Use of SPI and hydrological modelling to analyse the climate change effects on droughts: case study of the Jiet catchment in Romania

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ABSTRACT

Drought events are a worldwide phenomenon, their impacts and consequences, however, vary based on the characteristics of the region where they occur. The main consequences derived from extreme dryness are the reduction of cropping areas and runoff, lower rates of percolation for groundwater recharge, and scarcity of water used for different purposes. To estimate present and future droughts due to climate change, analysis was done using the Standardized Precipitation Index (SPI), and a hydrological model in HEC-HMS, covering time frames between 1990-2020; 2020-2050 and 2070-2100 in the Jiet river basin, Romania.

The SPI and HEC-HMS model were set up, calibrated and validated with information of physical characteristics, discharge, historical and projected meteorological data available for the catchment. SPI analysis was calculated for time scales of 3, 6, 12 and 24 months, which represented the estimation of meteorological, agricultural and hydrological droughts. HEC-HMS model was used only to evaluate and estimate hydrological droughts.

Results obtained from both analyses allowed to estimate the number of events, periods of occurrence, duration, and severity of the different types of droughts events. SPI results showed a total of 28 meteorological droughts, 14 agricultural droughts, and 7 hydrological droughts for past scenarios. For mid-century and end-century scenarios, the increment of droughts compared with past scenarios was between 10% and 17% for meteorological droughts, 71% and 100% for agricultural droughts, and for hydrological droughts the number of events where two or three times increased. Hydrological estimated droughts simulated with HEC-HMS were 9 for past scenarios, 19 for mid-century scenario and 26 for the end-century scenario. Duration and severity were also incremented for each projected scenario.

Droughts have a high probability to become more common and regular on the catchment, causing impacts in different sectors based on the type of drought. The results of this research, are the first step for estimation, assessment and analysis of the events in the Jiet due to climate change in the future.

Keywords: Drought, SPI, HEC-HMS, estimation, Meteorological, agricultural, hydrological, drought index.

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Last and more important, don’t forget to SMILE.

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Acronyms

DEM	Digital elevation model
C3S	Copernicus Climate Change Service
CORDEX	Coordinated Regional Climate Downscaling Experiment
ECMWF	European Centre for Medium-Range Weather Forecasts
FAO	Food and agriculture organization
GCM	Global Climate Models
GIOVANNI	Geospatial Interactive Online Visualization and Analysis Infrastructure.
GIS	Geographic information system
HEC- HMS	Hydrologic Engineering Centre - Hydrologic Modelling System
MAE	Mean Absolute Error
NetCDF	Network Common Data Form
NOAA	National Oceanic and Atmospheric Administration
NSE	Nash–Sutcliffe Efficiency
PCSM	Present conditions with station data model
PCRM	Present condition with reanalysis model
PDSI	Palmer Drought Severity Index
PET	Potential Evapotranspiration
PSL	Physical Sciences Laboratory
R2	Coefficient of Determination
RCM	Regional Climate Model
RCPs	Representative Concentration Pathways
RMSE	Root Mean Square Error
SPA	Standardized Precipitation Anomaly
SPI	Standardized Precipitation Index
SWAT	Soil and Water Assessment Tool
USACE	US Army Corps of Engineers
USGS	Unites states geological survey
UNFCCC	United Nations Framework Convention on Climate Change
WASP	Weighted Anomaly of Standardized Precipitation

WCRP	World Climate Research Program
WEAP	Water Evaluation and Planning System
WMO	World meteorological organization

1. Introduction

1.1. Background

Changes in temperature and weather patterns are the main characteristics associated with climate change, but in the last centuries, burning fossil fuels has been the main activity leading to the increase in temperature due to greenhouse gas emissions (NATIONS, 2022). Many consequences are derived from climate change, such as sea-level rise, floods, droughts, and scarcity of the amount of water needed for healthy ecosystems and living. (WWF, 2021). On the other hand, the speed of hydrological processes is increasing, the frequency of occurrence of hazards is longer, more intense, and their consequences are very expensive. (Mukherjee, et al., 2018).

Drought is a worldwide phenomenon with spatio-temporal characteristics and can be defined as the consequence of precipitation lack over a long period and high evaporation rates which have an impact on soil moisture, groundwater levels, runoff, and human activities (Van Lanen, et al., 2007).

Droughts are divided into four types; meteorological (scarcity of precipitation for long periods, number of days with no rainfall), agricultural (shortage of moisture on crop areas), hydrological (water levels below of regular levels on waterbodies), and social (socio-economic consequences due to water scarcity)(Estrela, et al., 2001). The event duration and intensity, vary based on the localization of the region and its characteristics as well as its consequences. For example, in arid areas, droughts tend to be more frequent and the consequences are more severe than in other regions (Van Lanen, et al., 2007). Over the twentieth century, many European areas faced drought events that lead to the start of many analyses of the phenomenon to study the causes, effects, and mitigation strategies. For instance, Romania has faced many periods of drought events in its history, the most affected areas within the country were the counties of Olt, Dolj, Galati, Braila, and Ialomita. When talking about droughts in Romania, the main effects are over soil/sediment, surface, groundwater levels, air, wildlife, plants and socio-economic aspects. (Lupu, et al., 2010).

Assessment of droughts is important, this can be done by analysing historical events as well as past, present, and future meteorological and Physical Characteristics conditions over an area. Based on the analysed data, mitigation alternatives can be developed for near or far future consequences derived from droughts. To do a proper analysis, different methodologies to calculate droughts have been developed by different scientists, such as the Palmer Drought Severity Index (PDSI) (Palmer, 1965) and the standardized precipitation index (SPI) (McKee, et al., 1993). In addition, to understand the hydrological processes in a catchment, different software such as Soil and Water Assessment Tool (SWAT) or Hydrologic Engineering Centre - Hydrologic Modelling System (HEC-HMS) have been used in different regions like India (Sankhua, et al., 2016), Texas (Samady, 2017), and Montecelos-Zamora, et al. (2018) in Cuba to study and analyse droughts and impacts due to climate change.

For this research, past, present, and future drought events are analysed in the Jiet catchment, located in the south of Romania. Drought events are analysed with two methodologies, first, a meteorological analysis using the standardised precipitation index (SPI) and a hydrological model with HEC-HMS software.

1.2. Problem statement

Danube river is very important in Romania, because, over a third of its length (37.7%) flows through its territory, also, Romania represents 29%of the surface area of the Danube basin. The country has 24 major tributaries to the Danube (>4000 km2), and 11 major basins, being the Jiu river catchment one of the tributaries, with a total area of 10.131 km^2 and a river length of 325km. Jiet river is a former course of Jiu's river which has a length of 52km and, nowadays is considered an independent river basin with an area of 600km^2. Jiet catchment is still a basin with not much data available, hence, the majority of past analysis and studies that include Jiet's area, have been done over bigger regions such as Romania, Oltenia plain, Dolj or Jiu catchment. Therefore, in the literature, there is a lack of previous studies that focus only on the Jiet catchment area.

National Administration and Dutch Water Authorities (2021), mention that the south part of Romania faces problems with sandy soils, aridity, and desertification processes which become more intense through the years. Also, climate change is affecting hydro climatological conditions in the Jiet catchment, making the frequency and intensity of droughts increase, as well as the scarcity of water, decrement of crop fields areas and socio-economic issues which are becoming an uncertainty and a threat for the future.

1.3. Research objectives

The main objective of this research is the analysis of droughts due to climate change in the Jiet catchment using SPI and hydrological modelling HEC-HMS.

The specific objectives are the following:

- To evaluate and analyse past, present and future conditions of Jiet catchment to assess droughts using SPI.
- To build hydrological models for past, present and future conditions in HEC-HMS to analyse hydrological droughts.
- To generate knowledge about droughts as well as the impacts within the catchment due to climate change for future scenarios based on historical analysis and projected data.

1.4. Research questions

The main question to be answered in this research work, is, what would be the impact of droughts on surface water in the Jiet catchment due to climate change?

The specific research questions are the following:

- What are the past, present and future hydrological drought conditions in the Jiet catchment?

- To what extent the assessment of current hydrological drought conditions in the Jiet catchment depends on the sources of meteorological data?
- What will be the changes in the hydrological drought conditions in the Jiet catchment due to climate change?

1.5. Innovation and practical value

Actual meteorological conditions are the principal cause of many drought events worldwide, nowadays a deeper study is needed also for smaller areas such as the Jiet. The analysis of these specific areas can be the key to identifying how the event behaves on small scales, to what intensity level the drought can be, and for how long the event can happen. The obtained information can then be scaled for bigger areas, or simulated for areas with similar conditions that are also exposed to droughts, and have similar physical characteristics. The analysis made in this research can help future stakeholders to make decisions, the information can be used for policies, prevention and mitigation plans, management of agricultural systems, water resource planning, or for adapting ecological systems to near future and future scenarios where climate change will have a bigger impact.

Innovation

- Use and implementation of data from reanalysis, remote sensing, and global modelling projections to make a hydrological model for the Jiet.
- Drought analysis with SPI over Jiet's region.
- Analysis of the different types of droughts in the Jiet area using different methods.

Practical value

- Application of HEC-HMS to analyse hydrological droughts due to climate change.
- Application of reanalysis, remote sensing and global data to build an HEC-HMS model to analyse hydrological droughts due to climate change.
- Application of index calculations to analyse different types of droughts over a region.
- Output data that will help in the management of water resources.

1.6. Outline

This research is outlined as follows:

- Chapter 1 - Introduction, introduces the general concepts of climate change, droughts, and the case study, followed by the main objective and questions proposed for this research.
- Chapter 2- Literature Review, gives deeper information found in papers, manuals, and publications about climate change, droughts and the different methodologies used for their assessment focused on previous studies using SPI and HEC-HMS in different countries and within Romania.
- Chapter 3 - Case study, has the description of the area and its main characteristics.
- Chapter 4 - Methodology, contains the frameworks of the research process, a description of the assumptions and steps made to develop the analysis proposed for this research,

includes an explanation of SPI methodology and the HEC-HMS model, as well as, a description of the collection, processing, and implementation of the data to develop each analysis.

- Chapter 5 - Results and discussion, This chapter, will show first, the initial values for each analysis, second, calibration values, third, optimal values to run simulations and finally, the results for the SPI and HEC-HMS model with a description, analysis, and discussion of the obtained outputs.
- Chapter 6 - Conclusions and recommendations
- References
- Appendices: Appendix A includes the general analysis of the precipitation data.
  Appendix B includes the ethics statement of the research.
  Appendix C has the research ethics approval.

2. Literature review

Van Lanen, et al. (2007, p1) give the following definition of drought, "Drought is a sustained and regionally extensive occurrence of below average natural water availability", they also claim, that spatio-temporal characteristics of droughts, change from place to place and is not the same as aridity process or scarcity of water, some regions are very arid and that does not mean that the area is having a drought event. A deeper explanation is made by Van Loon and Van Lanen (2013), that claimed that droughts are natural hazards product of climate variation and, water scarcity is the unsustainable use of the water resources (human influence), by making a comparison between drought and water scarcity using a hydrological model.

Estrela, et al. (2001) analysed and explained the historical extreme hydrological events that occurred in Europe, explaining the fields of, climate change, land use, land cover, socio-economic aspects, principal causes, prevention and mitigation plans related to droughts over the past 50 years. Projecting the future of Europe, they claim that changes will happen in the 30-year mean run-off by the year 2050 in around 30% of the south Europe area due to the decrement of annual rainfall, a situation in which dry regions are the most sensitive to face extreme scarcity of water. In addition, water demand in Europe is rising, land use and land cover are constantly changing mostly towards urbanization which affects directly the hydrology leading to the increment of dry areas in the southern countries of Europe where Romania is located.

Prăvălie, et al. (2019) did a depth analysis of spatio temporal changes of climate water balance in Romania from 1961 to 2013 using meteorological data from 70 stations distributed over the country. Authors found that the most affected areas by dryness, water scarcity and droughts due to the downward trend of climate water balance values are the southwestern and southeastern parts. These findings are also claimed by Lupu, et al. (2010) and Mateescu, et al. (2013). Mateescu, et al. (2013), found that precipitation changes have been noticed since 1961 when annual precipitation trends started to decrease, most significant years with rainfall deficits are 1992-1993, 1999-2003, 2006-2007 and 2011-2012, which had the multi-annual lowest values of rainfall and higher temperatures, making November of 2011 and July of 2012 the drouthiest months in since 1961. On the other hand, Lupu, et al. (2010) claimed that extreme agricultural droughts in the XXth century were 1990-1992-1993-1999-2000 and 2001-2002-2003-2007 and 2009 for XXIth century. Ontel (2013), also made an identification of droughts, based on meteorological data for 40 years, using Standardized Precipitation Anomaly, Hellman Criterion and deciles. The analysis showed that for the period between 1971 to 2010, the driest and most arid month is August due to the high air-temperatures and the years with regular water shortage were 1983, 1985, 1992, 1993 and 2000, although, years considered as extreme were 1994, 2000, 2002 and 2007.

In the report made by Mateescu, et al. (2013), they introduce how the monitoring system of droughts has been done, the importance of the knowledge about droughts, advising an improvement in the Romanian system in charge of monitoring, prevention and mitigation of droughts in the country, the reason is, with an accurate diagnose of droughts decision making is easier to develop and implement. Different types of methods have been used in the past to assess droughts. In the analysis made by Vlăduţ, et al. (2013), the Standardized precipitation anomaly (SPA) and the Weighted Anomaly of Standardized Precipitation (WASP) were used in the study of dry periods in the Oltenia plain from 1961 to 2010, with data sets from six meteorological stations. SPA results were very low especially over Bechet and Caracal stations, with the average and analysis of all six stations, years 1983, 1985, 1992, 1993, 2000 and 2008 were classified as dry or severely dry. WASP results are also compared with satellite products NDVI and LAI to have a closer look of monthly changes in the plain and the impacts of drought periods on crops and vegetation. May, June and July were identified as the months with the most deficit of rainfall and higher temperatures leading 2000 and 2008 to be the driest years

Apart from the SPA and WASP methods, the SPI is another important commonly used method for assessing droughts. McKee, et al. (1993) introduces the concept of the SPI, as an easier alternative for the assessment of droughts which considers the variation of time scales and only requires precipitation values to be calculated, once the index is calculated, the intensity of the event can be fitted into a category such as mild, moderate, severe and extreme drought. Studies using SPI have been done in many countries, to mention some, Das, et al. (2020) analysed the Lunin river catchment in India for time frames of 1, 3, 6, 9, 12 and 24 months, to identify the most affected areas by droughts and the times of occurrence, therefore, results can be used for the improvement of policies on water resources and forecasting, Sarker, et al. (2020) used SPI for the Rajshahi District in Bangladesh with the purpose of generate knowledge and early warnings for droughts due to the importance of agricultural activity in the country, Karavitis, et al. (2011) applied SPI for short and long time scales in Greece, which is a country with semi-arid conditions vulnerable to droughts. The index was used to find the spatial extent, severity and duration of the events in the country to develop prevention plans, mechanisms for droughts alerts and management strategies. Ionita, et al. (2016) performed the analysis for time scales of 3, 6 and 12 months, for 50 years of information in Romania, concluding that at a country level there is no spatial consistency in drought events. The majority of dry periods occurred in the south part being 2000-2001 the driest period in the study, they also claim that for short time scales the index tends to shift between values higher and lower than zero more frequently than when using long time scales and finally, Guenang and Kamga (2014) developed a drought analysis using different distribution functions to calculate SPI in Cameroon, finding that for areas below 10°N and time scales below 6 months, Weibull prevails over the gamma distribution, also, mention the fact that all calculations of drought indexes are done with Gamma without hesitation, therefore, is important to consider the case study area to perform a correct calculation of SPI.

An analysis of the implementation of global climate models was done in the study of Bartok, et al. (2021), which focuses on finding the best ensemble for climate projections for agriculture in Romania, taking projected data derived from the combination of 15 combinations of GCM and RCL from EURO-CORDEX, therefore, CORDEX data was compared against data from ROCADA gridded database which was developed by the Romanian National Meteorological Administration network for a period between 1971 to 2000. Authors found that among all the possible ensembles for different types of crops, the best results to use in future studies, are the combination of MPI-M-MPI-ESM-LR/ KNMI-RACMO22E_v1 and MOHC-HadGEM2-ES/ KNMI-RACMO22E_v2.

Besides the SPI analysis, according to Aliye, et al. (2020) most common software used in the assessment of hydrological droughts are the Hydrological Engineering Centre-Hydrologic Modelling System (HEC-HMS), the Hydrological Simulation Program-Fortran (HSPF) , Agricultural Non-Point Source (AGNPS), Soil and Water Assessment Tool (SWAT), and the Water modelling tool MIKE Powered by DHI (MIKE SHE).

Previous studies for drought analysis due to climate change for different time frames, using different hydrological software have been done in different places, for example, the study made by Montecelos-Zamora, et al. (2018) in the river Cauto in Cuba. The study aimed to assess for the first time the potential impacts of projected climate change on water availability in two sub-basins of the river using SWAT, finding out that in the future the mean annual temperature will increase by 1.5°C and mean annual precipitation will decrease by 18% and that with the study is possible to develop adaptation strategies against droughts.

Some examples of studies with HEC-HMS are Sankhua, et al. (2016), their analysis is in the Shivganga basin in India, simulating the rainfall-runoff from 2015 to 2030 to make a comparison of present and future streamflow as well as estimation of evapotranspiration using HEC-HMS, to check the performance of the indicators of the model RMSE and R2 were calculated, final founds were that the prediction for the hydrology of streams in the future depends on the performance for present scenarios in the HEC-HMS and that daily flows are well simulated but in validation years the software tends to underpredict high flows. The most commonly used method implemented when using HEC-HMS for analysis in different catchments is the soil moisture accounting, and the analysed parameter is the moisture deficit, for example, Lai, et al. (2021) made a review of the use of loss methods in HEC-HMS model for streamflow simulation under climate change, finding, that soil moisture accounting technique is effective in continuous simulations in the program, especially for climate change analysis, but it strongly depends on the amount of input data used in the model, another conclusion was that deficit and constant method work extremely good for climate change simulations and requires fewer input data making it simpler to use. Finally, Samady (2017) used HEC-HMS to develop and parameterize a continuous model with soil moisture accounting for the Highland Lakes in Central Texas finding that, extreme events were well simulated when all data is provided with the method and if there is missing data, that is a problem when setting up the model, because it will be very difficult to make the simulation in all the region of the study, especially if the model is a lumped model that depends on information from different stations.

In summary, all the literature mentioned above gave an initial idea of the definition of droughts, and the types of methodologies used by different authors to assess and analyse the events, including SPI and HEC-HMS, which are used for this research. Finally, historical years with droughts were identified in Jiet's region, and an idea of which are the best alternatives for projection of data to analyse droughts.

3. Case study

Jiet catchment is located in the South-West part of the country in the county of Dolj (Figure 1), has a total extension of 633Km^2 which can be categorized as a medium/big basin, with an average slope of 1% and upstream and downstream altitude of 55m and 22m respectively. (National Administration and Dutch Water Authorities, 2021)

Figure 1 Localization of Jiet catchment in Romania- Dolj County (Via ArcGIS)

Jiet river used to be part of Jiu's river course, but due to climate change and regularisation works in the area, Jiet river became a single river with a total length of 52km with its confluence in Bechet with the Danube river. Main tributaries of Jiet are the Georocel and the Valea Predestilor.(National Administration and Dutch Water Authorities, 2021). The basin has three reservoirs, the largest one is the Locusteni, which is located in the tributary Valea Predestilor river, shown below in Figure 2.

Jiet river used to be hydrologically monitored by the Jiu Water Basin Administration / Hydrology Service through a satellite hydrometric station, doing one measurement per month between 2006 and 2019. Hydrological measurements showed a multiannual average flow of 0.436 m^3/s, a maximum value of 0.658 m^3/s in December 2009 and a minimum record of 0.265 m^3/s in March 2018 according to National Administration and Dutch Water Authorities (2021).

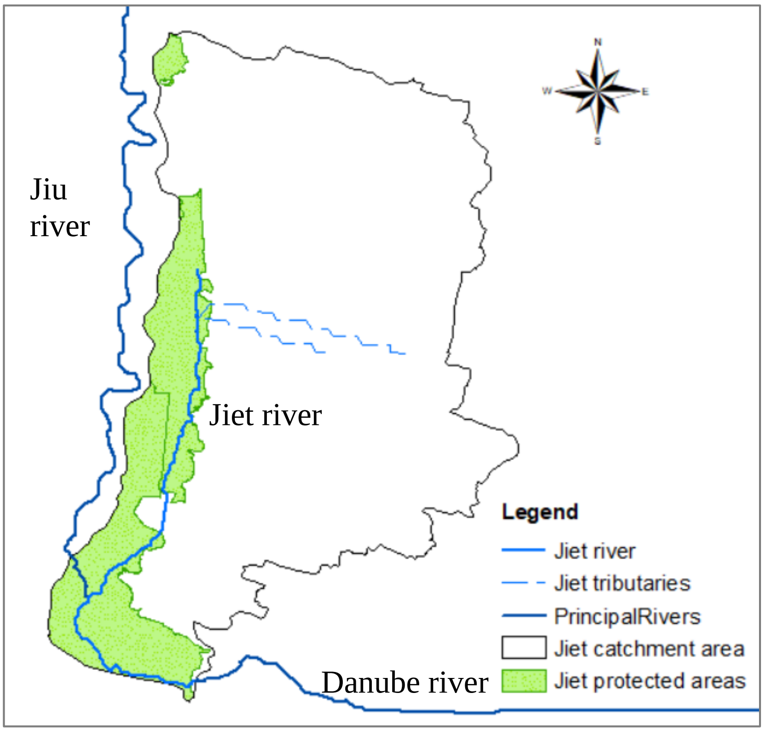


Figure 2 Jiet catchment area, water courses and protected areas.

