	0.93	0.25	0.31	0.76	0.71
4215	0.10	0.13	0.98	0.92	0.26	0.34	0.75	0.64
4410	0.13	0.16	0.98	0.91	0.26	0.34	0.74	0.54
4530	0.11	0.14	0.98	0.92	0.20	0.26	0.83	0.80
4540	0.10	0.13	0.98	0.93	0.24	0.29	0.79	0.75
4650	0.12	0.15	0.98	0.91	0.25	0.30	0.84	0.64

Table A.7: The calibration and validation results for Random Forest prediction model of SPEI forecast based on SPEI inputs

Basin	Calibration				Validation			
	MAE	RMSE	NSE	KGE	MAE	RMSE	NSE	KGE
0170	**0.04**	**0.06**	**1.00**	**0.97**	**0.09**	**0.12**	**0.96**	**0.92**
0180	0.04	0.07	1.00	0.97	0.09	0.13	0.96	0.90
0250	0.04	0.06	1.00	0.97	0.11	0.15	0.94	0.86
0580	0.04	0.07	1.00	0.97	0.11	0.17	0.94	0.83
0660	0.04	0.07	1.00	0.96	0.10	0.16	0.96	0.85
0840	0.04	0.07	0.99	0.96	0.12	0.16	0.97	0.88
0850	0.04	0.07	1.00	0.96	0.11	0.15	0.97	0.88
0900	0.04	0.06	1.00	0.96	0.13	0.19	0.97	0.87
0910	0.04	0.07	0.99	0.96	0.12	0.17	0.97	0.88
1020	0.04	0.07	1.00	0.96	0.12	0.20	0.97	0.88
1350	0.04	0.07	1.00	0.96	0.13	0.24	0.93	0.78
1430	0.04	0.07	1.00	0.96	0.14	0.26	0.93	0.78
1510	0.04	0.06	1.00	0.96	0.15	0.27	0.92	0.75
1790	0.04	0.06	1.00	0.97	0.13	0.20	0.94	0.81
1980	0.04	0.06	1.00	0.97	0.13	0.21	0.94	0.82
2110	0.04	0.07	1.00	0.97	0.11	0.17	0.95	0.84
2400	0.04	0.06	1.00	0.97	0.14	0.23	0.94	0.80
2940	0.04	0.07	1.00	0.97	0.13	0.20	0.94	0.81
3450	0.04	0.07	0.99	0.96	0.11	0.15	0.94	0.82
3511	0.04	0.06	1.00	0.97	0.11	0.16	0.93	0.83
3540	0.04	0.07	1.00	0.97	0.11	0.15	0.93	0.84
3550	0.04	0.07	1.00	0.97	0.11	0.15	0.94	0.84
4215	0.04	0.07	1.00	0.96	0.13	0.18	0.94	0.85
4410	0.04	0.07	0.99	0.96	0.12	0.16	0.95	0.83
4530	0.04	0.07	0.99	0.96	0.09	0.12	0.97	0.92
4540	0.04	0.07	0.99	0.96	0.10	0.13	0.97	0.90
4650	0.04	0.06	1.00	0.97	0.12	0.21	0.92	0.79

Table A.8: The calibration and validation results for Random Forest prediction model of PDSI forecast based on SPEI inputs

Basin	Calibration				Validation			
	MAE	RMSE	NSE	KGE	MAE	RMSE	NSE	KGE
0170	0.36	0.44	0.89	0.68	0.82	1.02	0.09	0.07
0180	0.36	0.44	0.89	0.69	0.92	1.13	-0.14	0.05
0250	0.35	0.42	0.90	0.70	0.90	1.08	0.22	0.16
0580	0.40	0.48	0.88	0.67	1.09	1.27	-0.01	0.04
0660	0.40	0.47	0.90	0.69	1.03	1.23	0.02	0.08
0840	0.37	0.44	0.89	0.69	1.14	1.29	0.11	0.09
0850	0.34	0.43	0.89	0.67	1.15	1.29	-0.02	0.09
0900	0.34	0.41	0.89	0.68	1.22	1.39	-0.07	0.06
0910	0.36	0.43	0.88	0.66	1.03	1.19	0.08	0.10
1020	0.39	0.47	0.90	0.71	1.19	1.34	0.46	0.19
1350	0.35	0.42	0.90	0.70	1.32	1.54	-0.62	0.02
1430	0.37	0.45	0.90	0.70	1.31	1.52	-0.11	0.05
1510	0.39	0.46	0.90	0.71	1.28	1.54	-0.05	0.05
1790	0.37	0.44	**0.91**	0.71	1.42	1.66	-0.16	0.03
1980	0.38	0.45	**0.91**	0.72	1.12	1.31	0.41	0.17
2110	0.39	0.47	0.90	0.70	1.12	1.26	-0.01	0.11
2400	0.39	0.46	**0.91**	0.71	1.16	1.35	0.13	0.10
2940	0.36	0.45	0.89	0.68	1.14	1.24	0.17	0.07
3450	0.36	0.43	0.88	0.65	1.09	1.22	0.08	0.10
3511	0.35	0.42	**0.91**	0.71	1.12	1.21	0.02	0.06
3540	0.38	0.46	0.89	0.68	1.08	1.23	0.03	0.10
3550	0.38	0.45	0.88	0.65	1.17	1.32	0.02	0.12
4215	0.38	0.47	0.88	0.66	1.11	1.23	0.16	0.08
4410	0.37	0.44	0.87	0.64	1.13	1.27	-0.16	0.05
4530	0.40	0.48	0.89	0.67	0.96	1.07	0.19	0.18
4540	0.41	0.48	0.89	0.68	0.84	0.98	0.33	0.18
4650	0.41	0.48	0.89	0.69	1.09	1.28	0.14	0.07

Table A.9: The calibration and validation results for Random Forest prediction model of scPDSI forecast based on SPEI inputs

Basin	Calibration				Validation			
	MAE	RMSE	NSE	KGE	MAE	RMSE	NSE	KGE
0170	0.46	0.59	0.93	0.78	1.42	1.65	-3.48	0.08
0180	0.47	0.59	0.92	0.78	1.95	2.14	-5.38	0.06
0250	0.45	0.53	0.92	0.78	1.54	1.71	-0.86	0.35
0580	0.52	0.62	0.91	0.75	1.84	2.22	-2.31	0.04
0660	0.53	0.63	0.92	0.76	1.85	2.14	-0.95	0.03
0840	0.48	0.60	0.91	0.79	1.38	1.59	-0.03	0.45
0850	0.57	0.72	0.91	0.83	1.00	1.26	0.34	0.53
0900	0.58	0.69	0.87	0.72	2.08	2.20	-1.18	0.37
0910	0.54	0.64	0.88	0.71	1.63	1.80	-0.73	0.34
1020	0.52	0.65	0.92	0.75	1.81	2.03	0.58	0.29
1350	0.46	0.55	0.92	0.76	1.44	1.69	0.31	0.20
1430	0.50	0.59	0.92	0.75	1.99	2.37	-0.47	0.04
1510	0.47	0.56	0.93	0.80	1.67	2.06	-0.28	0.04
1790	0.43	0.54	0.92	0.75	1.92	2.20	-0.46	0.04
1980	0.46	0.55	0.93	0.77	1.53	1.74	0.14	0.16
2110	0.51	0.62	0.92	0.75	1.67	1.80	-0.46	0.09
2400	0.46	0.56	0.93	0.78	1.92	2.06	0.17	0.07
2940	0.43	0.55	0.93	0.76	1.93	2.17	-0.59	0.02
3450	0.52	0.61	0.90	0.71	1.80	1.93	-0.82	0.12
3511	0.49	0.59	0.92	0.74	1.47	1.68	-0.41	0.20
3540	0.49	0.58	0.92	0.76	1.22	1.43	0.05	0.25
3550	0.50	0.61	0.90	0.72	1.56	1.83	-0.27	0.15
4215	0.44	0.52	0.93	0.78	1.33	1.66	-0.60	0.12
4410	0.44	0.57	**0.94**	0.81	2.30	2.66	-2.95	0.01
4530	0.52	0.62	0.91	0.71	2.03	2.18	-6.31	0.08
4540	0.47	0.56	0.93	0.78	1.76	1.96	-5.33	0.12
4650	0.53	0.64	0.91	0.76	1.27	1.66	0.10	0.11

Table A.10: The calibration and validation results for Random Forest prediction model of SSI forecast based on SPEI inputs

Basin	Calibration				Validation			
	MAE	RMSE	NSE	KGE	MAE	RMSE	NSE	KGE
0170	0.14	0.18	0.97	0.89	0.63	0.68	-0.82	0.81
0180	0.14	0.18	0.97	0.89	0.71	0.76	-1.02	0.68
0250	0.22	0.29	0.93	0.78	0.98	1.16	-1.72	0.31
0580	**0.10**	**0.13**	**0.98**	**0.94**	0.47	0.53	0.06	0.68
0660	0.11	0.14	0.98	0.93	0.42	0.49	0.27	0.34
0840	0.30	0.38	0.88	0.67	1.00	1.11	-5.54	0.06
0850	0.24	0.31	0.92	0.75	0.73	0.87	-1.36	0.21
0900	0.23	0.31	0.92	0.75	0.89	1.02	-1.13	0.39
0910	0.22	0.29	0.92	0.76	0.79	0.89	-0.68	0.36
1020	0.11	0.15	0.98	0.90	0.39	0.46	0.68	0.76
1350	0.22	0.29	0.93	0.77	0.74	0.88	-0.03	0.26
1430	0.13	0.17	0.97	0.89	0.41	0.47	0.73	0.57
1510	0.13	0.16	0.97	0.90	0.48	0.55	0.53	0.49
1790	0.14	0.18	0.97	0.88	0.54	0.68	0.04	0.33
1980	0.10	0.13	0.98	0.93	0.44	0.52	0.10	0.59
2110	0.16	0.21	0.96	0.86	0.50	0.59	0.09	0.07
2400	0.10	0.13	0.98	0.93	0.36	0.42	0.44	0.74
2940	**0.10**	**0.13**	**0.98**	**0.94**	**0.23**	**0.30**	**0.86**	0.70
3450	0.21	0.26	0.94	0.81	0.44	0.52	0.45	0.34
3511	0.20	0.24	0.95	0.83	0.28	0.37	0.71	0.57
3540	0.15	0.20	0.96	0.88	0.82	0.91	-1.21	0.17
3550	0.17	0.21	0.96	0.86	0.64	0.72	-0.40	0.36
4215	0.13	0.16	0.97	0.91	0.49	0.56	0.62	0.56
4410	0.16	0.20	0.96	0.87	0.60	0.75	-0.40	0.11
4530	0.12	0.15	0.98	0.92	0.38	0.50	0.71	0.79
4540	0.11	0.14	0.98	0.92	0.35	0.43	0.76	**0.86**
4650	0.14	0.18	0.97	0.90	0.53	0.59	-0.16	0.51

Table A.11: The calibration and validation results for Random Forest prediction model of SPI forecast based on PDSI inputs

Basin	Calibration				Validation			
	MAE	RMSE	NSE	KGE	MAE	RMSE	NSE	KGE
0170	0.18	0.23	0.94	0.80	0.38	0.45	0.55	0.43
0180	0.19	0.24	0.94	0.78	0.38	0.46	0.55	0.47
0250	**0.15**	**0.19**	**0.96**	**0.84**	0.38	0.47	0.44	0.52
0580	0.19	0.23	0.95	0.81	0.40	0.49	0.43	0.36
0660	0.19	0.23	0.95	0.82	0.50	0.62	0.21	0.21
0840	0.18	0.23	0.94	0.78	0.54	0.66	0.53	0.35
0850	0.16	0.21	0.95	0.82	0.39	0.50	0.66	0.62
0900	0.16	0.21	0.95	0.80	0.53	0.68	0.68	0.51
0910	0.19	0.24	0.93	0.76	0.48	0.63	0.63	0.44
1020	0.17	0.22	0.94	0.80	0.38	0.57	**0.76**	0.55
1350	0.18	0.23	0.94	0.80	0.54	0.69	0.42	0.26
1430	0.17	0.21	0.95	0.82	0.55	0.65	0.51	0.35
1510	0.16	0.21	0.95	0.82	0.56	0.66	0.52	0.35
1790	0.18	0.22	0.95	0.82	0.43	0.56	0.62	0.62
1980	0.19	0.24	0.94	0.80	0.54	0.64	0.44	0.36
2110	0.17	0.21	0.96	0.84	0.51	0.64	0.18	0.47
2400	0.19	0.23	0.94	0.80	0.54	0.62	0.54	0.40
2940	0.19	0.25	0.94	0.78	0.43	0.54	0.49	0.31
3450	0.18	0.24	0.94	0.78	0.39	0.50	0.40	0.51
3511	0.17	0.21	0.96	0.83	0.47	0.61	-0.25	0.39
3540	0.19	0.24	0.94	0.80	0.35	0.48	0.35	0.38
3550	0.20	0.26	0.93	0.77	0.38	0.50	0.35	0.52
4215	0.21	0.27	0.93	0.76	0.49	0.59	0.25	0.25
4410	0.22	0.28	0.93	0.75	0.57	0.64	0.10	0.28
4530	0.21	0.26	0.93	0.77	0.43	0.51	0.34	0.27
4540	0.20	0.25	0.94	0.78	0.45	0.54	0.31	0.22
4650	0.20	0.25	0.94	0.79	0.43	0.52	0.54	0.39

Table A.12: The calibration and validation results for Random Forest prediction model of SPEI forecast based on PDSI inputs

Basin	Calibration				Validation			
	MAE	RMSE	NSE	KGE	MAE	RMSE	NSE	KGE
0170	0.17	0.22	0.95	0.82	0.30	0.37	0.64	0.53
0180	0.17	0.22	0.95	0.81	**0.27**	**0.34**	0.71	0.58
0250	**0.15**	**0.19**	**0.96**	**0.84**	0.38	0.47	0.44	0.41
0580	0.18	0.22	0.95	0.82	0.44	0.53	0.41	0.37
0660	0.17	0.21	0.96	0.83	0.56	0.66	0.23	0.17
0840	0.19	0.24	0.93	0.78	0.49	0.62	0.53	0.40
0850	0.18	0.23	0.94	0.80	0.39	0.51	0.62	0.64
0900	0.17	0.22	0.94	0.80	0.43	0.57	0.69	0.58
0910	0.19	0.24	0.93	0.77	0.41	0.52	0.68	0.52
1020	0.16	0.20	0.95	0.84	0.36	0.50	0.78	0.62
1350	0.20	0.24	0.94	0.79	0.57	0.69	0.42	0.32
1430	0.16	0.21	0.96	0.82	0.61	0.70	0.50	0.43
1510	0.16	0.21	0.95	0.82	0.55	0.66	0.52	0.39
1790	0.18	0.22	0.95	0.82	0.50	0.64	0.45	0.55
1980	0.17	0.21	0.96	0.84	0.47	0.55	0.61	0.48
2110	0.16	0.20	0.96	0.85	0.47	0.58	0.41	0.51
2400	0.16	0.20	0.96	0.85	0.48	0.58	0.60	0.45
2940	0.19	0.24	0.94	0.79	0.44	0.55	0.56	0.36
3450	0.20	0.25	0.94	0.78	0.42	0.55	0.21	0.40
3511	0.17	0.21	0.95	0.83	0.48	0.59	-0.03	0.26
3540	0.17	0.22	0.95	0.82	0.46	0.57	0.09	0.26
3550	0.20	0.26	0.93	0.78	0.44	0.53	0.24	0.37
4215	0.19	0.24	0.94	0.78	0.48	0.61	0.34	0.28
4410	0.21	0.26	0.93	0.77	0.51	0.64	0.18	0.40
4530	0.20	0.25	0.94	0.79	0.40	0.53	0.46	0.36
4540	0.18	0.23	0.95	0.80	0.41	0.51	0.51	0.37
4650	0.18	0.23	0.95	0.81	0.43	0.51	0.55	0.36

Table A.13: The calibration and validation results for Random Forest prediction model of PDSI forecast based on PDSI inputs

Basin	Calibration				Validation			
	MAE	RMSE	NSE	KGE	MAE	RMSE	NSE	KGE
0170	0.07	0.12	0.99	0.94	0.16	0.24	0.95	0.85
0180	0.07	0.11	0.99	0.94	0.17	0.28	0.93	0.82
0250	**0.07**	**0.10**	**0.99**	**0.95**	0.24	0.35	0.92	0.79
0580	0.07	0.11	0.99	0.95	0.23	0.36	0.92	0.77
0660	0.07	0.12	0.99	0.95	0.16	0.24	0.96	0.86
0840	0.07	0.12	0.99	0.94	0.25	0.33	0.94	0.82
0850	0.06	0.12	0.99	0.94	0.22	0.30	0.94	0.83
0900	0.06	0.11	0.99	0.94	0.26	0.37	0.92	0.80
0910	0.07	0.11	0.99	0.94	0.21	0.32	0.93	0.82
1020	0.07	0.11	0.99	0.96	0.22	0.31	0.97	0.88
1350	0.07	0.12	0.99	0.94	0.30	0.52	0.81	0.66
1430	0.07	0.14	0.99	0.94	0.26	0.43	0.91	0.75
1510	0.07	0.13	0.99	0.94	0.30	0.51	0.88	0.70
1790	0.07	0.12	0.99	0.95	0.25	0.39	0.94	0.80
1980	0.07	0.12	0.99	0.95	0.21	0.35	0.96	0.83
2110	0.07	0.11	0.99	0.96	0.22	0.33	0.93	0.86
2400	0.07	0.11	0.99	0.95	0.24	0.41	0.92	0.76
2940	0.07	0.13	0.99	0.93	0.18	0.24	0.97	0.86
3450	0.07	0.13	0.99	0.93	0.25	0.35	0.93	0.79
3511	0.07	0.13	0.99	0.93	0.22	0.30	0.94	0.83
3540	0.07	0.12	0.99	0.95	0.23	0.30	0.94	0.84
3550	0.07	0.13	0.99	0.93	0.27	0.37	0.92	0.80
4215	0.07	0.14	0.99	0.93	0.17	0.22	0.97	0.89
4410	0.07	0.12	0.99	0.94	0.18	0.24	0.96	0.86
4530	0.07	0.13	0.99	0.94	0.17	0.23	0.96	0.87
4540	0.07	0.13	0.99	0.95	**0.15**	**0.21**	**0.97**	**0.89**
4650	0.07	0.11	0.99	0.96	0.21	0.43	0.90	0.76

Table A.14: The calibration and validation results for Random Forest prediction model of scPDSI forecast based on PDSI inputs

Basin	Calibration				Validation			
	MAE	RMSE	NSE	KGE	MAE	RMSE	NSE	KGE
0170	0.41	0.54	0.94	0.80	1.39	1.56	-3.01	0.35
0180	0.40	0.53	0.94	0.82	1.94	1.99	-4.55	0.43
0250	0.30	0.39	0.96	0.86	1.15	1.26	-0.01	0.56
0580	0.41	0.55	0.93	0.79	1.38	1.58	-0.67	0.31
0660	0.47	0.58	0.93	0.78	0.95	1.11	0.48	0.38
0840	0.40	0.50	0.93	0.84	0.83	1.07	0.53	0.61
0850	0.62	0.77	0.90	0.81	0.79	0.94	0.64	0.61
0900	0.51	0.63	0.90	0.76	1.26	1.44	0.07	0.54
0910	0.35	0.48	0.93	0.81	0.95	1.12	0.33	0.58
1020	0.34	0.48	0.95	0.85	1.06	1.41	0.79	0.57
1350	0.31	0.41	0.95	0.85	1.42	1.68	0.31	0.25
1430	0.33	0.45	0.95	0.84	0.86	1.13	0.67	0.50
1510	0.28	0.39	0.97	0.88	0.80	1.13	0.62	0.40
1790	0.28	0.37	0.96	0.86	**0.45**	**0.60**	**0.89**	**0.74**
1980	0.31	0.44	0.95	0.84	0.90	1.12	0.65	0.46
2110	0.42	0.56	0.94	0.80	0.51	0.61	0.83	0.69
2400	0.29	0.39	0.97	0.87	1.31	1.43	0.59	0.31
2940	0.43	0.56	0.92	0.76	1.10	1.35	0.38	0.37
3450	0.36	0.52	0.93	0.77	0.89	1.02	0.49	0.59
3511	0.28	0.40	0.96	0.85	0.69	0.87	0.62	0.62
3540	0.31	0.42	0.96	0.85	0.48	0.65	0.80	0.72
3550	0.35	0.48	0.94	0.80	0.59	0.71	0.81	0.73
4215	0.45	0.57	0.91	0.75	0.99	1.19	0.18	0.40
4410	0.54	0.68	0.91	0.75	1.07	1.26	0.12	0.21
4530	**0.26**	**0.36**	**0.97**	**0.87**	1.40	1.54	-2.64	0.22
4540	0.37	0.52	0.94	0.80	1.76	1.90	-4.97	0.19
4650	0.34	0.44	0.96	0.86	0.69	0.85	0.76	0.64

Table A.15: The calibration and validation results for Random Forest prediction model of SSI forecast based on PDSI inputs

Basin	Calibration				Validation			
	MAE	RMSE	NSE	KGE	MAE	RMSE	NSE	KGE
0170	0.21	0.27	0.93	0.78	0.65	0.76	-1.25	0.35
0180	0.22	0.27	0.93	0.78	0.63	0.76	-1.00	0.55
0250	0.26	0.33	0.91	0.72	1.16	1.33	-2.59	0.00
0580	0.19	0.23	0.95	0.82	0.91	1.09	-2.92	0.02
0660	0.20	0.25	0.94	0.80	0.74	1.00	-2.07	0.00
0840	0.32	0.43	0.84	0.60	1.11	1.28	-7.74	0.08
0850	0.34	0.45	0.83	0.58	1.02	1.16	-3.20	0.02
0900	0.31	0.40	0.86	0.63	1.06	1.21	-1.99	0.16
0910	0.30	0.39	0.86	0.63	1.01	1.10	-1.58	0.05
1020	0.18	0.25	0.93	0.79	0.47	0.58	0.49	0.61
1350	0.31	0.42	0.85	0.61	1.06	1.23	-1.03	0.02
1430	0.21	0.26	0.93	0.77	0.83	1.00	-0.24	0.26
1510	0.21	0.27	0.93	0.76	0.89	1.11	-0.93	0.06
1790	0.21	0.26	0.93	0.78	0.96	1.23	-2.15	0.03
1980	0.19	0.24	0.94	0.80	0.79	0.89	-1.70	0.17
2110	0.22	0.28	0.93	0.77	0.74	0.85	-0.92	0.03
2400	**0.17**	**0.21**	**0.96**	**0.84**	0.78	0.88	-1.41	0.09
2940	0.19	0.23	0.95	0.81	0.50	0.60	0.43	0.53
3450	0.28	0.37	0.89	0.68	1.30	1.49	-3.57	0.00
3511	0.28	0.36	0.89	0.69	0.98	1.20	-2.03	0.01
3540	0.21	0.28	0.93	0.76	1.14	1.45	-4.58	0.00
3550	0.26	0.33	0.90	0.70	0.99	1.24	-3.18	0.01
4215	0.21	0.27	0.93	0.76	0.93	1.07	-0.36	0.04
4410	0.24	0.30	0.92	0.74	1.15	1.39	-3.77	0.01
4530	0.20	0.25	0.93	0.78	0.71	0.84	0.18	0.27
4540	0.18	0.23	0.95	0.81	0.70	0.84	0.09	0.22
4650	0.22	0.27	0.93	0.78	0.60	0.83	-1.24	0.01

Table A.16: The calibration and validation results for Random Forest prediction model of SPI forecast based on scPDSI inputs

Basin	Calibration				Validation			
	MAE	RMSE	NSE	KGE	MAE	RMSE	NSE	KGE
0170	0.17	0.22	0.95	0.81	0.48	0.64	0.11	0.11
0180	0.19	0.25	0.93	0.78	0.62	0.78	-0.30	0.04
0250	**0.16**	**0.20**	**0.96**	**0.85**	0.52	0.62	0.04	0.51
0580	0.19	0.24	0.94	0.81	0.59	0.73	-0.28	0.13
0660	0.17	0.22	0.95	0.84	0.50	0.66	0.10	0.53
0840	0.16	0.21	0.95	0.82	0.57	0.69	0.48	0.30
0850	0.16	0.21	0.95	0.83	0.68	0.83	0.04	0.19
0900	0.18	0.22	0.94	0.79	0.58	0.76	0.59	0.36
0910	0.19	0.24	0.93	0.76	0.51	0.63	0.63	0.44
1020	0.16	0.21	0.95	0.82	0.45	0.61	**0.72**	0.49
1350	**0.16**	**0.20**	**0.96**	**0.85**	0.49	0.61	0.55	0.39
1430	0.16	0.21	0.96	0.84	0.56	0.69	0.44	0.34
1510	0.17	0.21	0.96	0.84	0.52	0.61	0.59	0.42
1790	0.17	0.22	0.95	0.83	0.40	0.51	0.69	0.60
1980	0.17	0.21	0.95	0.83	0.45	0.55	0.59	0.43
2110	0.16	0.21	0.96	0.86	0.48	0.58	0.32	0.53
2400	0.17	0.22	0.95	0.82	0.48	0.58	0.59	0.42
2940	0.16	0.21	0.96	0.84	0.53	0.73	0.07	0.14
3450	0.17	0.23	0.95	0.81	0.42	0.54	0.31	0.58
3511	0.16	0.21	0.96	0.84	0.62	0.72	-0.76	0.40
3540	0.17	0.23	0.95	0.82	0.40	0.50	0.29	0.35
3550	0.18	0.23	0.94	0.81	0.44	0.54	0.24	0.45
4215	0.17	0.22	0.95	0.82	0.52	0.60	0.22	0.31
4410	0.16	0.21	0.96	0.85	0.72	0.84	-0.54	0.38
4530	0.20	0.25	0.94	0.78	0.64	0.80	-0.65	0.14
4540	0.17	0.22	0.95	0.83	0.65	0.78	-0.44	0.38
4650	0.20	0.25	0.94	0.80	0.36	0.46	0.63	0.45

Table A.17: The calibration and validation results for Random Forest prediction model of SPEI forecast based on scPDSI inputs

Basin	Calibration				Validation			
	MAE	RMSE	NSE	KGE	MAE	RMSE	NSE	KGE
0170	0.16	0.20	0.96	0.84	0.46	0.57	0.12	0.12
0180	0.17	0.22	0.95	0.82	0.56	0.71	-0.29	0.02
0250	0.16	0.20	0.96	0.85	0.49	0.62	0.02	0.15
0580	0.18	0.23	0.95	0.82	0.54	0.65	0.13	0.26
0660	0.16	0.21	0.96	0.85	0.58	0.67	0.21	0.28
0840	0.17	0.22	0.94	0.81	0.57	0.71	0.37	0.19
0850	0.16	0.21	0.96	0.84	0.68	0.82	-0.01	0.22
0900	0.18	0.23	0.94	0.79	0.60	0.75	0.46	0.23
0910	0.19	0.24	0.93	0.77	0.47	0.63	0.54	0.34
1020	0.16	0.20	0.95	0.84	0.43	0.57	**0.71**	0.48
1350	0.16	0.21	0.95	0.84	0.46	0.61	0.55	0.45
1430	0.16	0.21	0.95	0.83	0.58	0.73	0.45	0.36
1510	0.16	0.22	0.95	0.83	0.50	0.60	0.61	0.40
1790	0.17	0.21	0.96	0.84	0.47	0.61	0.50	0.55
1980	0.15	0.19	0.96	0.85	0.44	0.54	0.62	0.42
2110	**0.15**	**0.19**	**0.96**	**0.87**	0.43	0.55	0.48	0.50
2400	0.16	0.20	0.96	0.85	0.68	0.77	0.29	0.25
2940	0.17	0.22	0.95	0.83	0.59	0.75	0.18	0.15
3450	0.18	0.24	0.94	0.80	0.53	0.67	-0.16	0.26
3511	0.17	0.21	0.95	0.83	0.52	0.63	-0.19	0.29
3540	0.17	0.22	0.95	0.83	0.41	0.50	0.30	0.28
3550	0.18	0.23	0.95	0.81	0.42	0.50	0.32	0.34
4215	0.15	0.20	0.96	0.84	0.54	0.62	0.31	0.30
4410	0.17	0.23	0.95	0.83	0.62	0.79	-0.25	0.32
4530	0.18	0.22	0.95	0.82	0.66	0.86	-0.47	0.06
4540	0.16	0.21	0.96	0.84	0.56	0.70	0.07	0.53
4650	0.18	0.22	0.95	0.83	0.36	0.46	0.63	0.42

Table A.18: The calibration and validation results for Random Forest prediction model of PDSI forecast based on scPDSI inputs

Basin	Calibration				Validation			
	MAE	RMSE	NSE	KGE	MAE	RMSE	NSE	KGE
0170	0.24	0.31	0.94	0.79	0.60	0.74	0.52	0.33
0180	0.20	0.27	0.96	0.85	0.97	1.20	-0.29	0.00
0250	0.21	0.28	0.96	0.83	0.74	0.96	0.37	0.23
0580	0.22	0.29	0.96	0.84	0.96	1.28	-0.02	0.02
0660	0.27	0.34	0.94	0.80	0.63	0.74	0.65	0.45
0840	0.25	0.32	0.94	0.80	1.05	1.26	0.14	0.08
0850	0.26	0.32	0.94	0.77	0.82	1.02	0.36	0.19
0900	0.25	0.32	0.93	0.77	1.21	1.40	-0.09	0.06
0910	0.21	0.27	0.95	0.82	0.87	1.06	0.28	0.17
1020	0.19	0.27	0.97	0.87	0.66	0.87	0.77	0.57
1350	0.19	0.25	0.97	0.86	1.12	1.40	-0.33	0.07
1430	0.19	0.26	0.97	0.86	0.70	1.01	0.51	0.30
1510	0.21	0.30	0.96	0.84	0.57	0.86	0.67	0.46
1790	**0.18**	**0.25**	**0.97**	**0.87**	0.58	0.77	0.75	0.53
1980	0.22	0.31	0.96	0.84	0.70	1.00	0.66	0.39
2110	0.22	0.30	0.96	0.84	0.44	0.55	**0.81**	0.62
2400	0.22	0.30	0.96	0.85	0.74	0.94	0.58	0.33
2940	0.24	0.32	0.94	0.79	0.64	0.77	0.68	0.44
3450	0.20	0.29	0.94	0.80	0.61	0.80	0.60	0.45
3511	0.19	0.27	0.96	0.84	0.63	0.82	0.55	0.37
3540	0.22	0.28	0.96	0.84	0.81	0.89	0.49	0.35
3550	0.21	0.30	0.95	0.81	0.83	0.96	0.48	0.34
4215	0.24	0.33	0.94	0.78	0.69	0.80	0.64	0.43
4410	0.25	0.32	0.93	0.77	0.68	0.82	0.51	0.30
4530	0.19	0.26	0.97	0.87	0.62	0.75	0.60	0.46
4540	0.25	0.34	0.95	0.81	0.66	0.86	0.48	0.40
4650	0.21	0.28	0.96	0.85	0.60	0.90	0.57	0.35

