Reconstructions of Droughts in Germany since 1500- combining hermeneutic information and instrumental records in historical and modern perspectives

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Abstract. The present article deals with the reconstruction of drought time series in Germany since 1500. The reconstructions are based on historical written records from the virtual research historical climate and environment environmental database tambora.org, early and official instrumental records.instrument data as well as precipitation and temperature indices. The historical records and recent data were related with each other via modern indices calculations, drought categories and their historical equivalents.

Historical and modern written documents are also taken into account to analyse the climatic effects and consequences on environment and society. These pathways of effects are derived and combined with different drought categories.

The derived Historical Precipitation Index (HPI) is correlated with the Standardized Precipitation Index (SPI). Finally, a Historical Drought Index (HDI) and a Historical Wet Index (HWI) are derived from the basic monthly hygric indices (PI) since 1500. Both are combined for the Historical Humidity index (HHI). On this basis, the long-term development of dryness and drought in Germany since 1500, as well as mid-term deviations of drier and wetter periods and individual extreme events are presented and discussed.

From the historical descriptions of the weather climatic processes and their effects and consequences for the environment and society, action paths and drought categories are derived. Furthermore, a historical precipitation index (HPI) is calculated and correlated with the SPI index. These are correlated and quantified in a rating scheme with modern rainfall indices and recent drought categories. Finally, a Historical Drought Index (HDI) and a Historical Wet Index (HWI) derived from the hygric indices are presented.

On this basis, the long-term development of dryness and drought and significant accumulations and extremes in Germany since 1500 are discussed.

Keywords:

Historical Drought Index, Historical Humidity Index, Pathways of Effects, Extreme Droughts

Historical Wet Index, Drought, SPI, Pathways

1 Introduction

In Central Europe exceptionally extreme droughts such as in 2018, 2015 and 2003 have occurred quite often in recent years (Erfurt et al. 2019, Blauhut et al. 2015a, b, 2016). The comparatively dense sequence raises the question to what extend this is another indicator of climate change. The overall damages add up to billions, with agriculture and forestry being primarily affected. Ongoing droughts also have negative consequences on water balance and water supply, ecology, economy and society. Over the last years, health issues as well as the impacts on infrastructure and transportation have been discussed (Kreibich et al. 2019, Bachmair et al., 2016, Stagge et al., 2013, 2015, Van Dijk et al., 2013).

Exceptional dry periods and long lasting drought events such as 2018, 2015, 2010 and 2003 have occurred in central Europe in recent years. The comparatively rapid consequence raises the question of how far this is another indicator of climate change. The consequential damages are in the billions, whereby primarily agriculture and forestry, but also water management is affected. More and more, the focus is set on the negative consequences onto environment and society, regarding health effects likewise heat stress, or the negative consequences on infrastructure and transportation (Kreibich et al. 2019, Erfurt et al. 2019, Blauhut et al. 2015a , b , 2016, Bachmair et al., 2016, Stagge et al., 2013, 2015, Van Dijk et al., 2013).

In addition to many climatological, ecological and social specifications, long-term reconstructions of droughts are helpful for a better, more holistic understanding.are necessary for comprehensive risk assessments. They contribute significantly to answering questions about long-term trends,

accumulations, recurrence times and the variability of extreme events. There is also evidence about societal contextualisations, especially the impacts and responses on environment and societies, which have changed fundamentally through time (Erfurt et al. 2019).

accumulations and recurrence times.

Droughts are generally referred to as a periods of extremely dry weather that persists long enough to cause a severe deficit in the water balance, which in turn causes environmental and social impacts and damages (Wilhite & Glantz 1985, Glaser & Erfurt 2019). From a statistical point of view, a drought is an exceptional event with a rare recurrence probability (Benestad 2003). According to a widely used scheme, droughts are subdivided into four types that reflect their chronological development: Basically, according to a widely used scheme, droughts will be subdivided into four types that reflect the time course: The A meteorological drought describes a period of considerable precipitation deficit, usually in comparison with a reference periodcomparable period. High air temperatures and wind speeds, more intensive solar radiation and cloudless skies freedom from clouds can aggravate the precipitation deficit (Wilhite & Glantz 1985). With continued duration, restrictions on the amount of plant-available soil water is reduced, andwith negative initial effects on plant growth ansas well as harvest yields development may occur. In this case, we speak of it is named an agricultural drought (Bernhofer et al., 2015). If the drought continues to progress, reduced surface runoff, sinking water and water levels and ultimately sinking groundwater levels occur -, the a so-called hydrological droughts, occurs. Lastly,At extremely extremely low groundwater levels or baseline flows are referred to as groundwater droughts.low groundwater levels or baseline flows, it is called a groundwater drought. Additionally, tThe term sSocio-economic drought is used, when it comes to impacts on people and the environment. The degree of severity depends on the needs assets,of the people, but also on the equipment, the adjustment options and the resilience of the affected society (Wilhite & Glantz 1985, McKee et al 1993).