Specific information about Jiet's conditions is hard to find and hardly any is available, therefore, descriptions of the southern part of Jiu catchment and Oltenia plain areas that cover the total region of the Jiet, are applicable. The Oltenia plain which is the area with the largest sandy soils in Romania and coarse sandy deposits, now, is going through aridization processes that are getting worst through the years, hence, agricultural activities are becoming very difficult to perform; in time, the vulnerability in socio-economic and ecological aspects will increase (National Administration and Dutch Water Authorities, 2021).

Nowadays, the Jiet area is well known for the traditionally crop production of watermelon (Dabuleni watermelon), melon, cereals and grapevine. Big farmers in the area have plots of wheat, sunflower and corn, all the agricultural fields represent more than 50% of the basin. As a result of aridization in the Jiet, farmers are implementing hybrid crops like blueberries, currants and sea buckthorn, which, need less water to survive and can resist the changes in the soil moisture and dryness conditions derived from climate change. In addition, water scarcity is already a problem in the area, according to the National Administration and Dutch Water Authorities (2021), groundwater sources are fully contaminated by pollution coming from agricultural activities, the irrigation system does not work, hence, only a few farmers can take water from the Danube for irrigation. Additionally, besides the area covered by crops, in the west and north-west part of Jiet, 255 km^2 protected areas covered by Natura sites 2000, are also exposed and hit by droughts and aridization.

The annual average temperature in the area between 1990 and 2020, was around 8.41°C and 11°C, with minimum temperatures down to -7.7°C and a maximum of 24.6°C. Dry seasons usually start in November until March, followed by the rainy season from April to October which is summer and autumn, seasons when temperature rises and evapotranspiration is higher. A decrease in the annual precipitation has been noticed after 1961 in the region and a downward trend in the frequency of rainfall events. In summary, the Jiet basin is facing the consequences of the increment of temperature and decrease in precipitation events, aridity and desertification, which lead to scarcity of water and droughts.

4. Methodology

Drought analysis and assessment of water on the surface, availability for crops, and supply from water bodies due to climate change in Jiet catchment, was made with a hydrological model made in HEC-HMS and the SPI methodology for past, present and future scenarios. The overall methodology is described in Figure 3

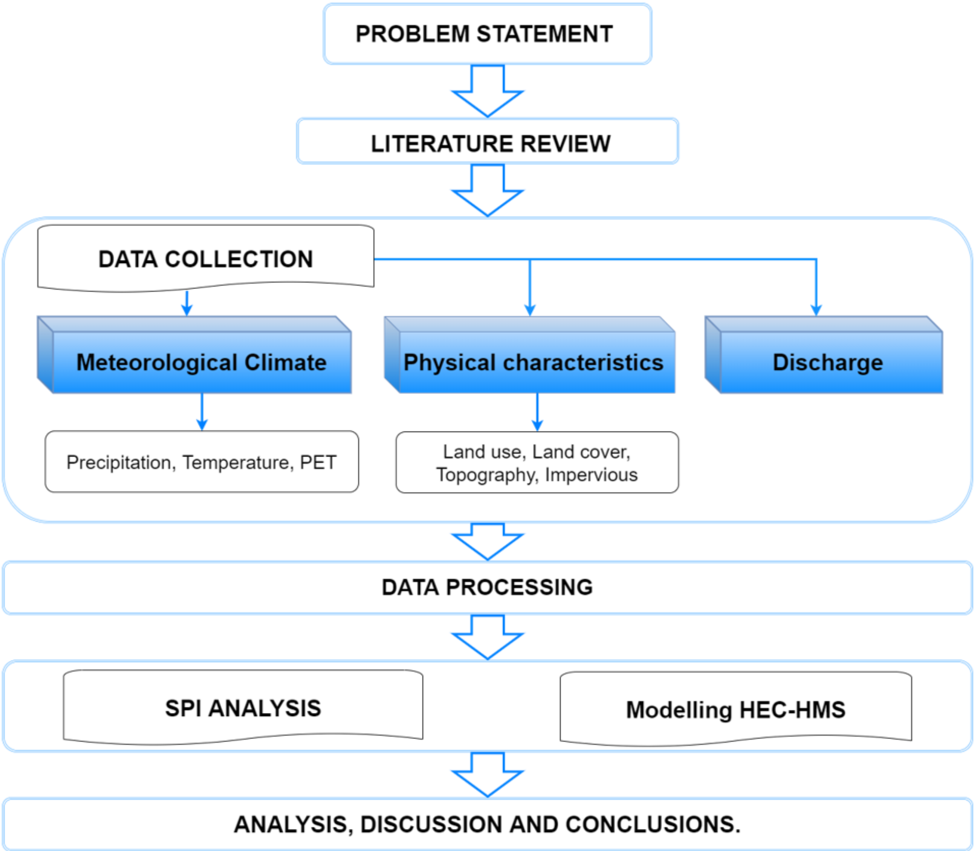


Figure 3. Methodology framework

At this point, knowing the problem statement and the background of the Jiet, the next step was the collection of all available meteorological, physical characteristics and discharge data for the basin, which later is used as input for the meteorological (SPI) and HEC-HMS model for the drought analysis.

Time scenarios chosen for the analysis are divided into three-time frames. First, for past scenario analysis, starts from 1990 until 2020, secondly, near-future scenario (Mid-century) goes from 2020 to 2050 also includes present conditions, and, finally, far future scenario (End-century) is from 2070 to 2100. Once all the data was gathered, transformation and manipulation were necessary to get the information as it was needed for the setup of the drought calculation methods. Next, setup and run of the SPI and HEC-HMS model were done for the three specified scenarios. Outputs such as graphics and heatmaps of different types of droughts due to climate change in the area were identified and analysed followed by a discussion. Finally, conclusions and mention of the limitations, assumptions or drawbacks identified during the whole research process were done.

4.1. Data Collection

4.1.1. Meteorological data

Meteorological data has certain patterns based on the location and season of the year. This type of data gives a very specific idea of when and where dry and wet periods occur. Precipitation, temperature, and evapotranspiration are collected from reanalysis, remote sensing and global modelling methods processed by different organizations, such as Copernicus Climate Change Service(C3S), Geospatial Interactive Online Visualization ANd aNalysis infrastructure. (Giovanni), The NOAA Physical Sciences Laboratory (PSL) and Climate Engine (Desert Research Institute, University of California MERCED and Google).

The obtained information was downloaded in Network Common Data Form (NetCDF) format, in a daily temporal resolution and different horizontal resolutions that go from fine grids of 0.1°or ~9km, 0.11°or ~12km, bigger grids of 0.2°or ~18km, 0.25°or ~20km and the thickest grid was 0.5°or ~40km.

Table 1 Meteorological Data Sets

Data set and type	Source	Resolution	Description
Data set 1 (Precipitation)	C3S	0.2° x 0.2°	Temperature and precipitation gridded data for global and regional domains derived from in-situ and satellite observations. (C3S, 2016)
Data set 2 (Precipitation)	C3S	0.1° x 0.1°	E-OBS daily gridded meteorological data for Europe from 1950 to present derived from in-situ observations (Cornes, et al., 2018)
Data set 3 (Precipitation)	C3S	0.1° x 0.1°	ERA5-Land hourly data from 1950 to present (Hersbach, et al., 2018b)
Data set 4 (Precipitation)	PSL	0.5° x 0.5°	CPC Global Unified Gauge-Based Analysis of Daily Precipitation (Xie and P.A. Arkin, 1997)
Data set 5 (Precipitation)	Giovanni	0.1° x 0.1°	GPM IMERG Final Precipitation L3 1 day 0.1 degree x 0.1 degree V06 (GPM_3IMERGDF) (Huffman, et al., 2019)
Data set 6 (Temperature)	C3S	0.25°x0.25°	ERA5 hourly data on single levels from 1979 to present (Hersbach, et al., 2018a)
Data set 7 (Potential Evapotranspiration)	Climate Engine	0.2° x 0.2°	Climate Forecast System (CFS) Reanalysis (Desert Research Institute, et al., N.D.)
Data set 8 (Projected precipitation)	C3S/ CORDEX	0.1° x 0.1°	CORDEX regional climate model data on single levels (C3S and CORDEX, N.D.)
Data set 9 (Projected Temperature)	C3S/ CORDEX	0.1° x 0.1°	CORDEX regional climate model data on single levels (C3S and CORDEX, N.D.)

- Precipitation past scenario

Collected data is the result of different mathematical models based on numerical methods, forecasting and observations, consequently, data collected and processed has no missing values. Data sets 1 to 5 (Table 1), were considered for past scenario analysis, however, only one of the sets was used for the drought analysis. The chosen data set that fits the most for this research purpose, was filtered based on the resolution because the analysis will be more accurate with finer resolution in the inputs. Data sets 1 and 4 have bigger resolutions compared to data sets 2, 3 and 5. Hence, data sets 1 and 4 were not considered further. Available precipitation records for data set 5 were from June of 2000 to December 2020, then, analysis for past scenarios would be incomplete, because, considered data goes from January 1st 1990 to December 31st 2020, hence, data set number 5 is also excluded.

As shown in Figure 4, trends for both data sets are similar among years, although, precipitation values for data set 3 were higher than for data set 2, having precipitations up to 1102m per year in 2005 and for the driest year a value of 408mm in 2000. According to Şmuleac, et al. (2020) and (Prăvălie, et al., 2019), average year precipitation rates for the period of 1990 to 2020 are between 500mm and 700mm. Therefore, based on statistical analysis and comparison of precipitation rates, chosen data for SPI and HEC-MS analysis was set number 2. Graphical representation of data sets and a deeper explanation of analysis made for data sets 2 and 3 are shown in Appendix A.

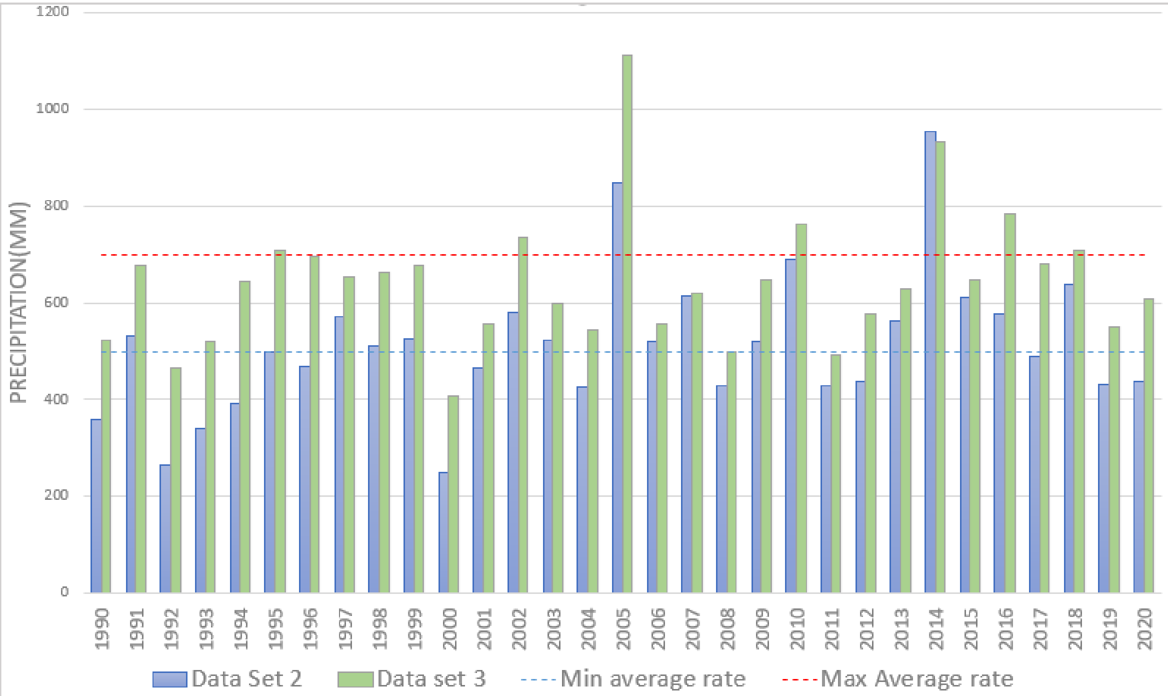


Figure 4 Comparison of total precipitation between data set 2 and data set 3 for past scenario (1990-2020)

- Potential evapotranspiration past scenario

Daily mean values for 30 years of Potential Evapotranspiration (PET), were downloaded from Desert Research Institute, et al. (N.D.). The information has a resolution of 0.2° x 0.2° and belongs to the delimitated region with coordinates NW= 44.19°, 23.76° and NE= 43.63°, 24.46° as shown in Figure 5.

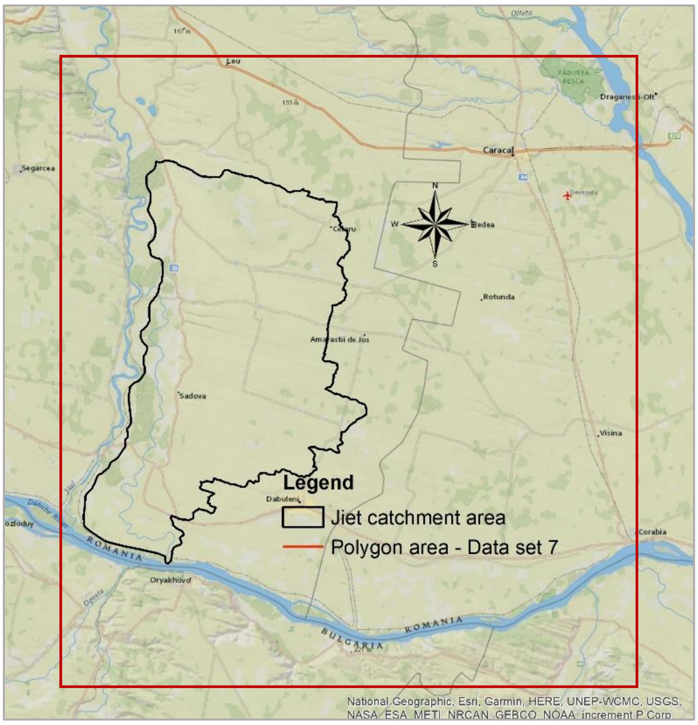


Figure 5 Delimitation of the area considered for Data set 7(PET data) - (Via ArcGIS)

- Projected precipitation and temperature

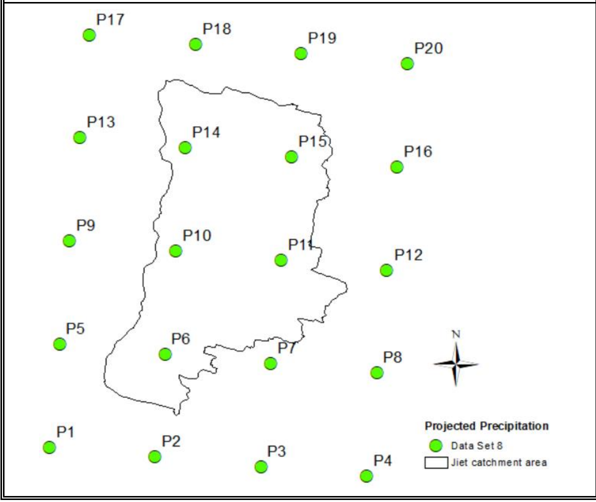
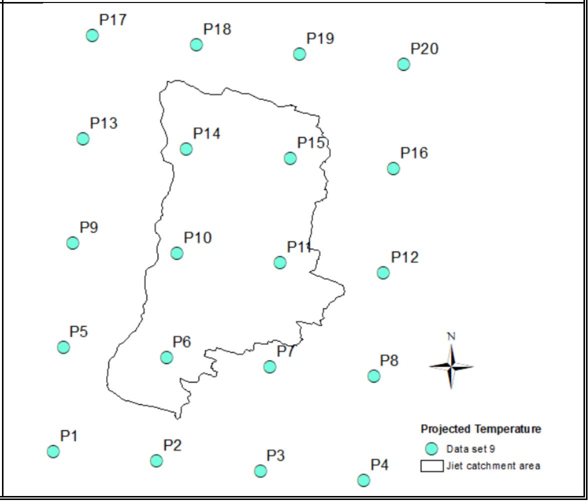
C3S provides a global data framework developed by the Coordinated Regional Climate Downscaling Experiment (CORDEX), which is a world climate research program(WCRP) that provides a regional climate model (RCM) from different experiments to get regional climate projections (CORDEX, 2022). Global climate models (GCM), provide projected climate change information in large scales, to get more accurate data with higher resolution, CORDEX projects the information to smaller scales, therefore, there is more accuracy in identifying and representing extreme events over specific regions. Regional climate models for different domains are obtained using different combinations of the following:

- GCM
- RCM
- Ensemble models
- Representative Concentration Pathways (RCPs) which is the green house concentration trajectory adopted by the Intergovernmental panel on climate change (IPCC), pathways are RCP2.6, RCP4.5, RCP6 and RCP8.5.

CORDEX has many domains of data, for the projected temperature and precipitation data in the Jiet. The chosen domain was EURO-CORDEX, which contains the ensemble of different experiments of multi- methods, multi-scenarios, multi-initial conditions and multi-models for Europe with a resolution of 0.1°(Benestad, et al., 2017).

Chosen parameters for this research are as follows, GCM downloaded from C3S comes from the 5th phase of the Coupled Model Intercomparison Project (CMIP5), RCP8.5 scenario and the r1i1p1 ensemble member. In addition, many possible combinations for GCM and RCM were possible, but according to Bartok, et al. (2021) one of the most accurate climate projections for Romania, is derived from the GCM=MPI-M-MPI-ESM-LR and the RCM=KNMI-RACMO22E combination. Table 2 shows the total points obtained for precipitation and temperature covering the basin.

Table 2 Projected Data future scenarios

Data set 8: (C3S/EURO-CORDEX) Res= 0.1° x 0.1	**Data set 9**: (C3S/EURO-CORDEX) Res= 0.1° x 0.1
	

- Projected Potential Evapotranspiration

Three equations are considered for potential evapotranspiration values. The first alternative is Penman-Monteith equation, which gives very accurate results due to the consideration of different variables (e.g., wind, energy, pressure, humidity), hence, making the PET calculation would imply making many assumptions for the inputs and the result will not as accurate as it should be. The second option is the Hargreaves method, which uses solar radiation and temperature for its calculation and according to Hargreaves (1994), final results are well correlated with Penman. Finally, Thornthwaite is the most worldwide used equation but tends to underestimate the final results. (Yates and Strzepek, 1994). Therefore, the Hargreaves equation is used to calculate the projected PET in the basin.

$$Hargreaves - PET = 0.0022 * Ra * \delta' T^{0.5} * (T + 17.8) \qquad (1)$$

Where:

Ra = Mean Extraterrestrial radiation (mm/month), which is a function of the latitude

$\delta' T$ = monthly mean difference between maximum and minimum temperatures in degrees Celsius

T = Average between maximum and minimum temperature in degrees Celsius

PET =Potential evapotranspiration (mm/month)

Jiet catchment is located in the latitude 43.91, hence, Ra values considered are the ones shown below in Table 3, as the data is in mm/day, it is necessary to make the conversion to mm/month to calculate PET.

Table 3 Extraterrestrial Radiation - Hargreaves

Radiation mm/day												
Latitude	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
43.91	5.3	7.4	10.5	13.8	16.3	17.4	16.9	15	11.9	8.6	5.9	4.5

4.1.2. Physical Characteristics

Physical Characteristics were collected from different sources, as described and shown in Table 4, Table 5 and Table 6.

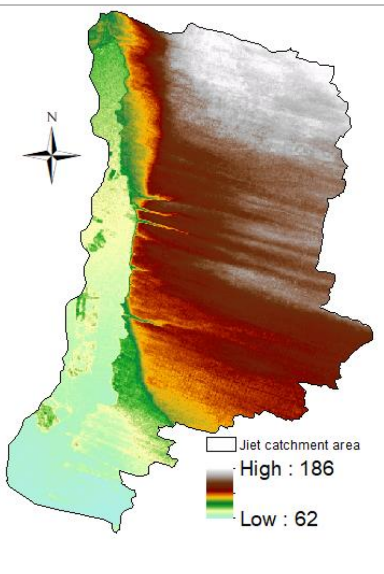
Table 4 Physical Characteristics

Data	Spatial resolution	Source
Digital Elevation Model	12.5m ×12.5m	Romanian waters
Impervious map	10m ×10m	Copernicus/Land Monitoring service (Copernicus, 2018)
Land Cover		Romanian waters
Soil map		Romanian waters

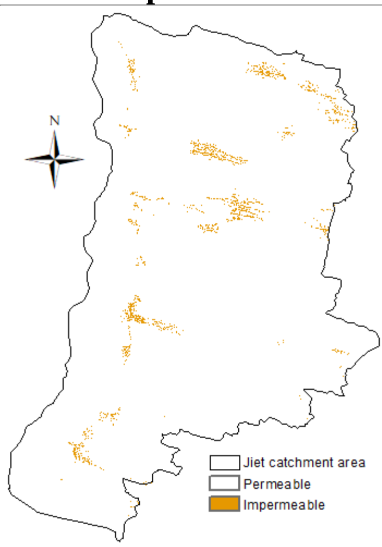
The Digital elevation model (DEM) will allow to understand the principal conditions of the terrain, such as the highest and lowest point on the surface, how the water can travel around the basin through the lower points of the terrain, where, generally the water courses are. The Jiet has some particular conditions. Therefore, impervious, land cover and soil maps give the necessary information related to the area to set up the model, solving questions like, how permeable is the soil, what kind of use the land has, how large are the rural and urban areas and what is the location of the confluence of the Jiet with the Danube.