Table A.19: The calibration and validation results for Random Forest prediction model of scPDSI forecast based on scPDSI inputs

Basin	Calibration				Validation			
	MAE	RMSE	NSE	KGE	MAE	RMSE	NSE	KGE
0170	0.07	0.12	1.00	0.98	**0.13**	**0.18**	**0.95**	**0.94**
0180	0.08	0.12	1.00	0.98	0.25	0.40	0.78	0.80
0250	0.08	0.12	1.00	0.97	0.40	0.66	0.72	0.76
0580	0.07	0.12	1.00	0.98	0.32	0.61	0.75	0.76
0660	0.08	0.12	1.00	0.98	0.21	0.28	0.97	0.89
0840	0.08	0.14	0.99	0.98	0.37	0.58	0.86	0.83
0850	0.07	0.13	1.00	0.99	0.20	0.27	0.97	0.94
0900	0.07	0.12	1.00	0.98	0.71	1.17	0.38	0.54
0910	0.07	0.12	1.00	0.97	0.30	0.55	0.83	0.80
1020	0.08	0.12	1.00	0.98	0.29	0.39	0.98	0.92
1350	0.07	0.12	1.00	0.97	0.39	0.65	0.90	0.76
1430	0.08	0.13	1.00	0.97	0.31	0.59	0.91	0.79
1510	0.09	0.14	1.00	0.97	0.37	0.69	0.86	0.65
1790	0.08	0.13	1.00	0.97	0.30	0.50	0.92	0.79
1980	**0.07**	**0.11**	**1.00**	**0.98**	0.21	0.33	0.97	0.87
2110	0.08	0.12	1.00	0.97	0.17	0.27	0.97	0.93
2400	**0.07**	**0.11**	**1.00**	**0.98**	0.28	0.45	0.96	0.85
2940	0.08	0.13	1.00	0.97	0.28	0.49	0.92	0.80
3450	0.08	0.13	1.00	0.97	0.25	0.33	0.95	0.91
3511	0.08	0.13	1.00	0.97	0.24	0.31	0.95	0.90
3540	0.07	0.12	1.00	0.97	0.21	0.30	0.96	0.91
3550	0.08	0.13	1.00	0.97	0.26	0.39	0.94	0.88
4215	0.07	0.12	1.00	0.97	0.21	0.35	0.93	0.89
4410	0.08	0.14	1.00	0.98	0.27	0.36	0.93	0.84
4530	0.08	0.13	1.00	0.97	0.31	0.45	0.69	0.78
4540	0.08	0.13	1.00	0.97	0.17	0.22	0.92	0.92
4650	**0.07**	**0.11**	**1.00**	**0.98**	0.27	0.50	0.92	0.83

Table A.20: The calibration and validation results for Random Forest prediction model of SSI forecast based on scPDSI inputs

Basin	Calibration				Validation			
	MAE	RMSE	NSE	KGE	MAE	RMSE	NSE	KGE
0170	0.19	0.26	0.94	0.80	0.82	0.95	-2.52	0.00
0180	0.21	0.28	0.93	0.78	0.87	1.00	-2.52	0.00
0250	0.26	0.34	0.91	0.71	1.20	1.28	-2.36	0.01
0580	0.20	0.25	0.94	0.80	1.01	1.17	-3.51	0.03
0660	0.20	0.26	0.94	0.81	0.83	1.05	-2.36	0.00
0840	0.30	0.41	0.86	0.63	0.75	0.90	-3.26	0.00
0850	0.26	0.35	0.90	0.70	1.53	1.74	-8.38	0.05
0900	0.24	0.34	0.90	0.70	0.90	1.11	-1.55	0.00
0910	0.27	0.36	0.88	0.66	0.88	1.02	-1.20	0.00
1020	0.17	0.23	0.94	0.82	0.66	0.77	0.13	0.33
1350	0.26	0.34	0.90	0.72	1.05	1.39	-1.58	0.07
1430	0.21	0.27	0.93	0.76	0.75	0.97	-0.17	0.14
1510	0.22	0.30	0.91	0.73	0.77	0.93	-0.35	0.08
1790	0.20	0.25	0.94	0.80	0.92	1.15	-1.78	0.07
1980	0.18	0.22	0.95	0.83	0.78	0.91	-1.82	0.10
2110	0.20	0.25	0.94	0.81	0.58	0.69	-0.26	0.07
2400	**0.17**	**0.22**	**0.95**	**0.84**	0.76	0.92	-1.66	0.08
2940	0.19	0.24	0.95	0.82	0.74	1.03	-0.68	0.04
3450	0.29	0.38	0.88	0.66	1.17	1.33	-2.61	0.00
3511	0.27	0.36	0.89	0.69	0.96	1.11	-1.57	0.05
3540	0.21	0.26	0.93	0.79	0.91	1.07	-2.05	0.00
3550	0.24	0.32	0.91	0.72	0.95	1.07	-2.09	0.02
4215	0.18	0.22	0.95	0.82	0.90	1.02	-0.24	0.05
4410	0.23	0.29	0.92	0.76	1.19	1.43	-4.03	0.00
4530	0.18	0.23	0.95	0.82	1.07	1.37	-1.18	0.02
4540	0.17	0.23	0.95	0.82	1.07	1.33	-1.27	0.10
4650	0.21	0.26	0.93	0.79	0.50	0.67	-0.48	0.06

Table A.21: The calibration and validation results for Random Forest prediction model of SPI forecast based on SSI inputs

Basin	Calibration				Validation			
	MAE	RMSE	NSE	KGE	MAE	RMSE	NSE	KGE
0170	0.16	0.20	0.95	0.84	0.78	0.88	-0.71	0.12
0180	**0.15**	**0.19**	**0.96**	**0.86**	0.93	1.07	-1.43	0.05
0250	0.20	0.26	0.92	0.76	1.07	1.21	-2.71	0.04
0580	0.15	0.20	0.96	0.86	0.75	0.92	-1.03	0.01
0660	0.18	0.23	0.95	0.83	0.44	0.55	0.38	0.25
0840	0.20	0.25	0.92	0.74	0.96	1.12	-0.36	0.01
0850	0.23	0.28	0.91	0.73	0.82	0.98	-0.33	0.00
0900	0.20	0.25	0.92	0.75	1.21	1.39	-0.35	0.04
0910	0.20	0.25	0.92	0.75	0.95	1.12	-0.14	0.03
1020	0.16	0.20	0.95	0.82	0.75	0.95	0.33	0.12
1350	0.21	0.27	0.92	0.73	0.97	1.18	-0.68	0.02
1430	0.19	0.25	0.94	0.78	0.48	0.69	0.46	0.33
1510	0.19	0.25	0.94	0.78	0.58	0.78	0.33	0.24
1790	0.19	0.25	0.94	0.80	0.70	0.93	-0.04	0.10
1980	0.17	0.22	0.95	0.83	0.53	0.69	0.35	0.19
2110	0.19	0.26	0.93	0.78	0.55	0.69	0.06	0.05
2400	0.18	0.23	0.95	0.82	0.51	0.69	0.41	0.20
2940	0.15	0.20	0.96	0.86	0.51	0.67	0.22	0.27
3450	0.19	0.25	0.93	0.78	0.70	0.84	-0.68	0.06
3511	0.20	0.26	0.93	0.78	0.51	0.61	-0.24	0.04
3540	0.20	0.25	0.94	0.79	0.92	1.12	-2.60	0.01
3550	0.20	0.25	0.94	0.80	0.77	0.88	-0.99	0.03
4215	0.18	0.23	0.95	0.83	0.68	0.79	-0.33	0.11
4410	0.20	0.26	0.94	0.80	0.73	0.94	-0.92	0.00
4530	0.17	0.21	0.95	0.84	0.58	0.72	-0.34	0.27
4540	0.15	0.20	0.96	0.86	0.57	0.72	-0.21	0.22
4650	0.18	0.24	0.94	0.81	0.68	0.86	-0.30	0.02

Table A.22: The calibration and validation results for Random Forest prediction model of SPEI forecast based on SSI inputs

Basin	Calibration				Validation			
	MAE	RMSE	NSE	KGE	MAE	RMSE	NSE	KGE
0170	0.16	0.20	0.95	0.84	0.78	0.88	-0.71	0.12
0180	**0.15**	**0.19**	**0.96**	**0.86**	0.93	1.07	-1.43	0.05
0250	0.20	0.26	0.92	0.76	1.07	1.21	-2.71	0.04
0580	0.15	0.20	0.96	0.86	0.75	0.92	-1.03	0.01
0660	0.18	0.23	0.95	0.83	0.44	0.55	0.38	0.25
0840	0.20	0.25	0.92	0.74	0.96	1.12	-0.36	0.01
0850	0.23	0.28	0.91	0.73	0.82	0.98	-0.33	0.00
0900	0.20	0.25	0.92	0.75	1.21	1.39	-0.35	0.04
0910	0.20	0.25	0.92	0.75	0.95	1.12	-0.14	0.03
1020	0.16	0.20	0.95	0.82	0.75	0.95	0.33	0.12
1350	0.21	0.27	0.92	0.73	0.97	1.18	-0.68	0.02
1430	0.19	0.25	0.94	0.78	0.48	0.69	0.46	0.33
1510	0.19	0.25	0.94	0.78	0.58	0.78	0.33	0.24
1790	0.19	0.25	0.94	0.80	0.70	0.93	-0.04	0.10
1980	0.17	0.22	0.95	0.83	0.53	0.69	0.35	0.19
2110	0.19	0.26	0.93	0.78	0.55	0.69	0.06	0.05
2400	0.18	0.23	0.95	0.82	0.51	0.69	0.41	0.20
2940	0.15	0.20	0.96	0.86	0.51	0.67	0.22	0.27
3450	0.19	0.25	0.93	0.78	0.70	0.84	-0.68	0.06
3511	0.20	0.26	0.93	0.78	0.51	0.61	-0.24	0.04
3540	0.20	0.25	0.94	0.79	0.92	1.12	-2.60	0.01
3550	0.20	0.25	0.94	0.80	0.77	0.88	-0.99	0.03
4215	0.18	0.23	0.95	0.83	0.68	0.79	-0.33	0.11
4410	0.20	0.26	0.94	0.80	0.73	0.94	-0.92	0.00
4530	0.17	0.21	0.95	0.84	0.58	0.72	-0.34	0.27
4540	0.15	0.20	0.96	0.86	0.57	0.72	-0.21	0.22
4650	0.18	0.24	0.94	0.81	0.68	0.86	-0.30	0.02

Table A.23: The calibration and validation results for Random Forest prediction model of PDSI forecast based on SSI inputs

Basin	Calibration				Validation			
	MAE	RMSE	NSE	KGE	MAE	RMSE	NSE	KGE
0170	0.36	0.45	0.89	0.67	1.08	1.23	-0.32	0.02
0180	0.35	0.44	0.89	0.69	1.25	1.45	-0.88	0.03
0250	0.39	0.48	0.87	0.64	1.40	1.55	-0.62	0.02
0580	0.37	0.47	0.89	0.68	1.27	1.49	-0.38	0.01
0660	0.40	0.50	0.88	0.67	1.12	1.38	-0.22	0.01
0840	0.37	0.47	0.88	0.66	1.41	1.64	-0.46	0.00
0850	0.37	0.46	0.87	0.64	1.20	1.46	-0.31	0.00
0900	0.36	0.45	0.87	0.64	1.35	1.53	-0.30	0.01
0910	0.37	0.46	0.86	0.63	1.29	1.47	-0.41	0.02
1020	0.43	0.52	0.88	0.66	1.55	1.74	0.08	0.03
1350	0.37	0.47	0.88	0.66	1.57	1.82	-1.28	0.00
1430	0.38	0.49	0.88	0.66	1.22	1.48	-0.05	0.07
1510	0.38	0.48	0.89	0.69	1.24	1.53	-0.05	0.04
1790	0.39	0.48	0.89	0.69	1.72	2.04	-0.75	0.00
1980	0.41	0.50	0.89	0.69	1.83	2.17	-0.61	0.00
2110	0.39	0.49	**0.90**	0.69	1.40	1.59	-0.60	0.00
2400	0.38	0.49	**0.90**	0.69	1.57	1.85	-0.63	0.00
2940	0.39	0.51	0.86	0.62	1.22	1.37	-0.01	0.02
3450	0.35	0.44	0.87	0.64	1.30	1.50	-0.39	0.00
3511	0.37	0.46	0.89	0.67	1.33	1.50	-0.51	0.02
3540	0.37	0.47	0.88	0.67	1.28	1.49	-0.43	0.01
3550	0.36	0.45	0.88	0.66	1.28	1.42	-0.14	0.04
4215	0.38	0.49	0.87	0.64	1.65	1.90	-1.00	0.00
4410	0.35	0.44	0.87	0.65	1.38	1.59	-0.83	0.00
4530	0.42	0.51	0.88	0.65	1.38	1.62	-0.84	0.00
4540	0.38	0.47	**0.90**	0.69	1.39	1.61	-0.79	0.00
4650	0.39	0.49	0.89	0.68	1.21	1.49	-0.18	0.01

Table A.24: The calibration and validation results for Random Forest prediction model of scPDSI forecast based on SSI inputs

Basin	Calibration				Validation			
	MAE	RMSE	NSE	KGE	MAE	RMSE	NSE	KGE
0170	0.38	0.50	**0.95**	0.82	2.28	2.52	-9.46	0.08
0180	0.41	0.55	0.93	0.80	3.37	3.54	-16.47	0.09
0250	0.48	0.63	0.90	0.72	3.15	3.29	-5.90	0.05
0580	0.45	0.57	0.92	0.78	2.81	3.11	-5.48	0.02
0660	0.46	0.58	0.93	0.77	1.88	2.22	-1.10	0.00
0840	0.44	0.57	0.91	0.80	2.31	2.72	-2.05	0.04
0850	0.58	0.77	0.90	0.82	2.64	3.34	-3.64	0.02
0900	0.49	0.63	0.90	0.76	3.00	3.27	-3.83	0.04
0910	0.43	0.55	0.91	0.76	1.97	2.34	-1.94	0.03
1020	0.46	0.59	0.93	0.78	2.46	2.96	0.10	0.08
1350	0.43	0.55	0.92	0.75	1.83	2.26	-0.24	0.07
1430	0.51	0.63	0.91	0.72	1.74	2.24	-0.31	0.08
1510	0.45	0.59	0.93	0.78	2.05	2.46	-0.82	0.01
1790	0.39	0.50	0.93	0.78	2.29	2.69	-1.18	0.01
1980	0.40	0.52	0.94	0.79	2.06	2.58	-0.88	0.00
2110	0.47	0.59	0.93	0.77	2.24	2.58	-1.99	0.00
2400	0.43	0.57	0.93	0.77	2.21	2.76	-0.50	0.00
2940	0.43	0.55	0.92	0.76	2.14	2.37	-0.90	0.00
3450	0.50	0.61	0.90	0.69	2.62	2.86	-3.01	0.01
3511	0.49	0.60	0.91	0.72	2.21	2.49	-2.08	0.01
3540	0.45	0.57	0.92	0.76	1.92	2.20	-1.25	0.03
3550	0.44	0.55	0.92	0.76	1.82	2.01	-0.53	0.13
4215	0.41	0.52	0.93	0.77	2.34	2.90	-3.88	0.00
4410	0.39	0.51	**0.95**	**0.84**	2.97	3.41	-5.48	0.08
4530	0.52	0.63	0.90	0.71	2.54	3.01	-12.90	0.00
4540	0.45	0.57	0.93	0.78	2.70	3.08	-14.65	0.00
4650	0.50	0.62	0.92	0.76	2.01	2.39	-0.85	0.01

Table A.25: The calibration and validation results for Random Forest prediction model of SSI forecast based on SSI inputs

Basin	Calibration				Validation			
	MAE	RMSE	NSE	KGE	MAE	RMSE	NSE	KGE
0170	**0.03**	**0.04**	**1.00**	**0.99**	**0.04**	**0.05**	**0.99**	**0.98**
0180	0.03	0.04	1.00	0.98	0.05	0.06	0.99	0.99
0250	0.03	0.06	1.00	0.98	0.06	0.10	0.98	0.90
0580	0.03	0.05	1.00	0.98	0.05	0.07	0.98	0.94
0660	**0.03**	**0.04**	**1.00**	**0.99**	0.06	0.09	0.98	0.94
0840	0.03	0.07	1.00	0.98	0.05	0.08	0.97	0.92
0850	0.03	0.06	1.00	0.98	0.07	0.10	0.97	0.90
0900	0.03	0.06	1.00	0.98	0.05	0.08	0.99	0.93
0910	0.03	0.05	1.00	0.98	0.05	0.09	0.98	0.91
1020	0.03	0.04	1.00	0.98	0.08	0.10	0.99	0.97
1350	0.03	0.06	1.00	0.98	0.13	0.25	0.92	0.78
1430	0.03	0.05	1.00	0.98	0.08	0.14	0.97	0.91
1510	0.03	0.05	1.00	0.98	0.10	0.17	0.96	0.87
1790	0.03	0.05	1.00	0.98	0.11	0.15	0.95	0.86
1980	0.03	0.04	1.00	0.98	0.07	0.10	0.97	0.93
2110	0.03	0.05	1.00	0.98	0.07	0.10	0.97	0.90
2400	0.03	0.05	1.00	0.98	0.06	0.08	0.98	0.94
2940	0.03	0.05	1.00	0.98	0.10	0.15	0.97	0.91
3450	0.03	0.05	1.00	0.98	0.08	0.16	0.95	0.81
3511	0.03	0.05	1.00	0.98	0.08	0.12	0.97	0.87
3540	**0.03**	**0.04**	**1.00**	**0.99**	0.07	0.10	0.98	0.91
3550	0.03	0.04	1.00	0.98	0.06	0.10	0.97	0.88
4215	0.03	0.04	1.00	0.98	0.11	0.14	0.98	0.95
4410	0.03	0.05	1.00	0.98	0.07	0.11	0.97	0.92
4530	0.03	0.04	1.00	0.98	0.08	0.10	0.99	0.98
4540	**0.03**	**0.04**	**1.00**	**0.99**	0.07	0.09	0.99	0.97
4650	**0.03**	**0.04**	**1.00**	**0.99**	0.07	0.09	0.97	0.96

Appendix B

Random Forest forecasting results

Random Forest forecasting models‘ performance based on drought indices inputs creating for 27 meteorological basins.

Table B.1: The calibration and validation results for Random Forest model of SPI forecast based on SPI inputs

Basin	Calibration				Validation			
	MAE	RMSE	NSE	KGE	MAE	RMSE	NSE	KGE
0170	0.14	0.18	0.96	0.88	0.35	0.47	0.52	0.39
0180	0.14	0.18	0.96	0.87	0.37	0.49	0.49	0.39
0250	0.14	0.18	0.96	0.88	0.33	0.42	0.57	0.45
0580	0.15	0.19	0.96	0.88	0.38	0.52	0.37	0.29
0660	0.15	0.20	0.96	0.88	0.30	0.41	0.68	0.46
0840	0.14	0.19	0.95	0.85	0.45	0.54	0.68	0.48
0850	0.14	0.19	0.96	0.86	0.40	0.48	0.67	0.45
0900	0.14	0.18	0.96	0.85	0.49	0.62	**0.73**	0.49
0910	0.14	0.19	0.96	0.85	0.44	0.56	0.70	0.48
1020	0.14	0.18	0.96	0.86	0.37	0.49	0.81	0.61
1350	0.15	0.20	0.96	0.86	0.50	0.68	0.45	0.28
1430	0.14	0.19	0.96	0.88	0.41	0.57	0.65	0.39
1510	0.14	0.19	0.97	0.88	0.43	0.60	0.63	0.35
1790	0.14	0.19	0.96	0.88	0.40	0.52	0.69	0.44
1980	0.14	0.18	0.97	0.88	0.34	0.49	0.69	0.46
2110	**0.14**	**0.18**	**0.97**	**0.89**	0.35	0.45	0.59	0.43
2400	0.14	0.18	0.96	0.88	0.35	0.51	0.70	0.47
2940	0.14	0.19	0.97	0.88	0.39	0.50	0.60	0.38
3450	0.15	0.19	0.96	0.87	0.39	0.50	0.47	0.30
3511	0.13	0.18	0.97	0.89	0.34	0.43	0.40	0.30
3540	0.14	0.18	0.97	0.88	0.36	0.44	0.48	0.34
3550	0.14	0.19	0.96	0.87	0.37	0.46	0.49	0.33
4215	0.15	0.20	0.96	0.86	0.42	0.51	0.47	0.34
4410	0.15	0.21	0.96	0.87	0.41	0.54	0.41	0.26
4530	0.15	0.20	0.96	0.86	0.35	0.45	0.49	0.42
4540	0.14	0.19	0.96	0.87	0.34	0.45	0.53	0.42
4650	0.15	0.19	0.96	0.87	0.38	0.50	0.58	0.36

Table B.2: The calibration and validation results for Random Forest model of SPEI forecast based on SPI inputs

Basin	Calibration				Validation			
	MAE	RMSE	NSE	KGE	MAE	RMSE	NSE	KGE
0170	0.16	0.21	0.96	0.85	0.34	0.44	0.48	0.39
0180	0.16	0.21	0.95	0.85	0.38	0.50	0.36	0.30
0250	0.16	0.20	0.96	0.85	0.44	0.54	0.30	0.31
0580	0.17	0.22	0.95	0.83	0.40	0.52	0.47	0.29
0660	0.17	0.22	0.95	0.84	0.39	0.50	0.59	0.37
0840	0.16	0.22	0.94	0.82	0.45	0.55	0.61	0.44
0850	0.16	0.21	0.95	0.84	0.41	0.51	0.61	0.40
0900	0.16	0.21	0.95	0.82	0.43	0.51	0.75	0.52
0910	0.18	0.23	0.94	0.81	0.43	0.56	0.63	0.43
1020	0.18	0.23	0.94	0.80	0.39	0.51	**0.77**	0.56
1350	0.16	0.21	0.95	0.84	0.47	0.58	0.61	0.37
1430	**0.15**	**0.20**	**0.96**	**0.86**	0.40	0.58	0.68	0.40
1510	**0.15**	**0.20**	**0.96**	**0.86**	0.44	0.58	0.65	0.38
1790	0.17	0.22	0.95	0.85	0.41	0.51	0.67	0.43
1980	0.16	0.21	0.95	0.84	0.46	0.58	0.59	0.39
2110	0.16	0.21	0.96	0.85	0.37	0.49	0.58	0.35
2400	0.18	0.23	0.94	0.82	0.48	0.60	0.58	0.41
2940	**0.15**	**0.20**	**0.96**	**0.86**	0.40	0.48	0.68	0.48
3450	0.16	0.21	0.96	0.85	0.42	0.52	0.38	0.26
3511	**0.15**	**0.20**	**0.96**	**0.86**	0.51	0.63	-0.10	0.20
3540	0.17	0.22	0.95	0.83	0.45	0.51	0.29	0.29
3550	0.17	0.21	0.95	0.84	0.49	0.58	0.14	0.23
4215	0.18	0.23	0.95	0.82	0.41	0.50	0.56	0.39
4410	0.19	0.24	0.94	0.81	0.44	0.53	0.47	0.25
4530	0.17	0.23	0.95	0.82	0.35	0.42	0.66	0.50
4540	0.16	0.22	0.95	0.83	0.36	0.45	0.64	0.46
4650	0.17	0.23	0.95	0.83	0.42	0.52	0.55	0.35

Table B.3: The calibration and validation results for Random Forest model of PDSI forecast based on SPI inputs

Basin	Calibration				Validation			
	MAE	RMSE	NSE	KGE	MAE	RMSE	NSE	KGE
0170	0.42	0.52	0.85	0.61	1.05	1.26	-0.39	0.00
0180	0.40	0.51	0.86	0.63	1.23	1.44	-0.82	0.00
0250	0.42	0.52	0.85	0.62	1.17	1.33	-0.19	0.03
0580	0.47	0.56	0.85	0.61	1.25	1.47	-0.32	0.01
0660	0.44	0.55	0.86	0.63	1.19	1.38	-0.19	0.01
0840	0.42	0.51	0.85	0.62	1.33	1.48	-0.22	0.02
0850	0.39	0.50	0.85	0.61	1.35	1.51	-0.46	0.01
0900	**0.39**	**0.48**	0.85	0.61	1.48	1.67	-0.57	0.00
0910	0.40	0.50	0.84	0.59	1.40	1.55	-0.59	0.00
1020	0.49	0.58	0.85	0.61	1.42	1.58	0.27	0.08
1350	0.41	0.51	0.86	0.63	1.59	1.89	-1.38	0.01
1430	0.43	0.52	0.87	0.63	1.44	1.72	-0.35	0.01
1510	0.45	0.54	0.87	0.64	1.52	1.88	-0.48	0.00
1790	0.42	0.52	0.87	0.65	1.56	1.86	-0.40	0.00
1980	0.44	0.52	**0.88**	**0.66**	1.69	2.02	-0.35	0.00
2110	0.43	0.54	0.87	0.65	1.21	1.43	-0.29	0.03
2400	0.47	0.56	0.86	0.64	1.56	1.86	-0.56	0.00
2940	0.43	0.56	0.83	0.58	1.18	1.33	0.11	0.04
3450	0.40	0.49	0.84	0.60	1.21	1.37	-0.12	0.05
3511	0.40	0.49	0.87	0.65	1.28	1.48	-0.40	0.03
3540	0.43	0.53	0.85	0.62	1.43	1.56	-0.54	0.01
3550	0.40	0.51	0.85	0.61	1.42	1.56	-0.33	0.04
4215	0.44	0.56	0.83	0.58	1.39	1.61	-0.39	0.00
4410	0.40	0.49	0.84	0.60	1.29	1.50	-0.64	0.00
4530	0.45	0.54	0.86	0.62	1.23	1.37	-0.30	0.01
4540	0.47	0.57	0.85	0.61	1.15	1.30	-0.15	0.04
4650	0.50	0.60	0.84	0.59	1.44	1.64	-0.39	0.00

Table B.4: The calibration and validation results for Random Forest model of scPDSI forecast based on SPI inputs

Basin	Calibration				Validation			
	MAE	RMSE	NSE	KGE	MAE	RMSE	NSE	KGE
0170	0.55	0.68	0.90	0.73	1.58	1.84	-4.27	0.06
0180	0.54	0.67	0.90	0.74	2.26	2.42	-6.39	0.09
0250	0.54	0.66	0.89	0.70	1.92	2.08	-1.57	0.27
0580	0.61	0.70	0.89	0.70	1.74	2.08	-1.66	0.07
0660	0.60	0.70	0.90	0.71	2.02	2.30	-1.10	0.00
0840	0.48	0.62	0.90	0.78	1.55	1.76	-0.23	0.44
0850	0.62	0.81	0.89	0.80	1.34	1.55	0.04	0.47
0900	0.53	0.66	0.89	0.74	2.28	2.67	-2.04	0.08
0910	0.55	0.68	0.86	0.69	2.01	2.25	-1.57	0.17
1020	0.59	0.72	0.90	0.71	2.31	2.61	0.33	0.10
1350	0.53	0.66	0.88	0.70	1.99	2.27	-0.20	0.00
1430	0.56	0.66	0.90	0.71	2.19	2.59	-0.62	0.02
1510	0.57	0.68	0.90	0.73	1.90	2.36	-0.55	0.00
1790	**0.48**	**0.60**	**0.90**	**0.71**	1.92	2.17	-0.35	0.02
1980	0.50	0.61	0.91	0.73	2.23	2.55	-0.70	0.01
2110	0.56	0.69	0.90	0.71	1.69	1.91	-0.56	0.10
2400	0.53	0.65	0.91	0.72	2.20	2.66	-0.32	0.06
2940	0.53	0.67	0.89	0.69	2.08	2.37	-0.75	0.02
3450	0.53	0.63	0.90	0.69	1.87	2.04	-0.89	0.10
3511	0.52	0.63	0.90	0.71	2.21	2.33	-1.53	0.12
3540	0.54	0.65	0.90	0.71	1.75	1.94	-0.64	0.13
3550	0.57	0.68	0.88	0.68	2.02	2.22	-0.76	0.10
4215	0.51	0.62	0.89	0.71	1.68	2.07	-1.28	0.07
4410	0.53	0.69	0.91	0.75	2.39	2.73	-2.96	0.01
4530	0.63	0.74	0.86	0.63	2.21	2.42	-7.52	0.02
4540	0.55	0.66	0.90	0.71	2.28	2.43	-8.19	0.07
4650	0.66	0.79	0.87	0.67	1.74	1.96	-0.18	0.06

Table B.5: The calibration and validation results for Random Forest model of SSI forecast based on SPI inputs

Basin	Calibration				Validation			
	MAE	RMSE	NSE	KGE	MAE	RMSE	NSE	KGE
0170	0.20	0.26	0.94	0.80	0.71	0.78	-1.14	0.72
0180	0.19	0.26	0.94	0.80	0.71	0.80	-0.98	0.61
0250	0.25	0.34	0.90	0.71	0.77	0.99	-0.57	0.14
0580	0.14	0.19	0.97	0.88	0.50	0.61	-0.13	0.37
0660	0.17	0.22	0.96	0.85	0.37	0.43	0.50	0.34
0840	0.31	0.42	0.86	0.62	0.88	1.00	-3.32	0.04
0850	0.30	0.40	0.86	0.64	0.78	0.88	-0.87	0.07
0900	0.26	0.36	0.89	0.68	0.88	0.97	-0.60	0.17
0910	0.26	0.36	0.88	0.66	0.77	0.86	-0.28	0.19
1020	0.18	0.24	0.94	0.80	0.49	0.57	0.53	0.52
1350	0.28	0.38	0.88	0.66	0.91	1.07	-0.22	0.06
1430	0.19	0.24	0.95	0.81	0.38	0.45	0.77	0.53
1510	0.20	0.25	0.94	0.80	0.51	0.58	0.55	0.42
1790	0.20	0.26	0.94	0.80	0.59	0.75	-0.01	0.22
1980	0.14	0.18	0.97	0.87	0.37	0.50	0.29	0.51
2110	0.22	0.27	0.93	0.78	0.49	0.59	0.11	0.05
2400	0.17	0.23	0.95	0.83	0.39	0.50	0.33	0.55
2940	0.14	0.17	0.97	0.90	**0.22**	**0.27**	**0.90**	**0.79**
3450	0.26	0.33	0.91	0.73	0.51	0.63	0.37	0.19
3511	0.27	0.34	0.91	0.73	0.37	0.47	0.62	0.42
3540	0.24	0.28	0.92	0.76	0.64	0.79	-0.39	0.12
3550	0.24	0.29	0.92	0.76	0.55	0.66	0.06	0.19
4215	0.17	0.22	0.95	0.84	0.55	0.63	0.54	0.30
4410	0.21	0.26	0.94	0.79	0.57	0.72	-0.14	0.04
4530	0.14	0.18	0.97	0.88	0.50	0.61	0.55	0.59
4540	**0.13**	**0.17**	**0.97**	**0.90**	0.46	0.57	0.58	0.61
4650	0.18	0.24	0.95	0.82	0.53	0.60	-0.16	0.13