Table 5 Physical characteristics Jiet catchment. Digital elevation model, Impervious and Land cover

DEM



Impervious



Land cover

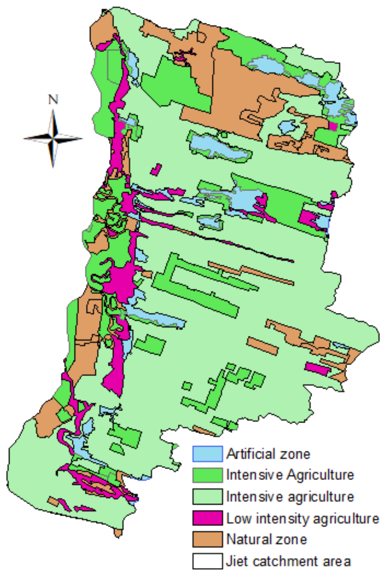
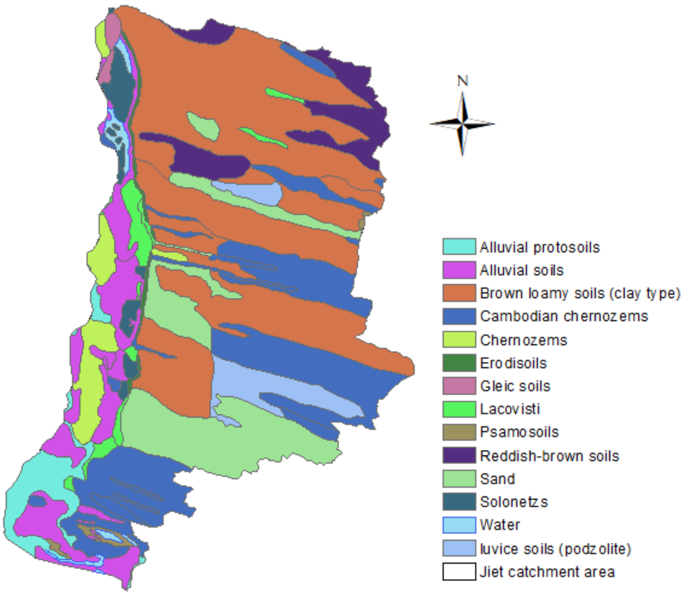


Table 6 Physical characteristics Jiet catchment. Soil map.

Soil map


4.1.3. Discharge data

Discharge data is very important when analysing droughts. If the discharge levels of a river are too high or below the average, that means there is something unusual happening. If low values are present for long periods a hydrological drought is possible to be happening. Usually, discharge data is measured in stations upstream or downstream of a river. For this research, discharge levels are a key component to analyse what kind of droughts occurred in the past or are currently happening in the Jiet.

Data of 48 discharge values distributed monthly for four years (2017-2020) was provided for the Jiet river at Ostroveni- satellite hydrometrical station, which is located upstream of the Danube river confluence with the Jiet river. Received data contains one monthly discharge value. Day and time of measurement are unknown.

Table 7 Monthly discharge data 2017-2020 Outlet Jiet river (Via Aba Jiu Romane (2020))

Year	Measurement/month of the year (m^3/s)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2017	0.42	0.41	0.42	0.45	0.47	0.47	0.40	0.43	0.48	0.46	0.46	0.43
2018	0.65	0.54	0.66	0.62	0.63	0.57	0.57	0.51	0.59	0.47	0.50	0.53
2019	0.93	0.81	0.92	0.91	0.90	0.75	0.80	0.76	0.77	0.81	0.48	0.86
2020	0.92	0.76	1.01	0.85	0.88	0.91	0.88	0.70	0.87	1.04	0.94	0.95

Data provided in Table 7 above, is used to calibrate and validate the HEC-HMS model.

4.2. Meteorological analysis

4.2.1. SPI Calculation

The standardized precipitation index method (SPI), was developed by (McKee, et al., 1993) initially, with the purpose of monitoring droughts (Edwards, 1997). The SPI can be defined as a simple probability-based method, used as a spatially invariant drought indicator for different time scales (Guttman, 1999), that reflects the precipitation deficit over an area and the impacts of droughts on the available water from water resources (Svoboda, et al., 2012).

The meteorological analysis, followed in this research is presented in Figure 6.

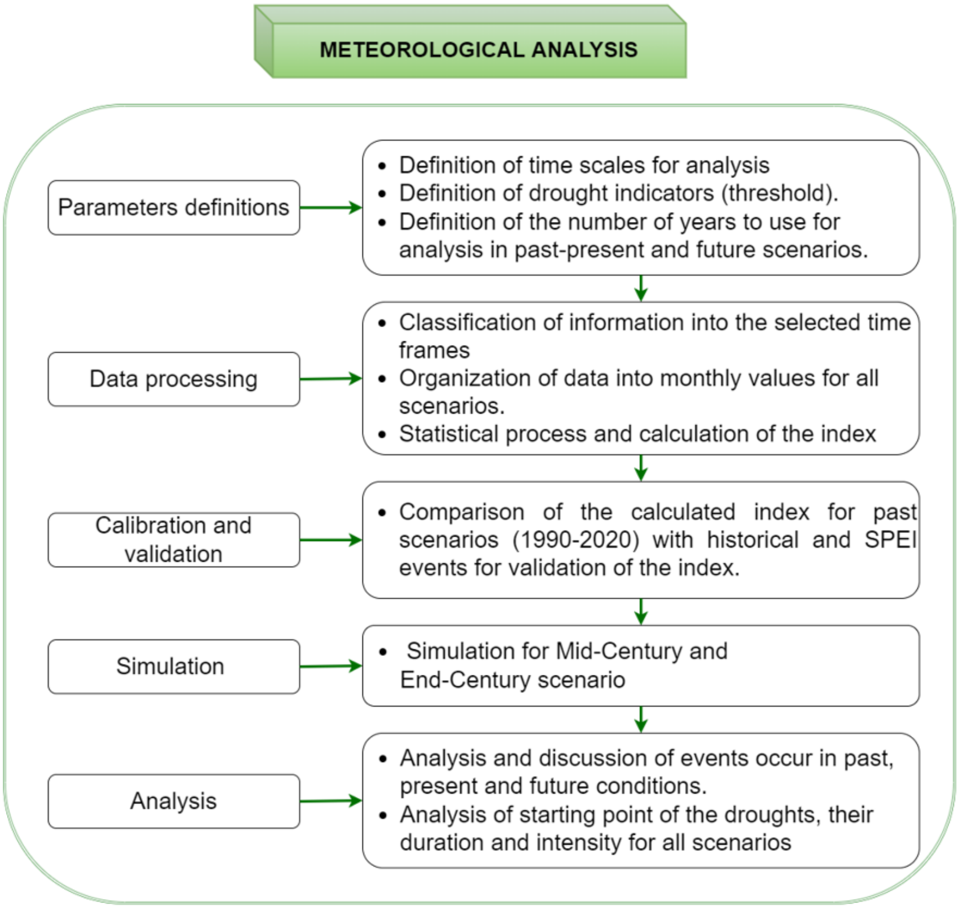


Figure 6. Framework Meteorological analysis (SPI Calculation)

The SPI works for any area that has precipitation records, preferably, at least 30 years of continuous monthly data is good to calculate the index (McKee, et al., 1993). The SPI uses precipitation for different time scales, which define the starting point, intensity and duration of the event. McKee, et al. (1993), defined different categories of drought intensity, for index values between -1 and -2, the drought category goes from moderate to severe, and for values below -2, the category is extreme droughts. Therefore, for this research considering McKee, et al. (1993) statement and the threshold used by Diaz, et al. (2020) as an indicator for droughts, SPI indexes below -1 were considered as drought and values below -2, extreme drought events, therefore, the lower the index, the more intense the event is. On the other hand, the first month with an index below -1 is the starting point of the drought and it finishes, when the index goes again above the threshold, the duration of the event is the sum of consecutive months with the same condition.

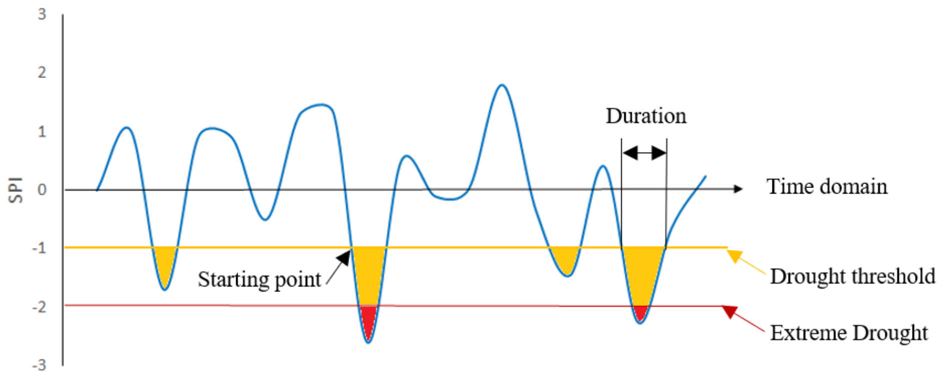


Figure 7 SPI Characteristics

Time scales for calculation of the index can go from 1 month up to 48 months, hence the quantification of precipitation deficit show the different types of droughts happening in the area. Once the time scale is defined, a density function (i.e. Gamma, exponential, lognormal, and Weibull), is fitted into the long-term time series, then, based on the fitted function, the cumulative distribution is calculated, and finally, transformed in standardized normal values which will represent the water deficit for the current period (SPI). According to Edwards (1997), Thom (1966) discovered that the Gamma function fits well the climatological precipitation series, in addition, Guenang and Kamga (2014), and Vicente-Serrano, et al. (2010) agree on the fact that gamma distribution is one of the best options for SPI calculation.

Therefore, the density function of the gamma distribution is:

$$g(x) = \frac{1}{\beta^{\alpha}\Gamma(\alpha)} x^{\alpha-1} e^{-x/\beta} \; for \; x > 0 \qquad (2)$$

Where:

α = Shape parameter

β = Scale parameter

x = Precipitation amount

Γ(α) = Gamma function

α , β and x have to be > 0

$$\hat{\alpha} = \frac{1}{4A}\left(1 + \sqrt{1 + \frac{4A}{3}}\right) \qquad (3)$$

$$\hat{\beta} = \frac{\bar{x}}{\hat{\alpha}} \qquad (4)$$

Where $\bar{x}$ is the mean precipitation and A is defined in Eq.5.

$$A = ln(\bar{x}) - n^{-1} \sum ln(x) \qquad (5)$$

n=number of precipitation observations

Cumulative provability is given by:

$$G(x) = \frac{1}{\hat{\beta}^{\hat{\alpha}}\Gamma(\hat{\alpha})}\int_0^x x^{\hat{\alpha}-1}e^{x/\hat{\beta}}dx \quad (6)$$

Making $t = x/\hat{\beta}$, then the gamma function becomes the incomplete gamma function.

$$G(x) = \frac{1}{\Gamma(\hat{\alpha})}\int_0^x t^{\hat{\alpha}-1}e^{-1}dt \quad (7)$$

As gamma distribution is not defined for x = 0, the cumulative probability turns in:

$$H(x) = q + (1 - q)G(x) \quad (8)$$

Where,

q = Probability for zero precipitation (positive value), can be m/n, where m is the number of zeros within the time series

The final step is to convert H(x) into the standardized normal, which is the value of the SPI.

Analysis for 3 months represents meteorological droughts (precipitation deficit), 6 months agricultural droughts (soil moisture deficit) and periods of 12 to 24 months represent long-term precipitation patterns that are related to hydrological droughts (reduction of water levels in water bodies) due to the shortage of rainfall for more than a year.

To get accurate results of the index in the Jiet for future scenarios, to calibrate the method, after obtaining the index values for past scenarios, a comparison was done with the historical events computed by Beguería, et al. (N.D.) using the Standardised Precipitation-Evapotranspiration Index (SPEI) within the same time frame, which is a method for drought analysis introduced by Vicente-Serrano, et al. (2010) that considers besides precipitation, temperature and evapotranspiration in the assessment of droughts. Further, results for past scenarios were also compared with historical data of dry years with drought events that took place in the area. Finally, once the comparison of results and validation of data is done, future scenarios calculations were performed with shape and scale (α and β) values obtained from past scenarios.

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4.3. HEC-HMS Modelling

Analysis of the hydrologic process within the Jiet catchment was using the software HEC-HMS, developed by the US Army Corps of Engineers (USACE). The software simulates the rainfall-runoff process in different types of catchments, it incorporates the physical representation and water bodies within the watershed. Precipitation, evapotranspiration, discharge at the outlet of the Jiet, and physical characteristics were used to make the simulation of the basin having as output, the runoff, and streamflow of the catchment. Set up, calibration, validation, and run of the model are divided into 3 steps. First, data is included in the model, then, different simulations are run to analyse the behaviour of the catchment with the inputs and changed if needed for the calibration, once the calibration is done, the model is validated and run for the past, mid-century and end-century scenarios, as shown in Figure 8

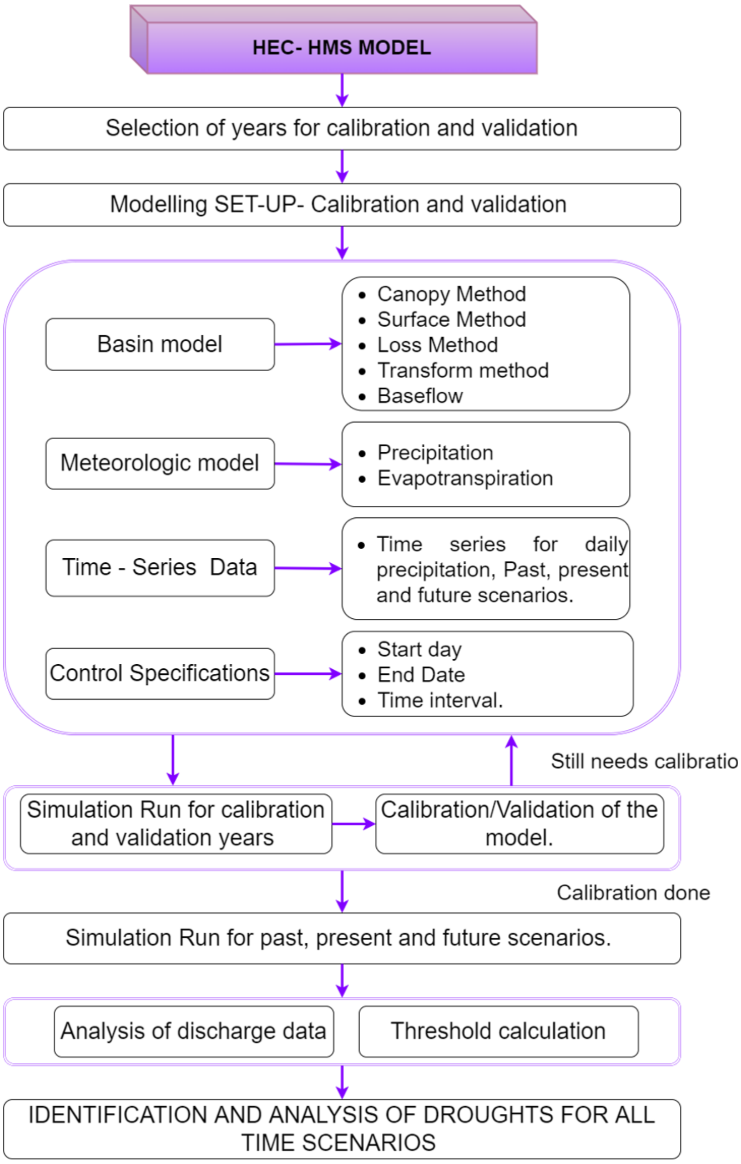

Figure 8. Framework HEC-HMS model

4.3.1. Model Set-up

Based on the information available for the study, it is necessary to define the model set-up, considering the meteorological and physical characteristics available information of the catchment. The model was a lumped model in which every coordinate of meteorological information obtained from the data sets were assumed as if they represented one station. The model has the following components:

- Basin model

Transforms the atmospheric conditions into streamflow, using canopy, surface, loss, transformation, and baseflow parameters.

- Canopy: Represents the water storage capacity of the plants, once the canopy is at the maximum storage, precipitation falls to the surface and goes as runoff or infiltration. Canopy is emptied through potential evapotranspiration. To calculate the storage and rates of evapotranspiration, canopy method uses five parameters.

    - Initial storage (%)
    - Maximum storage(mm)
    - Crop coefficient
    - Evapotranspiration
    - Uptake method

- Surface: Represents the soil surface storage capacity. Components for its calculation are:
    - Initial storage (%)
    - Max storage(mm)

- Loss: The method is used to know the infiltration rates within the basin, according to the type of event for which the simulation will be run, a total of 12 methods can be chosen as explained in Hydrologic Engineering Center (2021). For this study, a simulation of continuous events was done for three periods of 30 years in different time frames, hence, the chosen method to implement in this study is Deficit and constant. Deficit and constant loss consider only one layer of soil for constant variations in moisture content derivates from potential evapotranspiration, it is necessary to implement canopy and surface methods along with the loss because the water extracted from the soil is by canopy and the water that is in the surface infiltrates into the soil. Parameters for the deficit and constant method are:

    - Initial deficit (mm)
    - Maximum Deficit (mm)
    - Constant Rate (mm/hr)
    - Impervious (%)

Calculation of initial and maximum deficit y done with equations (9) and (10).

$$S = \frac{25400 - 254CN}{CN} \tag{9}$$

$$I = 0.6S \qquad (10)$$

Where,

S = Maximum potential retention

CN = Curve number

I = Initial deficit

- Transform method: Calculates the actual surface runoff.

  - Time of concentration(hr), is the longest period that would take to travel in the sub-basin and is calculated with Kirpich equation (3).

$$Tc = 0.066\left(\frac{Lc}{\sqrt{Sc}}\right)^{0.77} \qquad (11)$$

Where,

Lc = Length of the largest watercourse within the catchment (m)

Sc =Average slope of the basin

  - Storage coefficient (hr)

$$R = \frac{Tc}{1.46 - 0.0867 Lc^2/A} \qquad (12)$$

Where,

Tc = Time of concentration(hr)

A = area of the catchment (km^2)

- Baseflow: Available methods to calculate the actual subsurface in the catchment, generally consider monthly values of baseflow, initial discharges, and ratio values to reset the baseflow during an event.

- Meteorological model: This component will have the meteorological boundary conditions of the sub-catchments. For this research, just precipitation and evapotranspiration components were considered.

- Precipitation
  - Gage weights were calculated with Thiessen polygons using ArcGIS tool, to identify the points with a direct influence over the basin, then, weights were calculated.

- Evapotranspiration
  - Monthly average: Data input is the multiannual average depth of potential evapotranspiration per month.

- Time series data: Contains the information of all the gages used for the analysis, time interval used for input data was one day.

- Control specifications: Defines the time interval for simulation of the model.

4.3.2. Calibration and validation

Calibration of the model was done for a time frame chosen according to the quantity of data available from the catchment. Once the model was run, discharge peaks at the outlet were checked and compared with historical measured data, if the computed results had big differences compared with the historical values, changes were done in the parameters of different components or methods used for loss method and baseflow.

4.4. Simulation for past, present, and future scenarios

Once calibration was finished, simulation for the 3 specified scenarios was run, and then the following analysis was performed for discharge results at the Jiet river catchment.

- Discharge comparison between past scenarios 1990-2020 and historical data to compare results of reality and simulations.
- Definition of a threshold to identify dry periods in the catchment, based on past scenarios results and historical data.
- Discharge comparison between the three-time frames for the Jiet river to estimate the number of droughts for mid-century and end-century scenarios.
- Comparison of the number, magnitude, and duration of drought events, using SPI and the HEC-HMS model.

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5. Results and discussion

Droughts are derived from many causes, one of the most important is the lack of precipitation events for long periods. Data sets number 2 and 8 have daily data precipitation for 90 years, representing historical, present and future events, from which Figure 9, Figure 10 and Figure 11 were computed, calculating the multiannual values of precipitation for each time frame (30 years each) and their average value. For past and mid-century scenarios, the average value of precipitation oscillates around 500 mm/yr and, in the case of end-century scenario the average decreases around 16%, down to 430mm/yr. In 2014 was the highest annual precipitation with 936mm/yr and the lowest occurred in 2000 with 243.5mm/yr. For mid and end century scenarios, the lowest annual precipitations are expected to be around 2041 and 2085 with approximated values of 271.31 mm/yr and 238.9mm/yr. It is important to highlight that the lowest projected values of precipitation are almost the same as the year 2000, known as the driest year in Romania. Furthermore, rainfall events are projected to decrease in the long future, the reason is that rainfall events between 2020 and 2050 have similar values and trends as past scenarios events, hence, downward trends are expected to happen after 2070.