Table B.6: The calibration and validation results for Random Forest model of SPI forecast based on SPEI inputs

Basin	Calibration				Validation			
	MAE	RMSE	NSE	KGE	MAE	RMSE	NSE	KGE
0170	0.15	0.20	0.96	0.86	0.43	0.55	0.34	0.26
0180	0.15	0.19	0.96	0.85	0.44	0.54	0.39	0.32
0250	**0.15**	**0.19**	**0.96**	**0.86**	0.36	0.43	0.55	0.43
0580	0.18	0.23	0.95	0.83	0.43	0.58	0.22	0.20
0660	0.18	0.23	0.95	0.84	0.32	0.44	0.63	0.41
0840	0.16	0.21	0.95	0.82	0.47	0.56	0.65	0.43
0850	0.15	0.20	0.96	0.85	0.46	0.53	0.59	0.34
0900	0.15	0.20	0.95	0.83	0.54	0.65	0.70	0.46
0910	0.16	0.21	0.95	0.82	0.46	0.56	0.70	0.46
1020	0.16	0.20	0.95	0.83	0.42	0.54	**0.77**	0.53
1350	0.17	0.21	0.95	0.84	0.53	0.71	0.41	0.28
1430	0.15	0.20	0.96	0.86	0.47	0.63	0.56	0.31
1510	0.16	0.21	0.96	0.85	0.49	0.67	0.54	0.27
1790	0.16	0.21	0.96	0.85	0.48	0.67	0.49	0.27
1980	0.17	0.22	0.95	0.83	0.38	0.52	0.65	0.39
2110	0.17	0.22	0.95	0.84	0.36	0.48	0.55	0.38
2400	0.18	0.23	0.95	0.82	0.45	0.60	0.58	0.32
2940	0.15	0.20	0.96	0.87	0.45	0.57	0.48	0.27
3450	0.16	0.21	0.96	0.85	0.42	0.53	0.40	0.24
3511	0.15	0.20	0.96	0.87	0.36	0.45	0.37	0.30
3540	0.16	0.21	0.95	0.85	0.42	0.50	0.32	0.24
3550	0.16	0.21	0.95	0.85	0.41	0.51	0.39	0.28
4215	0.16	0.21	0.96	0.85	0.49	0.60	0.27	0.18
4410	0.19	0.24	0.94	0.82	0.44	0.59	0.29	0.16
4530	0.17	0.22	0.95	0.84	0.36	0.47	0.43	0.41
4540	0.17	0.21	0.95	0.85	0.42	0.53	0.34	0.36
4650	0.18	0.23	0.95	0.83	0.40	0.52	0.53	0.29

Table B.7: The calibration and validation results for Random Forest model of SPEI forecast based on SPEI inputs

Basin	Calibration				Validation			
	MAE	RMSE	NSE	KGE	MAE	RMSE	NSE	KGE
0170	0.14	0.18	0.97	0.88	0.33	0.43	0.52	0.41
0180	0.14	0.18	0.96	0.88	0.34	0.43	0.52	0.41
0250	0.15	0.19	0.96	0.87	0.38	0.48	0.44	0.35
0580	0.14	0.19	0.96	0.87	0.36	0.47	0.57	0.39
0660	0.15	0.20	0.96	0.87	0.31	0.44	0.68	0.49
0840	0.16	0.21	0.95	0.83	0.45	0.53	0.64	0.43
0850	0.15	0.20	0.96	0.86	0.43	0.51	0.60	0.38
0900	0.15	0.20	0.95	0.84	0.44	0.52	0.74	0.52
0910	0.15	0.20	0.95	0.84	0.42	0.51	0.69	0.48
1020	0.15	0.19	0.96	0.85	0.35	0.45	**0.82**	0.61
1350	0.16	0.20	0.96	0.86	0.44	0.57	0.63	0.40
1430	0.14	0.18	0.97	0.87	0.41	0.56	0.70	0.45
1510	0.14	0.18	0.97	0.87	0.43	0.58	0.66	0.39
1790	0.14	0.18	0.97	0.88	0.40	0.53	0.64	0.39
1980	0.14	0.18	0.97	0.88	0.36	0.50	0.70	0.46
2110	0.15	0.19	0.96	0.87	0.37	0.48	0.60	0.39
2400	0.14	0.19	0.96	0.87	0.40	0.53	0.68	0.44
2940	**0.13**	**0.18**	**0.97**	**0.88**	0.41	0.50	0.65	0.44
3450	0.16	0.20	0.96	0.86	0.40	0.48	0.46	0.31
3511	0.14	0.18	0.97	0.88	0.38	0.47	0.40	0.32
3540	0.14	0.19	0.96	0.87	0.40	0.47	0.42	0.33
3550	0.15	0.19	0.96	0.87	0.41	0.49	0.40	0.32
4215	0.14	0.19	0.96	0.87	0.43	0.52	0.54	0.37
4410	0.16	0.21	0.96	0.85	0.39	0.51	0.52	0.32
4530	0.15	0.19	0.96	0.86	0.34	0.43	0.65	0.52
4540	0.14	0.19	0.96	0.87	0.35	0.45	0.64	0.49
4650	0.15	0.19	0.96	0.87	0.38	0.51	0.57	0.36

Table B.8: The calibration and validation results for Random Forest model of PDSI forecast based on SPEI inputs

Basin	Calibration				Validation			
	MAE	RMSE	NSE	KGE	MAE	RMSE	NSE	KGE
0170	0.42	0.53	0.84	0.60	1.05	1.24	-0.34	0.00
0180	0.41	0.51	0.86	0.62	1.15	1.35	-0.61	0.00
0250	0.42	0.50	0.86	0.63	1.09	1.25	-0.06	0.06
0580	0.45	0.55	0.85	0.61	1.35	1.60	-0.56	0.00
0660	0.46	0.56	0.86	0.62	1.29	1.54	-0.48	0.00
0840	0.44	0.53	0.85	0.60	1.34	1.49	-0.23	0.01
0850	0.40	0.51	0.84	0.60	1.39	1.54	-0.53	0.00
0900	0.39	0.48	0.85	0.61	1.44	1.60	-0.45	0.00
0910	0.42	0.51	0.83	0.58	1.29	1.45	-0.39	0.00
1020	0.49	0.58	0.85	0.61	1.42	1.55	0.29	0.09
1350	0.43	0.53	0.85	0.61	1.52	1.77	-1.09	0.00
1430	0.43	0.53	0.86	0.63	1.56	1.81	-0.49	0.00
1510	0.45	0.54	**0.87**	0.64	1.52	1.85	-0.44	0.00
1790	0.43	0.52	**0.87**	0.65	1.66	1.97	-0.59	0.00
1980	0.46	0.54	**0.87**	0.65	1.36	1.63	0.13	0.03
2110	0.47	0.57	0.86	0.63	1.24	1.42	-0.28	0.03
2400	0.47	0.56	0.86	0.63	1.34	1.61	-0.18	0.01
2940	0.41	0.53	0.85	0.60	1.37	1.50	-0.14	0.01
3450	0.39	0.48	0.85	0.61	1.24	1.39	-0.17	0.03
3511	0.40	0.50	**0.87**	0.64	1.27	1.41	-0.27	0.01
3540	0.43	0.53	0.85	0.62	1.34	1.47	-0.37	0.02
3550	0.43	0.53	0.84	0.59	1.34	1.49	-0.22	0.04
4215	0.43	0.54	0.84	0.60	1.36	1.56	-0.29	0.00
4410	0.41	0.50	0.84	0.60	1.32	1.51	-0.66	0.00
4530	0.46	0.55	0.86	0.62	1.17	1.35	-0.27	0.02
4540	0.45	0.55	0.86	0.63	1.03	1.22	-0.01	0.04
4650	0.48	0.58	0.85	0.61	1.30	1.55	-0.24	0.00

Table B.9: The calibration and validation results for Random Forest model of scPDSI forecast based on SPEI inputs

Basin	Calibration				Validation			
	MAE	RMSE	NSE	KGE	MAE	RMSE	NSE	KGE
0170	0.50	0.63	**0.92**	0.76	1.48	1.75	-3.77	0.04
0180	0.51	0.65	0.91	0.75	2.02	2.26	-5.44	0.02
0250	0.51	0.62	0.90	0.73	1.71	1.88	-1.11	0.29
0580	0.56	0.68	0.90	0.72	2.02	2.52	-2.89	0.00
0660	0.58	0.69	0.90	0.72	2.11	2.39	-1.28	0.01
0840	0.51	0.66	0.88	0.76	1.51	1.70	-0.15	0.42
0850	0.61	0.78	0.89	0.81	1.15	1.37	0.26	0.47
0900	0.62	0.76	0.85	0.69	2.16	2.29	-1.23	0.35
0910	0.57	0.70	0.86	0.67	1.76	1.96	-0.95	0.27
1020	0.61	0.74	0.89	0.70	2.19	2.40	0.43	0.16
1350	0.55	0.67	0.88	0.69	1.79	2.07	0.01	0.06
1430	0.57	0.67	0.89	0.70	2.34	2.70	-0.75	0.00
1510	0.56	0.67	0.90	0.74	1.96	2.40	-0.59	0.00
1790	0.49	0.61	0.90	0.70	2.24	2.55	-0.86	0.00
1980	0.53	0.62	0.91	0.72	1.70	1.94	0.02	0.08
2110	0.58	0.69	0.90	0.71	1.81	1.97	-0.65	0.04
2400	0.52	0.63	0.91	0.74	2.15	2.33	-0.01	0.02
2940	0.48	0.61	0.91	0.72	2.25	2.50	-0.95	0.00
3450	0.57	0.67	0.88	0.66	1.94	2.11	-1.03	0.08
3511	0.53	0.65	0.90	0.70	1.64	1.90	-0.68	0.15
3540	0.54	0.65	0.90	0.72	1.46	1.72	-0.29	0.13
3550	0.57	0.68	0.88	0.68	1.80	2.12	-0.60	0.07
4215	0.47	0.57	0.91	0.74	1.47	1.89	-0.90	0.06
4410	0.50	0.65	**0.92**	0.78	2.44	2.84	-3.28	0.06
4530	0.57	0.68	0.89	0.67	2.36	2.50	-8.09	0.03
4540	0.54	0.64	0.91	0.73	1.97	2.18	-6.44	0.05
4650	0.60	0.74	0.89	0.70	1.58	1.98	-0.20	0.02

Table B.10: The calibration and validation results for Random Forest model of SSI forecast based on SPEI inputs

Basin	Calibration				Validation			
	MAE	RMSE	NSE	KGE	MAE	RMSE	NSE	KGE
0170	0.14	0.19	0.97	0.88	0.61	0.68	-0.62	0.78
0180	0.15	0.20	0.96	0.87	0.68	0.73	-0.68	0.68
0250	0.22	0.29	0.93	0.77	0.94	1.13	-1.07	0.27
0580	**0.11**	**0.14**	**0.98**	**0.93**	0.45	0.50	0.25	0.75
0660	0.12	0.15	0.98	0.92	0.38	0.46	0.43	0.42
0840	0.29	0.38	0.88	0.67	0.93	1.03	-3.65	0.03
0850	0.25	0.32	0.91	0.73	0.71	0.85	-0.73	0.20
0900	0.24	0.31	0.91	0.74	0.79	0.90	-0.39	0.41
0910	0.22	0.30	0.92	0.75	0.74	0.84	-0.21	0.34
1020	0.12	0.16	0.97	0.89	0.42	0.48	0.67	0.75
1350	0.23	0.31	0.92	0.75	0.77	0.91	0.13	0.18
1430	0.14	0.17	0.97	0.89	0.39	0.47	0.75	0.57
1510	0.13	0.17	0.97	0.89	0.50	0.56	0.59	0.48
1790	0.15	0.19	0.96	0.87	0.51	0.67	0.19	0.34
1980	0.11	0.14	0.98	0.92	0.45	0.51	0.26	0.61
2110	0.16	0.21	0.96	0.85	0.47	0.58	0.15	0.09
2400	**0.10**	**0.14**	**0.98**	**0.92**	0.38	0.44	0.48	0.74
2940	0.12	0.15	0.98	0.93	**0.26**	**0.33**	**0.85**	**0.66**
3450	0.22	0.27	0.94	0.80	0.42	0.51	0.60	0.39
3511	0.20	0.24	0.95	0.83	0.31	0.39	0.73	0.57
3540	0.16	0.21	0.96	0.86	0.77	0.87	-0.69	0.28
3550	0.18	0.22	0.95	0.85	0.59	0.70	-0.05	0.42
4215	0.13	0.16	0.97	0.90	0.49	0.57	0.63	0.56
4410	0.17	0.21	0.96	0.86	0.59	0.75	-0.22	0.12
4530	0.12	0.15	0.98	0.91	0.38	0.48	0.73	0.79
4540	0.12	0.15	0.98	0.92	0.34	0.41	0.78	0.86
4650	0.15	0.19	0.97	0.88	0.49	0.56	0.00	0.53

Table B.11: The calibration and validation results for Random Forest model of SPI forecast based on PDSI inputs

Basin	Calibration				Validation			
	MAE	RMSE	NSE	KGE	MAE	RMSE	NSE	KGE
0170	0.19	0.23	0.94	0.79	0.44	0.55	0.34	0.29
0180	0.19	0.25	0.93	0.77	0.46	0.56	0.34	0.33
0250	**0.16**	**0.20**	**0.96**	**0.83**	0.39	0.48	0.43	0.47
0580	0.20	0.24	0.94	0.79	0.43	0.52	0.36	0.30
0660	0.19	0.24	0.94	0.81	0.49	0.64	0.21	0.17
0840	0.19	0.24	0.93	0.77	0.55	0.66	0.51	0.33
0850	0.18	0.22	0.94	0.80	0.40	0.50	0.63	0.58
0900	0.16	0.21	0.94	0.79	0.53	0.67	0.68	0.50
0910	0.19	0.24	0.93	0.76	0.49	0.63	0.62	0.42
1020	0.17	0.22	0.94	0.80	0.37	0.56	**0.76**	0.55
1350	0.19	0.24	0.94	0.79	0.58	0.75	0.35	0.20
1430	0.18	0.24	0.95	0.80	0.55	0.66	0.52	0.32
1510	0.18	0.24	0.94	0.80	0.58	0.71	0.48	0.28
1790	0.19	0.24	0.94	0.80	0.43	0.52	0.69	0.58
1980	0.20	0.25	0.93	0.79	0.56	0.65	0.45	0.35
2110	0.18	0.23	0.95	0.82	0.53	0.64	0.19	0.42
2400	0.20	0.25	0.93	0.78	0.53	0.64	0.52	0.35
2940	0.20	0.27	0.93	0.76	0.50	0.62	0.39	0.22
3450	0.19	0.26	0.93	0.77	0.44	0.52	0.40	0.42
3511	0.17	0.23	0.95	0.82	0.48	0.62	-0.23	0.35
3540	0.20	0.24	0.94	0.79	0.39	0.49	0.35	0.31
3550	0.21	0.27	0.92	0.76	0.42	0.51	0.38	0.46
4215	0.21	0.27	0.93	0.75	0.52	0.63	0.19	0.20
4410	0.22	0.29	0.92	0.75	0.60	0.70	0.01	0.20
4530	0.21	0.27	0.92	0.76	0.51	0.59	0.10	0.14
4540	0.21	0.26	0.93	0.76	0.52	0.60	0.14	0.13
4650	0.22	0.27	0.93	0.77	0.45	0.56	0.45	0.29

Table B.12: The calibration and validation results for Random Forest model of SPEI forecast based on PDSI inputs

Basin	Calibration				Validation			
	MAE	RMSE	NSE	KGE	MAE	RMSE	NSE	KGE
0170	0.18	0.23	0.95	0.80	0.33	0.40	0.58	0.46
0180	0.18	0.24	0.94	0.79	0.32	0.40	0.59	0.47
0250	**0.16**	**0.20**	**0.96**	**0.83**	0.43	0.51	0.36	0.33
0580	0.19	0.24	0.94	0.80	0.44	0.54	0.43	0.34
0660	0.18	0.23	0.95	0.82	0.58	0.70	0.19	0.13
0840	0.20	0.25	0.93	0.77	0.49	0.61	0.52	0.39
0850	0.19	0.25	0.94	0.78	0.40	0.49	0.63	0.61
0900	0.18	0.23	0.93	0.78	0.42	0.57	0.69	0.56
0910	0.20	0.25	0.93	0.76	0.41	0.53	0.67	0.50
1020	0.16	0.21	0.95	0.82	0.38	0.51	**0.77**	0.61
1350	0.21	0.26	0.93	0.77	0.59	0.72	0.40	0.23
1430	0.17	0.22	0.95	0.81	0.61	0.71	0.52	0.40
1510	0.17	0.23	0.95	0.80	0.56	0.67	0.54	0.37
1790	0.19	0.23	0.95	0.81	0.47	0.61	0.52	0.54
1980	0.18	0.22	0.95	0.82	0.49	0.58	0.60	0.47
2110	0.17	0.21	0.96	0.84	0.50	0.60	0.38	0.44
2400	0.17	0.22	0.95	0.83	0.45	0.59	0.61	0.44
2940	0.20	0.25	0.93	0.77	0.49	0.62	0.48	0.29
3450	0.21	0.27	0.93	0.76	0.47	0.58	0.23	0.32
3511	0.18	0.23	0.95	0.81	0.50	0.60	-0.02	0.21
3540	0.18	0.23	0.95	0.81	0.48	0.58	0.10	0.21
3550	0.21	0.26	0.93	0.77	0.46	0.55	0.23	0.31
4215	0.20	0.26	0.93	0.77	0.54	0.67	0.22	0.20
4410	0.22	0.28	0.93	0.75	0.52	0.68	0.15	0.27
4530	0.20	0.26	0.93	0.77	0.49	0.61	0.29	0.22
4540	0.19	0.25	0.94	0.78	0.46	0.57	0.40	0.26
4650	0.19	0.24	0.94	0.80	0.45	0.55	0.50	0.31

Table B.13: The calibration and validation results for Random Forest model of PDSI forecast based on PDSI inputs

Basin	Calibration				Validation			
	MAE	RMSE	NSE	KGE	MAE	RMSE	NSE	KGE
0170	0.33	0.42	0.90	0.71	0.73	0.90	0.29	0.16
0180	0.31	0.40	0.92	0.74	0.79	0.96	0.18	0.13
0250	0.31	0.39	0.92	0.74	0.88	1.10	0.18	0.12
0580	0.35	0.44	0.90	0.72	1.00	1.21	0.11	0.07
0660	0.34	0.43	0.91	0.73	0.89	1.08	0.27	0.11
0840	0.31	0.40	0.91	0.73	0.88	1.05	0.39	0.22
0850	0.33	0.42	0.89	0.69	0.83	1.01	0.34	0.19
0900	0.31	0.39	0.90	0.71	0.97	1.12	0.29	0.19
0910	0.34	0.42	0.88	0.67	0.85	0.99	0.35	0.21
1020	0.32	0.42	0.92	0.76	0.85	1.05	0.68	0.40
1350	0.34	0.43	0.90	0.71	1.27	1.48	-0.48	0.01
1430	0.33	0.44	0.91	0.73	0.97	1.24	0.30	0.16
1510	0.33	0.43	0.91	0.74	1.10	1.40	0.17	0.08
1790	0.33	0.42	0.92	0.75	1.02	1.26	0.35	0.20
1980	0.35	0.45	0.91	0.75	1.00	1.27	0.47	0.20
2110	**0.30**	**0.40**	**0.93**	**0.78**	0.81	1.01	0.36	0.21
2400	0.31	0.40	0.93	0.78	0.92	1.24	0.30	0.12
2940	0.34	0.45	0.89	0.68	0.96	1.11	0.38	0.18
3450	0.32	0.41	0.89	0.69	0.93	1.13	0.23	0.11
3511	0.34	0.45	0.89	0.70	0.89	1.08	0.25	0.16
3540	0.33	0.41	0.91	0.73	0.90	1.08	0.26	0.16
3550	0.31	0.40	0.90	0.72	0.97	1.16	0.26	0.16
4215	0.35	0.46	0.88	0.68	0.96	1.08	0.38	0.21
4410	0.32	0.41	0.89	0.70	0.90	1.06	0.18	0.09
4530	0.33	0.41	0.92	0.75	0.83	0.97	0.35	0.23
4540	0.31	0.41	0.92	0.76	0.77	0.92	0.42	0.27
4650	0.33	0.43	0.92	0.75	0.94	1.30	0.13	0.09

Table B.14: The calibration and validation results for Random Forest model of scPDSI forecast based on PDSI inputs

Basin	Calibration				Validation			
	MAE	RMSE	NSE	KGE	MAE	RMSE	NSE	KGE
0170	0.49	0.62	0.92	0.76	1.51	1.67	-3.34	0.29
0180	0.49	0.64	0.91	0.76	2.10	2.17	-4.90	0.35
0250	0.41	0.52	0.93	0.79	1.29	1.46	-0.27	0.44
0580	0.51	0.64	0.91	0.74	1.58	1.81	-1.01	0.23
0660	0.55	0.67	0.91	0.73	1.25	1.47	0.14	0.16
0840	0.45	0.59	0.91	0.80	1.06	1.27	0.36	0.52
0850	0.65	0.83	0.88	0.79	0.94	1.11	0.51	0.52
0900	0.55	0.69	0.88	0.73	1.41	1.59	-0.08	0.51
0910	0.46	0.59	0.90	0.74	1.15	1.32	0.12	0.50
1020	0.48	0.62	0.92	0.77	1.44	1.79	0.68	0.41
1350	0.45	0.57	0.91	0.76	1.86	2.15	-0.07	0.00
1430	0.49	0.62	0.91	0.74	1.30	1.64	0.35	0.25
1510	0.44	0.55	0.93	0.80	1.46	1.81	0.09	0.05
1790	0.44	0.55	0.92	0.75	1.10	1.36	0.47	0.32
1980	0.42	0.55	0.93	0.77	1.22	1.41	0.48	0.25
2110	0.53	0.67	0.91	0.73	0.93	1.15	0.43	0.29
2400	**0.40**	**0.50**	**0.94**	**0.82**	1.62	1.82	0.39	0.13
2940	0.55	0.67	0.89	0.68	1.61	1.85	-0.06	0.12
3450	0.52	0.65	0.89	0.68	1.27	1.44	0.05	0.31
3511	0.44	0.55	0.93	0.77	1.09	1.29	0.23	0.33
3540	0.43	0.55	0.93	0.78	0.78	1.01	0.55	0.47
3550	0.49	0.61	0.90	0.72	0.87	1.07	0.60	0.53
4215	0.53	0.65	0.88	0.69	1.19	1.42	-0.06	0.31
4410	0.62	0.76	0.89	0.71	1.46	1.69	-0.52	0.01
4530	0.41	0.52	0.93	0.78	1.66	1.83	-3.89	0.11
4540	0.47	0.61	0.92	0.75	1.98	2.13	-6.09	0.09
4650	0.48	0.60	0.92	0.78	1.05	1.39	0.41	0.31

Table B.15: The calibration and validation results for Random Forest model of SSI forecast based on PDSI inputs

Basin	Calibration				Validation			
	MAE	RMSE	NSE	KGE	MAE	RMSE	NSE	KGE
0170	0.21	0.27	0.93	0.78	0.64	0.76	-1.03	0.42
0180	0.21	0.27	0.93	0.78	0.61	0.74	-0.69	0.58
0250	0.26	0.33	0.91	0.72	1.15	1.32	-1.83	0.00
0580	0.19	0.23	0.95	0.82	0.87	1.05	-2.26	0.06
0660	0.20	0.25	0.94	0.80	0.73	1.00	-1.65	0.00
0840	0.32	0.43	0.85	0.61	1.06	1.24	-5.73	0.04
0850	0.33	0.45	0.83	0.59	1.02	1.16	-2.22	0.00
0900	0.31	0.40	0.86	0.63	1.04	1.18	-1.39	0.21
0910	0.29	0.39	0.86	0.63	1.01	1.10	-1.08	0.08
1020	0.19	0.25	0.93	0.78	0.47	0.57	0.53	0.64
1350	0.31	0.42	0.85	0.61	1.07	1.26	-0.68	0.01
1430	0.20	0.26	0.94	0.78	0.80	0.99	-0.12	0.29
1510	0.21	0.27	0.93	0.76	0.88	1.10	-0.60	0.09
1790	0.21	0.26	0.93	0.77	0.93	1.21	-1.63	0.06
1980	0.19	0.24	0.94	0.80	0.79	0.88	-1.23	0.21
2110	0.22	0.28	0.93	0.77	0.72	0.85	-0.79	0.05
2400	**0.17**	**0.21**	**0.95**	**0.83**	0.77	0.87	-1.04	0.14
2940	0.20	0.24	0.95	0.81	0.51	0.61	0.47	0.50
3450	0.28	0.37	0.88	0.67	1.26	1.46	-2.34	0.00
3511	0.27	0.36	0.89	0.70	0.95	1.19	-1.45	0.00
3540	0.22	0.28	0.93	0.76	1.12	1.42	-3.49	0.00
3550	0.27	0.33	0.90	0.70	0.97	1.20	-2.14	0.02
4215	0.21	0.27	0.93	0.76	0.91	1.05	-0.29	0.05
4410	0.24	0.30	0.92	0.74	1.11	1.35	-3.00	0.01
4530	0.20	0.26	0.93	0.78	0.71	0.83	0.17	0.28
4540	0.18	0.23	0.95	0.81	0.69	0.84	0.08	0.20
4650	0.22	0.27	0.93	0.78	0.59	0.81	-1.13	0.01

Table B.16: The calibration and validation results for Random Forest model of SPI forecast based on scPDSI inputs

Basin	Calibration				Validation			
	MAE	RMSE	NSE	KGE	MAE	RMSE	NSE	KGE
0170	0.17	0.22	0.95	0.81	0.44	0.64	0.12	0.15
0180	0.19	0.24	0.93	0.78	0.65	0.84	-0.47	0.06
0250	0.16	0.20	0.95	0.84	0.49	0.57	0.22	0.39
0580	0.19	0.24	0.94	0.81	0.56	0.71	-0.18	0.07
0660	0.17	0.22	0.95	0.84	0.51	0.69	0.07	0.49
0840	0.16	0.21	0.95	0.81	0.55	0.67	0.50	0.30
0850	0.16	0.21	0.95	0.83	0.65	0.80	0.07	0.20
0900	0.17	0.21	0.94	0.79	0.59	0.77	0.58	0.35
0910	0.20	0.25	0.92	0.75	0.49	0.61	0.65	0.44
1020	0.16	0.21	0.94	0.81	0.43	0.58	**0.74**	0.52
1350	0.16	0.21	0.95	0.84	0.53	0.66	0.49	0.36
1430	0.18	0.23	0.95	0.82	0.59	0.70	0.47	0.31
1510	0.17	0.21	0.95	0.84	0.53	0.65	0.57	0.36
1790	0.18	0.22	0.95	0.82	0.39	0.49	0.72	0.58
1980	0.17	0.22	0.95	0.82	0.49	0.59	0.56	0.35
2110	0.16	0.21	0.96	0.85	0.49	0.59	0.29	0.52
2400	0.18	0.23	0.94	0.80	0.47	0.56	0.63	0.44
2940	0.17	0.23	0.95	0.82	0.53	0.71	0.20	0.14
3450	0.18	0.23	0.94	0.81	0.48	0.58	0.26	0.48
3511	0.17	0.21	0.95	0.84	0.62	0.73	-0.70	0.31
3540	0.18	0.23	0.94	0.82	0.43	0.52	0.24	0.27
3550	0.19	0.25	0.94	0.80	0.48	0.58	0.21	0.31
4215	0.17	0.23	0.95	0.82	0.49	0.58	0.32	0.30
4410	**0.16**	**0.21**	**0.96**	**0.86**	0.74	0.87	-0.54	0.35
4530	0.21	0.26	0.93	0.77	0.55	0.69	-0.22	0.27
4540	0.18	0.23	0.95	0.82	0.64	0.78	-0.44	0.32
4650	0.20	0.25	0.93	0.79	0.41	0.53	0.53	0.35

Table B.17: The calibration and validation results for Random Forest model of SPEI forecast based on scPDSI inputs

Basin	Calibration				Validation			
	MAE	RMSE	NSE	KGE	MAE	RMSE	NSE	KGE
0170	0.16	0.21	0.96	0.84	0.40	0.52	0.28	0.21
0180	0.17	0.22	0.95	0.82	0.55	0.74	-0.38	0.05
0250	0.16	0.20	0.96	0.84	0.45	0.61	0.11	0.09
0580	0.18	0.23	0.95	0.82	0.55	0.66	0.15	0.18
0660	0.16	0.21	0.96	0.85	0.55	0.68	0.24	0.30
0840	0.17	0.23	0.94	0.80	0.57	0.69	0.38	0.20
0850	0.16	0.21	0.95	0.84	0.64	0.79	0.05	0.23
0900	0.17	0.22	0.94	0.79	0.65	0.80	0.38	0.17
0910	0.19	0.25	0.93	0.77	0.44	0.59	0.59	0.37
1020	0.16	0.20	0.95	0.84	0.42	0.55	**0.73**	0.50
1350	0.16	0.21	0.95	0.84	0.48	0.59	0.60	0.44
1430	0.17	0.22	0.95	0.82	0.62	0.75	0.46	0.32
1510	0.16	0.21	0.96	0.84	0.51	0.61	0.62	0.39
1790	0.17	0.22	0.95	0.83	0.46	0.60	0.54	0.52
1980	**0.15**	**0.19**	**0.96**	**0.85**	0.50	0.63	0.52	0.31
2110	0.16	0.20	0.96	0.86	0.46	0.57	0.44	0.47
2400	0.16	0.21	0.96	0.84	0.66	0.76	0.35	0.25
2940	0.17	0.22	0.95	0.82	0.60	0.75	0.23	0.14
3450	0.18	0.24	0.94	0.80	0.59	0.72	-0.21	0.20
3511	0.17	0.22	0.95	0.83	0.56	0.67	-0.27	0.15
3540	0.17	0.22	0.95	0.83	0.42	0.53	0.26	0.24
3550	0.19	0.24	0.94	0.80	0.44	0.54	0.26	0.24
4215	0.16	0.21	0.96	0.84	0.48	0.58	0.43	0.32
4410	0.17	0.22	0.95	0.84	0.62	0.80	-0.20	0.33
4530	0.19	0.23	0.94	0.81	0.58	0.76	-0.10	0.21
4540	0.17	0.22	0.95	0.83	0.54	0.70	0.11	0.47
4650	0.18	0.22	0.95	0.83	0.43	0.52	0.54	0.35

Table B.18: The calibration and validation results for Random Forest model of PDSI forecast based on scPDSI inputs

Basin	Calibration				Validation			
	MAE	RMSE	NSE	KGE	MAE	RMSE	NSE	KGE
0170	0.36	0.46	0.88	0.67	0.80	0.99	0.14	0.06
0180	0.33	0.43	0.90	0.71	1.19	1.45	-0.86	0.01
0250	0.36	0.45	0.89	0.69	1.14	1.40	-0.32	0.00
0580	0.36	0.46	0.89	0.70	1.21	1.55	-0.47	0.00
0660	0.41	0.50	0.88	0.67	1.02	1.15	0.18	0.08
0840	0.39	0.48	0.87	0.65	1.37	1.60	-0.42	0.00
0850	0.36	0.45	0.87	0.65	1.10	1.33	-0.13	0.00
0900	0.38	0.47	0.86	0.63	1.63	1.88	-1.00	0.01
0910	0.35	0.44	0.87	0.65	1.21	1.40	-0.31	0.00
1020	0.35	0.44	0.91	0.74	0.93	1.16	0.60	0.34
1350	**0.33**	**0.42**	**0.90**	**0.72**	1.53	1.80	-1.17	0.00
1430	0.33	0.44	0.90	0.72	1.13	1.54	-0.08	0.03
1510	0.36	0.46	0.90	0.72	1.05	1.40	0.17	0.09
1790	0.35	0.44	0.91	0.73	1.13	1.41	0.19	0.10
1980	0.35	0.46	0.91	0.73	1.23	1.59	0.17	0.05
2110	0.37	0.47	0.90	0.72	0.78	1.00	0.38	0.21
2400	0.35	0.44	0.91	0.74	1.18	1.42	0.08	0.04
2940	0.37	0.47	0.88	0.66	1.12	1.31	0.14	0.05
3450	0.35	0.45	0.87	0.65	0.88	1.13	0.24	0.11
3511	0.35	0.44	0.89	0.69	0.94	1.20	0.08	0.05
3540	0.36	0.45	0.89	0.70	1.13	1.28	-0.04	0.06
3550	0.36	0.45	0.88	0.66	1.19	1.39	-0.06	0.03
4215	0.36	0.47	0.88	0.66	1.12	1.27	0.14	0.06
4410	0.38	0.46	0.86	0.63	0.94	1.13	0.08	0.04
4530	0.35	0.44	0.90	0.72	0.92	1.09	0.17	0.10
4540	0.38	0.48	0.89	0.70	0.93	1.14	0.11	0.06
4650	0.37	0.47	0.90	0.71	1.03	1.40	-0.01	0.03

Table B.19: The calibration and validation results for Random Forest model of scPDSI forecast based on scPDSI inputs

Basin	Calibration				Validation			
	MAE	RMSE	NSE	KGE	MAE	RMSE	NSE	KGE
0170	0.23	0.33	0.98	0.93	**0.37**	**0.47**	0.65	0.67
0180	0.25	0.35	0.97	0.91	0.56	0.72	0.34	0.37
0250	0.27	0.40	0.96	0.87	0.83	1.06	0.33	0.47
0580	0.25	0.37	0.97	0.90	0.71	0.94	0.46	0.56
0660	0.24	0.35	0.97	0.91	0.67	0.89	0.68	0.50
0840	0.25	0.37	0.96	0.91	0.74	0.91	0.67	0.67
0850	**0.22**	**0.34**	**0.98**	**0.96**	0.54	0.65	0.83	0.80
0900	0.24	0.37	0.96	0.91	1.62	2.45	-1.57	0.12
0910	0.24	0.36	0.96	0.89	0.89	1.39	0.02	0.16
1020	0.31	0.44	0.96	0.88	0.85	1.05	**0.89**	0.71
1350	0.27	0.39	0.96	0.87	0.94	1.21	0.66	0.51
1430	0.28	0.42	0.96	0.87	0.95	1.38	0.54	0.40
1510	0.29	0.42	0.96	0.88	1.04	1.50	0.38	0.18
1790	0.30	0.42	0.95	0.85	0.98	1.39	0.44	0.28
1980	0.22	0.35	0.97	0.90	0.73	1.05	0.71	0.49
2110	0.25	0.39	0.97	0.89	0.59	0.87	0.67	0.54
2400	0.24	0.36	0.97	0.90	0.81	1.18	0.74	0.53
2940	0.27	0.40	0.96	0.86	0.96	1.39	0.39	0.27
3450	0.29	0.41	0.96	0.85	0.64	0.86	0.66	0.56
3511	0.29	0.40	0.96	0.87	0.69	0.90	0.62	0.53
3540	0.25	0.36	0.97	0.90	0.57	0.75	0.75	0.66
3550	0.28	0.40	0.96	0.87	0.68	0.89	0.72	0.61
4215	0.25	0.38	0.96	0.88	0.63	0.91	0.56	0.56
4410	0.26	0.38	0.97	0.92	0.77	0.98	0.49	0.35
4530	0.29	0.41	0.96	0.86	0.85	1.05	-0.59	0.11
4540	0.26	0.38	0.97	0.90	0.49	0.57	0.48	0.49
4650	0.29	0.42	0.96	0.88	0.83	1.25	0.53	0.40

Table B.20: The calibration and validation results for Random Forest model of SSI forecast based on scPDSI inputs

Basin	Calibration				Validation			
	MAE	RMSE	NSE	KGE	MAE	RMSE	NSE	KGE
0170	0.18	0.25	0.94	0.81	0.86	0.97	-2.32	0.00
0180	0.20	0.27	0.93	0.78	0.79	0.92	-1.63	0.00
0250	0.25	0.32	0.91	0.72	1.15	1.23	-1.44	0.00
0580	0.19	0.25	0.94	0.80	0.95	1.10	-2.63	0.06
0660	0.20	0.25	0.94	0.81	0.81	1.05	-1.93	0.01
0840	0.30	0.40	0.86	0.63	0.76	0.92	-2.68	0.00
0850	0.26	0.35	0.90	0.70	1.60	1.83	-6.97	0.08
0900	0.22	0.31	0.92	0.74	0.86	1.11	-1.09	0.00
0910	0.26	0.36	0.88	0.66	0.89	1.02	-0.79	0.00
1020	0.17	0.23	0.95	0.82	0.64	0.74	0.22	0.37
1350	0.26	0.33	0.91	0.72	1.03	1.36	-0.93	0.08
1430	0.21	0.27	0.93	0.76	0.74	0.95	-0.03	0.19
1510	0.22	0.29	0.92	0.75	0.77	0.92	-0.11	0.11
1790	0.20	0.25	0.94	0.80	0.88	1.12	-1.29	0.12
1980	0.17	0.22	0.95	0.84	0.75	0.89	-1.27	0.14
2110	0.20	0.25	0.94	0.81	0.59	0.68	-0.17	0.11
2400	**0.16**	**0.21**	**0.95**	**0.84**	0.74	0.91	-1.27	0.12
2940	0.19	0.24	0.95	0.82	0.73	0.99	-0.38	0.06
3450	0.28	0.38	0.88	0.66	1.22	1.38	-2.00	0.00
3511	0.27	0.36	0.89	0.68	0.98	1.12	-1.18	0.02
3540	0.21	0.26	0.94	0.79	0.87	1.04	-1.40	0.01
3550	0.24	0.31	0.91	0.72	0.91	1.03	-1.29	0.05
4215	0.18	0.22	0.95	0.82	0.85	0.97	-0.09	0.09
4410	0.22	0.29	0.92	0.76	1.14	1.40	-3.28	0.01
4530	0.18	0.23	0.95	0.81	1.03	1.30	-1.02	0.02
4540	0.18	0.24	0.94	0.82	1.02	1.26	-1.09	0.15
4650	0.21	0.26	0.94	0.80	0.52	0.69	-0.54	0.06

Table B.21: The calibration and validation results for Random Forest model of SPI forecast based on SSI inputs

Basin	Calibration				Validation			
	MAE	RMSE	NSE	KGE	MAE	RMSE	NSE	KGE
0170	0.17	0.22	0.95	0.82	0.81	0.91	-0.79	0.07
0180	**0.16**	**0.21**	**0.95**	**0.83**	1.01	1.16	-1.78	0.02
0250	0.21	0.27	0.92	0.74	1.06	1.21	-2.58	0.03
0580	0.18	0.24	0.94	0.81	0.84	1.02	-1.43	0.00
0660	0.21	0.27	0.93	0.79	0.45	0.63	0.24	0.17
0840	0.21	0.26	0.92	0.73	0.96	1.15	-0.48	0.00
0850	0.23	0.30	0.90	0.71	0.84	1.01	-0.47	0.00
0900	0.19	0.24	0.92	0.75	1.20	1.40	-0.40	0.03
0910	0.21	0.26	0.91	0.73	0.97	1.15	-0.24	0.02
1020	0.18	0.24	0.93	0.77	0.80	1.01	0.21	0.07
1350	0.21	0.28	0.92	0.73	0.99	1.22	-0.73	0.01
1430	0.20	0.27	0.93	0.76	0.55	0.78	0.33	0.18
1510	0.20	0.28	0.92	0.75	0.61	0.85	0.25	0.13
1790	0.20	0.27	0.93	0.77	0.74	0.99	-0.13	0.03
1980	0.19	0.24	0.94	0.80	0.64	0.84	0.10	0.04
2110	0.21	0.27	0.93	0.76	0.62	0.77	-0.19	0.01
2400	0.20	0.25	0.93	0.78	0.58	0.83	0.19	0.07
2940	0.18	0.24	0.95	0.82	0.63	0.82	-0.07	0.07
3450	0.20	0.26	0.93	0.77	0.76	0.92	-0.83	0.02
3511	0.21	0.27	0.93	0.77	0.55	0.66	-0.38	0.03
3540	0.22	0.27	0.92	0.76	0.97	1.18	-2.79	0.00
3550	0.21	0.26	0.93	0.77	0.78	0.89	-0.90	0.02
4215	0.20	0.26	0.93	0.79	0.79	0.93	-0.78	0.01
4410	0.22	0.27	0.93	0.78	0.75	0.98	-0.96	0.00
4530	0.19	0.24	0.94	0.81	0.62	0.83	-0.74	0.10
4540	0.18	0.24	0.94	0.82	0.66	0.85	-0.70	0.07
4650	0.21	0.27	0.93	0.78	0.75	1.00	-0.70	0.00

Table B.22: The calibration and validation results for Random Forest model of SPEI forecast based on SSI inputs

Basin	Calibration				Validation			
	MAE	RMSE	NSE	KGE	MAE	RMSE	NSE	KGE
0170	0.17	0.22	0.95	0.82	0.81	0.91	-0.79	0.07
0180	**0.16**	**0.21**	**0.95**	**0.83**	1.01	1.16	-1.78	0.02
0250	0.21	0.27	0.92	0.74	1.06	1.21	-2.58	0.03
0580	0.18	0.24	0.94	0.81	0.84	1.02	-1.43	0.00
0660	0.21	0.27	0.93	0.79	0.45	0.63	0.24	0.17
0840	0.21	0.26	0.92	0.73	0.96	1.15	-0.48	0.00
0850	0.23	0.30	0.90	0.71	0.84	1.01	-0.47	0.00
0900	0.19	0.24	0.92	0.75	1.20	1.40	-0.40	0.03
0910	0.21	0.26	0.91	0.73	0.97	1.15	-0.24	0.02
1020	0.18	0.24	0.93	0.77	0.80	1.01	0.21	0.07
1350	0.21	0.28	0.92	0.73	0.99	1.22	-0.73	0.01
1430	0.20	0.27	0.93	0.76	0.55	0.78	0.33	0.18
1510	0.20	0.28	0.92	0.75	0.61	0.85	0.25	0.13
1790	0.20	0.27	0.93	0.77	0.74	0.99	-0.13	0.03
1980	0.19	0.24	0.94	0.80	0.64	0.84	0.10	0.04
2110	0.21	0.27	0.93	0.76	0.62	0.77	-0.19	0.01
2400	0.20	0.25	0.93	0.78	0.58	0.83	0.19	0.07
2940	0.18	0.24	0.95	0.82	0.63	0.82	-0.07	0.07
3450	0.20	0.26	0.93	0.77	0.76	0.92	-0.83	0.02
3511	0.21	0.27	0.93	0.77	0.55	0.66	-0.38	0.03
3540	0.22	0.27	0.92	0.76	0.97	1.18	-2.79	0.00
3550	0.21	0.26	0.93	0.77	0.78	0.89	-0.90	0.02
4215	0.20	0.26	0.93	0.79	0.79	0.93	-0.78	0.01
4410	0.22	0.27	0.93	0.78	0.75	0.98	-0.96	0.00
4530	0.19	0.24	0.94	0.81	0.62	0.83	-0.74	0.10
4540	0.18	0.24	0.94	0.82	0.66	0.85	-0.70	0.07
4650	0.21	0.27	0.93	0.78	0.75	1.00	-0.70	0.00

Table B.23: The calibration and validation results for Random Forest model of PDSI forecast based on SSI inputs

Basin	Calibration				Validation			
	MAE	RMSE	NSE	KGE	MAE	RMSE	NSE	KGE
0170	0.38	0.48	0.87	0.65	1.12	1.26	-0.39	0.02
0180	0.37	0.47	0.88	0.67	1.31	1.51	-1.01	0.03
0250	0.39	0.50	0.87	0.63	1.47	1.64	-0.82	0.00
0580	0.39	0.50	0.88	0.66	1.40	1.68	-0.71	0.00
0660	0.42	0.53	0.87	0.65	1.19	1.50	-0.41	0.00
0840	0.38	0.47	0.88	0.65	1.41	1.63	-0.48	0.00
0850	0.38	0.48	0.86	0.63	1.26	1.54	-0.52	0.00
0900	0.38	0.47	0.86	0.62	1.40	1.57	-0.40	0.01
0910	0.38	0.48	0.85	0.61	1.40	1.57	-0.64	0.01
1020	0.45	0.55	0.87	0.64	1.71	1.90	-0.06	0.00
1350	0.39	0.48	0.87	0.65	1.60	1.88	-1.38	0.00
1430	0.40	0.52	0.87	0.64	1.35	1.62	-0.19	0.03
1510	0.40	0.52	0.88	0.66	1.40	1.77	-0.31	0.01
1790	0.41	0.50	0.88	0.67	1.89	2.21	-1.00	0.00
1980	0.41	0.50	0.89	0.68	2.00	2.36	-0.84	0.00
2110	0.41	0.51	0.89	0.67	1.51	1.73	-0.87	0.00
2400	0.41	0.53	0.88	0.66	1.74	2.15	-1.09	0.01
2940	0.40	0.53	0.85	0.61	1.32	1.52	-0.17	0.00
3450	0.37	0.47	0.86	0.62	1.37	1.58	-0.50	0.00
3511	**0.37**	**0.46**	**0.88**	**0.67**	1.39	1.58	-0.61	0.01
3540	0.38	0.48	0.88	0.66	1.34	1.54	-0.50	0.00
3550	0.36	0.46	0.88	0.65	1.35	1.51	-0.26	0.02
4215	0.38	0.49	0.87	0.64	1.74	2.02	-1.16	0.02
4410	0.36	0.46	0.86	0.63	1.43	1.64	-0.95	0.00
4530	0.42	0.52	0.87	0.64	1.40	1.65	-0.90	0.00
4540	0.39	0.49	0.89	0.67	1.41	1.67	-0.91	0.00
4650	0.39	0.50	0.89	0.68	1.30	1.61	-0.34	0.00

Table B.24: The calibration and validation results for Random Forest model of scPDSI forecast based on SSI inputs

Basin	Calibration				Validation			
	MAE	RMSE	NSE	KGE	MAE	RMSE	NSE	KGE
0170	**0.39**	**0.53**	**0.94**	**0.81**	2.23	2.48	-8.60	0.08
0180	0.43	0.58	0.93	0.79	3.42	3.61	-15.45	0.09
0250	0.49	0.64	0.89	0.71	3.27	3.43	-6.01	0.04
0580	0.48	0.62	0.91	0.75	2.94	3.29	-5.64	0.01
0660	0.48	0.61	0.93	0.76	1.96	2.35	-1.20	0.01
0840	0.46	0.60	0.90	0.79	2.28	2.75	-2.01	0.01
0850	0.58	0.77	0.90	0.82	2.67	3.42	-3.66	0.04
0900	0.49	0.62	0.90	0.76	3.04	3.33	-3.73	0.04
0910	0.45	0.58	0.90	0.75	2.14	2.55	-2.28	0.02
1020	0.48	0.62	0.93	0.77	2.81	3.25	-0.04	0.02
1350	0.44	0.56	0.91	0.75	1.96	2.45	-0.39	0.03
1430	0.53	0.66	0.90	0.70	1.89	2.41	-0.40	0.05
1510	0.47	0.61	0.92	0.76	2.19	2.70	-1.02	0.00
1790	0.42	0.53	0.92	0.76	2.49	2.92	-1.44	0.03
1980	0.43	0.53	0.93	0.78	2.26	2.82	-1.08	0.00
2110	0.50	0.63	0.92	0.74	2.33	2.70	-2.13	0.01
2400	0.44	0.59	0.92	0.76	2.49	3.11	-0.80	0.00
2940	0.45	0.58	0.92	0.74	2.29	2.57	-1.06	0.00
3450	0.51	0.63	0.89	0.68	2.74	3.00	-3.10	0.01
3511	0.50	0.61	0.91	0.71	2.25	2.56	-2.06	0.01
3540	0.46	0.59	0.92	0.75	1.89	2.24	-1.19	0.02
3550	0.43	0.55	0.92	0.75	1.81	2.06	-0.50	0.12
4215	0.42	0.53	0.92	0.76	2.47	3.04	-3.89	0.00
4410	0.41	0.55	0.94	0.83	2.99	3.46	-5.35	0.15
4530	0.55	0.67	0.89	0.68	2.59	3.05	-12.56	0.00
4540	0.48	0.60	0.92	0.75	2.80	3.18	-14.81	0.00
4650	0.51	0.64	0.91	0.75	2.09	2.53	-0.96	0.01

Table B.25: The calibration and validation results for Random Forest model of SSI forecast based on SSI inputs

Basin	Calibration				Validation			
	MAE	RMSE	NSE	KGE	MAE	RMSE	NSE	KGE
0170	0.07	0.10	0.99	0.96	0.15	0.18	0.89	0.86
0180	0.07	0.10	0.99	0.96	**0.14**	**0.17**	0.90	0.88
0250	0.09	0.12	0.99	0.95	0.18	0.27	0.89	0.72
0580	0.08	0.10	0.99	0.95	0.16	0.22	0.86	0.74
0660	0.08	0.10	0.99	0.96	0.19	0.25	0.84	0.77
0840	0.08	0.13	0.99	0.94	0.18	0.24	0.75	0.62
0850	0.08	0.13	0.99	0.94	0.19	0.27	0.83	0.66
0900	0.07	0.11	0.99	0.95	0.14	0.20	0.93	0.80
0910	0.07	0.11	0.99	0.95	0.14	0.21	0.92	0.77
1020	**0.07**	**0.09**	**0.99**	**0.96**	0.20	0.24	0.91	0.84
1350	0.08	0.13	0.99	0.94	0.29	0.48	0.75	0.53
1430	0.08	0.12	0.99	0.94	0.21	0.31	0.89	0.77
1510	0.08	0.11	0.99	0.94	0.24	0.37	0.82	0.67
1790	0.08	0.11	0.99	0.94	0.30	0.37	0.75	0.55
1980	0.06	0.09	0.99	0.96	0.22	0.27	0.80	0.69
2110	0.08	0.11	0.99	0.95	0.19	0.27	0.81	0.65
2400	**0.07**	**0.09**	**0.99**	**0.96**	0.18	0.22	0.86	0.78
2940	**0.07**	**0.09**	**0.99**	**0.96**	0.27	0.35	0.83	0.69
3450	0.08	0.11	0.99	0.96	0.25	0.35	0.80	0.57
3511	0.07	0.11	0.99	0.95	0.22	0.30	0.85	0.69
3540	0.07	0.10	0.99	0.96	0.19	0.26	0.85	0.70
3550	0.07	0.10	0.99	0.96	0.18	0.24	0.87	0.70
4215	**0.07**	**0.09**	**0.99**	**0.96**	0.26	0.32	0.88	0.82
4410	0.08	0.10	0.99	0.96	0.21	0.28	0.83	0.69
4530	**0.07**	**0.09**	**0.99**	**0.96**	0.19	0.23	**0.94**	0.89
4540	**0.07**	**0.09**	**0.99**	**0.96**	0.21	0.25	0.92	**0.91**
4650	0.07	0.10	0.99	0.96	0.16	0.23	0.84	0.81

Appendix C

Extra-Trees prediction results

Extra-Trees prediction models‘ performance based on drought indices inputs creating for 27 meteorological basins.

Table C.1: The calibration and validation results for Extra-Trees prediction model of SPI forecast based on SPI inputs

Basin	Calibration				Validation			
	MAE	RMSE	NSE	KGE	MAE	RMSE	NSE	KGE
0170	0.11	0.15	0.98	0.93	0.36	0.48	0.50	0.54
0180	0.11	0.15	0.97	0.93	0.38	0.49	0.49	0.55
0250	0.11	0.14	0.98	0.93	0.34	0.42	0.58	0.66
0580	0.12	0.16	0.97	0.93	0.37	0.51	0.38	0.42
0660	0.12	0.16	0.98	0.93	0.31	0.42	0.66	-0.80
0840	0.11	0.16	0.97	0.91	0.45	0.54	0.67	0.56
0850	0.11	0.15	0.97	0.92	0.42	0.49	0.66	0.49
0900	0.11	0.15	0.97	0.92	0.49	0.62	0.72	0.48
0910	0.12	0.15	0.97	0.91	0.45	0.55	0.71	0.51
1020	0.11	0.15	0.97	0.92	0.36	0.48	**0.82**	0.28
1350	0.12	0.16	0.97	0.92	0.49	0.66	0.49	0.34
1430	0.11	0.15	0.98	0.93	0.42	0.57	0.64	0.20
1510	0.11	0.15	0.98	0.93	0.42	0.59	0.64	-0.62
1790	0.12	0.15	0.98	0.93	0.41	0.53	0.67	0.26
1980	0.11	0.15	0.98	0.93	0.33	0.48	0.70	0.47
2110	**0.11**	**0.14**	**0.98**	**0.94**	0.36	0.46	0.57	0.53
2400	0.11	0.15	0.98	0.93	0.35	0.51	0.69	-1.67
2940	0.11	0.16	0.98	0.93	0.41	0.51	0.58	0.41
3450	0.12	0.15	0.98	0.93	0.39	0.50	0.46	0.44
3511	0.11	0.15	0.98	0.94	0.37	0.45	0.35	0.41
3540	0.11	0.15	0.98	0.93	0.36	0.44	0.47	0.51
3550	0.12	0.15	0.98	0.93	0.38	0.47	0.47	0.50
4215	0.12	0.16	0.97	0.92	0.43	0.51	0.46	0.53
4410	0.13	0.17	0.97	0.92	0.42	0.54	0.39	0.27
4530	0.12	0.16	0.97	0.92	0.33	0.43	0.53	0.65
4540	0.11	0.16	0.98	0.93	0.36	0.48	0.47	0.59
4650	0.12	0.16	0.98	0.93	0.38	0.52	0.54	0.44

Table C.2: The calibration and validation results for Extra-Trees prediction model of SPEI forecast based on SPI inputs

Basin	Calibration				Validation			
	MAE	RMSE	NSE	KGE	MAE	RMSE	NSE	KGE
0170	0.13	0.17	0.97	0.92	0.33	0.44	0.50	0.65
0180	0.13	0.17	0.97	0.91	0.37	0.47	0.44	0.58
0250	0.13	0.16	0.97	0.91	0.42	0.52	0.33	0.52
0580	0.13	0.18	0.97	0.91	0.40	0.52	0.47	0.47
0660	0.13	0.18	0.97	0.91	0.41	0.52	0.56	-0.40
0840	0.13	0.18	0.96	0.90	0.44	0.54	0.62	0.57
0850	0.13	0.17	0.97	0.91	0.43	0.51	0.60	0.44
0900	0.13	0.17	0.96	0.90	0.42	0.51	0.75	0.62
0910	0.14	0.18	0.96	0.89	0.42	0.54	0.65	0.51
1020	0.14	0.18	0.96	0.89	0.38	0.51	**0.77**	0.09
1350	0.13	0.16	0.97	0.91	0.47	0.58	0.60	0.54
1430	0.12	0.16	0.97	0.92	0.40	0.57	0.69	0.11
1510	0.12	0.16	0.97	0.92	0.41	0.55	0.70	-0.33
1790	0.13	0.17	0.97	0.91	0.41	0.51	0.67	0.51
1980	0.12	0.16	0.97	0.92	0.43	0.55	0.63	0.08
2110	0.13	0.17	0.97	0.92	0.38	0.51	0.55	0.35
2400	0.14	0.18	0.97	0.90	0.48	0.61	0.57	-3.83
2940	0.12	0.16	0.97	0.92	0.41	0.49	0.67	0.53
3450	0.13	0.17	0.97	0.92	0.42	0.51	0.39	0.44
3511	**0.12**	**0.16**	**0.97**	**0.93**	0.54	0.65	-0.20	0.16
3540	0.14	0.18	0.97	0.91	0.45	0.52	0.26	0.36
3550	0.13	0.17	0.97	0.91	0.49	0.58	0.16	0.34
4215	0.14	0.18	0.97	0.90	0.40	0.49	0.59	0.51
4410	0.14	0.19	0.97	0.90	0.46	0.55	0.44	0.33
4530	0.13	0.18	0.97	0.90	0.36	0.43	0.65	0.63
4540	0.13	0.17	0.97	0.91	0.37	0.46	0.61	0.62
4650	0.14	0.18	0.97	0.90	0.45	0.55	0.49	0.34

Table C.3: The calibration and validation results for Extra-Trees prediction model of PDSI forecast based on SPI inputs

Basin	Calibration				Validation			
	MAE	RMSE	NSE	KGE	MAE	RMSE	NSE	KGE
0170	0.29	0.37	0.92	0.77	1.08	1.28	-0.44	-0.48
0180	0.28	0.36	0.93	0.78	1.22	1.45	-0.84	-0.53
0250	0.31	0.38	0.92	0.76	1.19	1.35	-0.24	-0.19
0580	0.33	0.40	0.92	0.75	1.25	1.49	-0.35	-0.44
0660	0.32	0.40	0.93	0.77	1.21	1.39	-0.20	-0.70
0840	0.29	0.37	0.93	0.76	1.34	1.48	-0.22	-0.22
0850	0.28	0.37	0.92	0.75	1.34	1.50	-0.43	-0.38
0900	0.29	0.35	0.92	0.75	1.50	1.67	-0.57	-0.48
0910	0.30	0.37	0.91	0.73	1.35	1.51	-0.50	-0.50
1020	0.35	0.42	0.92	0.76	1.34	1.52	0.33	-0.14
1350	0.30	0.38	0.92	0.76	1.54	1.82	-1.22	-0.75
1430	0.31	0.38	0.93	0.78	1.45	1.71	-0.33	-0.50
1510	0.31	0.39	0.93	0.78	1.46	1.79	-0.35	-0.63
1790	0.31	0.38	0.93	0.78	1.58	1.88	-0.43	-0.63
1980	0.31	0.38	0.94	0.79	1.65	1.98	-0.29	-2.44
2110	0.31	0.39	0.93	0.80	1.23	1.44	-0.30	-0.26
2400	0.33	0.40	0.93	0.78	1.52	1.82	-0.51	-1.43
2940	0.32	0.42	0.91	0.73	1.18	1.33	0.11	-0.10
3450	**0.28**	**0.35**	**0.92**	**0.76**	1.21	1.37	-0.13	-0.27
3511	0.29	0.36	0.93	0.79	1.29	1.46	-0.37	-0.25
3540	0.31	0.39	0.92	0.76	1.41	1.54	-0.50	-0.37
3550	0.29	0.37	0.92	0.76	1.39	1.54	-0.29	-0.27
4215	0.33	0.42	0.90	0.72	1.37	1.59	-0.34	-0.48
4410	0.29	0.37	0.91	0.74	1.30	1.51	-0.65	-0.76
4530	0.34	0.41	0.92	0.75	1.24	1.38	-0.33	-0.24
4540	0.33	0.41	0.92	0.77	1.19	1.34	-0.24	-0.19
4650	0.35	0.42	0.92	0.75	1.45	1.65	-0.40	-0.55

Table C.4: The calibration and validation results for Extra-Trees prediction model of scPDSI forecast based on SPI inputs