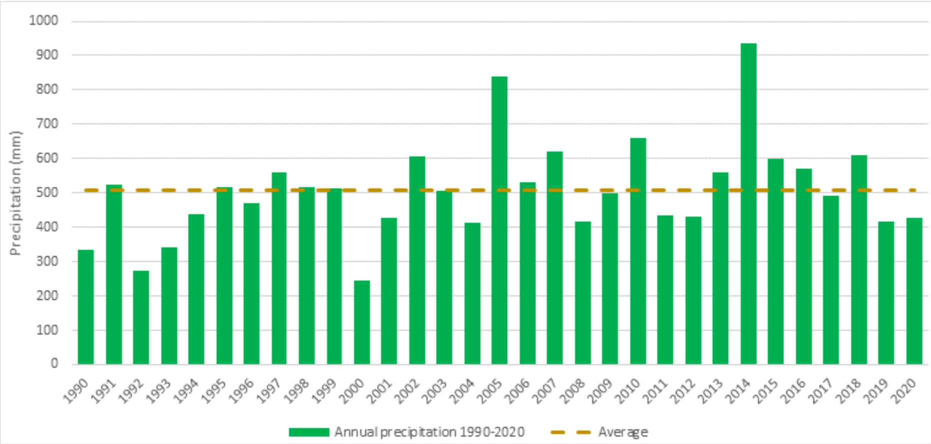


Figure 9 Annual precipitation for Past scenario

Figure 10 Annual precipitation for Mid-Century scenario

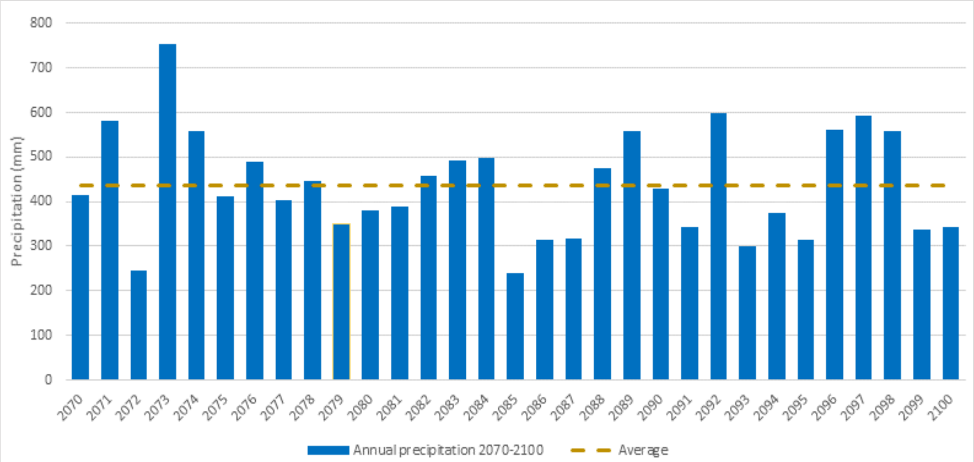


Figure 11 Annual precipitation for End-Century scenario

Making the comparison between values of precipitation and temperature for past and future scenarios, both have opposite trends. The following figure shows the annual average temperature for all scenarios, starting with temperature values for past scenario, the minimum value was 8.4 °C and the maximum was 11°C. For present, and future scenarios obtained from data set number 9 (Table 1), show that rates star to increase through years, for example, maximum projected value for mid-century scenario reaches 15°C and for end-century goes up to 19°C. The rate of increase is about 4°C between scenarios, perhaps the high increment, is linked to the scenario from which the data was obtained which is RCP 8.5.

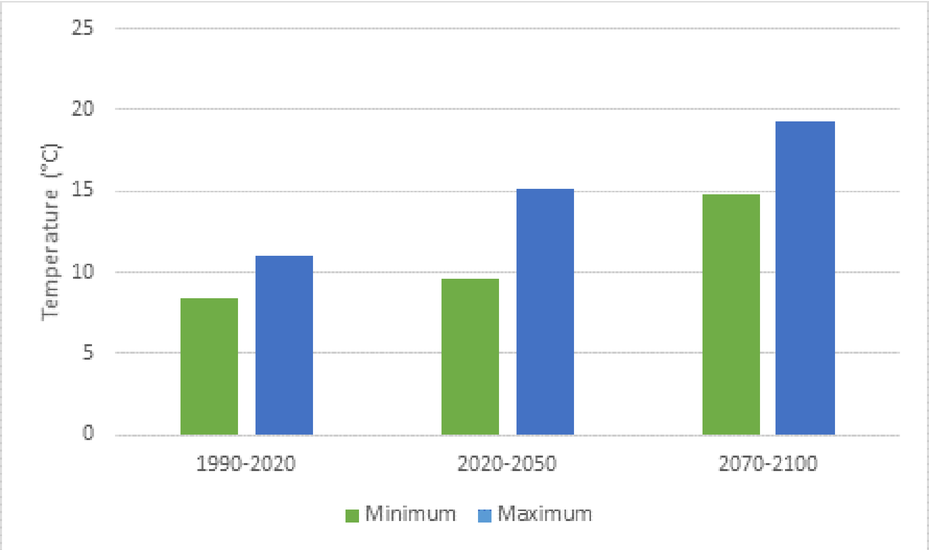


Figure 12 Max and min values of average annual temperature for past, mid-century and end-future scenarios

Higher temperatures have an impact on the potential evapotranspiration, making it increase. Generally, a year is divided into 2 seasons, one with high values of PET(April-September) and the second one with lower values (October-March). As a result of PET calculations, the highest increment occurs in the mid-century scenario, as shown in Figure 13. Upward trends of PET happen throughout the whole year for future scenarios, although, rising values of January and February in end-century scenario increased almost 3 times compared with past scenario values and the remaining month rates, which are almost doubled.

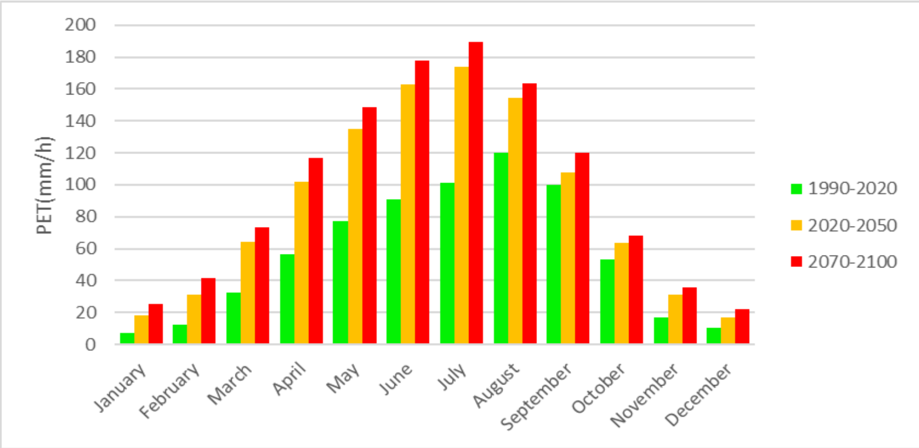


Figure 13 Monthly average PET values for past and future scenarios

5.1. Meteorological analysis (SPI Calculation)

To develop this method, first step, is to define time scales, thresholds and years of analysis. Therefore, in this research, selected time scales were 3, 6, 12, and 24 months, to identify meteorological, agricultural and hydrological droughts. Threshold defined previously was -1, and years of analysis are 3 periods of 30 years each, for past (1990-2020), present (2020-2050) and future (2070-2100) scenarios.

For analysis and discussion, SPI results are shown in two different representations, first, a column chart where the threshold of -1 allows to see the multiannual index values and how droughts change according to the time scale. Second, a SPI heatmap is presented subdivided into dry and rainy months (colours grey and blue), and vertical doted lines that illustrate the seasons of the year, thus, droughts can be analysed and discussed by season and months.

- Past scenario analysis (1990-2020)

Monthly precipitation data used for this analysis was taken from the grid of 30 points covering the area of the Jiet catchment of data set 2 as shown in Table 19. Index results for time scales of 3, 6, 12 and 24 months are represented in Figure 14, where it is visible how the number of events have a downward trend as the time scale increases. Meteorological droughts are mostly the most frequent event (SPI3), with a total of 28 droughts, followed by 14 agricultural droughts which have a high intensity (index value below-2) during 1992-1994; 2000-2002 and 2012. SPI 12 presented a total of 7 hydrological droughts with a higher intensity in years previous to 2003 and for SPI 24, total droughts were 3, happening between 1992-1994 and 2000-2003.

For SPI 12 and SPI 24, the charts represent that, after 2003 the accumulation of precipitation deficit was present in some years, although drought events only happened in 2012 and 2020, hence, it could be said that after 2003 the problem was mainly soil moisture deficit, as it is also shown is SPI6 chart, where the same years had agricultural droughts with high intensity. In contrast, the deficit before 2003 shows a high intensity and duration for hydrological droughts, which become more intense during rainy season in 1993, due to the accumulation of the deficit for the past months of dry season plus the high evapotranspiration rate of summer but then, in the following years, the event gets less intense. Figure 9, shows that after 1993 the precipitation rate started to increase, which could be the reason why the intensity of the droughts from 1994 started to decrease and increase again after 1999 when the annual precipitation rate goes from 500mm/yr to 243.5mm/yr in 2020.

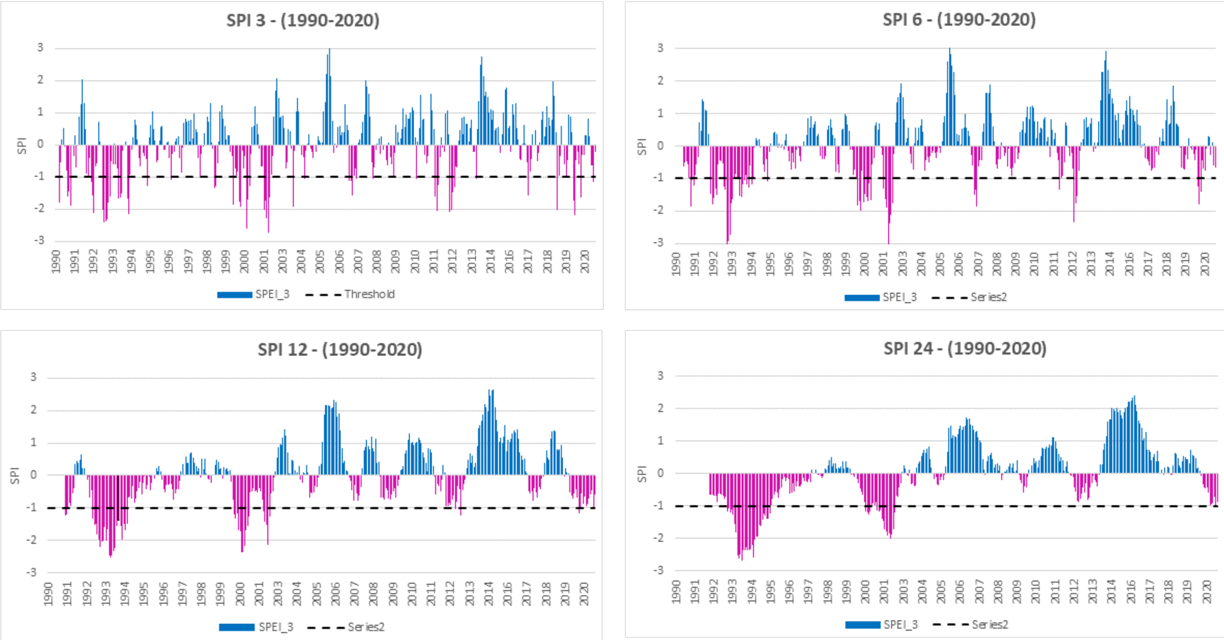


Figure 14 SPI Results -Past scenario

Heatmaps in Figure 15 show in more detail drought information, for example, index results for SPI 3, illustrate that majority of droughts occur during the end of rainy season and during full dry season. Moreover, time scale of 3 months, represents the first stage of droughts, if the deficit continues for more time, for example, 6 months, soil moisture decreases and it is the start of the agricultural droughts, which is the case of the periods between 1992-1994; 2000-2002 and years 2012, 2019 and 2020. The Heatmap of SPI 24, shows very clearly the intensity and duration of the hydrological drought that occurred between 1992-1994, starting at the end of 1992 until mid-1995. It is also possible to identify that the higher intensity was in 1994, which is the accumulation of 24 months of deficit precipitation.

For all time scales, when extreme droughts (index below -2) are visible at least once and its duration is for more than a month, that usually means (not for all cases), that the event is worse than the scale in which is being represented. For example, the event occurred in autumn of 1992 appeared in all time scales, being the 3 month and 6 months index the most intense, but later as time scale increased, the deficit accumulation showed the type of drought that occurred between 1992-1994. The opposite case, is the event occurred in autumn of 2018 for meteorological drought (SPI3), which had a high intensity but its duration was only one month. That is why in SPI6 is not shown as a drought event, although it was still dry, the accumulated deficit was not enough for an agricultural drought to happen.

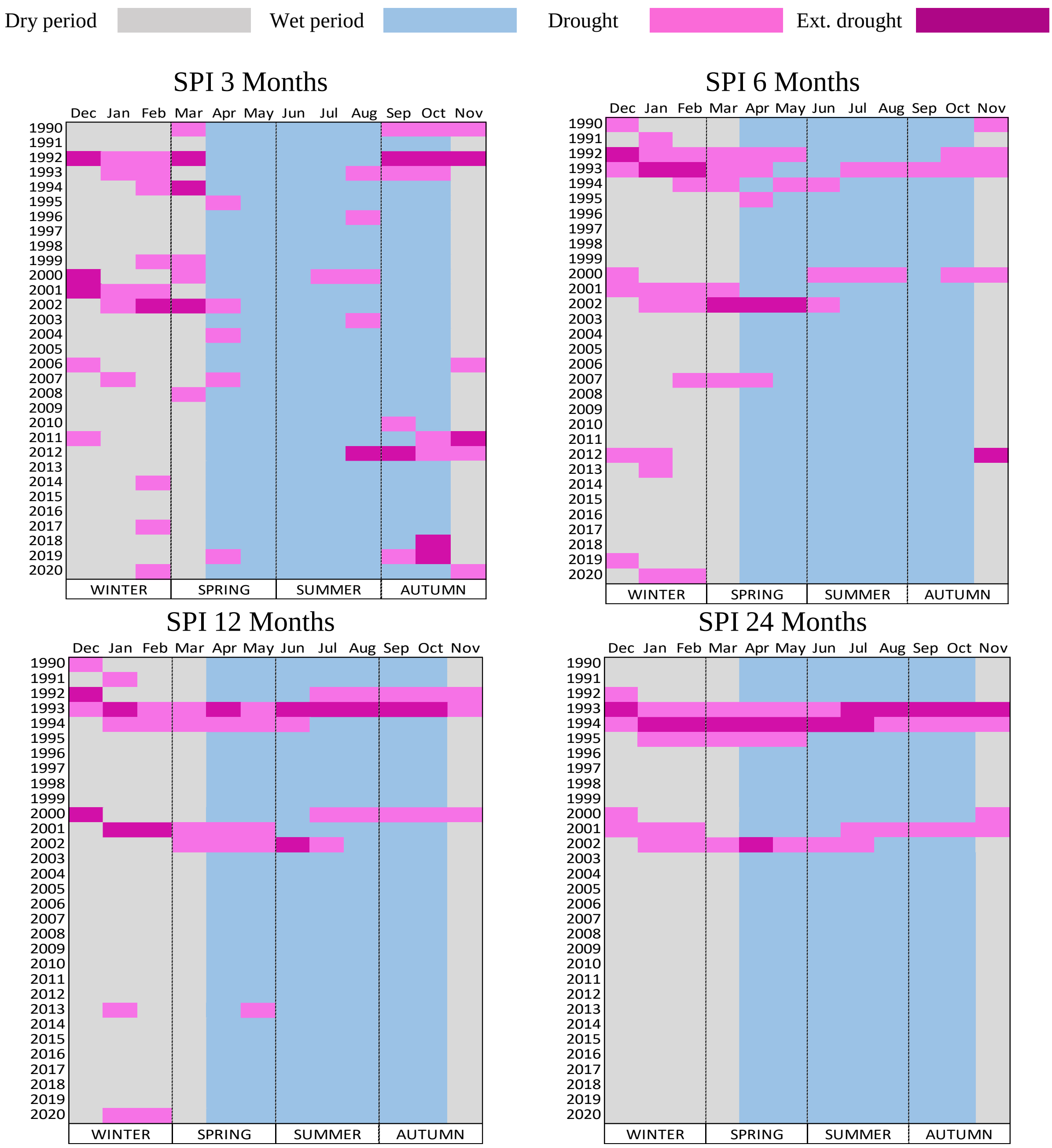


Figure 15 Heatmap with seasonal representation of SPI results for Past scenarios

Results of calculated SPI values for past scenario, were compared with historical droughts over Jiet's catchment from literature, and events identified in the downloaded data from the Global drought monitor(GDM) (Beguería, et al.), for the period between 1990 and 2020. To make an accurate analysis, downloaded data was from time scales of 3, 6, 12 and 24 months and the threshold of -1 was used to identify the droughts (dotted line), as illustrated in Figure 16.

The latest information about drought analysis was founded in Ionita, et al. (2016), meaning that identified events in literature were covered until 2016. The GDM had available information for the whole period of past scenario, including years after 2016. From literature, according to Ionita, et al. (2016) years 2000 and 2001 were the driest in the south part of Romania, Ontel (2013) identified years 1992, 1993, 2000, 2002 and 2007 as dry years in the Dolj county and finally, Vlăduţ, et al. (2013) also classified 1992, 1993, 2000 and 2008 as dry years in the Oltenia plain.

From the charts of time scales shown below in Figure 16, it is visible the occurrence of many meteorological droughts during the entire period, agricultural and hydrological droughts were identified between 1993-1995; 2000-2002; 2012-2014, and the years 2007 and 2020. The longest duration of agricultural drought was between 1992-1994 and the most intense occurred in 2013. The most critical hydrological droughts can be seen in SPEI12 and SPEI24, between years 1992-1995; 2000-2003 and 2012-2014.

Although, hydrological droughts were identified in year intervals of 1992-1995 and 2000-2003 which are the same years of historical droughts and results of SPI, the index values for the interval between 2012-2014 in Figure 14, are not as intense as the ones shown in Figure 16 below, hence, one possible explanation for that is, the rising rates of temperature and evapotranspiration for those years, meaning that SPEI event were more related to high evapotranspiration than for precipitation deficit.

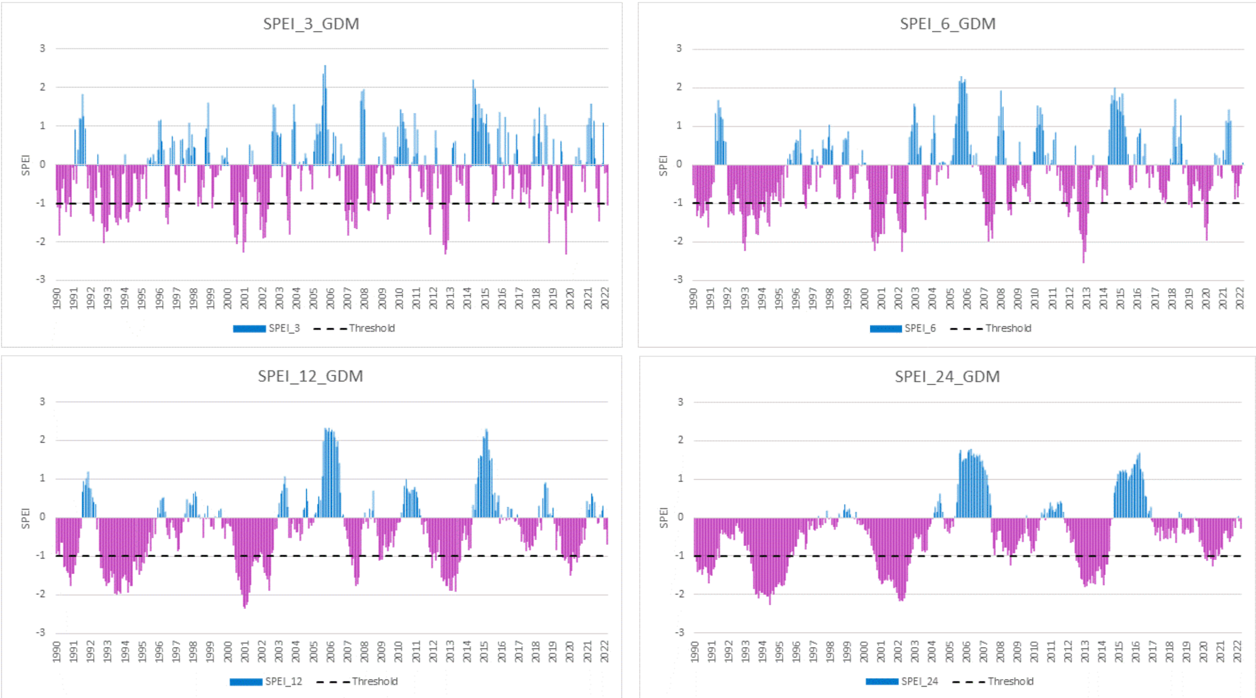


Figure 16 Results of SPEI Over Jiet's region for past scenarios(1990-2020)- (via (Beguería, et al., N.D.))

To summarize, a total of 9 years were identified to have droughts in the past scenario after comparing literature review and the analysis of GMD. Drought years are 1992, 1993, 2000, 2001, 2002, 2007, 2012, 2013 and 2014.

Calibration of the SPI method was done based on historical data of precipitation and drought events in the Jiet. The shape and scale parameters calculated for SPI from 1990 to 2020 were used for calculations of the index for future scenarios. Index for future scenarios were calculated using values in Table 8 for gamma distribution.

Table 8 Alpha and Betha parameters used for past, present and future scenarios.