Basin	Calibration				Validation			
	MAE	RMSE	NSE	KGE	MAE	RMSE	NSE	KGE
0170	0.37	0.46	0.96	0.86	1.66	1.91	-4.66	0.15
0180	0.37	0.47	0.95	0.85	2.33	2.49	-6.82	0.14
0250	0.39	0.48	0.94	0.82	1.93	2.10	-1.63	0.28
0580	0.43	0.50	0.94	0.82	1.82	2.15	-1.84	0.21
0660	0.42	0.49	0.95	0.85	2.07	2.35	-1.21	-0.82
0840	0.35	0.48	0.94	0.82	1.58	1.78	-0.27	0.51
0850	0.47	0.61	0.94	0.82	1.31	1.52	0.08	0.62
0900	0.41	0.50	0.93	0.80	2.26	2.59	-1.87	0.15
0910	0.41	0.51	0.92	0.77	1.97	2.21	-1.46	0.15
1020	0.43	0.53	0.95	0.82	2.20	2.49	0.39	-0.52
1350	0.40	0.49	0.93	0.81	1.82	2.04	0.03	-0.04
1430	0.39	0.47	0.95	0.83	2.13	2.52	-0.53	-0.21
1510	0.40	0.49	0.95	0.84	1.76	2.22	-0.37	-1.34
1790	0.35	0.44	0.95	0.83	1.94	2.21	-0.40	-0.35
1980	**0.35**	**0.43**	**0.96**	**0.85**	2.12	2.43	-0.54	-1.60
2110	0.40	0.51	0.95	0.85	1.74	1.97	-0.66	-0.32
2400	0.39	0.47	0.95	0.84	2.20	2.67	-0.33	-4.82
2940	0.38	0.47	0.94	0.83	2.06	2.33	-0.69	-0.26
3450	0.37	0.45	0.95	0.83	1.94	2.11	-1.02	-0.07
3511	0.38	0.47	0.95	0.85	2.20	2.33	-1.52	-0.05
3540	0.40	0.49	0.95	0.83	1.75	1.95	-0.66	0.04
3550	0.41	0.49	0.94	0.82	1.99	2.20	-0.72	0.02
4215	0.38	0.46	0.94	0.83	1.67	2.11	-1.36	0.07
4410	0.39	0.51	0.95	0.85	2.43	2.76	-3.04	-1.04
4530	0.45	0.53	0.93	0.78	2.23	2.42	-7.51	-0.04
4540	0.40	0.49	0.95	0.84	2.32	2.48	-8.61	-0.01
4650	0.47	0.55	0.94	0.80	1.72	1.94	-0.15	0.07

Table C.5: The calibration and validation results for Extra-Trees prediction model of SSI forecast based on SPI inputs

Basin	Calibration				Validation			
	MAE	RMSE	NSE	KGE	MAE	RMSE	NSE	KGE
0170	0.15	0.20	0.96	0.89	0.68	0.74	-0.91	-10.57
0180	0.14	0.19	0.97	0.89	0.67	0.75	-0.74	-10.41
0250	0.20	0.26	0.94	0.82	0.80	1.00	-0.62	-2.80
0580	**0.10**	**0.14**	**0.98**	**0.94**	0.53	0.64	-0.21	-402.58
0660	0.12	0.16	0.98	0.92	0.35	0.43	0.52	0.38
0840	0.22	0.30	0.92	0.77	0.85	0.94	-2.82	-0.99
0850	0.22	0.30	0.92	0.78	0.78	0.87	-0.81	-0.60
0900	0.19	0.25	0.94	0.83	0.80	0.88	-0.33	-1.63
0910	0.19	0.26	0.94	0.81	0.76	0.83	-0.19	-1.46
1020	0.14	0.18	0.97	0.89	0.48	0.55	0.57	-0.02
1350	0.22	0.28	0.93	0.81	0.91	1.06	-0.19	-2.11
1430	0.14	0.18	0.97	0.90	0.46	0.53	0.68	-0.39
1510	0.15	0.19	0.97	0.90	0.49	0.58	0.56	-0.18
1790	0.15	0.19	0.96	0.89	0.60	0.75	-0.03	-0.33
1980	0.10	0.14	0.98	0.93	0.35	0.47	0.37	0.52
2110	0.16	0.20	0.96	0.89	0.51	0.60	0.09	0.18
2400	0.13	0.17	0.97	0.91	0.39	0.49	0.35	0.62
2940	0.11	0.14	0.98	0.94	**0.20**	**0.25**	**0.91**	-0.58
3450	0.19	0.24	0.95	0.85	0.48	0.60	0.43	-1.30
3511	0.19	0.24	0.95	0.86	0.34	0.44	0.66	0.02
3540	0.18	0.22	0.95	0.87	0.61	0.76	-0.27	-2.22
3550	0.17	0.21	0.96	0.87	0.52	0.64	0.11	-41.14
4215	0.13	0.16	0.97	0.92	0.55	0.62	0.55	-1.69
4410	0.15	0.19	0.97	0.89	0.59	0.76	-0.27	-0.22
4530	0.11	0.14	0.98	0.93	0.48	0.58	0.59	-0.17
4540	**0.10**	**0.13**	**0.98**	**0.94**	0.44	0.55	0.61	-1.02
4650	0.13	0.18	0.97	0.90	0.51	0.60	-0.15	0.06

Table C.6: The calibration and validation results for Extra-Trees prediction model of SPI forecast based on SPEI inputs

Basin	Calibration				Validation			
	MAE	RMSE	NSE	KGE	MAE	RMSE	NSE	KGE
0170	0.12	0.15	0.97	0.92	0.44	0.56	0.32	0.43
0180	0.12	0.15	0.97	0.92	0.46	0.56	0.36	0.45
0250	0.12	0.15	0.97	0.93	0.36	0.43	0.54	0.60
0580	0.14	0.18	0.97	0.91	0.45	0.60	0.16	0.30
0660	0.14	0.18	0.97	0.91	0.33	0.45	0.61	-1.05
0840	0.13	0.17	0.96	0.90	0.46	0.56	0.65	0.50
0850	0.12	0.16	0.97	0.92	0.44	0.51	0.62	0.44
0900	0.12	0.16	0.97	0.91	0.53	0.66	0.69	0.39
0910	0.13	0.16	0.97	0.90	0.47	0.58	0.69	0.48
1020	0.12	0.16	0.97	0.91	0.42	0.54	**0.77**	0.40
1350	0.13	0.17	0.97	0.91	0.53	0.71	0.41	0.24
1430	0.12	0.16	0.97	0.92	0.48	0.64	0.56	0.13
1510	0.12	0.16	0.97	0.92	0.48	0.65	0.56	0.10
1790	0.13	0.17	0.97	0.91	0.47	0.65	0.52	-0.13
1980	0.14	0.18	0.97	0.91	0.40	0.55	0.61	0.61
2110	0.13	0.17	0.97	0.92	0.36	0.47	0.55	0.59
2400	0.14	0.18	0.97	0.90	0.46	0.61	0.56	0.14
2940	0.12	0.16	0.97	0.93	0.46	0.58	0.47	0.37
3450	0.12	0.16	0.97	0.92	0.43	0.53	0.38	0.39
3511	**0.12**	**0.15**	**0.98**	**0.93**	0.37	0.46	0.34	0.53
3540	0.13	0.17	0.97	0.92	0.42	0.49	0.33	0.52
3550	0.13	0.16	0.97	0.92	0.40	0.50	0.41	0.56
4215	0.12	0.16	0.97	0.92	0.49	0.59	0.28	0.51
4410	0.15	0.19	0.97	0.91	0.47	0.62	0.20	-0.09
4530	0.13	0.17	0.97	0.92	0.39	0.50	0.36	0.66
4540	0.13	0.17	0.97	0.92	0.44	0.56	0.27	0.54
4650	0.14	0.18	0.97	0.91	0.39	0.54	0.51	0.43

Table C.7: The calibration and validation results for Extra-Trees prediction model of SPEI forecast based on SPEI inputs

Basin	Calibration				Validation			
	MAE	RMSE	NSE	KGE	MAE	RMSE	NSE	KGE
0170	0.11	0.15	0.98	0.94	0.34	0.44	0.49	0.68
0180	0.12	0.15	0.98	0.93	0.34	0.45	0.50	0.63
0250	0.12	0.15	0.98	0.93	0.39	0.48	0.43	0.57
0580	0.11	0.15	0.98	0.93	0.36	0.47	0.56	0.57
0660	0.12	0.16	0.98	0.93	0.31	0.44	0.67	0.13
0840	0.13	0.17	0.97	0.91	0.44	0.52	0.65	0.58
0850	0.12	0.16	0.97	0.92	0.43	0.50	0.61	0.48
0900	0.12	0.16	0.97	0.91	0.44	0.52	0.74	0.57
0910	0.13	0.17	0.97	0.91	0.42	0.51	0.69	0.55
1020	0.12	0.16	0.97	0.92	0.34	0.45	**0.82**	0.54
1350	0.13	0.16	0.97	0.92	0.43	0.57	0.63	0.49
1430	0.11	0.15	0.98	0.93	0.42	0.56	0.70	0.32
1510	0.11	0.15	0.98	0.93	0.41	0.55	0.70	0.21
1790	0.12	0.15	0.98	0.93	0.39	0.52	0.66	0.21
1980	0.11	0.15	0.98	0.93	0.35	0.50	0.69	0.65
2110	0.12	0.15	0.98	0.93	0.36	0.48	0.60	0.47
2400	0.11	0.15	0.98	0.93	0.37	0.52	0.69	0.02
2940	0.11	0.15	0.98	0.93	0.41	0.51	0.65	0.50
3450	0.12	0.16	0.97	0.92	0.41	0.50	0.42	0.45
3511	**0.11**	**0.14**	**0.98**	**0.94**	0.39	0.48	0.34	0.53
3540	0.12	0.16	0.97	0.93	0.38	0.45	0.45	0.56
3550	0.12	0.15	0.98	0.93	0.41	0.49	0.40	0.54
4215	0.11	0.15	0.98	0.93	0.42	0.51	0.55	0.63
4410	0.13	0.17	0.97	0.92	0.41	0.52	0.49	0.32
4530	0.12	0.16	0.97	0.92	0.34	0.43	0.65	0.68
4540	0.11	0.15	0.98	0.93	0.35	0.45	0.64	0.64
4650	0.12	0.15	0.98	0.93	0.37	0.51	0.57	0.50

Table C.8: The calibration and validation results for Extra-Trees prediction model of PDSI forecast based on SPEI inputs

Basin	Calibration				Validation			
	MAE	RMSE	NSE	KGE	MAE	RMSE	NSE	KGE
0170	0.30	0.37	0.92	0.76	1.03	1.23	-0.32	-0.37
0180	0.29	0.36	0.93	0.78	1.14	1.35	-0.61	-0.41
0250	0.31	0.37	0.92	0.77	1.14	1.31	-0.17	-0.10
0580	0.33	0.40	0.92	0.76	1.34	1.58	-0.52	-0.55
0660	0.33	0.40	0.92	0.77	1.27	1.49	-0.39	-1.00
0840	0.31	0.38	0.92	0.75	1.31	1.46	-0.19	-0.23
0850	0.29	0.37	0.92	0.75	1.35	1.50	-0.44	-0.41
0900	0.29	0.35	0.92	0.75	1.41	1.57	-0.39	-0.32
0910	0.30	0.37	0.91	0.72	1.28	1.45	-0.40	-0.42
1020	0.35	0.42	0.92	0.77	1.36	1.49	0.35	-0.01
1350	0.32	0.40	0.91	0.74	1.52	1.77	-1.09	-0.68
1430	0.31	0.38	0.93	0.78	1.52	1.78	-0.44	-0.53
1510	0.32	0.39	0.93	0.79	1.51	1.83	-0.40	-0.55
1790	0.32	0.39	0.93	0.78	1.61	1.94	-0.53	-0.72
1980	0.33	0.39	0.93	0.79	1.40	1.65	0.11	-1.01
2110	0.34	0.41	0.93	0.78	1.26	1.44	-0.30	-0.34
2400	0.34	0.41	0.93	0.77	1.35	1.62	-0.19	-0.76
2940	0.30	0.39	0.91	0.75	1.33	1.46	-0.08	-0.17
3450	**0.28**	**0.35**	**0.92**	**0.75**	1.26	1.41	-0.20	-0.30
3511	0.29	0.36	0.93	0.79	1.25	1.40	-0.25	-0.10
3540	0.30	0.38	0.92	0.76	1.36	1.48	-0.39	-0.32
3550	0.30	0.37	0.92	0.75	1.38	1.51	-0.25	-0.22
4215	0.32	0.41	0.91	0.74	1.36	1.54	-0.27	-0.34
4410	0.29	0.36	0.92	0.74	1.33	1.52	-0.68	-0.82
4530	0.32	0.38	0.93	0.77	1.20	1.37	-0.30	-0.21
4540	0.33	0.39	0.93	0.78	1.08	1.25	-0.08	-0.04
4650	0.35	0.42	0.92	0.76	1.35	1.58	-0.28	-0.33

Table C.9: The calibration and validation results for Extra-Trees prediction model of scPDSI forecast based on SPEI inputs

Basin	Calibration				Validation			
	MAE	RMSE	NSE	KGE	MAE	RMSE	NSE	KGE
0170	**0.35**	**0.44**	**0.96**	**0.87**	1.57	1.87	-4.42	0.04
0180	0.37	0.46	0.95	0.86	2.13	2.40	-6.25	-0.10
0250	0.37	0.47	0.94	0.83	1.80	1.98	-1.34	0.35
0580	0.41	0.50	0.94	0.83	2.20	2.60	-3.13	-0.15
0660	0.40	0.49	0.95	0.85	2.14	2.41	-1.32	-0.86
0840	0.39	0.50	0.93	0.81	1.56	1.74	-0.21	0.50
0850	0.47	0.60	0.94	0.83	1.15	1.35	0.28	0.68
0900	0.46	0.56	0.92	0.77	2.11	2.24	-1.15	0.38
0910	0.43	0.54	0.92	0.76	1.70	1.90	-0.83	0.31
1020	0.44	0.53	0.94	0.83	2.13	2.32	0.47	-0.04
1350	0.40	0.49	0.93	0.80	1.79	2.05	0.02	0.01
1430	0.41	0.49	0.94	0.82	2.27	2.61	-0.64	-0.25
1510	0.40	0.49	0.95	0.84	1.96	2.39	-0.58	-1.21
1790	0.35	0.44	0.95	0.83	2.20	2.52	-0.82	-0.59
1980	0.38	0.45	0.95	0.85	1.64	1.89	0.07	-0.84
2110	0.41	0.49	0.95	0.84	1.87	2.02	-0.74	-0.36
2400	0.39	0.46	0.95	0.85	2.25	2.47	-0.14	-2.31
2940	0.34	0.43	0.95	0.85	2.21	2.43	-0.84	-0.30
3450	0.41	0.48	0.94	0.82	1.93	2.12	-1.05	-0.07
3511	0.37	0.45	0.95	0.85	1.65	1.94	-0.75	0.18
3540	0.39	0.47	0.95	0.84	1.48	1.74	-0.33	0.11
3550	0.41	0.50	0.94	0.82	1.81	2.11	-0.58	0.04
4215	0.34	0.42	0.95	0.85	1.43	1.86	-0.84	0.17
4410	0.36	0.46	0.96	0.87	2.54	2.92	-3.51	-1.25
4530	0.40	0.47	0.94	0.82	2.37	2.51	-8.21	-0.02
4540	0.39	0.45	0.95	0.86	2.07	2.28	-7.11	0.01
4650	0.46	0.55	0.94	0.81	1.56	1.93	-0.13	0.01

Table C.10: The calibration and validation results for Extra-Trees prediction model of SSI forecast based on SPEI inputs

Basin	Calibration				Validation			
	MAE	RMSE	NSE	KGE	MAE	RMSE	NSE	KGE
0170	0.11	0.14	0.98	0.93	0.61	0.67	-0.60	-9.63
0180	0.12	0.15	0.98	0.93	0.65	0.70	-0.55	-10.16
0250	0.18	0.22	0.96	0.86	0.96	1.11	-0.98	-4.06
0580	0.08	0.11	0.99	0.96	0.49	0.54	0.15	-383.67
0660	0.09	0.11	0.99	0.96	0.39	0.47	0.41	-0.25
0840	0.22	0.28	0.93	0.80	0.88	0.97	-3.07	-1.06
0850	0.18	0.24	0.95	0.85	0.70	0.82	-0.62	-0.51
0900	0.17	0.22	0.96	0.86	0.76	0.85	-0.23	-1.56
0910	0.17	0.22	0.96	0.87	0.70	0.79	-0.07	-1.49
1020	0.09	0.12	0.98	0.94	0.43	0.48	0.68	-0.33
1350	0.17	0.23	0.96	0.86	0.79	0.92	0.11	-1.49
1430	0.11	0.13	0.98	0.94	0.42	0.49	0.72	-0.40
1510	0.10	0.13	0.98	0.94	0.51	0.57	0.57	-0.13
1790	0.12	0.15	0.98	0.93	0.51	0.68	0.17	-0.28
1980	0.08	0.11	0.99	0.96	0.42	0.48	0.34	0.32
2110	0.12	0.16	0.98	0.92	0.46	0.57	0.19	-0.28
2400	**0.08**	**0.10**	**0.99**	**0.96**	0.37	0.45	0.46	0.14
2940	0.09	0.11	0.99	0.96	**0.27**	**0.33**	**0.84**	-0.52
3450	0.16	0.20	0.97	0.89	0.41	0.52	0.58	-1.41
3511	0.14	0.18	0.97	0.91	0.31	0.38	0.75	0.66
3540	0.12	0.15	0.98	0.93	0.73	0.83	-0.54	-3.90
3550	0.13	0.16	0.98	0.92	0.57	0.67	0.03	-81.55
4215	0.10	0.12	0.98	0.95	0.48	0.55	0.65	-3.40
4410	0.12	0.16	0.98	0.92	0.58	0.71	-0.11	-0.42
4530	0.09	0.11	0.99	0.95	0.36	0.45	0.76	-0.08
4540	0.09	0.11	0.99	0.95	0.34	0.41	0.78	-0.64
4650	0.11	0.14	0.98	0.94	0.48	0.54	0.05	-1.58

Table C.11: The calibration and validation results for Extra-Trees prediction model of SPI forecast based on PDSI inputs

Basin	Calibration				Validation			
	MAE	RMSE	NSE	KGE	MAE	RMSE	NSE	KGE
0170	0.13	0.17	0.97	0.88	0.40	0.51	0.44	0.41
0180	0.14	0.18	0.96	0.87	0.42	0.53	0.42	0.42
0250	**0.12**	**0.15**	**0.98**	**0.91**	0.41	0.50	0.40	0.69
0580	0.14	0.18	0.97	0.88	0.40	0.48	0.46	0.65
0660	0.14	0.18	0.97	0.89	0.46	0.60	0.30	-2.22
0840	0.14	0.18	0.96	0.88	0.54	0.66	0.52	0.58
0850	0.14	0.17	0.97	0.89	0.41	0.51	0.62	0.02
0900	0.12	0.16	0.97	0.89	0.55	0.69	0.67	0.54
0910	0.14	0.17	0.96	0.87	0.48	0.62	0.64	0.55
1020	0.13	0.17	0.97	0.89	0.37	0.55	**0.77**	0.22
1350	0.14	0.18	0.97	0.88	0.58	0.74	0.36	0.26
1430	0.13	0.17	0.97	0.90	0.56	0.67	0.52	-0.22
1510	0.13	0.18	0.97	0.89	0.61	0.73	0.45	-2.46
1790	0.15	0.18	0.97	0.89	0.43	0.53	0.68	0.02
1980	0.15	0.19	0.96	0.88	0.59	0.69	0.40	-1.62
2110	0.14	0.18	0.97	0.90	0.56	0.65	0.15	-0.94
2400	0.15	0.19	0.96	0.88	0.52	0.63	0.53	-6.99
2940	0.14	0.18	0.97	0.88	0.49	0.62	0.39	0.51
3450	0.14	0.19	0.96	0.87	0.44	0.54	0.36	0.62
3511	0.13	0.17	0.97	0.90	0.48	0.61	-0.20	0.13
3540	0.15	0.18	0.97	0.88	0.39	0.49	0.33	0.50
3550	0.16	0.20	0.96	0.86	0.43	0.51	0.37	0.61
4215	0.15	0.19	0.96	0.86	0.48	0.59	0.28	0.49
4410	0.16	0.20	0.96	0.86	0.60	0.72	-0.06	-0.33
4530	0.16	0.20	0.96	0.86	0.46	0.55	0.23	0.48
4540	0.15	0.19	0.96	0.87	0.47	0.55	0.29	0.45
4650	0.17	0.20	0.96	0.87	0.44	0.56	0.45	0.45

Table C.12: The calibration and validation results for Extra-Trees prediction model of SPEI forecast based on PDSI inputs

Basin	Calibration				Validation			
	MAE	RMSE	NSE	KGE	MAE	RMSE	NSE	KGE
0170	0.13	0.17	0.97	0.89	**0.27**	**0.35**	0.67	0.74
0180	0.14	0.17	0.97	0.88	0.29	0.38	0.64	0.68
0250	**0.12**	**0.15**	**0.98**	**0.90**	0.45	0.53	0.31	0.61
0580	0.14	0.17	0.97	0.89	0.43	0.51	0.49	0.56
0660	0.14	0.17	0.97	0.90	0.55	0.67	0.25	0.10
0840	0.15	0.19	0.96	0.87	0.50	0.61	0.52	0.66
0850	0.15	0.19	0.96	0.88	0.41	0.51	0.61	0.16
0900	0.13	0.17	0.96	0.88	0.44	0.57	0.69	0.50
0910	0.14	0.18	0.96	0.87	0.41	0.52	0.68	0.63
1020	0.13	0.16	0.97	0.91	0.38	0.49	**0.78**	**0.82**
1350	0.15	0.19	0.96	0.87	0.58	0.70	0.43	0.31
1430	0.12	0.16	0.97	0.90	0.59	0.69	0.54	-1.30
1510	0.12	0.16	0.97	0.90	0.56	0.66	0.56	-2.23
1790	0.14	0.17	0.97	0.90	0.47	0.62	0.51	-2.12
1980	0.13	0.17	0.97	0.90	0.50	0.59	0.58	-1.27
2110	0.13	0.16	0.97	0.91	0.49	0.59	0.41	-0.49
2400	0.13	0.16	0.97	0.91	0.42	0.57	0.63	-3.46
2940	0.14	0.18	0.97	0.88	0.49	0.61	0.49	0.56
3450	0.15	0.19	0.96	0.86	0.48	0.60	0.17	0.53
3511	0.13	0.18	0.97	0.89	0.54	0.64	-0.13	0.45
3540	0.13	0.16	0.97	0.90	0.49	0.59	0.08	0.47
3550	0.15	0.19	0.96	0.87	0.49	0.58	0.15	0.58
4215	0.14	0.18	0.97	0.88	0.51	0.65	0.28	0.51
4410	0.16	0.21	0.96	0.86	0.53	0.68	0.13	-0.59
4530	0.15	0.19	0.96	0.87	0.47	0.59	0.34	0.50
4540	0.14	0.18	0.97	0.88	0.46	0.57	0.42	0.50
4650	0.15	0.18	0.97	0.89	0.44	0.52	0.54	0.59

Table C.13: The calibration and validation results for Extra-Trees prediction model of PDSI forecast based on PDSI inputs

Basin	Calibration				Validation			
	MAE	RMSE	NSE	KGE	MAE	RMSE	NSE	KGE
0170	0.25	0.32	0.94	0.83	0.75	0.90	0.29	0.19
0180	**0.24**	**0.31**	**0.95**	**0.84**	0.81	0.99	0.14	0.18
0250	0.25	0.31	0.95	0.84	0.85	1.05	0.26	0.29
0580	0.27	0.34	0.94	0.83	1.04	1.26	0.04	0.00
0660	0.27	0.35	0.94	0.84	0.91	1.08	0.27	0.27
0840	**0.24**	**0.31**	**0.95**	**0.84**	0.89	1.04	0.39	0.36
0850	0.26	0.33	0.93	0.81	0.87	1.03	0.32	0.33
0900	**0.24**	**0.30**	**0.94**	**0.82**	1.04	1.17	0.22	0.19
0910	0.26	0.32	0.93	0.80	0.87	1.00	0.34	0.32
1020	0.26	0.33	0.95	0.86	0.86	1.06	0.67	0.46
1350	0.26	0.33	0.94	0.83	1.32	1.53	-0.58	-0.38
1430	0.26	0.34	0.94	0.84	1.00	1.25	0.29	0.14
1510	0.26	0.34	0.95	0.85	1.09	1.37	0.21	0.03
1790	0.26	0.33	0.95	0.85	1.01	1.25	0.37	0.15
1980	0.26	0.34	0.95	0.86	1.05	1.31	0.44	-0.06
2110	0.25	0.32	0.95	0.87	0.83	1.03	0.34	0.40
2400	0.25	0.32	0.95	0.87	0.95	1.28	0.25	0.13
2940	0.26	0.35	0.93	0.81	1.02	1.16	0.32	0.06
3450	0.25	0.32	0.93	0.81	0.96	1.16	0.19	0.16
3511	0.26	0.34	0.94	0.83	0.89	1.09	0.24	0.29
3540	0.25	0.32	0.95	0.84	0.95	1.11	0.22	0.23
3550	0.25	0.32	0.94	0.83	1.02	1.21	0.20	0.22
4215	0.27	0.36	0.93	0.80	1.04	1.15	0.30	0.16
4410	0.25	0.31	0.94	0.81	0.92	1.07	0.16	0.12
4530	0.26	0.33	0.95	0.85	0.91	1.03	0.27	0.28
4540	0.25	0.33	0.95	0.86	0.82	0.95	0.38	0.37
4650	0.26	0.34	0.95	0.85	0.99	1.32	0.10	0.14

Table C.14: The calibration and validation results for Extra-Trees prediction model of scPDSI forecast based on PDSI inputs

Basin	Calibration				Validation			
	MAE	RMSE	NSE	KGE	MAE	RMSE	NSE	KGE
0170	0.37	0.46	0.96	0.86	1.43	1.57	-2.83	0.43
0180	0.37	0.48	0.95	0.86	2.08	2.15	-4.82	0.45
0250	0.32	0.40	0.96	0.87	1.29	1.43	-0.22	0.59
0580	0.38	0.48	0.95	0.84	1.62	1.84	-1.07	0.34
0660	0.40	0.49	0.95	0.85	1.27	1.47	0.14	0.12
0840	0.35	0.46	0.94	0.84	1.03	1.22	0.41	0.52
0850	0.49	0.64	0.93	0.80	0.89	1.04	0.57	0.67
0900	0.42	0.52	0.93	0.79	1.40	1.57	-0.06	0.48
0910	0.37	0.47	0.94	0.82	1.10	1.25	0.21	0.61
1020	0.37	0.48	0.96	0.88	1.45	1.79	0.68	0.28
1350	0.35	0.44	0.95	0.84	1.79	2.04	0.03	-0.12
1430	0.35	0.45	0.95	0.85	1.33	1.67	0.33	0.31
1510	0.33	0.41	0.96	0.89	1.49	1.79	0.11	-0.33
1790	0.34	0.42	0.95	0.86	1.09	1.39	0.45	0.31
1980	0.32	0.42	0.96	0.87	1.19	1.40	0.49	0.51
2110	0.41	0.52	0.94	0.85	0.92	1.12	0.46	0.56
2400	**0.31**	**0.38**	**0.97**	**0.89**	1.72	1.90	0.33	0.05
2940	0.40	0.49	0.94	0.82	1.68	1.90	-0.13	-0.02
3450	0.37	0.45	0.95	0.83	1.25	1.43	0.07	0.43
3511	0.33	0.42	0.96	0.87	1.09	1.31	0.20	0.54
3540	0.34	0.43	0.96	0.87	0.80	1.05	0.51	0.63
3550	0.35	0.42	0.95	0.85	0.91	1.11	0.56	0.69
4215	0.39	0.46	0.94	0.82	1.21	1.43	-0.09	0.40
4410	0.45	0.55	0.94	0.82	1.37	1.58	-0.32	-0.04
4530	0.32	0.40	0.96	0.88	1.66	1.83	-3.86	0.23
4540	0.34	0.43	0.96	0.87	1.97	2.09	-5.81	0.17
4650	0.37	0.46	0.96	0.87	1.11	1.47	0.34	0.40

Table C.15: The calibration and validation results for Extra-Trees prediction model of SSI forecast based on PDSI inputs

Basin	Calibration				Validation			
	MAE	RMSE	NSE	KGE	MAE	RMSE	NSE	KGE
0170	0.16	0.20	0.96	0.87	0.61	0.71	-0.78	-9.84
0180	0.16	0.21	0.96	0.87	0.64	0.74	-0.73	-10.13
0250	0.20	0.25	0.95	0.83	1.10	1.25	-1.52	-3.56
0580	0.14	0.17	0.97	0.89	0.79	0.95	-1.72	-595.42
0660	0.15	0.19	0.97	0.89	0.73	0.96	-1.45	-2.05
0840	0.24	0.32	0.91	0.74	0.99	1.16	-4.85	-1.40
0850	0.24	0.33	0.91	0.73	0.91	1.00	-1.39	-0.88
0900	0.23	0.30	0.92	0.77	0.96	1.12	-1.14	-2.27
0910	0.22	0.30	0.92	0.77	0.88	0.98	-0.65	-1.95
1020	0.15	0.19	0.96	0.88	0.51	0.60	0.48	-0.41
1350	0.22	0.31	0.92	0.75	1.05	1.23	-0.59	-3.06
1430	0.15	0.19	0.96	0.88	0.76	0.95	-0.03	-5.48
1510	0.16	0.20	0.96	0.87	0.82	1.02	-0.38	-1.31
1790	0.15	0.19	0.96	0.88	0.95	1.24	-1.78	-1.46
1980	0.14	0.18	0.97	0.89	0.81	0.90	-1.30	-0.35
2110	0.16	0.21	0.96	0.88	0.72	0.85	-0.82	-27.30
2400	**0.13**	**0.16**	**0.97**	**0.91**	0.73	0.83	-0.86	-0.96
2940	0.14	0.18	0.97	0.88	0.47	0.57	0.54	-3.75
3450	0.22	0.30	0.93	0.78	1.12	1.36	-1.93	-8.54
3511	0.20	0.27	0.94	0.81	0.84	1.07	-1.00	-1.35
3540	0.16	0.21	0.96	0.86	1.10	1.39	-3.28	-6.01
3550	0.20	0.25	0.94	0.82	0.97	1.18	-2.05	-127.60
4215	0.15	0.20	0.96	0.86	0.89	1.03	-0.23	-5.00
4410	0.20	0.24	0.95	0.83	1.13	1.35	-2.99	-2.21
4530	0.15	0.20	0.96	0.87	0.67	0.78	0.27	-0.46
4540	0.14	0.18	0.97	0.88	0.65	0.78	0.21	-1.45
4650	0.17	0.22	0.96	0.87	0.55	0.77	-0.91	-2.07

Table C.16: The calibration and validation results for Extra-Trees prediction model of SPI forecast based on scPDSI inputs

Basin	Calibration				Validation			
	MAE	RMSE	NSE	KGE	MAE	RMSE	NSE	KGE
0170	0.13	0.16	0.97	0.90	0.47	0.64	0.13	0.29
0180	0.14	0.18	0.97	0.89	0.62	0.82	-0.40	0.07
0250	0.13	0.16	0.97	0.91	0.49	0.57	0.21	0.23
0580	0.15	0.18	0.97	0.89	0.56	0.70	-0.16	0.14
0660	0.13	0.17	0.97	0.91	0.49	0.67	0.13	-4.52
0840	0.13	0.16	0.97	0.89	0.54	0.65	0.52	0.50
0850	0.12	0.16	0.97	0.91	0.65	0.79	0.09	-0.64
0900	0.13	0.16	0.97	0.88	0.58	0.76	0.59	0.49
0910	0.14	0.18	0.96	0.87	0.47	0.59	0.67	0.62
1020	0.12	0.16	0.97	0.90	0.42	0.56	**0.75**	-1.20
1350	0.12	0.16	0.97	0.92	0.57	0.70	0.43	0.32
1430	0.13	0.17	0.97	0.91	0.61	0.72	0.43	-0.40
1510	0.13	0.16	0.97	0.91	0.55	0.66	0.55	-2.00
1790	0.14	0.17	0.97	0.90	0.41	0.52	0.69	0.10
1980	0.13	0.17	0.97	0.90	0.49	0.58	0.57	-0.53
2110	0.13	0.16	0.97	0.92	0.50	0.61	0.25	-0.79
2400	0.14	0.18	0.97	0.89	0.45	0.54	0.65	-0.54
2940	0.13	0.18	0.97	0.91	0.54	0.73	0.16	0.22
3450	0.13	0.17	0.97	0.89	0.45	0.57	0.30	0.32
3511	0.12	0.16	0.97	0.92	0.63	0.74	-0.74	-0.43
3540	0.14	0.17	0.97	0.90	0.43	0.52	0.25	0.45
3550	0.15	0.19	0.96	0.89	0.45	0.55	0.27	0.48
4215	0.13	0.17	0.97	0.91	0.48	0.57	0.34	0.24
4410	**0.12**	**0.16**	**0.98**	**0.92**	0.78	0.91	-0.71	-1.45
4530	0.15	0.19	0.96	0.88	0.56	0.70	-0.24	0.06
4540	0.14	0.18	0.97	0.90	0.65	0.79	-0.48	-0.16
4650	0.16	0.20	0.96	0.89	0.42	0.53	0.52	0.50

Table C.17: The calibration and validation results for Extra-Trees prediction model of SPEI forecast based on scPDSI inputs

Basin	Calibration				Validation			
	MAE	RMSE	NSE	KGE	MAE	RMSE	NSE	KGE
0170	0.12	0.16	0.98	0.92	0.41	0.52	0.29	0.47
0180	0.13	0.16	0.97	0.91	0.54	0.73	-0.33	0.09
0250	0.13	0.16	0.97	0.91	0.46	0.60	0.11	0.16
0580	0.14	0.18	0.97	0.90	0.53	0.65	0.16	0.24
0660	0.12	0.15	0.98	0.92	0.56	0.69	0.21	-0.05
0840	0.14	0.17	0.97	0.88	0.53	0.66	0.44	0.45
0850	0.12	0.16	0.97	0.91	0.64	0.79	0.05	-0.58
0900	0.13	0.16	0.97	0.89	0.63	0.77	0.42	0.37
0910	0.15	0.18	0.96	0.87	0.42	0.55	0.64	0.59
1020	0.12	0.15	0.97	0.91	0.39	0.52	**0.76**	0.05
1350	0.12	0.16	0.97	0.91	0.53	0.64	0.53	0.51
1430	0.12	0.16	0.97	0.91	0.62	0.75	0.46	-1.18
1510	0.12	0.16	0.97	0.91	0.52	0.62	0.62	-1.37
1790	0.13	0.16	0.97	0.91	0.45	0.58	0.57	-1.78
1980	0.12	0.15	0.98	0.92	0.47	0.60	0.57	-0.57
2110	0.12	0.15	0.98	0.93	0.47	0.57	0.44	-0.37
2400	0.12	0.16	0.97	0.92	0.65	0.73	0.39	0.22
2940	0.13	0.17	0.97	0.90	0.60	0.75	0.23	0.30
3450	0.14	0.18	0.97	0.89	0.56	0.69	-0.12	0.17
3511	0.12	0.16	0.97	0.91	0.58	0.70	-0.36	0.19
3540	0.14	0.17	0.97	0.90	0.40	0.51	0.31	0.52
3550	0.14	0.18	0.96	0.89	0.44	0.54	0.27	0.52
4215	**0.11**	**0.15**	**0.98**	**0.92**	0.44	0.54	0.49	0.41
4410	0.13	0.17	0.97	0.91	0.66	0.85	-0.34	-1.49
4530	0.14	0.17	0.97	0.90	0.60	0.79	-0.19	-0.12
4540	0.13	0.18	0.97	0.91	0.51	0.66	0.21	0.09
4650	0.14	0.17	0.97	0.91	0.42	0.52	0.54	0.59

Table C.18: The calibration and validation results for Extra-Trees prediction model of PDSI forecast based on scPDSI inputs

Basin	Calibration				Validation			
	MAE	RMSE	NSE	KGE	MAE	RMSE	NSE	KGE
0170	0.27	0.34	0.94	0.81	0.85	1.05	0.03	0.05
0180	0.26	0.32	0.94	0.83	1.18	1.43	-0.80	-0.38
0250	0.27	0.34	0.94	0.82	1.14	1.39	-0.31	-0.24
0580	0.28	0.35	0.94	0.83	1.28	1.61	-0.57	-0.62
0660	0.31	0.38	0.93	0.81	1.03	1.17	0.14	0.29
0840	0.29	0.36	0.93	0.80	1.36	1.58	-0.39	-0.49
0850	0.27	0.34	0.93	0.80	1.09	1.31	-0.09	-0.15
0900	0.28	0.34	0.93	0.78	1.50	1.71	-0.65	-0.69
0910	0.27	0.33	0.93	0.79	1.18	1.38	-0.25	-0.39
1020	**0.27**	**0.35**	**0.95**	**0.85**	0.90	1.18	0.60	0.42
1350	0.26	0.33	0.94	0.84	1.49	1.76	-1.06	-0.51
1430	0.25	0.34	0.94	0.84	1.15	1.56	-0.10	-0.15
1510	0.27	0.35	0.94	0.84	1.04	1.37	0.22	-0.01
1790	0.28	0.35	0.94	0.84	1.15	1.43	0.17	0.01
1980	0.27	0.36	0.94	0.85	1.29	1.67	0.08	-0.26
2110	**0.27**	**0.35**	**0.95**	**0.85**	0.78	0.99	0.39	0.39
2400	**0.27**	**0.35**	**0.95**	**0.85**	1.14	1.37	0.15	0.06
2940	0.27	0.36	0.93	0.80	1.17	1.38	0.03	-0.01
3450	0.26	0.33	0.93	0.79	0.92	1.17	0.17	0.16
3511	0.26	0.33	0.94	0.83	0.95	1.22	0.04	0.14
3540	0.27	0.34	0.94	0.84	1.17	1.31	-0.08	-0.07
3550	0.26	0.33	0.93	0.81	1.23	1.43	-0.12	-0.13
4215	0.27	0.35	0.93	0.80	1.12	1.27	0.14	0.03
4410	0.27	0.33	0.93	0.79	0.97	1.17	0.00	0.09
4530	0.27	0.34	0.94	0.84	0.89	1.09	0.18	0.19
4540	0.27	0.34	0.95	0.84	0.93	1.13	0.12	0.17
4650	0.28	0.35	0.95	0.84	1.01	1.35	0.07	0.12

Table C.19: The calibration and validation results for Extra-Trees prediction model of scPDSI forecast based on scPDSI inputs

Basin	Calibration				Validation			
	MAE	RMSE	NSE	KGE	MAE	RMSE	NSE	KGE
0170	0.19	0.27	0.98	0.96	**0.37**	**0.46**	**0.67**	**0.78**
0180	0.21	0.29	0.98	0.95	0.56	0.72	0.35	0.49
0250	0.23	0.34	0.97	0.92	0.82	1.07	0.31	0.46
0580	0.20	0.30	0.98	0.95	0.66	0.90	0.50	0.58
0660	0.20	0.30	0.98	0.95	0.71	0.92	0.66	0.65
0840	0.21	0.32	0.97	0.93	0.72	0.91	0.67	0.60
0850	**0.17**	**0.30**	**0.98**	**0.97**	0.54	0.67	0.82	0.74
0900	0.21	0.31	0.97	0.93	1.54	2.32	-1.29	-0.55
0910	0.21	0.30	0.97	0.93	0.88	1.29	0.16	0.33
1020	0.26	0.36	0.97	0.93	0.84	1.05	0.89	0.27
1350	0.22	0.32	0.97	0.92	0.88	1.15	0.69	0.55
1430	0.23	0.33	0.97	0.93	0.93	1.35	0.56	0.50
1510	0.24	0.35	0.97	0.93	1.07	1.49	0.39	0.02
1790	0.24	0.33	0.97	0.92	0.98	1.37	0.46	0.36
1980	0.18	0.28	0.98	0.95	0.78	1.08	0.70	0.57
2110	0.21	0.34	0.98	0.94	0.63	0.89	0.66	0.71
2400	0.20	0.30	0.98	0.94	0.78	1.16	0.75	-0.55
2940	0.23	0.32	0.97	0.93	1.02	1.43	0.37	0.40
3450	0.24	0.33	0.97	0.92	0.69	0.92	0.62	0.67
3511	0.24	0.33	0.97	0.93	0.70	0.91	0.61	0.69
3540	0.20	0.29	0.98	0.95	0.62	0.78	0.73	0.72
3550	0.22	0.31	0.98	0.93	0.71	0.93	0.69	0.70
4215	0.20	0.30	0.98	0.93	0.67	0.99	0.48	0.50
4410	0.21	0.29	0.98	0.95	0.78	0.97	0.50	0.61
4530	0.24	0.34	0.97	0.92	0.72	0.92	-0.23	0.28
4540	0.22	0.32	0.98	0.94	0.47	0.56	0.51	0.65
4650	0.24	0.35	0.98	0.94	0.81	1.16	0.59	0.61

Table C.20: The calibration and validation results for Extra-Trees prediction model of SSI forecast based on scPDSI inputs

Basin	Calibration				Validation			
	MAE	RMSE	NSE	KGE	MAE	RMSE	NSE	KGE
0170	0.13	0.18	0.97	0.90	0.81	0.93	-2.08	-9.86
0180	0.14	0.18	0.97	0.89	0.78	0.91	-1.56	-4.09
0250	0.19	0.26	0.95	0.83	1.15	1.23	-1.42	-3.55
0580	0.14	0.18	0.97	0.90	0.93	1.09	-2.55	-730.20
0660	0.15	0.19	0.97	0.90	0.79	1.03	-1.81	-2.09
0840	0.22	0.31	0.92	0.76	0.79	0.95	-2.90	-0.76
0850	0.19	0.26	0.94	0.83	1.50	1.68	-5.77	-2.17
0900	0.17	0.23	0.95	0.85	0.92	1.12	-1.14	-1.32
0910	0.20	0.28	0.93	0.79	0.86	0.97	-0.63	-1.40
1020	0.14	0.18	0.97	0.90	0.64	0.74	0.22	-0.33
1350	0.20	0.25	0.94	0.85	1.03	1.33	-0.87	-2.80
1430	0.16	0.20	0.96	0.87	0.68	0.90	0.09	-4.34
1510	0.16	0.20	0.96	0.87	0.74	0.90	-0.07	-1.01
1790	0.14	0.18	0.97	0.90	0.86	1.10	-1.21	-1.22
1980	0.13	0.17	0.97	0.91	0.76	0.89	-1.28	-0.29
2110	0.14	0.18	0.97	0.91	0.60	0.70	-0.24	-18.70
2400	**0.12**	**0.16**	**0.98**	**0.92**	0.73	0.88	-1.11	-0.61
2940	0.14	0.18	0.97	0.90	0.75	1.01	-0.44	-7.36
3450	0.21	0.30	0.92	0.78	0.94	1.25	-1.47	-6.95
3511	0.19	0.26	0.95	0.83	1.04	1.19	-1.44	-2.03
3540	0.16	0.20	0.96	0.88	0.87	1.03	-1.34	-4.24
3550	0.19	0.25	0.94	0.83	0.88	1.00	-1.19	-111.46
4215	0.13	0.16	0.98	0.91	0.86	0.97	-0.10	-6.17
4410	0.16	0.21	0.96	0.87	1.18	1.40	-3.27	-2.27
4530	0.14	0.18	0.97	0.89	1.03	1.31	-1.03	-2.32
4540	0.14	0.19	0.97	0.90	1.00	1.22	-0.96	-4.48
4650	0.15	0.19	0.97	0.90	0.50	0.69	-0.54	-1.24

Table C.21: The calibration and validation results for Extra-Trees prediction model of SPI forecast based on SSI inputs

Basin	Calibration				Validation			
	MAE	RMSE	NSE	KGE	MAE	RMSE	NSE	KGE
0170	0.13	0.16	0.97	0.91	0.85	0.95	-0.96	-0.10
0180	**0.12**	**0.16**	**0.97**	**0.91**	1.02	1.16	-1.82	-0.29
0250	0.16	0.21	0.95	0.85	1.05	1.20	-2.49	-0.70
0580	0.14	0.18	0.97	0.90	0.84	1.02	-1.44	-0.52
0660	0.16	0.20	0.96	0.89	0.46	0.63	0.22	-3.12
0840	0.15	0.20	0.95	0.84	0.94	1.10	-0.35	-0.53
0850	0.17	0.22	0.95	0.84	0.82	0.98	-0.39	-0.81
0900	0.15	0.19	0.95	0.85	1.19	1.40	-0.40	-0.94
0910	0.15	0.20	0.95	0.85	0.96	1.13	-0.21	-0.51
1020	0.14	0.19	0.96	0.88	0.79	1.01	0.21	-3.24
1350	0.16	0.21	0.95	0.84	1.04	1.26	-0.84	-0.67
1430	0.15	0.20	0.96	0.87	0.54	0.77	0.35	-0.79
1510	0.16	0.22	0.95	0.86	0.56	0.82	0.31	-3.22
1790	0.15	0.20	0.96	0.88	0.73	0.99	-0.13	-1.40
1980	0.15	0.19	0.96	0.89	0.60	0.79	0.19	-0.18
2110	0.15	0.20	0.96	0.87	0.57	0.71	0.01	-0.50
2400	0.15	0.19	0.96	0.88	0.58	0.84	0.18	-3.95
2940	0.14	0.18	0.97	0.91	0.64	0.82	-0.09	-0.24
3450	0.15	0.19	0.96	0.88	0.71	0.87	-0.63	-0.42
3511	0.16	0.20	0.96	0.87	0.56	0.67	-0.43	-0.07
3540	0.16	0.20	0.96	0.88	0.91	1.11	-2.38	-0.79
3550	0.16	0.20	0.96	0.87	0.69	0.81	-0.55	-0.15
4215	0.16	0.21	0.96	0.88	0.82	0.95	-0.85	-0.29
4410	0.17	0.22	0.96	0.88	0.79	1.03	-1.16	-1.71
4530	0.15	0.19	0.96	0.89	0.64	0.84	-0.78	0.14
4540	0.14	0.18	0.97	0.91	0.67	0.88	-0.81	-0.03
4650	0.16	0.20	0.96	0.88	0.72	0.95	-0.56	-0.11

Table C.22: The calibration and validation results for Extra-Trees prediction model of SPEI forecast based on SSI inputs

Basin	Calibration				Validation			
	MAE	RMSE	NSE	KGE	MAE	RMSE	NSE	KGE
0170	0.13	0.16	0.97	0.91	0.85	0.95	-0.96	-0.10
0180	**0.12**	**0.16**	**0.97**	**0.91**	1.02	1.16	-1.82	-0.29
0250	0.16	0.21	0.95	0.85	1.05	1.20	-2.49	-0.70
0580	0.14	0.18	0.97	0.90	0.84	1.02	-1.44	-0.52
0660	0.16	0.20	0.96	0.89	0.46	0.63	0.22	-3.12
0840	0.15	0.20	0.95	0.84	0.94	1.10	-0.35	-0.53
0850	0.17	0.22	0.95	0.84	0.82	0.98	-0.39	-0.81
0900	0.15	0.19	0.95	0.85	1.19	1.40	-0.40	-0.94
0910	0.15	0.20	0.95	0.85	0.96	1.13	-0.21	-0.51
1020	0.14	0.19	0.96	0.88	0.79	1.01	0.21	-3.24
1350	0.16	0.21	0.95	0.84	1.04	1.26	-0.84	-0.67
1430	0.15	0.20	0.96	0.87	0.54	0.77	0.35	-0.79
1510	0.16	0.22	0.95	0.86	0.56	0.82	0.31	-3.22
1790	0.15	0.20	0.96	0.88	0.73	0.99	-0.13	-1.40
1980	0.15	0.19	0.96	0.89	0.60	0.79	0.19	-0.18
2110	0.15	0.20	0.96	0.87	0.57	0.71	0.01	-0.50
2400	0.15	0.19	0.96	0.88	0.58	0.84	0.18	-3.95
2940	0.14	0.18	0.97	0.91	0.64	0.82	-0.09	-0.24
3450	0.15	0.19	0.96	0.88	0.71	0.87	-0.63	-0.42
3511	0.16	0.20	0.96	0.87	0.56	0.67	-0.43	-0.07
3540	0.16	0.20	0.96	0.88	0.91	1.11	-2.38	-0.79
3550	0.16	0.20	0.96	0.87	0.69	0.81	-0.55	-0.15
4215	0.16	0.21	0.96	0.88	0.82	0.95	-0.85	-0.29
4410	0.17	0.22	0.96	0.88	0.79	1.03	-1.16	-1.71
4530	0.15	0.19	0.96	0.89	0.64	0.84	-0.78	0.14
4540	0.14	0.18	0.97	0.91	0.67	0.88	-0.81	-0.03
4650	0.16	0.20	0.96	0.88	0.72	0.95	-0.56	-0.11

Table C.23: The calibration and validation results for Extra-Trees prediction model of PDSI forecast based on SSI inputs

Basin	Calibration				Validation			
	MAE	RMSE	NSE	KGE	MAE	RMSE	NSE	KGE
0170	0.28	0.36	0.93	0.80	1.18	1.32	-0.53	-0.31
0180	0.28	0.36	0.93	0.81	1.26	1.46	-0.88	-0.21
0250	0.29	0.38	0.92	0.77	1.46	1.64	-0.81	-0.42
0580	0.29	0.37	0.93	0.80	1.42	1.71	-0.78	-0.63
0660	0.32	0.39	0.93	0.79	1.20	1.49	-0.39	-0.51
0840	0.29	0.37	0.93	0.78	1.33	1.56	-0.36	-0.42
0850	0.29	0.37	0.92	0.77	1.19	1.48	-0.40	-0.32
0900	0.29	0.36	0.91	0.76	1.44	1.62	-0.48	-0.35
0910	0.28	0.37	0.91	0.76	1.47	1.65	-0.80	-0.48
1020	0.34	0.43	0.92	0.78	1.76	1.94	-0.10	-1.16
1350	0.30	0.37	0.92	0.78	1.69	1.96	-1.57	-0.70
1430	0.31	0.40	0.92	0.77	1.32	1.60	-0.17	-0.27
1510	0.30	0.40	0.93	0.79	1.35	1.72	-0.24	-0.35
1790	0.31	0.39	0.93	0.80	1.77	2.10	-0.79	-0.50
1980	0.32	0.39	0.93	0.81	1.95	2.32	-0.77	-0.53
2110	0.31	0.38	0.94	0.80	1.49	1.71	-0.84	-0.70
2400	0.30	0.39	0.94	0.80	1.76	2.20	-1.19	-1.55
2940	0.30	0.39	0.92	0.76	1.29	1.47	-0.10	-0.32
3450	**0.26**	**0.34**	0.92	0.78	1.43	1.62	-0.58	-0.57
3511	0.28	0.36	0.93	0.80	1.43	1.61	-0.66	-0.31
3540	0.28	0.35	0.93	0.80	1.34	1.53	-0.48	-0.39
3550	0.27	0.35	0.93	0.79	1.42	1.58	-0.37	-0.29
4215	0.31	0.40	0.91	0.76	1.72	1.96	-1.04	-0.91
4410	0.27	0.36	0.92	0.78	1.42	1.63	-0.92	-0.84
4530	0.32	0.40	0.92	0.78	1.40	1.65	-0.90	-0.38
4540	0.29	0.37	0.94	0.81	1.42	1.70	-0.98	-0.56
4650	0.29	0.36	**0.94**	**0.82**	1.36	1.67	-0.42	-0.36

Table C.24: The calibration and validation results for Extra-Trees prediction model of scPDSI forecast based on SSI inputs

Basin	Calibration				Validation			
	MAE	RMSE	NSE	KGE	MAE	RMSE	NSE	KGE
0170	**0.27**	**0.37**	**0.97**	**0.90**	2.25	2.55	-9.10	-0.11
0180	0.32	0.43	0.96	0.87	3.36	3.55	-14.84	-0.09
0250	0.35	0.47	0.94	0.82	3.19	3.36	-5.73	-0.04
0580	0.35	0.45	0.95	0.85	3.03	3.37	-5.95	-0.24
0660	0.35	0.43	0.96	0.87	1.87	2.26	-1.04	-0.65
0840	0.34	0.45	0.95	0.82	2.16	2.62	-1.74	-0.17
0850	0.44	0.60	0.94	0.81	2.56	3.31	-3.35	-0.64
0900	0.33	0.45	0.95	0.84	3.06	3.35	-3.78	-0.11
0910	0.33	0.43	0.94	0.83	2.31	2.73	-2.78	-0.12
1020	0.36	0.48	0.96	0.87	2.74	3.21	-0.02	-4.27
1350	0.32	0.42	0.95	0.83	2.06	2.52	-0.47	-0.23
1430	0.37	0.47	0.95	0.82	1.82	2.35	-0.34	-0.08
1510	0.34	0.46	0.95	0.85	2.17	2.71	-1.03	-2.02
1790	0.33	0.42	0.95	0.86	2.43	2.82	-1.28	-0.75
1980	0.31	0.40	0.96	0.88	2.31	2.87	-1.16	-1.06
2110	0.36	0.45	0.96	0.86	2.29	2.62	-1.94	-0.96
2400	0.33	0.45	0.96	0.86	2.46	3.11	-0.80	-4.74
2940	0.32	0.41	0.96	0.87	2.28	2.58	-1.08	-0.53
3450	0.35	0.44	0.95	0.82	2.70	2.93	-2.91	-0.48
3511	0.36	0.45	0.95	0.83	2.25	2.56	-2.04	-0.22
3540	0.32	0.41	0.96	0.87	1.92	2.30	-1.31	-0.20
3550	0.32	0.41	0.96	0.86	1.90	2.22	-0.75	0.04
4215	0.32	0.41	0.95	0.86	2.44	2.95	-3.62	-0.36
4410	0.31	0.42	0.97	0.89	3.25	3.61	-5.91	-1.87
4530	0.38	0.48	0.94	0.82	2.48	2.98	-11.93	-0.56
4540	0.34	0.43	0.96	0.86	2.77	3.20	-14.97	-0.66
4650	0.38	0.48	0.95	0.85	1.98	2.45	-0.82	-0.27

Table C.25: The calibration and validation results for Extra-Trees prediction model of SSI forecast based on SSI inputs

Basin	Calibration				Validation			
	MAE	RMSE	NSE	KGE	MAE	RMSE	NSE	KGE
0170	0.05	0.08	0.99	0.98	0.14	0.19	0.87	0.44
0180	0.05	0.08	0.99	0.98	**0.14**	**0.17**	0.91	0.89
0250	0.07	0.09	0.99	0.97	0.17	0.25	0.90	0.85
0580	0.06	0.08	0.99	0.98	0.17	0.22	0.85	-33.82
0660	0.06	0.08	0.99	0.98	0.19	0.24	0.85	0.80
0840	0.07	0.10	0.99	0.97	0.18	0.23	0.76	0.69
0850	0.06	0.10	0.99	0.97	0.20	0.27	0.83	0.72
0900	0.06	0.09	0.99	0.97	0.14	0.20	0.93	0.83
0910	0.06	0.09	0.99	0.97	0.16	0.22	0.92	0.80
1020	0.05	0.07	0.99	0.98	0.19	0.24	0.92	0.88
1350	0.06	0.10	0.99	0.97	0.28	0.48	0.76	0.56
1430	0.07	0.09	0.99	0.97	0.21	0.31	0.89	0.89
1510	0.06	0.09	0.99	0.97	0.25	0.36	0.83	0.78
1790	0.06	0.09	0.99	0.97	0.29	0.37	0.75	0.64
1980	**0.05**	**0.07**	**1.00**	**0.98**	0.26	0.31	0.72	0.76
2110	0.06	0.09	0.99	0.97	0.20	0.29	0.79	-1.43
2400	0.05	0.07	0.99	0.98	0.18	0.24	0.85	0.90
2940	**0.05**	**0.07**	**1.00**	**0.98**	0.28	0.37	0.81	0.00
3450	0.06	0.08	0.99	0.97	0.25	0.35	0.80	0.71
3511	0.06	0.09	0.99	0.98	0.22	0.29	0.86	0.61
3540	0.06	0.08	0.99	0.98	0.20	0.26	0.85	0.80
3550	0.05	0.07	0.99	0.98	0.19	0.24	0.87	-1.57
4215	0.05	0.07	0.99	0.98	0.27	0.33	0.87	0.30
4410	0.06	0.08	0.99	0.98	0.21	0.29	0.82	0.79
4530	**0.05**	**0.07**	**1.00**	**0.98**	0.19	0.23	**0.94**	**0.94**
4540	**0.05**	**0.07**	**1.00**	**0.98**	0.22	0.26	0.91	0.84
4650	0.06	0.08	0.99	0.98	0.17	0.24	0.82	0.90

Appendix D

Extra-Trees forecasting results

Extra-Trees forecasting models‘ performance based on drought indices inputs creating for 27 meteorological basins.