Parameter	SPI 3	SPI 6	SPI 12	SPI 24
α	4.55	8.19	14.88	25
β	9.53	5.3	2.93	1.75

- Mid-century scenario analysis (2020-2050)

This scenario covers present and near future conditions in the Jiet catchment, overall view of the results show the increment of droughts for all time scales which means, the increment of duration and intensity of dry periods. Compared with the number of droughts for past scenarios, mid-century simulation results showed that droughts increased in all time scales. For SPI3, three more events could be expected, having in total 31 meteorological events in 30 years. For SPI 6, a total of 24 events, which is 10 more droughts than for past scenarios, for SPI 12 the increment was 5 events more, and for SPI 24 a total of 12 droughts, 9 more than past scenarios. The increment in the intensity of agricultural and hydrological droughts mean that soil moisture and levels of water bodies (ponds, lakes, reservoirs), will be the most affected for the next 30 years. This is illustrated in time scales 6 and 12, which seem to be the most prominent, having a high number of events, with index values below -2 or very close.

Although the number of events in SPI-24 increased compared with past scenario, droughts are less intense than it was historically, but the duration is expected to be longer. Therefore, a good alternative could be to drive attention into the scarcity for shorter periods so, future droughts can be mitigated.

Figure 17 SPI Mid-century scenario

For this specific scenario, simulations for SPI3 and SPI6 present a specific pattern for droughts happening during stations. Compared with past scenarios, a larger number of extreme events might happen during the rainy season, which might not have much sense because the precipitation deficit should be lower compared with dry season, one possible explanation for those events happening during that time, are more related to the upward trend of evapotranspiration (Figure 13) and the lower precipitation rate of some years for this scenario (Figure 10). For a very close future, first meteorological, agricultural and hydraulic droughts are expected to happen soon.

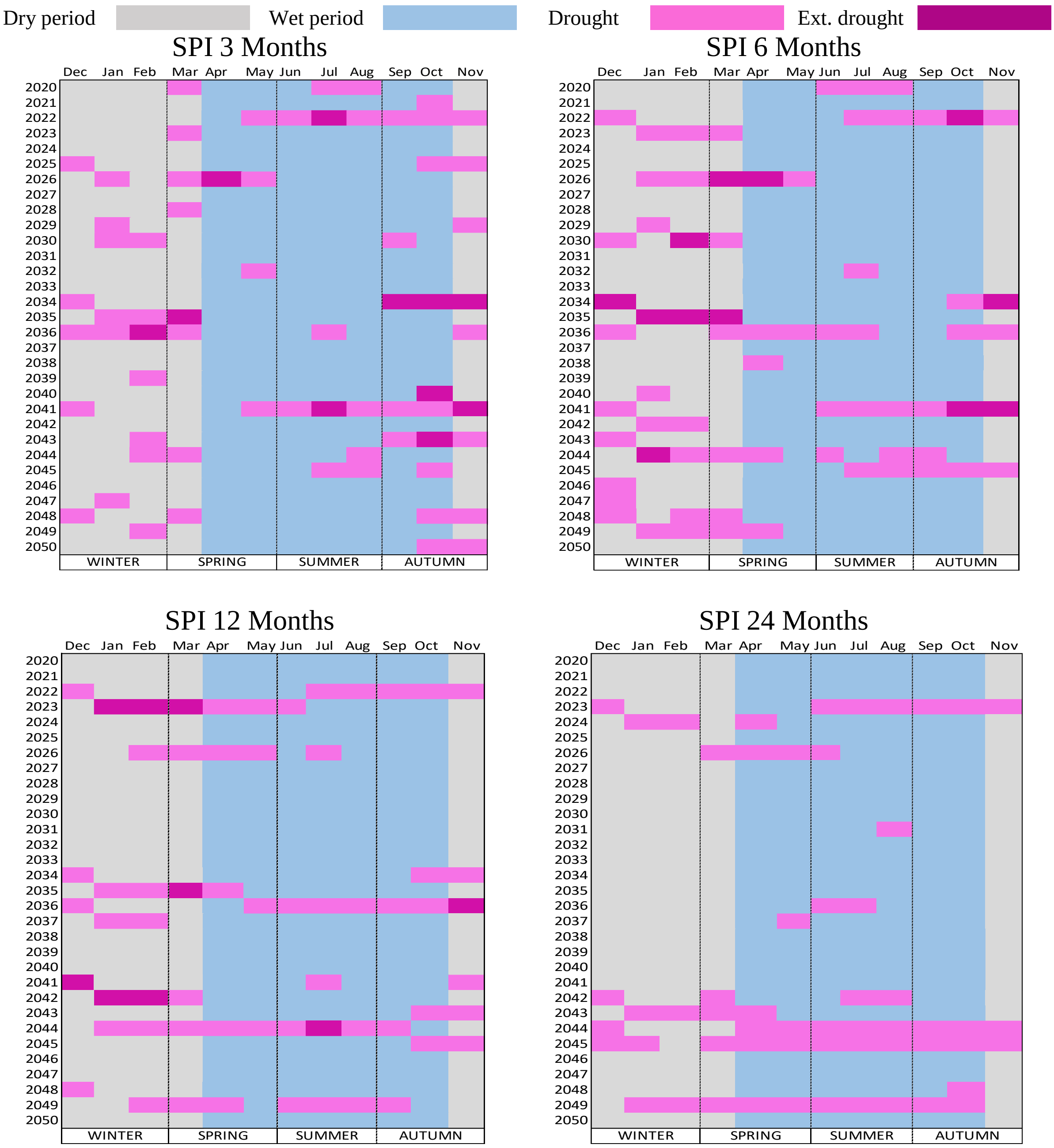


Figure 18 - Heatmap with seasonal representation of SPI results for Mid-century scenario

- End-century scenario analysis (2070-2100)

Is the most critical scenario of the three scenarios, it presents extreme events for all time scales with more frequent events with indexes below -2, which represent greater intensity in the events, therefore, the duration is longer than in previous scenarios as illustrated in Figure 19. Only late years of the simulation appear to be affected by meteorological droughts. Compared with past scenario results, all types of droughts increase in numbers, SPI3 goes up to 33 events, SPI6 increases to double the number of events reaching a total of 28, for SPI12 and SPI24, events are around 3 times higher than initial events calculated for past scenarios, reaching 23 events for SPI12 and 9 for SPI24.

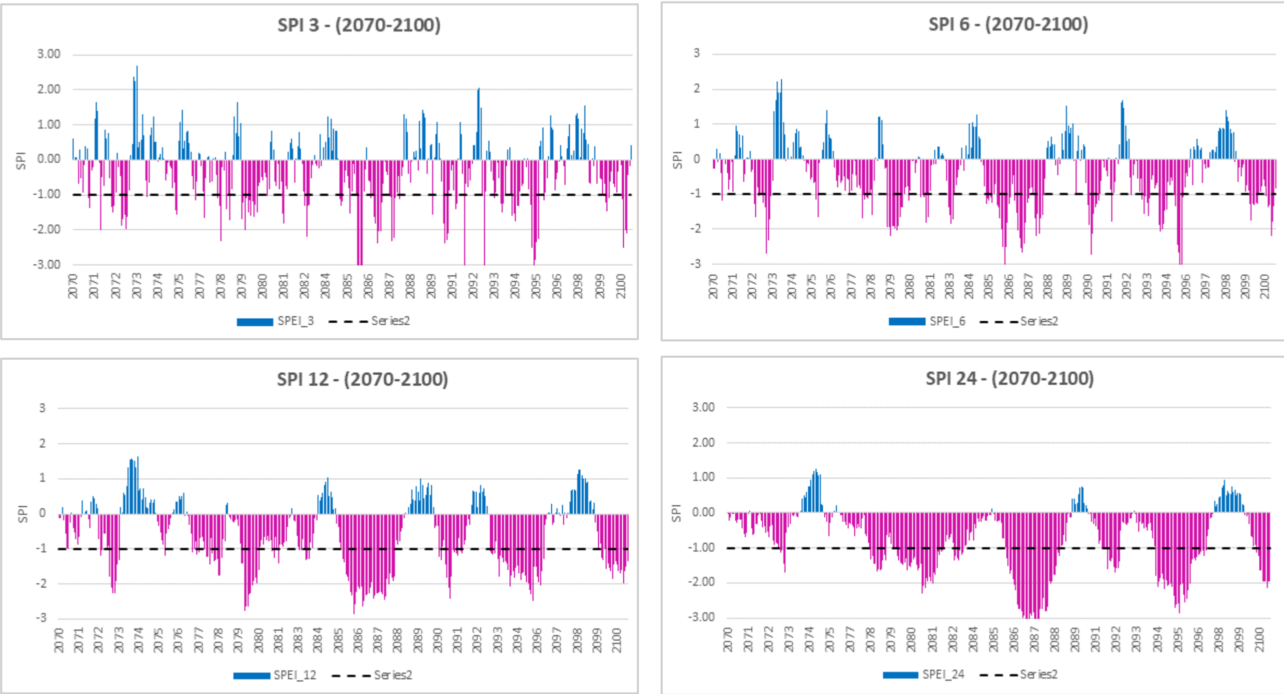
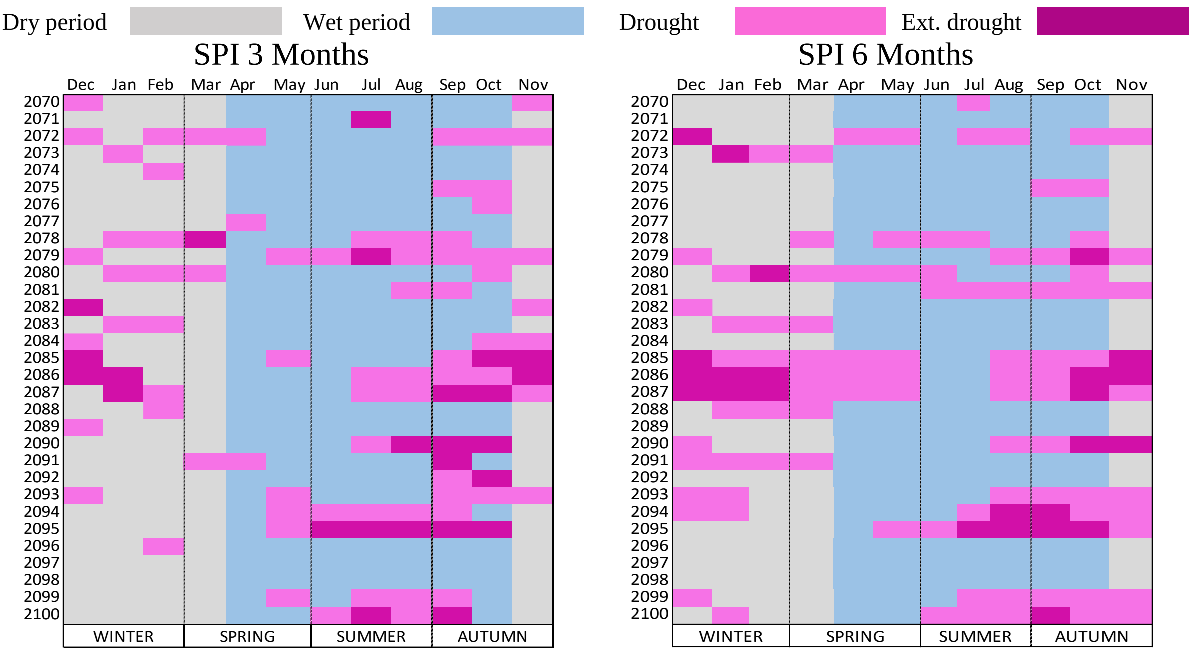


Figure 19 SPI End-century scenario

Different drought patterns start to appear, for example, droughts occur during all wet and dry seasons, although, extreme events are mostly depicted at the end of the rainy season. SPI24 shows very intense and prolonged hydrological droughts throughout the 30 years of simulation, getting worst by the year until the end of the century.

Longer and more intense drought events are projected for this simulation, which is not a very promising scenario, because water bodies, soil moisture, and even groundwater levels will all have an impact derived from these prolonged periods of droughts. SPI24 also represents the longest projected droughts which could last up to 9 years. The more intense droughts are projected with index values between -1 down to -3.31.



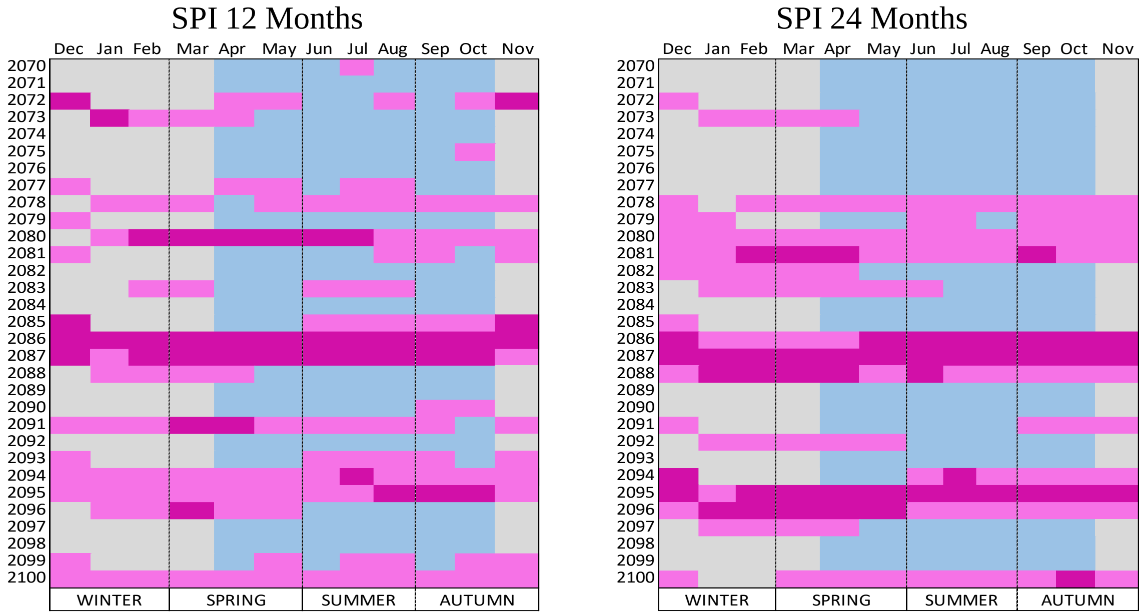


Figure 20 Heatmap with seasonal representation of SPI results for End-century scenario

To summarize, Figure 21, shows the number of drought events for all three scenarios for each time scale. The upward trend is similar, except for SPI 24 where the highest number of droughts is expected to occur during the mid-century, and goes down again in the end-century scenario. Although the number of events have changes over time, it is very important to consider as well the duration and intensity of all when drought analysis is being made.

For each scenario and time frame projected, droughts are expected to increase between 10% and 17% for SPI3, 71% to 100% for SPI6, 71% to 220% for SPI12 and finally for SPI24, the percentage of increment in the number of droughts are the highest with 300% for mid-century scenario and 200%for end-century scenario.

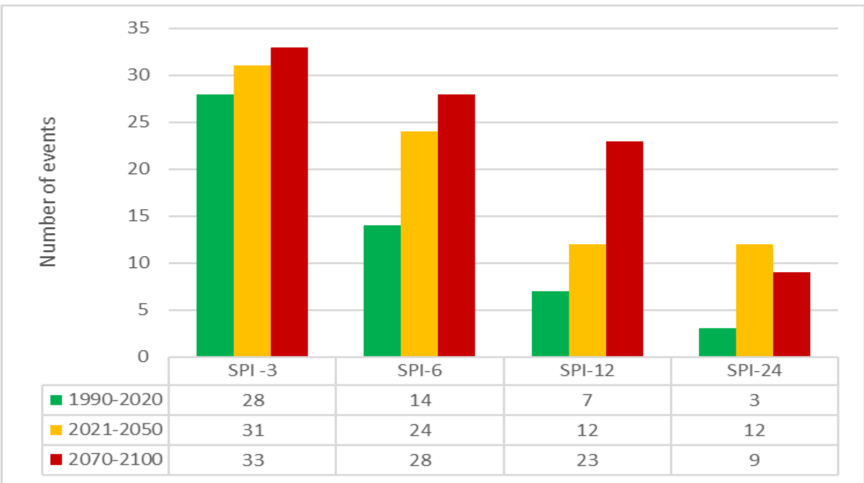


Figure 21 Total number of droughts calculated with SPI method

5.2. HEC-HMS model

The Jiet basin is a flat area with small slopes, with arid characteristics and has few impermeable areas, hence, runoff in the catchment is small. All these characteristics of the basin, in addition with meteorological and discharge data of from 2017 until 2020 were initially used to set up, calibrate and validate the proposed HEC-HMS model. Below, all methods, components and parameters explained in the methodology will be applied in Jiet catchment.

5.2.1. Model set-up

- Basin model: Due to the topography of the catchment, the area was not divided into sub-basins, and the whole area was considered as a sub-basin with a unique junction which is located in the outlet of the Jiet to the Danube in the southern part of the catchment as shown in Figure 22.

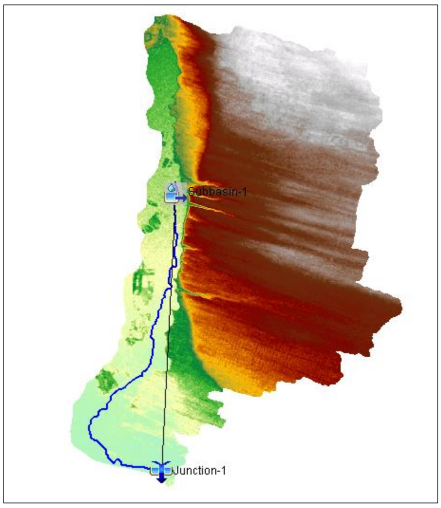


Figure 22 Basin model HEC – HMS

For an accurate simulation of the catchment, it is important to include the sub-basin elements that allow the calculation of the discharge, using different methods. The basin model components considered for this model were, canopy, surface, loss, transform, and baseflow.

- Canopy: Simple canopy which represents the water that is intercepted during rainfall by the plants over the area.

Table 9 Simple Canopy parameters

Initial storage (%)	*0*
Max storage (mm)	*2*
Crop Coefficient	*0.95*
Evapotranspiration	*Wet and dry periods*
Uptake method	*Simple*

- Initial storage (%) was assumed to be zero each time the simulation started.
- Maximum storage(mm) value was taken from Verbeiren, et al. (2016), for maximum interception capacity for croplands which is the main type of plant within the basin.

- Crop coefficient value of 0.95, is the average per season value of Kc for land principally occupied by agriculture, with significant areas of natural vegetation. Table 2 (Nistor, et al., 2018).
- Evapotranspiration was set up to take water from the soil storage during all seasons, not only during dry periods.
- Uptake method was set up as simple which uses the PET rate to extract the water from the soil.

- Surface: Simple surface method was chosen, which represents the soil surface that can store water coming from precipitation events and then infiltrated to the soil.

Table 10 Simple surface parameters

Initial storage (%)	*0*
Max Storage (mm)	*12.7*

- Initial storage, when simulation starts, the surface storage was set up with a value of zero percent, meaning that there is no storage on the surface.
- Max storage (mm), based on Table 2 Bennett (1998), as cited in (Singh and Jain, 2015), the slope of the catchment surface was classified as moderate to gentle with a value of storage of 12.7mm.

- Loss, Deficit and constant: Initial values to set up the model, were calculated with equations 9 and 10, results are presented in Table 11 below. For calibration, these values were recalculated and changed in the model until calibration was finished.

Table 11 Deficit and constant, Loss method parameters

Initial deficit (mm)	*50.8*
Maximum deficit (mm)	*254*
Constant rate (mm/hr)	*116.8*
Impervious (%)	*0.66*

- Constant rate (mm/h): Jiet catchment is an area with mostly sandy soils, hence, considering sands as the predominant soil in the basin, values were taken from (Rawls, et al., 1983).
- Impervious (%): Most of Jiet's area was used for agriculture and natural areas, only a small part is impermeable as illustrated in Table 5. Impervious value was calculated making the relation between the total area of the catchment and the artificial area, obtaining a percentage of impermeable area of 0.7 in the catchment.

- Transform: Clark unit hydrograph was chosen for calculation of the unit hydrograph of the catchment, calculated inputs as explained in the methodology are given in Table 12.

Table 12 Clark unit hydrograph. Transform method parameters

Method	*Standard*
Time of concentration (hr)	*13.5*
Storage coefficient (hr)	*12.7*
Time-Area method	*Default*

- Baseflow: Constant monthly and Recession methods were considered for the model. First, value of 0.4 m^3/s was used as input for constant monthly values, which is the lowest value of discharge measured in the outlet of the Jiet according to the Romanian waters. Results of its implementation will be discussed further in this document. In the next phase, in order to get more appropriate results, the baseflow method was changed to recession.

Table 13 Recession method. Baseflow parameters

Initial type	*Discharge*
Initial discharge (m^3/s)	*0.26*
Recession constant	*0.9*
Threshold type	*Ratio to peak*
Ratio	*0.9*

  - Initial discharge(m^3/s), was set up in 0.2 which according to National Administration and Dutch Water Authorities (2021), the lowest value of discharge was 0.265 m^3/s in December 2009.

- Meteorological model:

  - Precipitation- Gage weights:

    The area of influence for each point of data set 2 over the catchment was calculated using Thiessen polygons tool in ArcGIS as shown in Figure 23, concluding that only 14 points of data out of 30 had a direct influence over Jiet's area.

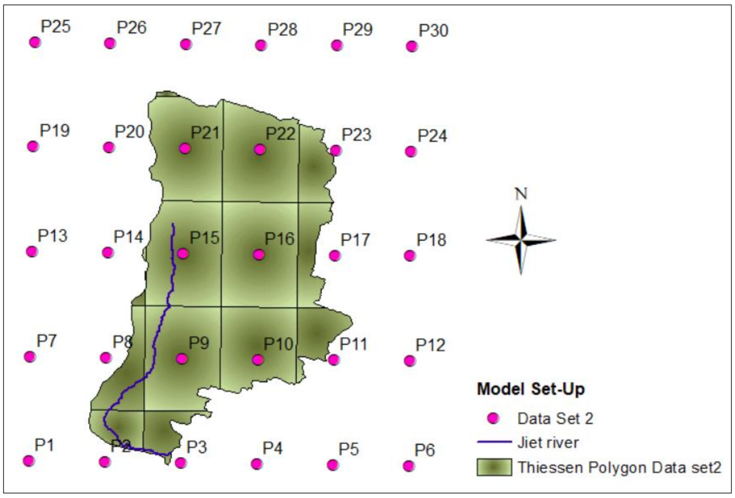


Figure 23 Thiessen polygons representation for data set 2

To be able to use the gage weight method, the weighted value of each point was calculated in two steps. First, the Thiessen polygon areas were calculated. Second, the area was divided by the total area of the catchment, as presented bellow in Table 14.

Table 14 Weights Data set 2

Point	Latitude	Longitude	Thiessen Areas (km^2)	Weight
P2	43.75	23.85	21	0.033
P3	43.75	23.95	20	0.032

Point	Latitude	Longitude	Thiessen Areas (km^2)	Weight
P8	43.85	23.85	31	0.049
P9	43.85	23.95	85	0.134
P10	43.85	24.05	66	0.104
P11	43.85	24.15	25	0.039
P14	43.95	23.85	2	0.003
P15	43.95	23.95	85	0.134
P16	43.95	24.05	89	0.140
P17	43.95	24.15	27	0.043
P21	44.05	23.95	79	0.125
P22	44.05	24.05	77	0.121
P23	44.05	24.15	26	0.041
P27	44.15	23.95	1	0.002

- Evapotranspiration – Monthly average: Average rate per month was calculated from Data set 7 (Table 15). Coefficient value was assumed as one, the reason is that, evapotranspiration values were downloaded from reanalysis data, as explained in chapter 4.1.1 and not from a direct pan measure station.

Table 15 HEC-HMS Input values of PET for Past scenarios

Month	Past scenario PET Rate (mm/month)
Jan	7.1
Feb	12.1
Mar	32.8
Apr	56.6
May	77.4
Jun	91.0
Jul	101.4
Aug	119.8
Sep	100.2
Oct	53.5
Nov	16.9
Dec	10.4

5.2.2. Calibration and Validation

Data provided in Table 7 was used to calibrate and validate the model. As there is only one value per month, first assumption for calibration and validation was to assign each value to a specific day in the month, day selected was every 15th. Measured data of the Jiet has an increasing trend, meanwhile, precipitation has the opposite tendency (Figure 24/Figure 25). Years 2017 and 2018 present the highest peaks of precipitation, which are not represented in the measured flow, instead, the tendency of the flow is to grow by year reaching the highest values in 2020, and based on SPI analysis, 2020 was the driest year between 2017 and 2020. Reasons for these differences in trends of precipitation and discharge observations are not known.

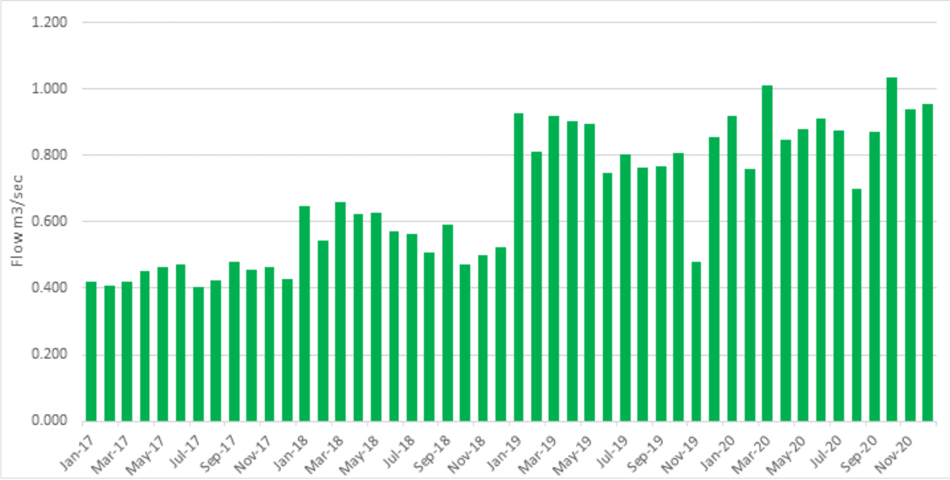


Figure 24 Discharge 2017-2020 used for calibration/validation

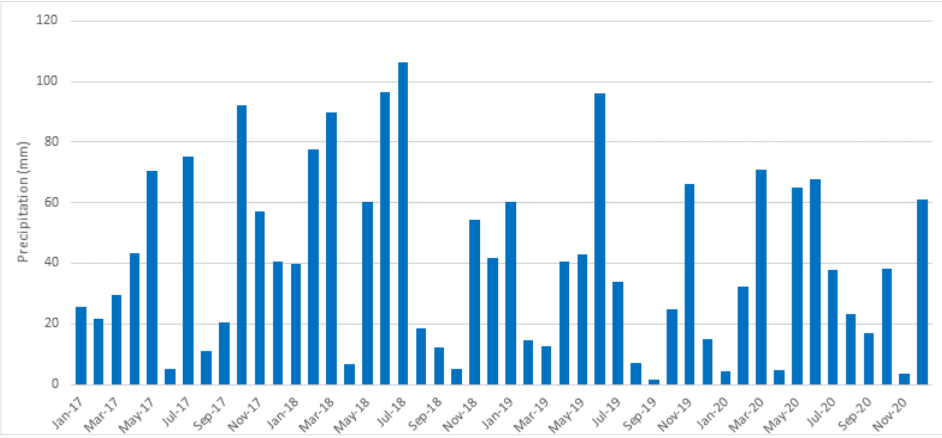


Figure 25 Precipitation 2017-2020

Calibration was done for years 2017 and 2018 with a period of validation in years 2019 and 2020.Graphs and results shown and discuss bellow cover the whole period of four years.

In total, 11 simulations were made to calibrate and validate the model, as shown in Table 16. First, in simulations 1 to 5, components changed for calibration were, deficit and constant (loss method), and monthly baseflow method. Secondly, in simulations 6 to 11, only baseflow method was changed from constant monthly to recession. Changes in parameter values for calibration were based on soil types, curve numbers, impervious percentage and known values of discharge. As precipitation and measured flow have opposite tendencies, calibration was stopped when the majority of the measure discharge was between the maximum and minimum values of simulated discharge.

Table 16 Calibration of HEC-HMS model

Loss Method-Deficit and constant											
Simulation No.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Initial deficit(mm)	50.8	50.8	33.8	33.8	41.5	50.8	50.8	33.8	33.8	41.5	33.8
Maximum deficit (mm)	254	254	169.3	169.3	207.8	254	254	169.3	169.3	207.8	169.3
Constant rate(mm/h)	116.8	30.5	30.5	30.5	30.5	116.8	30.5	30.5	30.5	30.5	29.9
Impervious (%)	0.66	0.66	0.6	1	1	0.66	0.66	0.66	1	1	0.7
Baseflow-Constant Monthly											
Simulation No.	**1**	**2**	**3**	**4**	**5**						
Discharge per month	0.265	0.4	0.4	0.4	0.4						
Baseflow-Recession											
Simulation Number						**6**	**7**	**8**	**9**	**10**	**11**
Initial discharge (m3/s)						0.26	0.26	0.26	0.4	0.4	0.26
Recession constant						0.9	0.95	0.99	0.99	0.95	0.95
Ratio						0.9	0.95	0.99	0.99	0.99	0.99

Model simulations 1 to 5 had obviously no changes in the minimum values of discharge, as the input data used in the model (0.265m^3/s and 0.4m^3/s) was always the lowest value, as shown in Figure 26. For these model, modelled discharge and precipitation present similar behaviour, because, when there is a high peak in precipitation, the expected response of the catchment is the increment of runoff as well as discharge. Moving forward in the analysis of simulations 1 to 5, first months of the year soil moisture starts almost saturated in 2017, then, the catchment reaches the maximum deficit during August and September and starts to be filled until is completely saturated in February and March of 2018 due to the frequent precipitation events happening in those months that allow surface water to infiltrate in the soil and then percolate. Finally, when comparing the simulated and measured discharge values there were differences of up to 0.6m^3/s specially in the years 2019 and 2020, therefore more simulations were needed with a different alternative, for this case, baseflow method was changed from simulation 6 to recession.

In Figure 27, is visible that values of measured discharge (green bars) are similar to simulated discharge (cyan line). Further, precipitation starts to decrease during the validation years, which can also be seen in the reduction of infiltration (dark purple bars), increment of moisture deficit (red line) and absence of percolation (purple bars) during 2019 and 2020.

Finally, for the validation period, comparison between discharge values presented more discrepancy specially in 2019, which can be due to the crossed tendencies between the input data explained before. Although discharge values of 2020 fit better with measured data, there is still very evident different in the second semester of the year.

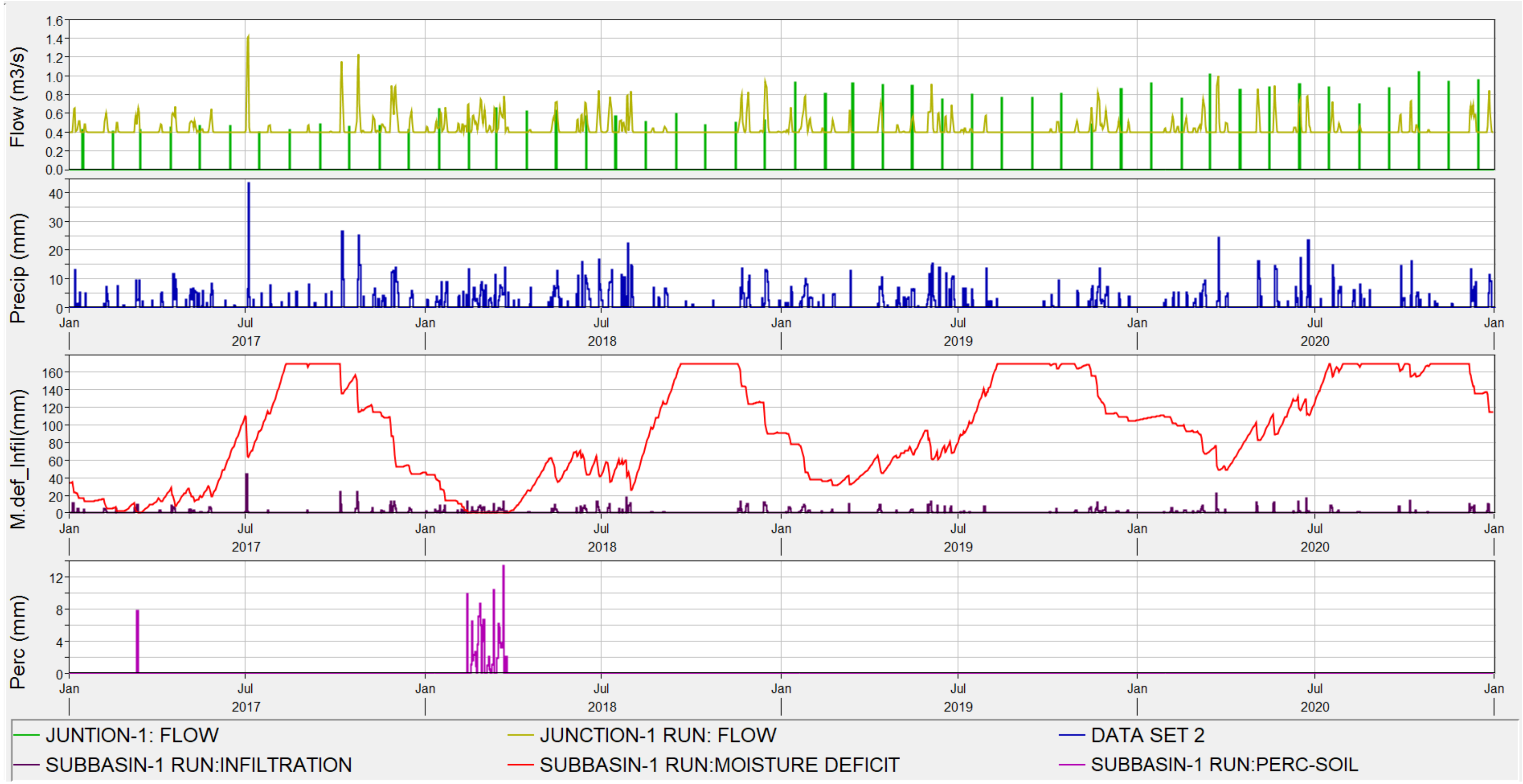


Figure 26 Simulation 3 results. Plots for measured and calculated flow, precipitation, moisture deficit, infiltration and percolation for calibration of HEC-HMS model.

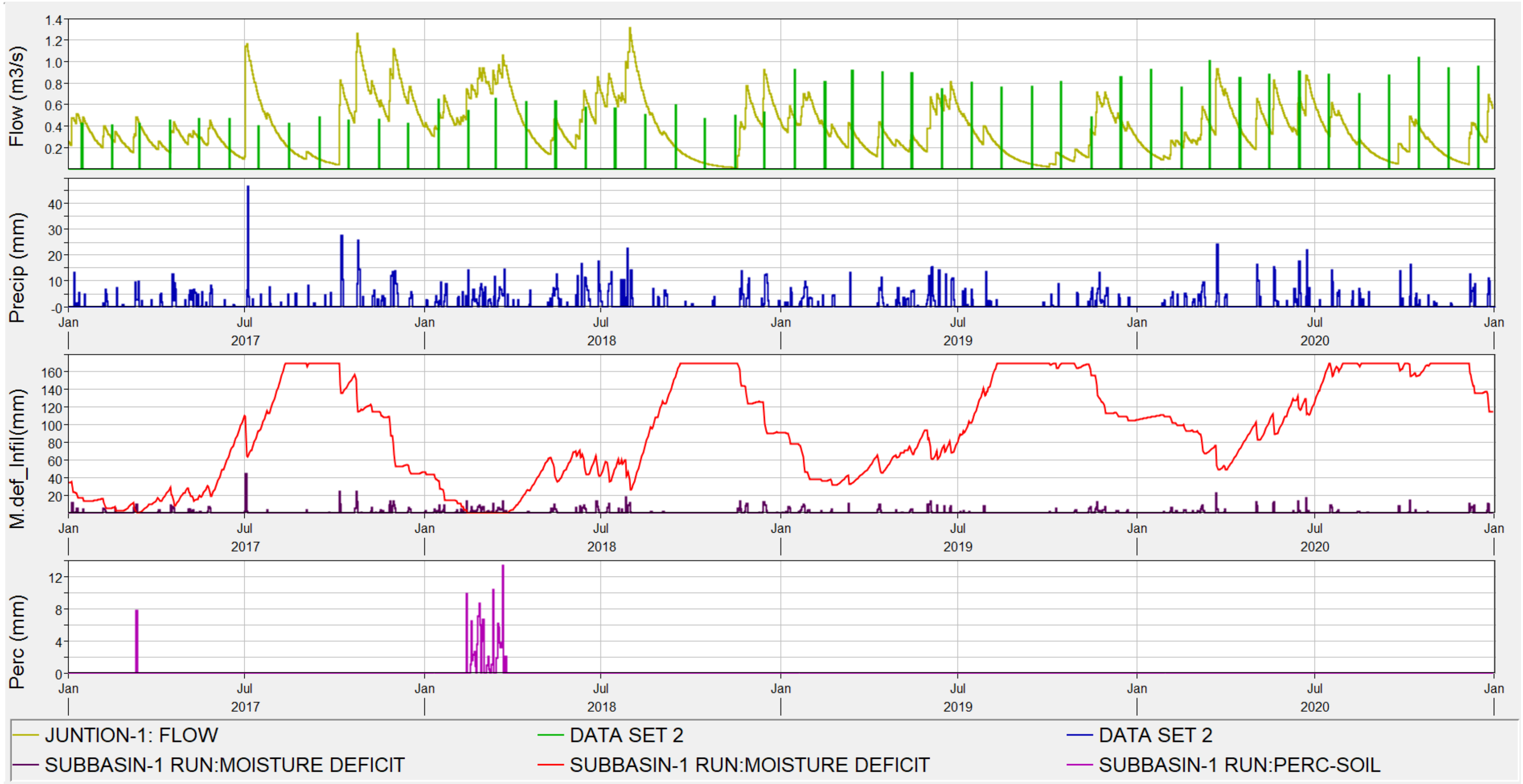


Figure 27 Simulation 11 results. Plots for measured and calculated flow, precipitation, moisture deficit, infiltration and percolation for calibration and validation of HEC-HMS model.

5.2.3. Model simulation for past, present, and future scenarios

- Past simulation (1990-2020)

Once calibration is done, simulation for 30 years starting in 1990 until 2020 was done with the same parameters used for calibration except for the meteorological data, which were changed according to the years of simulation.

The model for past scenarios (Figure 28), shows how the main components of the hydrological cycle behave over 30 years, moisture deficit has several changes especially between 2004-2006; 2013-2015 and 2018, where soil storage was full and high percolation was possible in the catchment. With high peaks of precipitation like the ones happened in July/2008, July/2009, Oct/2013 and July/2017, infiltration rates were high, but percolation did not happen, the reason for that, could be that moisture deficit was at its maximum, hence, water was first storage in the surface until the soil was saturated and, in addition, high peaks happened during rainy seasons, when rates of evapotranspiration are the highest during the year, as showed before in Figure 13. During the simulation the maximum discharge happens during an event in august 2005, when percolation and infiltration were also happening. Moreover, soil storage was fully saturated (moisture deficit=0).

To identify dryness and possible drought events with the results of the simulations from the HEC-HMS model, the following characteristics were identified. First, periods with percolation values equal to zero for 4 or more months. Second, periods with low precipitation, infiltration and discharge values. Identified years under those characteristics were, periods between 1990-1994; 2000-2002; and years 2007, 2012, 2017 and 2020.

Another alternative to identify droughts for past scenarios using HEC-HMS was, first, consider the total of drought years identified for past scenarios which were 1992, 1993, 2000, 2001, 2002, 2007, 2012, 2013 and 2014. Second, those 9 years, represent the 30% of the sample of years used for past scenario, 30 years. Third, percentile 30 was calculated for the discharge values from HEC-HMS obtaining a value of $0.1m^3/s$, therefore, all values below a discharge of $0.1m^3/s$ represented drought events for past scenarios. Finally, as outputs were daily flow, further data processing was needed, only years with discharge below 0.1m3/s, during 4 months or more, were considered as drought events having as result droughts in 1990, 1992, 1993, 1994, 2000, 2001, 2002, 2003, 2004, 2008, 2011, 2012, 2017, 2020.

Finally, based on the results for past scenario, identification of hydrological droughts for mid-century scenario (2020-2050) and end-century scenario (2070-2100), were done using a threshold of 0.1m3/s occurring for 4 or more months over the simulation years.