Table D.1: The calibration and validation results for Extra-Trees model of SPI forecast based on SPI inputs

Basin	Calibration				Validation			
	MAE	RMSE	NSE	KGE	MAE	RMSE	NSE	KGE
0170	0.04	0.05	1.00	0.97	0.10	0.16	0.94	0.84
0180	0.04	0.05	1.00	0.97	0.11	0.18	0.93	0.83
0250	0.04	0.05	1.00	0.97	**0.10**	**0.13**	**0.96**	**0.88**
0580	0.04	0.05	1.00	0.98	0.13	0.20	0.91	0.76
0660	0.04	0.05	1.00	0.98	0.09	0.14	0.96	-0.19
0840	0.03	0.05	1.00	0.97	0.16	0.20	0.96	0.85
0850	0.04	0.05	1.00	0.97	0.13	0.16	0.96	0.84
0900	0.03	0.05	1.00	0.97	0.21	0.32	0.93	0.74
0910	0.03	0.05	1.00	0.97	0.16	0.23	0.95	0.81
1020	0.03	0.05	1.00	0.97	0.15	0.23	0.96	0.35
1350	0.04	0.05	1.00	0.97	0.19	0.35	0.85	0.66
1430	0.04	0.05	1.00	0.97	0.16	0.28	0.91	0.52
1510	0.03	0.05	1.00	0.97	0.16	0.29	0.91	-0.48
1790	**0.03**	**0.05**	**1.00**	**0.98**	0.14	0.22	0.94	0.62
1980	**0.03**	**0.05**	**1.00**	**0.98**	0.12	0.18	0.96	0.82
2110	**0.03**	**0.05**	**1.00**	**0.98**	0.11	0.15	0.96	0.84
2400	0.03	0.05	1.00	0.97	0.12	0.20	0.95	0.51
2940	0.04	0.06	1.00	0.97	0.15	0.21	0.92	0.68
3450	0.04	0.05	1.00	0.98	0.13	0.18	0.92	0.77
3511	**0.03**	**0.05**	**1.00**	**0.98**	0.12	0.17	0.90	0.77
3540	0.04	0.05	1.00	0.98	0.12	0.16	0.92	0.80
3550	0.04	0.05	1.00	0.98	0.12	0.18	0.92	0.78
4215	0.04	0.05	1.00	0.97	0.13	0.17	0.94	0.84
4410	0.04	0.06	1.00	0.97	0.14	0.21	0.91	0.74
4530	0.04	0.05	1.00	0.97	0.12	0.16	0.93	0.88
4540	0.04	0.05	1.00	0.97	0.12	0.17	0.93	0.87
4650	0.04	0.05	1.00	0.97	0.12	0.19	0.94	0.78

Table D.2: The calibration and validation results for Extra-Trees model of SPEI forecast based on SPI inputs

Basin	Calibration				Validation			
	MAE	RMSE	NSE	KGE	MAE	RMSE	NSE	KGE
0170	0.08	0.10	0.99	0.96	0.18	0.22	0.87	0.84
0180	0.07	0.10	0.99	0.96	0.17	0.20	0.90	**0.90**
0250	**0.06**	**0.08**	**0.99**	**0.96**	0.21	0.25	0.84	0.77
0580	0.08	0.11	0.99	0.95	0.22	0.27	0.85	0.72
0660	0.09	0.11	0.99	0.95	0.27	0.32	0.82	-0.13
0840	0.07	0.09	0.99	0.96	0.18	0.24	0.93	0.89
0850	0.07	0.09	0.99	0.96	**0.15**	**0.19**	0.94	0.80
0900	0.07	0.09	0.99	0.96	0.17	0.24	**0.95**	0.88
0910	0.08	0.10	0.99	0.95	0.17	0.26	0.92	0.78
1020	0.09	0.12	0.98	0.94	0.23	0.30	0.92	-0.04
1350	0.07	0.09	0.99	0.96	0.22	0.31	0.88	0.74
1430	0.07	0.10	0.99	0.96	0.21	0.31	0.90	0.55
1510	0.08	0.10	0.99	0.96	0.25	0.32	0.89	-0.12
1790	0.08	0.11	0.99	0.95	0.24	0.28	0.89	0.60
1980	0.08	0.10	0.99	0.95	0.30	0.34	0.85	0.53
2110	0.08	0.10	0.99	0.96	0.20	0.26	0.88	0.65
2400	0.09	0.12	0.98	0.94	0.32	0.39	0.82	-13.32
2940	0.07	0.09	0.99	0.96	0.16	0.22	0.93	0.71
3450	0.07	0.09	0.99	0.96	0.19	0.24	0.86	0.75
3511	0.07	0.09	0.99	0.96	0.36	0.41	0.50	0.38
3540	0.10	0.12	0.99	0.95	0.25	0.30	0.75	0.62
3550	0.09	0.10	0.99	0.96	0.29	0.33	0.70	0.56
4215	0.09	0.11	0.99	0.95	0.20	0.25	0.89	0.70
4410	0.09	0.12	0.99	0.95	0.29	0.34	0.78	0.72
4530	0.09	0.11	0.99	0.95	0.19	0.23	0.90	0.76
4540	0.09	0.11	0.99	0.95	0.22	0.26	0.87	0.74
4650	0.09	0.11	0.99	0.95	0.27	0.33	0.82	0.59

Table D.3: The calibration and validation results for Extra-Trees model of PDSI forecast based on SPI inputs

Basin	Calibration				Validation			
	MAE	RMSE	NSE	KGE	MAE	RMSE	NSE	KGE
0170	0.26	0.31	0.94	0.81	0.87	1.07	0.01	-0.05
0180	0.25	0.31	0.95	0.82	1.02	1.24	-0.36	-0.18
0250	0.27	0.33	0.94	0.80	0.98	1.12	0.14	0.09
0580	0.28	0.33	0.94	0.80	1.08	1.27	-0.01	-0.13
0660	0.28	0.34	0.95	0.82	1.01	1.15	0.15	-0.38
0840	0.25	0.31	0.95	0.82	1.16	1.31	0.07	-0.00
0850	0.25	0.31	0.94	0.81	1.16	1.29	-0.03	-0.13
0900	0.26	0.31	0.94	0.79	1.31	1.45	-0.17	-0.16
0910	0.26	0.31	0.93	0.78	1.15	1.30	-0.09	-0.14
1020	0.31	0.37	0.94	0.81	1.20	1.34	0.46	-0.09
1350	**0.25**	**0.30**	**0.95**	**0.82**	1.23	1.45	-0.43	-0.23
1430	0.27	0.32	0.95	0.83	1.18	1.41	0.04	-0.26
1510	0.27	0.33	0.95	0.83	1.19	1.44	0.08	-0.34
1790	0.26	0.32	0.95	0.83	1.28	1.46	0.11	-0.17
1980	0.27	0.32	0.96	0.84	1.44	1.67	0.04	-2.24
2110	**0.26**	**0.32**	**0.96**	**0.85**	1.13	1.30	-0.08	-0.18
2400	0.29	0.34	0.95	0.83	1.32	1.60	-0.22	-1.26
2940	0.28	0.35	0.93	0.79	0.97	1.09	0.36	0.19
3450	0.25	0.31	0.94	0.79	1.09	1.23	0.06	-0.10
3511	0.26	0.31	0.95	0.83	1.18	1.33	-0.17	-0.13
3540	0.28	0.34	0.94	0.80	1.12	1.25	0.00	-0.06
3550	0.26	0.31	0.94	0.80	1.20	1.34	-0.02	-0.10
4215	0.30	0.36	0.93	0.77	1.14	1.27	0.10	-0.08
4410	0.26	0.31	0.94	0.79	1.11	1.25	-0.14	-0.35
4530	0.31	0.36	0.94	0.79	1.01	1.11	0.14	0.11
4540	0.30	0.36	0.94	0.80	0.99	1.09	0.18	0.14
4650	0.31	0.37	0.94	0.80	1.19	1.36	0.03	-0.11

Table D.4: The calibration and validation results for Extra-Trees model of scPDSI forecast based on SPI inputs

Basin	Calibration				Validation			
	MAE	RMSE	NSE	KGE	MAE	RMSE	NSE	KGE
0170	0.35	0.43	0.96	0.87	1.58	1.82	-4.45	0.19
0180	0.35	0.43	0.96	0.86	2.22	2.37	-6.86	0.20
0250	0.36	0.43	0.95	0.85	1.76	1.89	-1.28	0.36
0580	0.40	0.46	0.95	0.84	1.59	1.89	-1.40	0.32
0660	0.39	0.45	0.96	0.87	1.86	2.12	-0.91	-0.71
0840	0.33	0.44	0.95	0.84	1.41	1.62	-0.08	0.55
0850	0.44	0.57	0.94	0.84	1.17	1.39	0.20	0.65
0900	0.39	0.47	0.94	0.82	2.11	2.40	-1.60	0.27
0910	0.39	0.48	0.93	0.80	1.79	1.99	-1.13	0.28
1020	0.39	0.48	0.96	0.85	1.91	2.18	0.51	0.13
1350	0.33	0.40	0.96	0.86	1.44	1.66	0.32	0.25
1430	0.35	0.41	0.96	0.86	1.81	2.17	-0.23	-0.04
1510	0.36	0.43	0.96	0.87	1.56	1.87	-0.05	-1.22
1790	0.32	0.39	0.96	0.86	1.61	1.80	0.03	-0.14
1980	**0.32**	**0.39**	**0.96**	**0.87**	1.90	2.21	-0.37	-1.69
2110	0.35	0.44	0.96	0.87	1.63	1.88	-0.59	-0.30
2400	0.36	0.44	0.96	0.86	1.93	2.35	-0.09	-6.82
2940	0.34	0.42	0.96	0.86	1.80	2.08	-0.46	-0.14
3450	0.34	0.40	0.96	0.86	1.81	1.94	-0.85	-0.00
3511	0.34	0.41	0.96	0.87	2.04	2.17	-1.34	0.00
3540	0.37	0.45	0.95	0.85	1.47	1.65	-0.26	0.17
3550	0.37	0.44	0.95	0.85	1.78	1.95	-0.44	0.12
4215	0.36	0.42	0.95	0.85	1.48	1.80	-0.88	0.22
4410	0.35	0.46	0.96	0.88	2.20	2.52	-2.55	-0.86
4530	0.41	0.48	0.94	0.82	1.99	2.15	-6.08	0.13
4540	0.37	0.44	0.96	0.86	2.08	2.22	-7.09	0.07
4650	0.43	0.51	0.95	0.83	1.41	1.65	0.12	0.27

Table D.5: The calibration and validation results for Extra-Trees model of SSI forecast based on SPI inputs

Basin	Calibration				Validation			
	MAE	RMSE	NSE	KGE	MAE	RMSE	NSE	KGE
0170	0.14	0.19	0.97	0.90	0.72	0.78	-1.40	-7.96
0180	0.15	0.19	0.97	0.90	0.73	0.80	-1.26	-24.95
0250	0.19	0.25	0.95	0.83	0.83	1.04	-1.22	-2.51
0580	0.10	0.13	0.98	0.94	0.56	0.67	-0.49	-11.43
0660	0.12	0.16	0.98	0.93	0.38	0.45	0.38	0.37
0840	0.23	0.31	0.92	0.77	0.90	1.00	-4.34	-1.04
0850	0.22	0.30	0.93	0.79	0.79	0.88	-1.41	-0.55
0900	0.20	0.26	0.94	0.83	0.85	0.95	-0.86	-1.51
0910	0.20	0.26	0.94	0.82	0.79	0.87	-0.59	-1.30
1020	0.13	0.18	0.97	0.90	0.50	0.57	0.51	0.12
1350	0.22	0.28	0.93	0.81	0.90	1.03	-0.42	-1.67
1430	0.14	0.18	0.97	0.90	0.44	0.52	0.66	-0.41
1510	0.15	0.19	0.97	0.90	0.49	0.58	0.48	-0.15
1790	0.15	0.19	0.97	0.90	0.66	0.78	-0.27	-0.26
1980	0.10	0.14	0.98	0.93	0.37	0.49	0.18	0.48
2110	0.15	0.19	0.97	0.89	0.53	0.61	0.03	-0.13
2400	0.13	0.17	0.97	0.92	0.37	0.49	0.26	0.53
2940	0.10	0.13	0.98	0.95	**0.21**	**0.28**	**0.87**	-7.37
3450	0.19	0.24	0.95	0.86	0.49	0.58	0.31	-0.88
3511	0.19	0.24	0.95	0.86	0.30	0.40	0.66	0.04
3540	0.18	0.21	0.96	0.88	0.66	0.80	-0.70	-1.69
3550	0.18	0.22	0.96	0.88	0.53	0.64	-0.10	-3.94
4215	0.13	0.16	0.97	0.92	0.59	0.66	0.48	-7.88
4410	0.15	0.18	0.97	0.89	0.63	0.77	-0.48	-0.27
4530	0.10	0.13	0.98	0.94	0.49	0.60	0.58	-0.43
4540	**0.09**	**0.12**	**0.99**	**0.95**	0.46	0.57	0.58	-1.71
4650	0.13	0.18	0.97	0.91	0.55	0.62	-0.27	-0.70

Table D.6: The calibration and validation results for Extra-Trees model of SPI forecast based on SPEI inputs

Basin	Calibration				Validation			
	MAE	RMSE	NSE	KGE	MAE	RMSE	NSE	KGE
0170	0.07	0.09	0.99	0.96	0.28	0.36	0.71	0.57
0180	0.07	0.09	0.99	0.96	0.27	0.33	0.77	0.63
0250	**0.06**	**0.08**	**0.99**	**0.97**	0.20	0.24	0.86	0.71
0580	0.10	0.13	0.98	0.95	0.27	0.37	0.67	0.55
0660	0.09	0.12	0.99	0.95	0.21	0.26	0.86	0.10
0840	0.07	0.09	0.99	0.96	0.21	0.28	**0.92**	0.74
0850	0.06	0.08	0.99	0.96	0.18	0.24	**0.92**	0.77
0900	0.07	0.08	0.99	0.96	0.30	0.41	0.88	0.58
0910	0.07	0.09	0.99	0.95	0.25	0.33	0.90	0.72
1020	0.09	0.11	0.99	0.95	0.32	0.41	0.87	0.78
1350	0.07	0.09	0.99	0.96	0.31	0.44	0.76	0.45
1430	0.07	0.09	0.99	0.96	0.26	0.38	0.83	0.36
1510	0.08	0.10	0.99	0.96	0.28	0.40	0.83	0.23
1790	0.08	0.10	0.99	0.96	0.29	0.40	0.81	0.02
1980	0.09	0.11	0.99	0.95	0.27	0.34	0.84	0.78
2110	0.08	0.10	0.99	0.96	**0.18**	**0.23**	0.89	0.90
2400	0.10	0.13	0.98	0.94	0.33	0.43	0.78	-0.01
2940	0.07	0.09	0.99	0.96	0.26	0.33	0.81	0.66
3450	**0.06**	**0.08**	**0.99**	**0.97**	0.22	0.29	0.80	0.66
3511	0.07	0.09	0.99	0.97	0.25	0.30	0.69	0.48
3540	0.09	0.11	0.99	0.95	0.24	0.29	0.75	0.75
3550	0.08	0.10	0.99	0.96	0.23	0.30	0.78	0.68
4215	0.08	0.10	0.99	0.96	0.26	0.34	0.75	0.82
4410	0.10	0.13	0.98	0.95	0.27	0.36	0.71	0.26
4530	0.08	0.11	0.99	0.95	0.24	0.30	0.77	**0.87**
4540	0.08	0.10	0.99	0.96	0.27	0.33	0.74	0.78
4650	0.10	0.12	0.99	0.95	0.25	0.31	0.84	0.74

Table D.7: The calibration and validation results for Extra-Trees model of SPEI forecast based on SPEI inputs

Basin	Calibration				Validation			
	MAE	RMSE	NSE	KGE	MAE	RMSE	NSE	KGE
0170	0.03	0.05	1.00	0.98	0.10	0.13	0.96	0.91
0180	0.04	0.05	1.00	0.98	**0.09**	**0.13**	**0.96**	**0.89**
0250	0.03	0.05	1.00	0.98	0.12	0.16	0.93	0.83
0580	0.03	0.05	1.00	0.98	0.12	0.17	0.94	0.83
0660	0.04	0.05	1.00	0.98	0.10	0.15	0.96	0.67
0840	0.03	0.05	1.00	0.97	0.13	0.16	0.97	0.87
0850	0.04	0.05	1.00	0.97	0.13	0.15	0.97	0.84
0900	0.03	0.05	1.00	0.97	0.15	0.20	0.96	0.83
0910	0.03	0.05	1.00	0.97	0.13	0.17	0.97	0.85
1020	**0.03**	**0.04**	**1.00**	**0.98**	0.12	0.18	0.97	0.80
1350	0.04	0.05	1.00	0.97	0.14	0.22	0.94	0.77
1430	0.03	0.05	1.00	0.97	0.15	0.24	0.94	0.62
1510	0.03	0.05	1.00	0.98	0.15	0.24	0.94	0.33
1790	0.03	0.05	1.00	0.98	0.13	0.19	0.95	0.63
1980	0.03	0.05	1.00	0.98	0.12	0.19	0.95	0.86
2110	0.04	0.05	1.00	0.98	0.11	0.15	0.96	0.81
2400	0.03	0.05	1.00	0.98	0.13	0.21	0.95	-0.29
2940	0.03	0.05	1.00	0.98	0.14	0.19	0.94	0.76
3450	0.04	0.05	1.00	0.98	0.13	0.18	0.92	0.77
3511	0.03	0.05	1.00	0.98	0.13	0.17	0.91	0.82
3540	0.03	0.05	1.00	0.98	0.12	0.16	0.93	0.80
3550	0.04	0.05	1.00	0.98	0.13	0.17	0.92	0.80
4215	0.04	0.05	1.00	0.97	0.14	0.18	0.94	0.87
4410	0.04	0.05	1.00	0.97	0.13	0.18	0.93	0.75
4530	0.04	0.05	1.00	0.97	0.11	0.14	0.96	0.90
4540	0.04	0.05	1.00	0.97	0.12	0.16	0.95	0.87
4650	0.03	0.05	1.00	0.98	0.13	0.20	0.93	0.79

Table D.8: The calibration and validation results for Extra-Trees model of PDSI forecast based on SPEI inputs

Basin	Calibration				Validation			
	MAE	RMSE	NSE	KGE	MAE	RMSE	NSE	KGE
0170	0.26	0.31	0.94	0.81	0.84	1.05	0.05	-0.00
0180	0.26	0.31	0.95	0.82	0.93	1.15	-0.17	-0.04
0250	0.26	0.32	0.94	0.81	0.94	1.13	0.14	0.13
0580	0.28	0.35	0.94	0.81	1.10	1.27	-0.01	-0.06
0660	0.29	0.34	0.95	0.82	1.01	1.19	0.08	-0.56
0840	0.27	0.32	0.94	0.81	1.15	1.29	0.10	0.01
0850	0.25	0.31	0.94	0.80	1.13	1.27	0.01	-0.12
0900	0.26	0.31	0.94	0.80	1.21	1.37	-0.05	-0.06
0910	0.27	0.32	0.93	0.78	1.04	1.22	0.03	-0.03
1020	0.29	0.35	0.95	0.83	1.17	1.29	0.50	0.19
1350	0.26	0.32	0.94	0.81	1.30	1.53	-0.60	-0.29
1430	0.26	0.32	0.95	0.83	1.26	1.46	-0.03	-0.24
1510	0.28	0.33	0.95	0.83	1.25	1.50	0.00	-0.32
1790	0.27	0.33	0.95	0.83	1.41	1.64	-0.13	-0.40
1980	0.28	0.33	0.95	0.84	1.16	1.31	0.41	-0.64
2110	0.28	0.34	0.95	0.83	1.14	1.26	-0.00	-0.11
2400	0.29	0.35	0.95	0.82	1.18	1.38	0.10	-0.55
2940	0.26	0.33	0.94	0.80	1.13	1.24	0.17	0.15
3450	0.26	0.31	0.94	0.79	1.11	1.23	0.06	-0.09
3511	**0.25**	**0.30**	**0.95**	**0.83**	1.13	1.22	0.01	0.08
3540	0.27	0.33	0.94	0.81	1.09	1.22	0.05	0.01
3550	0.27	0.33	0.94	0.79	1.17	1.30	0.04	-0.03
4215	0.28	0.35	0.93	0.79	1.10	1.21	0.18	0.08
4410	0.26	0.32	0.94	0.79	1.13	1.27	-0.17	-0.37
4530	0.28	0.33	0.95	0.81	0.99	1.10	0.15	0.13
4540	0.30	0.35	0.94	0.81	0.90	1.02	0.28	0.29
4650	0.30	0.36	0.94	0.81	1.15	1.32	0.08	0.01

Table D.9: The calibration and validation results for Extra-Trees model of scPDSI forecast based on SPEI inputs

Basin	Calibration				Validation			
	MAE	RMSE	NSE	KGE	MAE	RMSE	NSE	KGE
0170	0.32	0.41	**0.97**	**0.89**	1.51	1.76	-4.11	0.15
0180	0.34	0.42	0.96	0.87	2.06	2.29	-6.32	0.00
0250	0.34	0.40	0.96	0.86	1.63	1.79	-1.05	0.41
0580	0.37	0.46	0.95	0.85	2.00	2.30	-2.54	0.08
0660	0.38	0.45	0.96	0.87	1.90	2.17	-1.00	-0.71
0840	0.36	0.46	0.94	0.83	1.39	1.57	-0.01	0.56
0850	0.44	0.55	0.95	0.85	1.02	1.22	0.38	0.70
0900	0.44	0.53	0.93	0.79	2.02	2.14	-1.07	0.42
0910	0.40	0.49	0.93	0.79	1.57	1.72	-0.60	0.41
1020	0.38	0.47	0.96	0.86	1.85	2.04	0.57	0.40
1350	0.34	0.41	0.95	0.85	1.44	1.67	0.32	0.25
1430	0.36	0.43	0.96	0.86	1.91	2.27	-0.35	-0.04
1510	0.35	0.42	0.96	0.88	1.68	2.07	-0.29	-1.20
1790	0.31	0.38	0.96	0.86	1.91	2.17	-0.42	-0.41
1980	0.33	0.40	0.96	0.87	1.52	1.74	0.15	-0.90
2110	0.35	0.43	0.96	0.87	1.71	1.85	-0.53	-0.26
2400	0.34	0.41	0.96	0.87	2.05	2.23	0.02	-3.20
2940	**0.31**	**0.38**	0.96	0.87	1.93	2.16	-0.57	-0.12
3450	0.38	0.45	0.95	0.84	1.80	1.95	-0.87	0.01
3511	0.34	0.41	0.96	0.87	1.46	1.70	-0.44	0.27
3540	0.35	0.42	0.96	0.87	1.26	1.48	-0.02	0.25
3550	0.37	0.45	0.95	0.85	1.55	1.81	-0.24	0.18
4215	0.32	0.38	0.96	0.87	1.27	1.60	-0.48	0.30
4410	0.32	0.41	**0.97**	**0.89**	2.35	2.69	-3.05	-1.02
4530	0.36	0.43	0.95	0.85	2.08	2.21	-6.52	0.14
4540	0.34	0.40	0.96	0.88	1.88	2.07	-6.04	0.09
4650	0.40	0.49	0.95	0.85	1.30	1.64	0.13	0.24

Table D.10: The calibration and validation results for Extra-Trees model of SSI forecast based on SPEI inputs

Basin	Calibration				Validation			
	MAE	RMSE	NSE	KGE	MAE	RMSE	NSE	KGE
0170	0.11	0.14	0.98	0.94	0.63	0.68	-0.81	-6.78
0180	0.11	0.14	0.98	0.94	0.69	0.73	-0.89	-23.33
0250	0.17	0.22	0.96	0.87	1.01	1.16	-1.74	-3.42
0580	0.08	0.10	0.99	0.97	0.51	0.56	-0.03	-10.45
0660	0.08	0.11	0.99	0.96	0.42	0.50	0.24	-0.16
0840	0.22	0.28	0.93	0.81	0.95	1.05	-4.83	-1.14
0850	0.18	0.23	0.95	0.86	0.71	0.84	-1.17	-0.46
0900	0.17	0.22	0.96	0.87	0.83	0.93	-0.78	-1.47
0910	0.17	0.22	0.96	0.87	0.74	0.84	-0.50	-1.33
1020	0.08	0.11	0.99	0.95	0.41	0.47	0.67	-0.15
1350	0.17	0.22	0.96	0.87	0.75	0.88	-0.05	-1.16
1430	0.10	0.13	0.98	0.94	0.42	0.48	0.71	-0.28
1510	0.10	0.13	0.98	0.94	0.48	0.55	0.53	-0.04
1790	0.11	0.14	0.98	0.94	0.54	0.68	0.04	-0.18
1980	0.08	0.10	0.99	0.96	0.42	0.50	0.17	0.32
2110	0.12	0.16	0.98	0.93	0.49	0.58	0.11	-0.20
2400	**0.07**	**0.09**	**0.99**	**0.96**	0.37	0.45	0.37	0.17
2940	0.08	0.10	0.99	0.97	**0.23**	**0.30**	**0.86**	-8.44
3450	0.15	0.20	0.97	0.90	0.43	0.52	0.44	-0.93
3511	0.14	0.18	0.97	0.92	0.28	0.36	0.72	0.45
3540	0.11	0.15	0.98	0.93	0.77	0.87	-1.00	-2.88
3550	0.13	0.16	0.98	0.93	0.63	0.71	-0.36	-8.68
4215	0.10	0.12	0.99	0.95	0.48	0.55	0.64	-13.55
4410	0.12	0.15	0.98	0.93	0.58	0.72	-0.29	-0.41
4530	0.08	0.10	0.99	0.96	0.38	0.47	0.75	-0.35
4540	0.08	0.10	0.99	0.96	0.36	0.42	0.77	-1.34
4650	0.10	0.13	0.98	0.95	0.52	0.57	-0.06	-3.36

Table D.11: The calibration and validation results for Extra-Trees model of SPI forecast based on PDSI inputs

Basin	Calibration				Validation			
	MAE	RMSE	NSE	KGE	MAE	RMSE	NSE	KGE
0170	0.13	0.16	0.97	0.88	**0.33**	**0.41**	0.63	0.53
0180	0.14	0.17	0.97	0.88	0.37	0.45	0.58	0.49
0250	**0.11**	**0.14**	**0.98**	**0.91**	0.39	0.48	0.41	**0.67**
0580	0.13	0.16	0.97	0.89	0.37	0.45	0.50	0.63
0660	0.13	0.17	0.97	0.90	0.47	0.58	0.32	-9.80
0840	0.13	0.17	0.97	0.89	0.54	0.66	0.53	0.54
0850	0.12	0.16	0.97	0.90	0.40	0.51	0.64	-0.39
0900	0.12	0.15	0.97	0.89	0.56	0.69	0.67	0.47
0910	0.13	0.17	0.96	0.87	0.49	0.63	0.64	0.43
1020	0.13	0.16	0.97	0.90	0.37	0.56	**0.77**	-2.62
1350	0.13	0.17	0.97	0.89	0.55	0.69	0.42	0.31
1430	0.12	0.15	0.98	0.91	0.54	0.65	0.52	-0.64
1510	0.12	0.15	0.98	0.91	0.59	0.69	0.48	-5.95
1790	0.14	0.17	0.97	0.90	0.44	0.57	0.61	-0.73
1980	0.14	0.17	0.97	0.90	0.57	0.66	0.40	-0.99
2110	0.13	0.16	0.97	0.91	0.53	0.64	0.19	-1.40
2400	0.14	0.17	0.97	0.89	0.54	0.62	0.53	-3.21
2940	0.13	0.16	0.97	0.89	0.40	0.52	0.53	0.62
3450	0.14	0.17	0.97	0.88	0.40	0.52	0.35	0.54
3511	0.12	0.16	0.98	0.91	0.47	0.61	-0.27	-0.08
3540	0.14	0.17	0.97	0.89	0.37	0.49	0.32	0.48
3550	0.15	0.19	0.96	0.87	0.39	0.50	0.35	0.53
4215	0.14	0.18	0.97	0.87	0.46	0.56	0.33	0.44
4410	0.15	0.19	0.97	0.87	0.58	0.68	-0.00	-0.61
4530	0.15	0.19	0.96	0.87	0.39	0.48	0.42	0.54
4540	0.15	0.18	0.97	0.88	0.40	0.48	0.45	0.54
4650	0.16	0.19	0.96	0.88	0.42	0.52	0.54	0.34

Table D.12: The calibration and validation results for Extra-Trees model of SPEI forecast based on PDSI inputs

Basin	Calibration				Validation			
	MAE	RMSE	NSE	KGE	MAE	RMSE	NSE	KGE
0170	0.12	0.15	0.98	0.90	**0.24**	**0.31**	**0.74**	**0.81**
0180	0.13	0.16	0.97	0.89	0.26	0.34	0.70	0.76
0250	**0.11**	**0.14**	**0.98**	**0.91**	0.39	0.48	0.40	0.68
0580	0.13	0.16	0.97	0.90	0.42	0.51	0.46	0.48
0660	0.13	0.16	0.98	0.91	0.52	0.62	0.32	-0.37
0840	0.15	0.18	0.96	0.88	0.49	0.62	0.53	0.60
0850	0.14	0.17	0.97	0.89	0.40	0.51	0.62	-0.19
0900	0.12	0.16	0.97	0.89	0.44	0.58	0.68	0.38
0910	0.14	0.17	0.97	0.87	0.40	0.51	0.69	0.52
1020	0.12	0.15	0.97	0.91	0.36	0.49	0.79	0.70
1350	0.14	0.17	0.97	0.88	0.56	0.67	0.44	0.22
1430	**0.11**	**0.14**	**0.98**	**0.91**	0.58	0.68	0.53	-2.18
1510	**0.11**	**0.14**	**0.98**	0.91	0.54	0.65	0.55	-4.65
1790	0.13	0.16	0.98	0.91	0.50	0.65	0.43	-4.55
1980	0.12	0.15	0.98	0.91	0.48	0.56	0.60	-0.73
2110	0.12	0.15	0.98	0.92	0.48	0.58	0.42	-0.84
2400	0.12	0.15	0.98	0.92	0.45	0.56	0.63	-19.34
2940	0.13	0.16	0.97	0.89	0.43	0.54	0.58	0.62
3450	0.15	0.18	0.97	0.87	0.44	0.57	0.15	0.47
3511	0.13	0.16	0.97	0.90	0.49	0.61	-0.09	0.45
3540	0.12	0.15	0.98	0.91	0.46	0.57	0.09	0.47
3550	0.15	0.18	0.97	0.88	0.46	0.55	0.19	0.60
4215	0.13	0.17	0.97	0.89	0.47	0.59	0.38	0.54
4410	0.15	0.19	0.96	0.87	0.53	0.67	0.11	-0.98
4530	0.14	0.18	0.97	0.88	0.41	0.52	0.47	0.53
4540	0.13	0.16	0.97	0.89	0.41	0.51	0.51	0.55
4650	0.14	0.17	0.97	0.90	0.41	0.49	0.59	0.60

Table D.13: The calibration and validation results for Extra-Trees model of PDSI forecast based on PDSI inputs

Basin	Calibration				Validation			
	MAE	RMSE	NSE	KGE	MAE	RMSE	NSE	KGE
0170	0.06	0.08	1.00	0.96	**0.15**	**0.21**	0.96	0.82
0180	0.06	0.08	1.00	0.96	0.18	0.25	0.94	0.80
0250	0.06	0.08	1.00	0.96	0.24	0.33	0.93	0.77
0580	0.06	0.08	1.00	0.96	0.26	0.37	0.92	0.71
0660	0.06	0.08	1.00	0.96	0.18	0.23	0.97	0.85
0840	**0.05**	**0.07**	**1.00**	**0.96**	0.27	0.34	0.94	0.79
0850	0.05	0.08	1.00	0.96	0.25	0.31	0.94	0.80
0900	**0.05**	**0.07**	**1.00**	**0.96**	0.31	0.39	0.92	0.74
0910	0.05	0.07	1.00	0.95	0.23	0.29	0.94	0.79
1020	0.06	0.08	1.00	0.97	0.24	0.32	**0.97**	**0.88**
1350	0.06	0.08	1.00	0.96	0.41	0.58	0.77	0.55
1430	0.06	0.10	1.00	0.96	0.28	0.43	0.91	0.71
1510	0.06	0.09	1.00	0.96	0.30	0.48	0.90	0.65
1790	0.06	0.09	1.00	0.96	0.25	0.37	0.94	0.74
1980	0.06	0.09	1.00	0.96	0.26	0.36	0.95	0.72
2110	0.06	0.08	1.00	0.97	0.23	0.29	0.95	0.84
2400	0.06	0.09	1.00	0.96	0.25	0.39	0.93	0.75
2940	0.06	0.09	1.00	0.95	0.21	0.26	0.96	0.79
3450	0.05	0.08	1.00	0.95	0.27	0.36	0.92	0.74
3511	0.06	0.09	1.00	0.96	0.24	0.32	0.93	0.79
3540	0.06	0.08	1.00	0.96	0.23	0.28	0.95	0.81
3550	0.06	0.08	1.00	0.96	0.29	0.37	0.92	0.76
4215	0.06	0.10	1.00	0.95	0.23	0.26	0.96	0.80
4410	**0.05**	**0.07**	**1.00**	**0.96**	0.21	0.25	0.95	0.80
4530	0.06	0.09	1.00	0.96	0.19	0.23	0.96	0.84
4540	0.07	0.09	1.00	0.96	0.21	0.25	0.96	0.82
4650	0.06	0.09	1.00	0.96	0.25	0.41	0.91	0.74

Table D.14: The calibration and validation results for Extra-Trees model of scPDSI forecast based on PDSI inputs