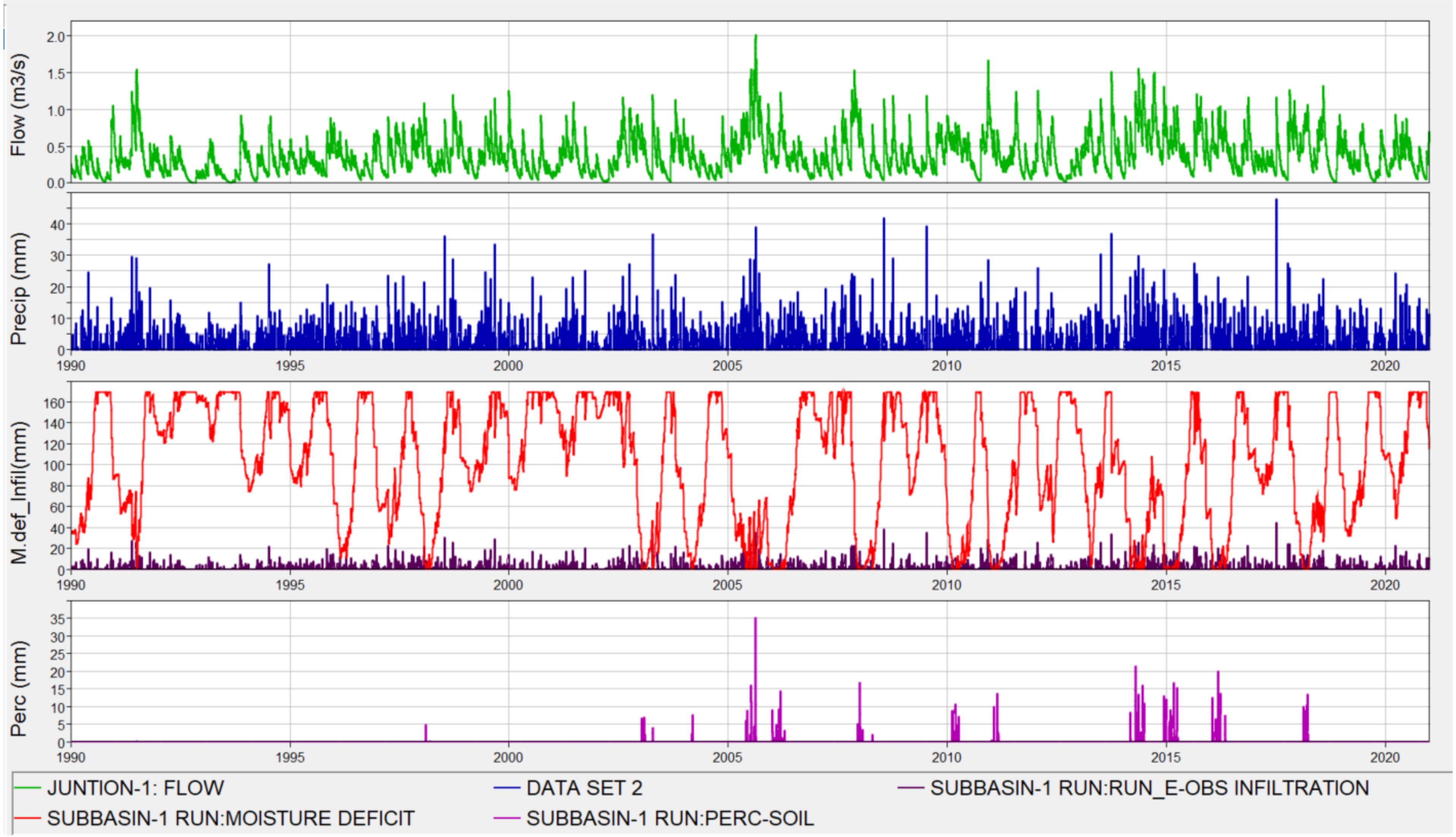


Figure 28 Simulation Past scenarios 1990-2020.Results. Plots for measured and calculated flow, precipitation, moisture deficit, infiltration and percolation for calibration and validation of HEC-HMS model

- Future

Data set number 8, which contains the projected precipitation values (described in sub-chapter 4.1.1), was used for the simulation. Basin model components remain the same, on the other hand, gage weights values used in the meteorological model changed, because the location of the grid points is not the same as data set number 2 (historical precipitation) used for past scenarios. For future scenario simulations, a total of 20 points were considered for Thiessen polygons calculations, as displayed in Figure 29.

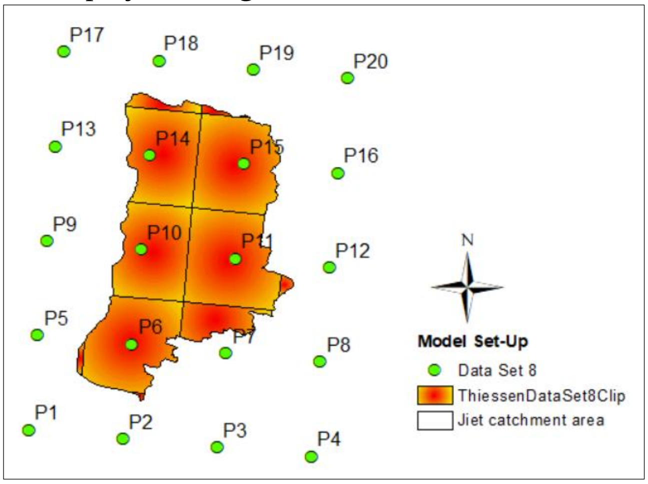


Figure 29 Thiessen Polygons Data Set 8

A total of 11 points of the projected data set have a direct influence on the Jiet. Gage weights were calculated as it was done for past scenario, obtaining the results in Table 17.

Table 17 Weights Data set 8

Point	**Latitude**	**Longitude**	**Thiessen Polygon Area (km^2)**	**Weight**
P10	43.92	23.92	107	0.169
P11	43.91	24.07	129	0.205
P12	43.90	24.23	2	0.005
P14	44.03	23.94	104	0.165
P15	44.02	24.09	119	0.188
P18	44.14	23.95	10	0.017
P19	44.13	24.10	2	0.004
P2	43.70	23.90	1	0.001
P5	43.82	23.76	2.4	0.004
P6	43.81	23.91	116	0.184
P7	43.80	24.06	36	0.058

Evapotranspiration data was calculated for mid and end century scenarios (Figure 17).

Table 18 PET values for future scenarios

Month	Mid-century PET Rate (mm/month)	End-century PET Rate (mm/month)
Jan	18.0	25.3
Feb	31.0	41.5
Mar	64.2	73.6
Apr	101.8	117.1
May	135.0	148.5
Jun	162.7	177.5
Jul	173.8	189.6
Aug	154.7	163.5

Month	Mid-century PET Rate (mm/month)	End-century PET Rate (mm/month)
Sep	108.0	120.3
Oct	63.6	68.4
Nov	31.3	36.0
Dec	17.1	22.4

- Mid–Century (2020-2050)

As a general description of the simulation, changes from high to low peaks can be seen in moisture deficit, soil gets saturated and emptied with more frequency compared to how it was in the past, this could be due to meteorological changes, like higher temperatures during 2020 to 2050 (Figure 12), but, in the opposite side, precipitation rates remain very similar to past scenarios with an average around 500mm/yr (Figure 10), hence, infiltration and percolation rates are also similar to past scenarios. Percolation presents a better distribution during the 30 years of simulation, when compared with past scenario that only had percolation happening after 2002.

Implementing the drought threshold assumed in past conditions scenario, a total of 19 hydrological droughts could be expected in the near future years, which compared to past scenarios is increased to double the number of events. Therefore, if precipitation is almost the same, possible explanations for future droughts increment could be the increment of temperature and evapotranspiration in the Jiet area.

- End–Century (2070-2100)

This last scenario compared with past and mid-century, can be classified as the most critical one, Figure 32 gives a clear representation of how the flow peaks decrease through time, as well as precipitation events and infiltration, highest precipitation rates happened during the first years of the scenario, then, as shown in Figure 11, precipitation starts to decrease until year 2100 whit some fluctuations above the average in between which can also be seen in Figure 32. Moisture deficit is at its maximum value almost during the whole simulation and percolation is projected to be practically absent.

Analysing the discharge values with the threshold of $0.1m^3/s$, 26 hydrological droughts are predicted to happen along all the simulated years which is 3 times the number of droughts presented between 1990 and 2020.

Final results of simulations made to calculate the number of hydrological droughts modelling the catchment with HEC-HMS, are shown in Figure 30. Perhaps a light comparison can be done between number of events from the model and the number of droughts calculated for SPI 12 (Figure 21), which also represent hydrological droughts in the area. Although the number of events are not the same, they are not very far apart and their incremental rate is also similar

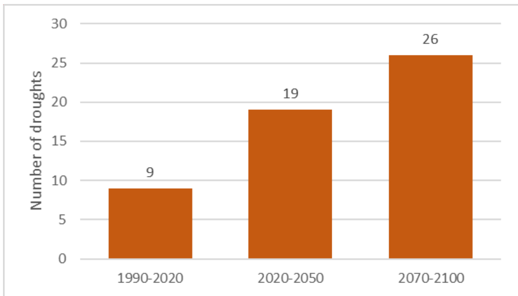


Figure 30 Number of droughts simulated in HEC-HMS for all scenarios

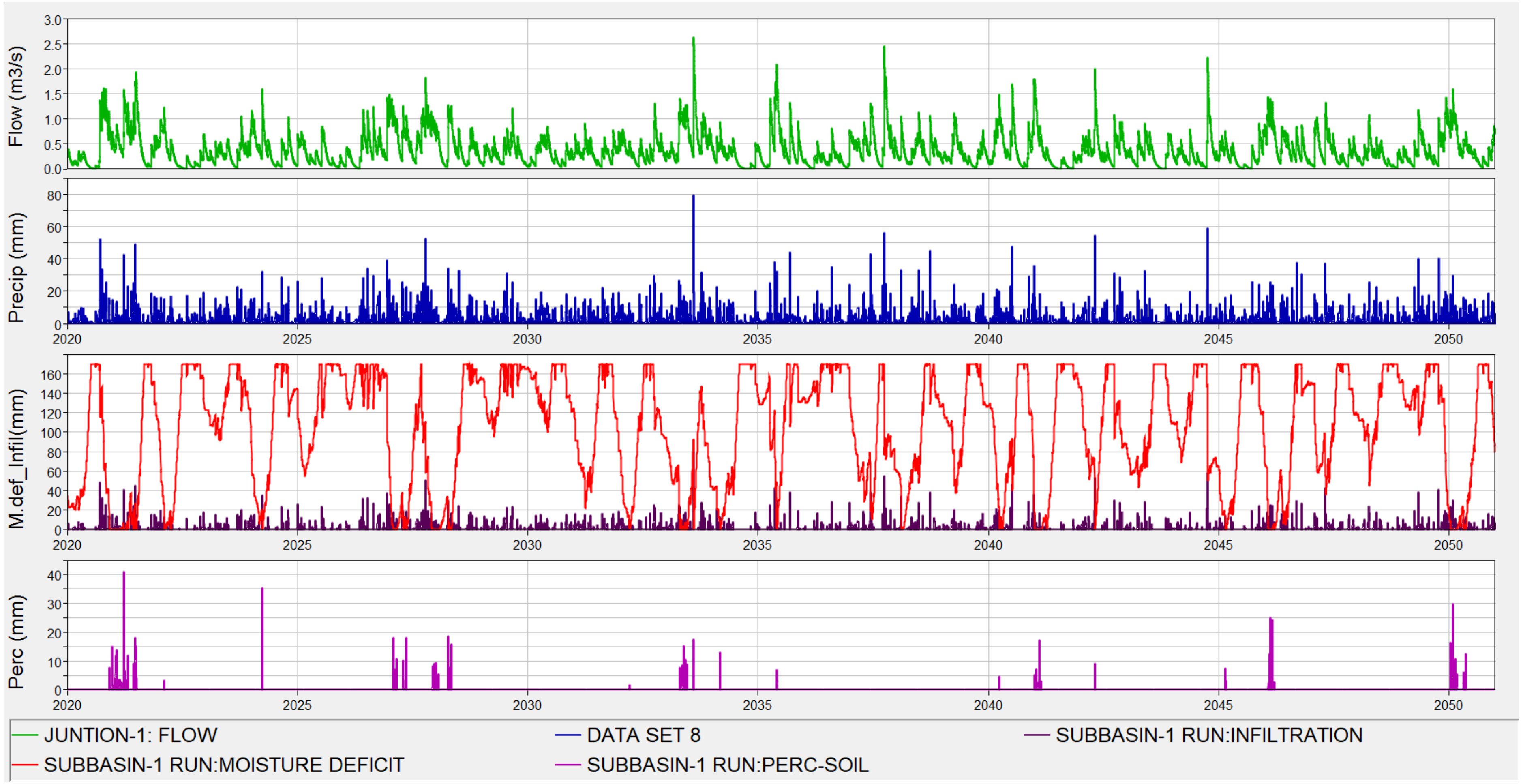


Figure 31 Simulation Mid-century 2020-2050. Results. Plots for measured and calculated flow, precipitation, moisture deficit, infiltration and percolation for calibration and validation of HEC-HMS model

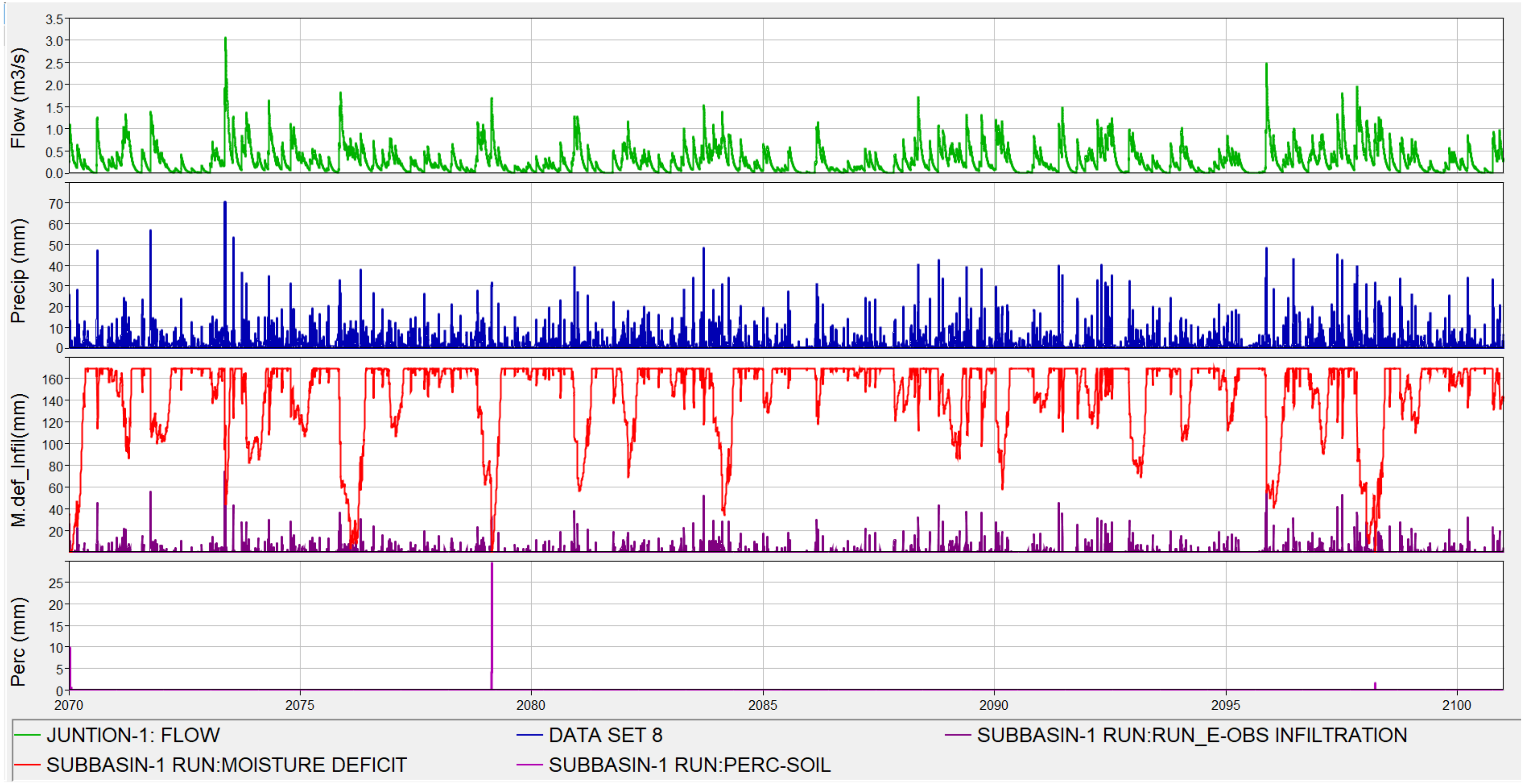


Figure 32 Simulation End-century 2070-2100.Results. Plots for measured and calculated flow, precipitation, moisture deficit, infiltration and percolation for calibration and validation of HEC-HMS model

6. Conclusions and recommendations

- Years identified to have droughts in past scenarios with SPI method were 1992, 1993, 1994, 2000, 2001, 2002, 2012, 2019 and 2020. Identified years with the HEC-HMS model were, 1990, 1992, 1993, 1994, 2000, 2001, 2002, 2003, 2004, 2008, 2011, 2012, 2017, 2020. When comparing SPI and HEC-HMS values with historical data and results from the GDM, the results are more or less the same, although identified years with the model aim more to cover dry years that were close to droughts and years when droughts occur.

- Present and future conditions in Jiet point to become very dry, especially in the end-century scenario, when droughts are projected to increase two to three times in number. Simulations and projections show that the values of surface water and soil moisture would fall to very low values, affecting further the agriculture, the water sources, the economy and social fields of the area.

- The current hydrological drought conditions in the basin were possible to analyse and assess using the meteorological conditions present in the Jiet in the SPI method. Meteorological data provided a very good base to be able to carry out hydrological analysis in the basin, and also, most of the hydrological cycle basically depends on precipitation, temperature and evapotranspiration. Therefore, meteorological data is very important when calculating and analysing hydrological droughts.

- Hydrological droughts for both methods had the tendency to increase in the future scenarios. HEC-HMS gave the higher number of events, with differences of 2 events from past scenario, 7 events for mid-century and 3 events for the end-century scenario.

- Both methodologies simulate higher density, intensity and prolonged agricultural and hydrological droughts, which are projected to happen in the mid-century and end-century scenarios.

- Previous Jiet catchment studies are very few, most assumptions and analysis had to be done from neighbour catchments and plains. It would be good to make more studies over the area to know it more, and understand the current and coming issues related to droughts.

- The analysis of droughts due to climate change was achieved, using historical and projected meteorological data. For past scenarios, it was possible to understand and identify the usual rates of precipitation, temperature and evapotranspiration in the area, making it possible to have the basis of comparison for the projected results, to then carry out, the analysis for mid-century and end-century.

- A closer analysis of assessment of droughts was possible using both methods, but the HEC-HMS model obtained from this research is still a gross simplification of the catchment hydrology, and has to be considered as a first step of future analysis over the Jiet and not as a whole truth. Different methods and better quality of data for calibration can be used to improve the model, especially for the projection of droughts.

6.1. Assumptions and limitations

6.1.1. Assumptions

- Precipitation data used for the SPI analysis is the average of the total precipitation for the whole area, data from each grid point was summarized and then divided into the number of points of the grid.

- For the case of precipitation data used as input in the HEC-HMS model, the grid points were assumed as stations, next, with the Thiessen polygon analysis, the number of stations was reduced considering only the ones having a direct influence on the catchment.

- Assumptions about precipitation data assumed for SPI and HEC-HMS model were possible due to the similarity in precipitation events from point to point explained in Appendix A.

6.1.2. Limitations

- There was not enough data for developing the soil moisture account, the method could not be used in the model due to the quantity of assumptions it would have implied and uncertainties that could have follow after.

- Manual calibration had to be done in the model due to the uncertainties and quality of discharge data. Measured discharge trend is not what it was expected, the values were increasing as the precipitation is decreasing which has no sense. A possible explanation for that behaviour could be related to, uncalibrated instruments, change on the location of the flow measurement station or more influence of discharge from the Danube river over the station than from the Jiet river.

6.2. Recommendations

- For future analysis an improvement of the HEC – HMS model can be done using for calibration and validation, meteorological and discharge data from stations in the catchment with better quality and resolution. Additionally, add information about groundwater and soil moisture will get a closer look to Jiet's behaviour.

- Further analysis with different types of models can be used for a deeper analysis of droughts, as shown in Table 19, good and certificated data with different resolutions from different organizations can be used with that purpose.

- Include aridization progress in the area in the model, to have better projections of droughts in the catchment.