Basin	Calibration				Validation			
	MAE	RMSE	NSE	KGE	MAE	RMSE	NSE	KGE
0170	0.32	0.40	0.97	0.89	1.34	1.47	-2.58	0.41
0180	0.29	0.38	0.97	0.89	1.91	1.95	-4.33	0.51
0250	0.24	0.31	0.98	0.91	1.12	1.21	0.06	0.66
0580	0.31	0.41	0.96	0.88	1.37	1.56	-0.62	0.49
0660	0.34	0.41	0.97	0.88	0.98	1.10	0.49	0.30
0840	0.31	0.39	0.96	0.87	0.80	1.02	0.57	0.57
0850	0.47	0.59	0.94	0.82	0.69	0.87	0.69	0.73
0900	0.38	0.47	0.94	0.82	1.28	1.43	0.08	0.53
0910	0.29	0.38	0.96	0.87	0.95	1.09	0.36	0.66
1020	0.27	0.39	0.97	0.91	1.08	1.42	0.79	0.75
1350	0.25	0.32	0.97	0.90	1.34	1.57	0.40	0.27
1430	0.24	0.32	0.97	0.91	0.86	1.10	0.68	0.60
1510	**0.21**	**0.28**	**0.98**	**0.93**	0.86	1.15	0.60	0.14
1790	0.22	0.29	0.98	0.92	0.44	0.61	**0.89**	0.69
1980	0.24	0.33	0.97	0.91	0.88	1.05	0.69	0.74
2110	0.33	0.44	0.96	0.89	0.51	0.60	0.84	0.79
2400	0.23	0.29	0.98	0.93	1.40	1.49	0.56	0.49
2940	0.32	0.40	0.96	0.86	1.14	1.36	0.38	0.29
3450	0.26	0.35	0.97	0.88	0.90	1.04	0.47	0.56
3511	0.22	0.31	0.98	0.91	0.73	0.92	0.58	0.71
3540	0.25	0.34	0.97	0.91	0.48	0.67	0.79	0.76
3550	0.26	0.34	0.97	0.89	0.59	0.72	0.80	**0.81**
4215	0.33	0.39	0.96	0.86	0.99	1.18	0.20	0.55
4410	0.39	0.48	0.96	0.85	0.98	1.15	0.26	0.33
4530	0.22	0.29	0.98	0.92	1.44	1.58	-2.81	0.39
4540	0.27	0.36	0.97	0.89	1.77	1.89	-4.85	0.24
4650	0.27	0.34	0.98	0.91	0.72	0.89	0.74	0.68

Table D.15: The calibration and validation results for Extra-Trees model of SSI forecast based on PDSI inputs

Basin	Calibration				Validation			
	MAE	RMSE	NSE	KGE	MAE	RMSE	NSE	KGE
0170	0.16	0.20	0.96	0.87	0.64	0.72	-1.05	-7.00
0180	0.16	0.20	0.96	0.87	0.66	0.76	-1.05	-22.52
0250	0.20	0.25	0.95	0.83	1.10	1.25	-2.16	-3.04
0580	0.14	0.17	0.97	0.90	0.83	0.99	-2.25	-16.86
0660	0.15	0.19	0.97	0.89	0.74	0.97	-1.88	-1.70
0840	0.24	0.33	0.91	0.74	1.04	1.21	-6.82	-1.44
0850	0.25	0.34	0.90	0.72	0.93	1.03	-2.28	-0.84
0900	0.24	0.30	0.92	0.77	0.99	1.15	-1.71	-1.95
0910	0.22	0.29	0.92	0.77	0.91	1.00	-1.11	-1.65
1020	0.14	0.19	0.96	0.89	0.52	0.62	0.43	-0.29
1350	0.22	0.31	0.92	0.75	1.04	1.19	-0.91	-2.23
1430	0.15	0.20	0.96	0.87	0.78	0.95	-0.14	-3.70
1510	0.16	0.20	0.96	0.87	0.84	1.04	-0.69	-1.10
1790	0.15	0.19	0.96	0.88	0.99	1.26	-2.34	-1.28
1980	0.14	0.18	0.97	0.89	0.81	0.92	-1.83	-0.29
2110	0.16	0.21	0.96	0.88	0.72	0.84	-0.88	-8.83
2400	**0.13**	**0.16**	**0.97**	**0.91**	0.75	0.84	-1.22	-0.78
2940	0.14	0.18	0.97	0.88	0.46	0.56	0.50	-22.83
3450	0.22	0.29	0.93	0.78	1.11	1.35	-2.74	-5.31
3511	0.20	0.27	0.94	0.82	0.85	1.08	-1.46	-2.46
3540	0.16	0.21	0.96	0.87	1.14	1.42	-4.35	-4.52
3550	0.20	0.26	0.94	0.82	0.98	1.21	-2.99	-13.73
4215	0.15	0.19	0.96	0.86	0.91	1.04	-0.30	-18.93
4410	0.19	0.23	0.95	0.84	1.18	1.38	-3.68	-2.05
4530	0.15	0.20	0.96	0.87	0.68	0.79	0.29	-0.65
4540	0.14	0.19	0.97	0.88	0.67	0.78	0.22	-2.16
4650	0.17	0.21	0.96	0.87	0.57	0.80	-1.08	-4.02

Table D.16: The calibration and validation results for Extra-Trees model of SPI forecast based on scPDSI inputs

Basin	Calibration				Validation			
	MAE	RMSE	NSE	KGE	MAE	RMSE	NSE	KGE
0170	0.12	0.16	0.97	0.91	0.49	0.63	0.13	0.30
0180	0.14	0.18	0.96	0.88	0.60	0.77	-0.25	0.16
0250	0.13	0.16	0.97	0.91	0.52	0.61	0.04	0.12
0580	0.14	0.18	0.97	0.89	0.55	0.68	-0.11	0.12
0660	0.13	0.17	0.97	0.92	0.50	0.65	0.13	-14.41
0840	0.12	0.16	0.97	0.90	0.55	0.68	0.50	0.48
0850	0.13	0.16	0.97	0.91	0.67	0.82	0.08	-1.06
0900	0.13	0.16	0.97	0.88	0.59	0.76	0.59	0.49
0910	0.14	0.17	0.96	0.87	0.48	0.60	0.66	0.59
1020	0.13	0.16	0.97	0.90	0.43	0.61	**0.72**	-5.74
1350	0.12	0.16	0.97	0.92	0.54	0.66	0.48	0.49
1430	**0.12**	**0.15**	**0.98**	**0.92**	0.56	0.71	0.43	-0.94
1510	**0.12**	**0.15**	**0.98**	**0.92**	0.54	0.64	0.55	-5.06
1790	0.13	0.16	0.97	0.91	0.40	0.52	0.68	-0.37
1980	0.13	0.16	0.97	0.91	0.45	0.54	0.59	-0.42
2110	0.12	0.16	0.98	0.92	0.48	0.60	0.28	-1.07
2400	0.13	0.17	0.97	0.90	0.48	0.57	0.61	0.21
2940	0.12	0.16	0.98	0.92	0.52	0.73	0.07	-0.03
3450	0.13	0.17	0.97	0.90	0.41	0.53	0.34	0.28
3511	**0.12**	**0.15**	**0.98**	**0.92**	0.62	0.72	-0.74	-0.60
3540	0.13	0.16	0.97	0.91	0.42	0.53	0.19	0.39
3550	0.14	0.18	0.97	0.90	0.43	0.53	0.28	0.42
4215	0.13	0.16	0.97	0.91	0.50	0.58	0.27	0.04
4410	**0.12**	**0.15**	**0.98**	**0.92**	0.73	0.85	-0.58	-1.54
4530	0.15	0.19	0.96	0.88	0.62	0.78	-0.58	-0.09
4540	0.13	0.17	0.97	0.90	0.68	0.82	-0.58	-0.28
4650	0.16	0.19	0.96	0.89	0.39	0.48	0.60	0.49

Table D.17: The calibration and validation results for Extra-Trees model of SPEI forecast based on scPDSI inputs

Basin	Calibration				Validation			
	MAE	RMSE	NSE	KGE	MAE	RMSE	NSE	KGE
0170	0.12	0.15	0.98	0.92	0.47	0.57	0.14	0.35
0180	0.12	0.16	0.97	0.91	0.54	0.70	-0.24	0.14
0250	0.12	0.16	0.97	0.91	0.48	0.60	0.08	0.14
0580	0.14	0.17	0.97	0.90	0.54	0.65	0.11	0.15
0660	0.12	0.15	0.98	0.92	0.58	0.67	0.21	-0.39
0840	0.13	0.17	0.97	0.89	0.54	0.68	0.42	0.47
0850	0.13	0.16	0.97	0.91	0.64	0.79	0.06	-0.91
0900	0.13	0.17	0.97	0.88	0.59	0.75	0.46	0.42
0910	0.14	0.18	0.96	0.87	0.44	0.57	0.62	0.59
1020	0.12	0.15	0.97	0.92	0.42	0.55	**0.73**	-0.71
1350	0.12	0.16	0.97	0.92	0.50	0.64	0.50	0.70
1430	0.12	0.15	0.98	0.92	0.59	0.74	0.44	-1.97
1510	0.12	0.15	0.98	0.92	0.51	0.61	0.60	-3.27
1790	0.12	0.15	0.98	0.92	0.45	0.59	0.53	-3.76
1980	0.12	0.15	0.98	0.92	0.43	0.53	0.63	-0.43
2110	0.12	0.15	0.98	0.93	0.44	0.56	0.45	-0.57
2400	0.12	0.15	0.98	0.93	0.67	0.75	0.32	-1.50
2940	0.13	0.16	0.97	0.91	0.60	0.76	0.16	0.09
3450	0.13	0.17	0.97	0.89	0.51	0.64	-0.06	0.17
3511	0.12	0.15	0.98	0.92	0.54	0.65	-0.25	0.20
3540	0.13	0.16	0.97	0.91	0.40	0.50	0.30	0.53
3550	0.14	0.18	0.97	0.90	0.43	0.51	0.30	0.56
4215	**0.11**	**0.15**	**0.98**	**0.92**	0.50	0.57	0.41	0.32
4410	0.13	0.17	0.97	0.91	0.65	0.83	-0.35	-1.69
4530	0.13	0.16	0.97	0.90	0.65	0.86	-0.47	-0.26
4540	0.12	0.16	0.97	0.91	0.52	0.67	0.16	0.01
4650	0.13	0.17	0.97	0.92	0.38	0.48	0.59	0.61

Table D.18: The calibration and validation results for Extra-Trees model of PDSI forecast based on scPDSI inputs

Basin	Calibration				Validation			
	MAE	RMSE	NSE	KGE	MAE	RMSE	NSE	KGE
0170	0.17	0.22	0.97	0.88	0.63	0.76	0.50	0.50
0180	0.15	0.19	0.98	0.91	0.87	1.07	-0.03	0.15
0250	0.16	0.20	0.98	0.91	0.65	0.82	0.54	0.44
0580	0.16	0.22	0.98	0.91	1.01	1.29	-0.03	-0.05
0660	0.20	0.25	0.97	0.88	0.66	0.77	0.62	**0.70**
0840	0.19	0.24	0.97	0.88	1.02	1.23	0.18	0.13
0850	0.19	0.24	0.97	0.87	0.79	0.97	0.42	0.33
0900	0.18	0.23	0.97	0.87	1.11	1.27	0.10	0.05
0910	0.16	0.21	0.97	0.89	0.81	0.98	0.38	0.26
1020	0.15	0.20	0.98	0.92	0.61	0.82	0.80	0.22
1350	0.15	0.20	0.98	0.91	1.09	1.35	-0.25	-0.09
1430	**0.14**	**0.19**	**0.98**	**0.92**	0.70	0.98	0.54	0.38
1510	0.16	0.23	0.98	0.91	0.55	0.81	0.71	0.36
1790	0.15	0.21	0.98	0.92	0.58	0.71	0.79	0.52
1980	0.16	0.23	0.98	0.91	0.75	1.05	0.62	0.34
2110	0.17	0.22	0.98	0.92	0.44	0.53	**0.82**	0.64
2400	0.17	0.23	0.98	0.91	0.72	0.86	0.65	0.63
2940	0.17	0.23	0.97	0.88	0.60	0.76	0.69	0.61
3450	0.14	0.19	0.98	0.89	0.62	0.82	0.59	0.48
3511	0.14	0.19	0.98	0.91	0.63	0.83	0.54	0.51
3540	0.16	0.21	0.98	0.91	0.79	0.86	0.52	0.36
3550	0.16	0.21	0.97	0.89	0.85	0.99	0.45	0.30
4215	0.17	0.23	0.97	0.88	0.70	0.81	0.64	0.47
4410	0.18	0.22	0.97	0.87	0.64	0.79	0.55	0.50
4530	0.15	0.20	0.98	0.92	0.59	0.72	0.64	0.57
4540	0.17	0.23	0.98	0.90	0.68	0.87	0.47	0.50
4650	0.16	0.22	0.98	0.91	0.57	0.83	0.63	0.51

Table D.19: The calibration and validation results for Extra-Trees model of scPDSI forecast based on scPDSI inputs

Basin	Calibration				Validation			
	MAE	RMSE	NSE	KGE	MAE	RMSE	NSE	KGE
0170	0.06	0.09	1.00	0.99	**0.15**	**0.20**	**0.94**	**0.91**
0180	0.07	0.10	1.00	0.98	0.28	0.41	0.77	0.66
0250	0.07	0.09	1.00	0.98	0.41	0.68	0.70	0.60
0580	0.06	0.09	1.00	0.98	0.32	0.59	0.77	0.68
0660	0.06	0.09	1.00	0.99	0.23	0.31	0.96	0.88
0840	0.06	0.10	1.00	0.98	0.38	0.57	0.87	0.72
0850	0.06	0.09	1.00	0.99	0.23	0.30	0.96	0.87
0900	0.06	0.09	1.00	0.98	0.77	1.29	0.25	0.35
0910	0.06	0.09	1.00	0.98	0.33	0.57	0.82	0.71
1020	0.07	0.10	1.00	0.98	0.29	0.40	0.98	0.88
1350	0.06	0.10	1.00	0.98	0.38	0.63	0.90	0.75
1430	0.07	0.10	1.00	0.98	0.32	0.59	0.91	0.78
1510	0.06	0.09	1.00	0.98	0.38	0.62	0.88	0.54
1790	0.07	0.10	1.00	0.98	0.30	0.50	0.92	0.77
1980	0.06	0.09	1.00	0.98	0.26	0.37	0.96	0.85
2110	0.06	0.09	1.00	0.98	0.21	0.31	0.96	0.91
2400	0.06	0.09	1.00	0.98	0.26	0.43	0.96	0.28
2940	0.07	0.10	1.00	0.98	0.31	0.47	0.92	0.80
3450	0.07	0.10	1.00	0.98	0.27	0.37	0.93	0.84
3511	0.07	0.10	1.00	0.98	0.26	0.35	0.94	0.85
3540	**0.06**	**0.08**	**1.00**	**0.98**	0.22	0.31	0.96	0.88
3550	0.06	0.09	1.00	0.98	0.28	0.41	0.94	0.83
4215	0.06	0.09	1.00	0.98	0.21	0.34	0.93	0.81
4410	0.06	0.09	1.00	0.99	0.30	0.38	0.92	0.85
4530	0.07	0.10	1.00	0.98	0.27	0.40	0.76	0.66
4540	0.06	0.09	1.00	0.98	0.16	0.20	0.93	0.85
4650	0.07	0.10	1.00	0.98	0.30	0.51	0.92	0.80

Table D.20: The calibration and validation results for Extra-Trees model of SSI forecast based on scPDSI inputs

Basin	Calibration				Validation			
	MAE	RMSE	NSE	KGE	MAE	RMSE	NSE	KGE
0170	0.14	0.18	0.97	0.90	0.79	0.93	-2.40	-7.26
0180	0.15	0.19	0.97	0.89	0.82	0.95	-2.15	-14.02
0250	0.19	0.26	0.94	0.82	1.20	1.28	-2.36	-3.30
0580	0.14	0.18	0.97	0.90	1.00	1.16	-3.47	-21.61
0660	0.15	0.19	0.97	0.90	0.79	1.02	-2.20	-1.60
0840	0.23	0.32	0.92	0.76	0.76	0.92	-3.46	-0.73
0850	0.19	0.27	0.94	0.83	1.49	1.67	-7.59	-2.01
0900	0.18	0.25	0.95	0.83	0.93	1.11	-1.55	-1.31
0910	0.21	0.28	0.93	0.79	0.84	0.94	-0.88	-1.19
1020	0.14	0.18	0.97	0.90	0.67	0.76	0.14	-0.16
1350	0.20	0.26	0.94	0.84	1.06	1.37	-1.54	-2.21
1430	0.16	0.20	0.96	0.87	0.71	0.93	-0.09	-2.94
1510	0.16	0.22	0.95	0.85	0.76	0.92	-0.31	-0.87
1790	0.14	0.17	0.97	0.90	0.91	1.13	-1.69	-1.05
1980	0.14	0.18	0.97	0.91	0.79	0.93	-1.89	-0.27
2110	0.15	0.18	0.97	0.91	0.58	0.69	-0.27	-5.99
2400	**0.12**	**0.16**	**0.97**	**0.92**	0.75	0.90	-1.53	-0.47
2940	0.14	0.17	0.97	0.90	0.77	1.06	-0.77	-38.78
3450	0.21	0.30	0.93	0.78	0.90	1.21	-1.99	-4.08
3511	0.19	0.25	0.95	0.83	1.02	1.16	-1.84	-3.20
3540	0.16	0.20	0.96	0.88	0.91	1.07	-2.05	-3.26
3550	0.19	0.25	0.94	0.83	0.88	1.02	-1.84	-11.96
4215	0.13	0.16	0.97	0.90	0.91	1.03	-0.26	-22.85
4410	0.17	0.21	0.96	0.87	1.21	1.42	-4.01	-2.07
4530	0.14	0.19	0.96	0.90	1.09	1.38	-1.22	-2.90
4540	0.13	0.18	0.97	0.90	1.04	1.28	-1.12	-6.02
4650	0.16	0.19	0.96	0.90	0.50	0.69	-0.56	-2.66

Table D.21: The calibration and validation results for Extra-Trees model of SPI forecast based on SSI inputs

Basin	Calibration				Validation			
	MAE	RMSE	NSE	KGE	MAE	RMSE	NSE	KGE
0170	0.12	0.15	0.98	0.92	0.78	0.87	-0.66	-0.09
0180	**0.11**	**0.14**	**0.98**	**0.92**	0.92	1.05	-1.34	-0.22
0250	0.15	0.20	0.96	0.87	1.04	1.17	-2.46	-0.70
0580	0.12	0.16	0.98	0.93	0.74	0.89	-0.92	-0.40
0660	0.14	0.18	0.97	0.92	0.43	0.54	0.39	-8.50
0840	0.15	0.19	0.96	0.85	0.95	1.09	-0.27	-0.57
0850	0.16	0.21	0.95	0.85	0.84	1.01	-0.40	-1.32
0900	0.15	0.19	0.95	0.86	1.17	1.38	-0.32	-1.05
0910	0.15	0.19	0.95	0.86	0.93	1.07	-0.06	-0.49
1020	0.12	0.16	0.97	0.90	0.73	0.94	0.34	-8.69
1350	0.16	0.21	0.95	0.84	1.02	1.22	-0.81	-0.67
1430	0.15	0.19	0.96	0.88	0.49	0.69	0.45	-1.27
1510	0.15	0.20	0.96	0.88	0.53	0.73	0.40	-7.00
1790	0.14	0.19	0.96	0.90	0.68	0.92	-0.02	-2.29
1980	0.14	0.17	0.97	0.91	0.50	0.67	0.39	-0.29
2110	0.14	0.19	0.97	0.89	0.52	0.64	0.18	-0.44
2400	0.13	0.17	0.97	0.90	0.50	0.68	0.44	-1.09
2940	0.12	0.16	0.98	0.93	0.50	0.65	0.26	-0.19
3450	0.14	0.18	0.97	0.89	0.68	0.82	-0.61	-0.48
3511	0.15	0.19	0.96	0.88	0.50	0.59	-0.18	0.08
3540	0.15	0.19	0.96	0.89	0.90	1.09	-2.42	-0.84
3550	0.15	0.19	0.96	0.89	0.69	0.79	-0.59	-0.23
4215	0.14	0.18	0.97	0.91	0.67	0.78	-0.29	-0.13
4410	0.15	0.20	0.96	0.89	0.77	0.98	-1.07	-1.87
4530	0.13	0.17	0.97	0.92	0.60	0.74	-0.40	0.23
4540	0.12	0.16	0.98	0.93	0.59	0.74	-0.29	0.12
4650	0.14	0.18	0.97	0.90	0.66	0.84	-0.22	0.06

Table D.22: The calibration and validation results for Extra-Trees model of SPEI forecast based on SSI inputs

Basin	Calibration				Validation			
	MAE	RMSE	NSE	KGE	MAE	RMSE	NSE	KGE
0170	0.12	0.15	0.98	0.92	0.78	0.87	-0.66	-0.09
0180	**0.11**	**0.14**	**0.98**	**0.92**	0.92	1.05	-1.34	-0.22
0250	0.15	0.20	0.96	0.87	1.04	1.17	-2.46	-0.70
0580	0.12	0.16	0.98	0.93	0.74	0.89	-0.92	-0.40
0660	0.14	0.18	0.97	0.92	0.43	0.54	0.39	-8.50
0840	0.15	0.19	0.96	0.85	0.95	1.09	-0.27	-0.57
0850	0.16	0.21	0.95	0.85	0.84	1.01	-0.40	-1.32
0900	0.15	0.19	0.95	0.86	1.17	1.38	-0.32	-1.05
0910	0.15	0.19	0.95	0.86	0.93	1.07	-0.06	-0.49
1020	0.12	0.16	0.97	0.90	0.73	0.94	0.34	-8.69
1350	0.16	0.21	0.95	0.84	1.02	1.22	-0.81	-0.67
1430	0.15	0.19	0.96	0.88	0.49	0.69	0.45	-1.27
1510	0.15	0.20	0.96	0.88	0.53	0.73	0.40	-7.00
1790	0.14	0.19	0.96	0.90	0.68	0.92	-0.02	-2.29
1980	0.14	0.17	0.97	0.91	0.50	0.67	0.39	-0.29
2110	0.14	0.19	0.97	0.89	0.52	0.64	0.18	-0.44
2400	0.13	0.17	0.97	0.90	0.50	0.68	0.44	-1.09
2940	0.12	0.16	0.98	0.93	0.50	0.65	0.26	-0.19
3450	0.14	0.18	0.97	0.89	0.68	0.82	-0.61	-0.48
3511	0.15	0.19	0.96	0.88	0.50	0.59	-0.18	0.08
3540	0.15	0.19	0.96	0.89	0.90	1.09	-2.42	-0.84
3550	0.15	0.19	0.96	0.89	0.69	0.79	-0.59	-0.23
4215	0.14	0.18	0.97	0.91	0.67	0.78	-0.29	-0.13
4410	0.15	0.20	0.96	0.89	0.77	0.98	-1.07	-1.87
4530	0.13	0.17	0.97	0.92	0.60	0.74	-0.40	0.23
4540	0.12	0.16	0.98	0.93	0.59	0.74	-0.29	0.12
4650	0.14	0.18	0.97	0.90	0.66	0.84	-0.22	0.06

Table D.23: The calibration and validation results for Extra-Trees model of PDSI forecast based on SSI inputs

Basin	Calibration				Validation			
	MAE	RMSE	NSE	KGE	MAE	RMSE	NSE	KGE
0170	0.27	0.35	0.93	0.81	1.13	1.28	-0.41	-0.26
0180	0.28	0.35	0.93	0.82	1.22	1.42	-0.80	-0.21
0250	0.29	0.37	0.93	0.79	1.38	1.54	-0.59	-0.30
0580	0.29	0.36	0.93	0.81	1.31	1.53	-0.45	-0.41
0660	0.31	0.38	0.93	0.80	1.11	1.37	-0.22	-0.34
0840	0.28	0.36	0.93	0.79	1.32	1.52	-0.25	-0.38
0850	0.28	0.36	0.92	0.78	1.18	1.45	-0.30	-0.27
0900	0.28	0.35	0.92	0.78	1.35	1.53	-0.29	-0.26
0910	0.28	0.35	0.92	0.77	1.38	1.57	-0.59	-0.39
1020	0.32	0.40	0.93	0.80	1.60	1.80	0.02	-1.52
1350	0.28	0.36	0.93	0.79	1.63	1.86	-1.36	-0.57
1430	0.30	0.38	0.93	0.79	1.20	1.46	-0.02	-0.16
1510	0.29	0.38	0.94	0.81	1.19	1.48	0.02	-0.15
1790	0.30	0.37	0.94	0.81	1.66	1.94	-0.58	-0.47
1980	0.31	0.37	**0.94**	**0.82**	1.77	2.11	-0.52	-0.56
2110	0.29	0.36	**0.94**	**0.82**	1.39	1.57	-0.56	-0.47
2400	0.29	0.37	**0.94**	**0.82**	1.60	1.90	-0.71	-1.25
2940	0.30	0.38	0.92	0.77	1.22	1.38	-0.03	-0.23
3450	0.26	0.33	0.93	0.79	1.36	1.55	-0.49	-0.50
3511	0.28	0.35	0.93	0.80	1.33	1.50	-0.51	-0.22
3540	0.28	0.35	0.94	0.81	1.34	1.55	-0.54	-0.38
3550	0.27	0.35	0.93	0.80	1.38	1.51	-0.30	-0.21
4215	0.30	0.39	0.92	0.77	1.62	1.84	-0.88	-0.80
4410	0.27	0.35	0.92	0.79	1.36	1.57	-0.78	-0.79
4530	0.32	0.39	0.93	0.79	1.37	1.59	-0.78	-0.28
4540	0.28	0.36	**0.94**	**0.82**	1.35	1.61	-0.81	-0.44
4650	0.29	0.36	**0.94**	**0.82**	1.28	1.55	-0.27	-0.28

Table D.24: The calibration and validation results for Extra-Trees model of scPDSI forecast based on SSI inputs

Basin	Calibration				Validation			
	MAE	RMSE	NSE	KGE	MAE	RMSE	NSE	KGE
0170	**0.26**	**0.34**	**0.98**	**0.91**	2.28	2.57	-9.91	-0.14
0180	0.32	0.41	0.96	0.88	3.36	3.53	-16.38	-0.08
0250	0.35	0.45	0.95	0.83	3.12	3.27	-5.79	-0.01
0580	0.33	0.43	0.96	0.87	2.87	3.16	-5.69	-0.14
0660	0.33	0.41	0.97	0.88	1.79	2.13	-0.92	-0.60
0840	0.32	0.43	0.95	0.83	2.14	2.55	-1.68	-0.10
0850	0.44	0.61	0.93	0.81	2.57	3.28	-3.48	-0.59
0900	0.33	0.45	0.95	0.84	3.02	3.30	-3.90	-0.11
0910	0.31	0.42	0.95	0.84	2.19	2.59	-2.60	-0.09
1020	0.34	0.44	0.96	0.88	2.53	3.01	0.07	-2.47
1350	0.32	0.41	0.95	0.84	1.99	2.39	-0.39	-0.19
1430	0.36	0.45	0.95	0.83	1.66	2.15	-0.21	0.02
1510	0.33	0.45	0.96	0.86	2.06	2.49	-0.87	-2.24
1790	0.31	0.39	0.96	0.87	2.28	2.62	-1.06	-0.69
1980	0.29	0.37	0.97	0.89	2.10	2.64	-0.97	-1.22
2110	0.33	0.41	0.96	0.88	2.20	2.50	-1.81	-0.88
2400	0.33	0.44	0.96	0.87	2.28	2.82	-0.57	-7.35
2940	0.30	0.39	0.96	0.87	2.16	2.42	-0.98	-0.44
3450	0.34	0.43	0.95	0.83	2.61	2.80	-2.86	-0.45
3511	0.35	0.43	0.95	0.84	2.20	2.47	-2.05	-0.21
3540	0.32	0.40	0.96	0.87	2.00	2.31	-1.47	-0.18
3550	0.31	0.40	0.96	0.86	1.86	2.13	-0.71	0.06
4215	0.30	0.39	0.96	0.87	2.32	2.85	-3.70	-0.33
4410	0.30	0.40	0.97	0.90	3.20	3.55	-6.05	-1.86
4530	0.37	0.46	0.95	0.84	2.44	2.95	-12.33	-0.55
4540	0.32	0.40	0.96	0.88	2.68	3.10	-14.80	-0.61
4650	0.37	0.47	0.95	0.86	1.90	2.29	-0.70	-0.20

Table D.25: The calibration and validation results for Extra-Trees model of SSI forecast based on SSI inputs

Basin	Calibration				Validation			
	MAE	RMSE	NSE	KGE	MAE	RMSE	NSE	KGE
0170	**0.02**	**0.03**	**1.00**	**0.99**	0.05	0.06	0.98	0.94
0180	**0.02**	**0.03**	**1.00**	**0.99**	**0.04**	**0.06**	**0.99**	**0.93**
0250	0.02	0.04	1.00	0.99	0.05	0.09	0.98	0.91
0580	**0.02**	**0.03**	**1.00**	**0.99**	0.05	0.07	0.98	0.79
0660	**0.02**	**0.03**	**1.00**	**0.99**	0.06	0.09	0.98	0.93
0840	0.03	0.05	1.00	0.99	0.06	0.08	0.97	0.91
0850	0.03	0.04	1.00	0.99	0.07	0.10	0.97	0.87
0900	0.02	0.04	1.00	0.99	0.05	0.07	0.99	0.93
0910	0.02	0.04	1.00	0.99	0.05	0.08	0.99	0.90
1020	**0.02**	**0.03**	**1.00**	**0.99**	0.08	0.10	0.98	0.95
1350	0.02	0.04	1.00	0.99	0.12	0.23	0.93	0.77
1430	0.03	0.04	1.00	0.99	0.08	0.13	0.98	0.92
1510	0.02	0.04	1.00	0.99	0.10	0.15	0.96	0.89
1790	**0.02**	**0.03**	**1.00**	**0.99**	0.11	0.15	0.95	0.86
1980	**0.02**	**0.03**	**1.00**	**0.99**	0.11	0.13	0.94	0.89
2110	**0.02**	**0.03**	**1.00**	**0.99**	0.08	0.12	0.96	0.59
2400	**0.02**	**0.03**	**1.00**	**0.99**	0.07	0.10	0.97	0.96
2940	**0.02**	**0.03**	**1.00**	**0.99**	0.12	0.17	0.96	-0.18
3450	**0.02**	**0.03**	**1.00**	**0.99**	0.09	0.16	0.95	0.78
3511	0.02	0.04	1.00	0.99	0.07	0.10	0.98	0.83
3540	**0.02**	**0.03**	**1.00**	**0.99**	0.07	0.10	0.97	0.91
3550	**0.02**	**0.03**	**1.00**	**0.99**	0.07	0.09	0.98	0.88
4215	**0.02**	**0.03**	**1.00**	**0.99**	0.12	0.15	0.97	0.27
4410	**0.02**	**0.03**	**1.00**	**0.99**	0.08	0.13	0.96	0.89
4530	**0.02**	**0.03**	**1.00**	**0.99**	0.08	0.10	0.99	0.98
4540	**0.02**	**0.03**	**1.00**	**0.99**	0.09	0.10	0.99	0.96
4650	**0.02**	**0.03**	**1.00**	**0.99**	0.07	0.09	0.97	0.96