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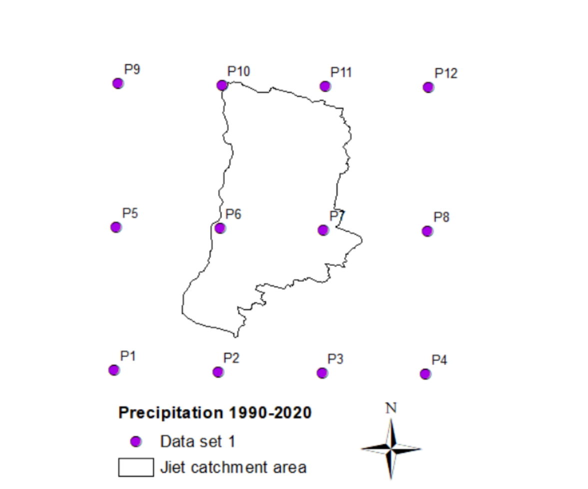
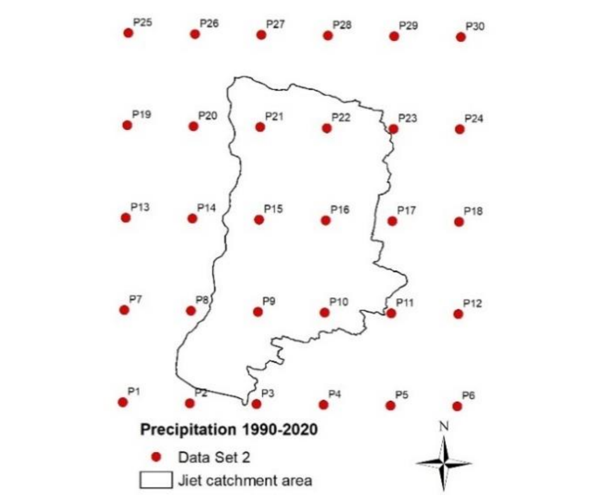
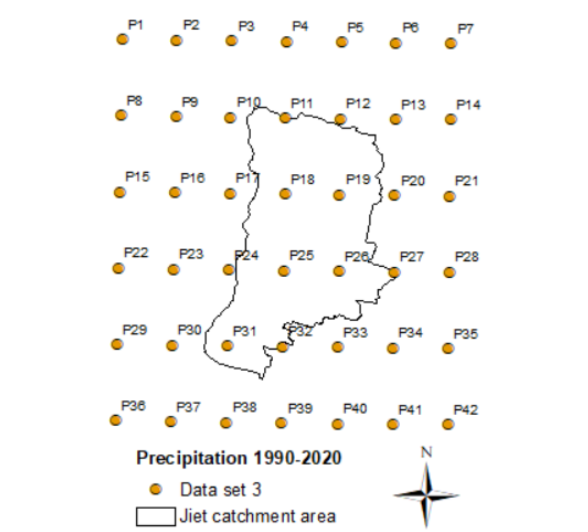
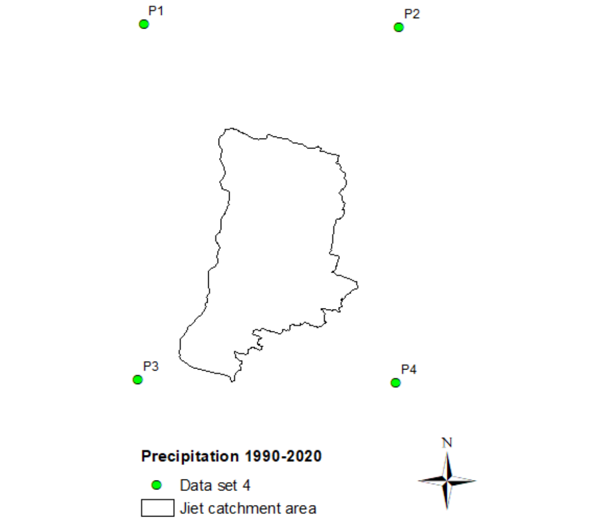
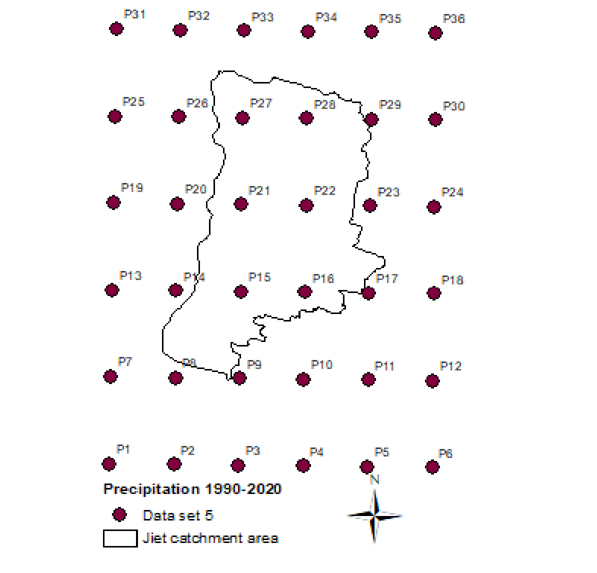
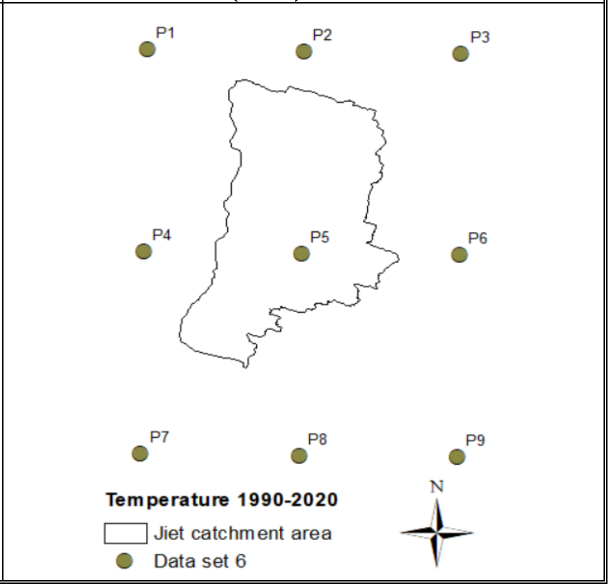
Appendices

Appendix A - Data set analysis

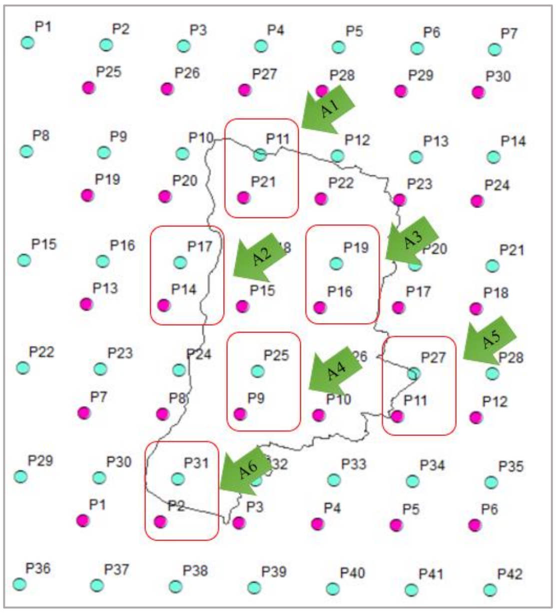
In Chapter 4 of this research, sources from downloaded data sets are mentioned. Downloaded information for precipitation for past scenarios have 4 different resolutions, that cover the Jiet's area as shown in Table 19 below. Data with resolution below 0.1°, was discarded, which means data sets number 1, 4 and 5. Further, data set number 5 only was available from the year 2000 until 2020, which was not enough, because the whole analysis of past scenarios also include data from 1990 until 1999, for that reason, data set number 5 was not considered further.

Table 19 Past Scenarios-Precipitation data sets comparison

Data set 1: (C3S) Res=0.2° x 0.2°	**Data set 2**: (C3S) Res=0.1° x 0.1°
	
Data set 3: (C3S) Res= 0.1° x 0.1°	**Data set 4**: (PSL) Res= 0.5° x 0.5°
	

Data set 5: (Giovanni) Res= 0.1° x 0.1°	**Data set 6**: (C3S) Res=0.25°x0.25°
	

Data set number 2 and data set number 3, were then the last alternatives for precipitation sources to be used in the analysis of droughts. To choose which data set was more accurate for the methodologies used in the research, different comparisons and analysis had to be made. First, an overall comparison of annual precipitation data for both data sets was made in chapter 4.1.1 and Figure 4. Second, 6 different pairs of near points from both data sets where chosen, trying to cover the total of the region, as seen in Figure 33.

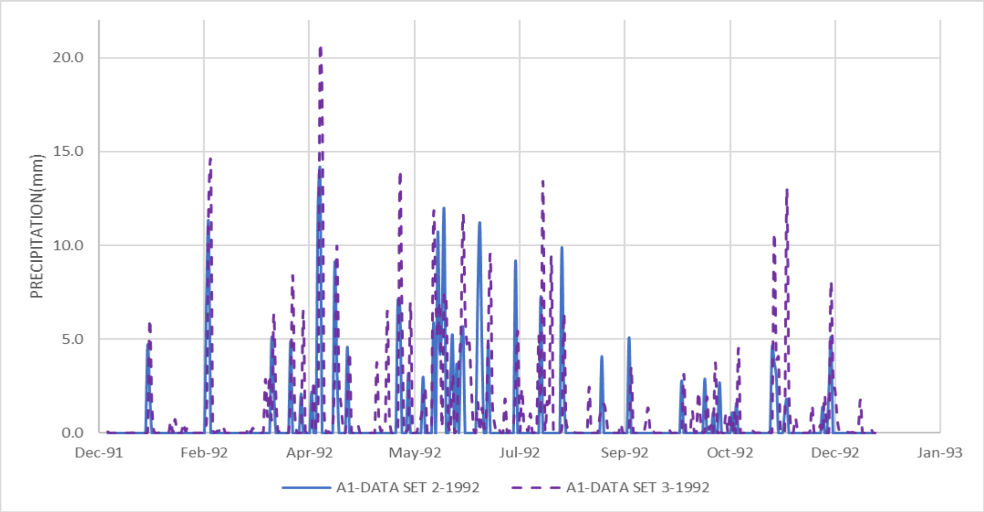


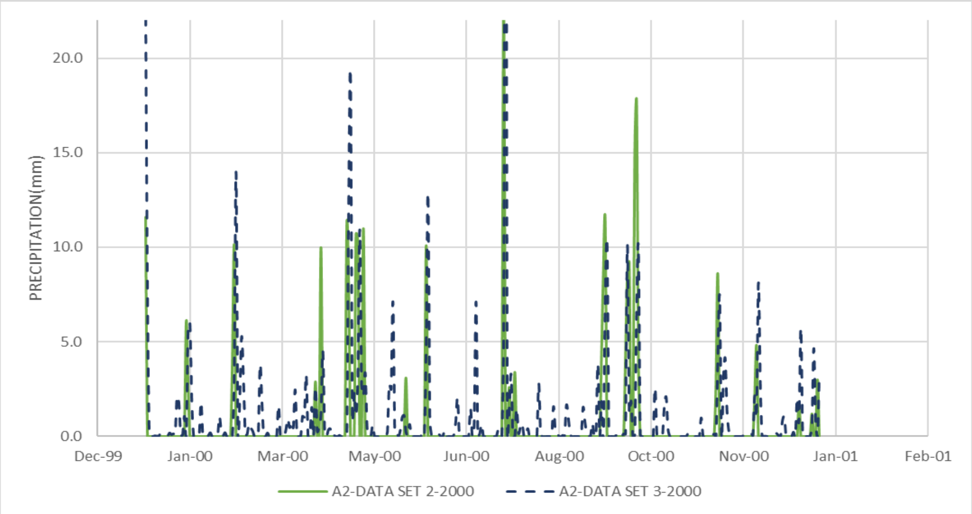
Analysis locations	Data set 3	Data set 2
A1	P11	P21
A2	P17	P14
A3	P19	P16
A4	P25	P9
A5	P27	P11
A6	P31	P2

Figure 33 Analysed precipitation points from data set number 2 and 3

Daily precipitation data was downloaded for 30 years, hence, making an analysis and comparison of that big amount of data would imply a lot of time and machine memory. To make a reliable and shorter comparison with a good analysis and results, the drought years identified in literature and from the global drought monitor (Beguería, et al., N.D.) were analysed for the 6 couple of points selected above. Years selected were 1992, 2000, 2007, 2012 and 2020.

The following graphs, represent the daily precipitation for one year with droughts and in a different location within the Jiet shown in Figure 33. The graphical analysis was not done for locations A1 to A6 for every year, only one location was plotted per year except for year 2020, which has plots for locations A3 and A6 because it was the driest year identified. This was done in this way, because the data behaves very similar, hence, there is no point in making that many plots.





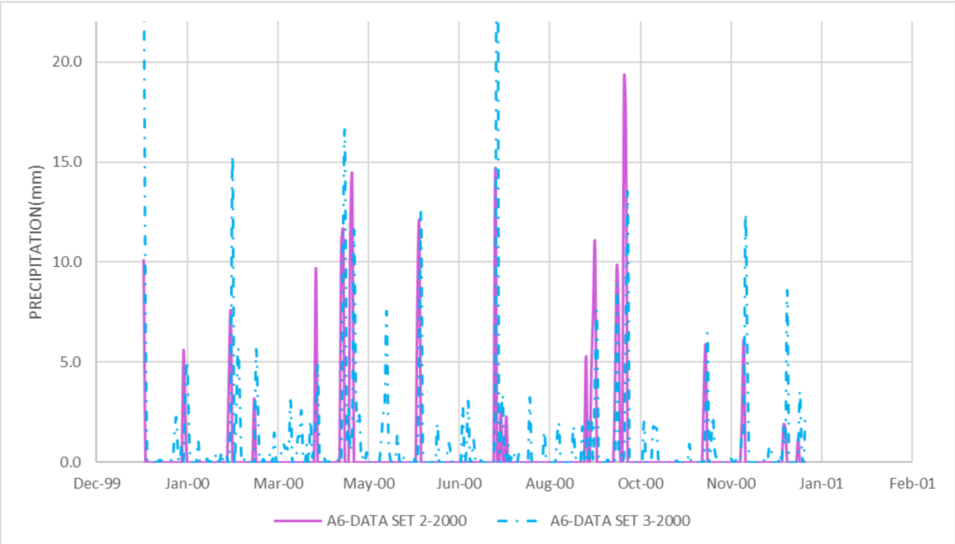


Figure 34 Daily precipitation comparison between data sets 2 and data set 3 for different drought years iiat different locations

From the charts shown above, is seen that both data sets behave very similar during all selected years. High and low peaks occur during the same periods and the difference in magnitude of precipitation also does not differ much from one data set to the other. Most pronounced differences were identified during 2000 when data set number 3 has more peaks while data set number 2 is practically zero.

The statistic values calculated for drought years in the different localizations for data set number 2 and 3, were the standard deviation, the variance, the median and the average od the precipitation. Average values for all years were very similar, being data set number 3 always the data set with higher numbers, except for the year 2007 when the average for both data sets were almost the same. Variance values had the same trend, being years 2000 and 2012 the years with bigger differences between data sets and in year 2000, the higher values were presented for data set 2.

Table 20 Statistical values for localization A1 to A6 for the year 1992

1992	A1	A2	A3	A4	A5	A6
Average						
Data set 2	0.73	0.71	0.75	0.75	0.74	0.77
Data set 3	1.21	1.31	1.24	1.32	1.26	1.38
Standard deviation						
Data set 2	2.16	2.14	2.21	2.23	2.24	2.25
Data set 3	2.83	3.04	2.91	3.05	2.92	3.20
Variance						
Data set 2	4.67	4.59	4.9	4.97	5	5.007
Data set 3	7.98	9.25	8.44	9.33	8.53	10.25
Median						
Data set 2	0	0	0	0	0	0
Data set 3	0.03	0.03	0.02	0.02	0.02	0.02

Table 21 Statistical values for localization A1 to A6 for the year 2000

2000	A1	A2	A3	A4	A5	A6
Average						
Data set 2	0.76	0.68	0.71	0.61	0.67	0.65
Data set 3	1.11	1.12	1.11	1.11	1.1	1.09
Standard deviation						
Data set 2	2.84	2.58	2.62	2.47	2.55	2.51
Data set 3	3.51	3.39	3.45	3.41	3.42	3.28
Variance						
Data set 2	8.04	6.64	6.87	6.12	6.48	6.31
Data set 3	12.31	11.48	11.91	11.65	11.66	10.76
Median						
Data set 2	0	0	0	0	0	0
Data set 3	0.04	0.04	0.04	0.04	0.04	0.03

Table 22 Statistical values for localization A1 to A6 for the year 2007

2007	A1	A2	A3	A4	A5	A6
Average						
Data set 2	1.77	1.70	1.75	1.72	1.75	1.73
Data set 3	1.7	1.73	1.67	1.72	1.66	1.75
Standard deviation						
Data set 2	4.49	4.24	4.22	4.11	4.04	4
Data set 3	4.05	4.05	3.86	3.93	3.78	4
Variance						
Data set 2	20.17	17.94	17.82	16.89	16.33	16.02
Data set 3	16.41	16.41	14.92	15.48	14.30	16.04
Median						
Data set 2	0	0	0	0	0	0
Data set 3	0.03	0.03	0.03	0.03	0.03	0.02

Table 23 Statistical values for localization A1 to A6 for the year 2012

2012	A1	A2	A3	A4	A5	A6
Average						
Data set 2	1.20	1.21	1.17	1.17	1.18	1.11
Data set 3	1.54	1.61	1.55	1.61	1.53	1.62
Standard deviation						
Data set 2	3.12	3.07	3.03	3.02	3.03	2.96
Data set 3	3.61	3.88	3.69	3.92	3.74	4.06
Variance						
Data set 2	9.76	9.41	9.15	9.09	9.21	8.78
Data set 3	13.04	15.07	13.6	15.37	13.99	16.46
Median						
Data set 2	0	0	0	0	0	0
Data set 3	0.05	0.05	0.05	0.04	0.06	0.05

Table 24 Statistical values for localization A1 to A6 for the year 2020

2020	A1	A2	A3	A4	A5	A6
Average						
Data set 2	1.22	1.21	1.19	1.17	1.18	1.17
Data set 3	1.66	1.68	1.64	1.65	1.58	1.59
Standard deviation						
Data set 2	3.43	3.34	3.26	3.23	3.16	3.21
Data set 3	3.78	3.81	3.69	3.7	3.52	3.50
Variance						
Data set 2	11.78	11.17	10.61	10.43	9.96	10.29
Data set 3	14.31	14.48	13.63	13.7	12.37	12.28
Median						
Data set 2	0	0	0	0	0	0
Data set 3	0.06	0.05	0.04	0.05	0.05	0.05

Among all years, the values for both data sets are statistically very similar, one possible criteria for choosing one data set, could be to select the one with the lower rates of variance for the majority of the analysed years, which in this case is data set number 2.

Appendix B - Research Ethics Statement

The following is the statement of research ethics for my research, *Use of SPI and hydrological modelling to analyse the climate change effects on droughts: case study of the Jiet catchment in Romania.* This statement is done entirely by myself, voluntarily and without intermission of others.

About the research design, the research topic comes from the collaboration within the framework of Blue Deal with DWA and Romanian Waters, Jiu Administration, which seek to know, how river basin management plans can be improved. Aim set by the water framework directive. The scope of the research is to analyse drought events due to climate change in the Jiet catchment. To develop in a satisfactory way my research, I got information of physical characteristics (land use, land cover, digital elevation model data), discharge data of one station in the outlet of the Jiet river, a previous report with detailed characteristics of the Oltenia plain, which covers the area of the Jiet and shape files with information of the location of the Jiet, location of reservoirs and the protected areas covered by Natura 2000. Additionally, I gather all possible and available data from different papers, from which after reading it, I adopted similar assumptions for my study. The first research method included in the research design, was a model made in HEC-HMS, but after analysing the available data given to me and founded in the literature, together with my mentors and supervisor, the SPI method was chosen to be calculated as an extra reliable analysis for the droughts occurring in the Jiet. My research is scientific and its results are beneficial for Romania.

About the conduct research of my work, all my hypotheses are supported by previous studies and literature, and uncertainty of the procedures was also considered while developing the methods and the analysis done, follows the exact procedure described in the methodology. The results of the analysis of droughts due to climate changes in the past, present and future, which is the main objective of my research, has a level of uncertainty mentioned in the document, for each method used in the calculations that depend on the input data. For this research, meteorological past and projected data was downloaded from official institutes that provides free information, all institutions and type of data used for the research is referenced and named accordingly. For the data processing, I improved my knowledge in python scripts which allowed me to organise the downloaded information in order to feed the parameters to the calculation of drought events. Besides, in general my knowledge about the methodologies used in the research increased, amplifying my knowledge as well in everything related to understand what is a drought, what are its causes and consequences.

The analysis results were first analysed for past scenarios and compared with historical data from different sources to check the uncertainty and to make a proper calibration of the models in order to have accurate results from the SPI analysis and the model made in HEC-HMS. Results obtained in this research are and approximation and estimation of real scenarios, meteorological events or physical conditions of the Jiet, could change due to different factors, hence, obtained data has to be taken as such. All the necessary information to make the calculations for droughts is clearly explained in the document. The results obtained in this research could be used in the future to create knowledge about droughts in the area and regions with similar characteristics, to create or improve plans of mitigation. The results do not have any personal interest.

Regarding assessment & peer Review, all previous, partial and final results were discussed in regular meetings with mentors and supervisor from IHE, to whom I acknowledge and mention in my document. Additionally, meetings with different members involved in the research from the Dutch authorities and Romanian waters were held to explain partial results and progress. I avoided supporting or using journals that do not follow quality and ethical standards.

Regarding communication of Research, all my discussions and conclusions are based on my analysis and calculated simulations of the models, everything has evidence of how was done and the results obtained. I wrote my report and results in a very accurate way, without omitting anything, considering academic writing, as well the standards and requirements of the institute, using the best possible English and improving it, by reading a lot of literature review from the same topic and rewriting some of things that were not enough clear. I did not introduce any personal biases in my research, all assumptions have their own support. And finally, the entire document was intended to be written as clear as possible. Hence, anyone who reads this research in the future, could understand the main idea, assumptions, limitations, methodologies, work done and results obtained for the droughts due to climate change in different times frames in the Jiet.

As for promoting ethics, I always gave honest and all my opinions when feedback was asked, trying to be as accurate as possible to be understood of what I wanted to say, always maintaining the principles to follow the scientific methods. I will always try to maintain an honest and clear attitude to cooperate with other colleagues or organizations and if conflicts or doubts merge, I will try to deal with them in a professional way, always looking at the problem with academic eyes and from an impartial point of view. All possible errors published with the research, must be acknowledge and disclosed properly.

This research had founding from the Dutch authorities, distributed within the 6 months, that took to develop the research. The work is intended to know more about the Jiet catchment and its possible response and vulnerability facing droughts.

In conclusion, all the work done is based on self-work that had regular feedback from mentors and supervisors. All results, discussions and conclusions were not copied from others. There are no conflicts of any kind. And finally, this research did not involve human or animal subjects.

Appendix C - Research Ethics approval

United Nations Educational, Scientific and Cultural Organization
IHE DELFT Institute for Water Education under the auspices of UNESCO

Research Ethics Committee
IHE Delft Institute for
Water Education
E ResearchEthicsCommitee@un-ihe.org

Date:	2022-03-02
To:	Cindy Dayana Beltran Mora
MSc Programme:	HI
Approval Number:	IHE-RECO 2021-231

Subject: Research Ethics approval

Dear Cindy Dayana Beltran Mora

Based on your application for Ethical Approval, the Research Ethics Committee (RECO), IHE Delft RECO gives ethical clearance for your research topic Use of SPI and hydrological modelling to analyse the climate change effects on droughts: Case study of the Jiet catchment in Romania.

This approval valid until April 19, 2022. Please notify the RECO if your research protocol is modified in any way. If you do not complete your research by the specified date, contact RECO to request an extension for the ethical clearance.

Please keep this letter for your records and include a copy in the final version of your MSc. thesis, together with your personal ethics reflection.

On behalf of the Research Ethics Committee, I wish you success in the completion of your research.

Yours sincerely,

Dr. Angeles Mendoza Sammet
Coordinator, Research Ethics Committee IHE Delft

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