Droughts can be defined numerically according to very different criteria, which result in corresponds to the a large number of indices. They differ in the type of input data, the temporal and spatial coverage and the consequences for different sectors. While tThe input data used for the meteorological droughts are temperature and precipitation, data. Aassessments of hydrological droughts are based on gauging data, groundwater levels and runoff. The timeframes temporal reference ranges from days over weeks and months to years (Bernhofer et al., 2015)., Similarly, the size of the study area the spatial relationship also varies according to the question.

Common drought indices include the Standardized Precipitation Index (SPI), the Standardized Precipitation Evapotranspiration Index (SPEI) and the Palmer Drought Severity Index (PDSI). In the US, the PDSI is the most common drought index, , which is also used ~~and also~~as the basis for the US Drought Monitor (Palmer 1965 , McKee et al 1993, Vicente-Serrano et al 2010, Zargar et al 2011, Svoboda et al 2012). T~~In t~~he German Drought Monitor (Dürremonitor Deutschland) represents~~,~~ the current monthly status of the soil ~~is represented~~ in five drought~~y~~ categories~~lasses~~ (Zink et al 2016, DWD 2019). Moreover, drought assessments also examine ecological and social consequences ~~Beyond the indices, the consequences are also taken into account when assessing drought~~ (Stahl et al., 2016).

The strengths and weaknesses of the SPI are widely discussed in literature (Briffa et al 1994, Cook et al 2015). Cook et al. (2015) or Mikšovský (2019) for example used the more complex scPDSI, which needs inter alia soil water information and additional temperature data. The present study is based on the SPI because of its wide distribution, simple calculation and its ability to integrate historical events.

Numerous studies on droughts with an explicitly historical perspective have been presented in recent years, for example by Gil-Guirado et al (2019), Brazdil et al. (2018, 2019) and Erfurt et al. (2019), implementing a wide range of content and methodological aspects. The spectrum ranges from analyses of outstanding individual years (Wetter et al., 2014) and the derivation of regional time series in different climatic zones (Noone et al 2017, Kiss 2017, Dobrovolný et al., 2018, Nash et al., 2019) to a focus on drought effects (Glaser et al., 2017).

The aim of the present contribution is the reconstruction of long-term drought time series in Germany since 1500 baesd~~on the basis of~~on written records. For this purpose, a rating scheme was~~is to be~~ developed in order ~~which makes it possible~~ to correlate recent parameters and criteria of drought valuations with historical ones. For this purpose, various drought indices and drought categories ~~are~~ were derived~~developed~~ and evaluated. The long-term development ~~should be evaluated~~was assesed, ~~in~~ particularly the question to what extent the current developments differ from the previous phases.

2 Data

The analysis is based on two main ~~he~~ comprehensive data sets. The first data set – available ~~-on weather, weather and climate as well as their consequences on the environment and society in Germany, as they are available~~ in the historical climate and environmental database tambora.org (tambora.org, Riemann et al. 2016, Glaser et al. 2018) - consists of written documents related to weather and climate as well as the impacts and consequences on the environment and society of Central Europe. The second, modern data set comprises official precipitation data for Germany from 1881 onward.~~.~~

The approximately ~~280~~330,000 historical records in *tambora.org* for Central Europe ~~relevant to Germany~~ are ~~written documents~~ taken from weather diaries, chronicles, pamphlets, official reports and newspaper~~-reports~~. ~~These are supplemented by oth~~Other~~er~~ media such as flood marks, hunger stones, pictures and lyrics supplement these.

The 330,000 coded records in *tambora.org* are represented as blue dots in Fig. 1, while the red dots represent the 54,000 records indicating precipitation and specific information regarding dryness and droughts. Additionally, the green dots indicate the 12,600 records describing the impacts and consequences of dryness, drought and lack of precipitation. Such descriptions include water shortages, low water levels of larger rivers, fish kills, forest fires, emergency slaughteries, crop failures or prayers for rain. In total, the information covers large parts of Central Europe. The southwest and the center as well as the eastern parts of Germany are particularly well depicted, but also the larger river systems such as Main, Rhine and Elbe. Additionally, the spatial distribution concentrates around the cultural, political, economic and religious centers such as Nuremberg, Cologne, Leipzig, Erfurt, Hamburg and Mainz as well as other larger cities and monasteries. The coastline is also well represented, specifically the harbour locations like Hamburg, Lübeck and Rostock. Temporal coverage is very good, with information for every month since 1500. As expected, average and inconspicuous months are less documented than more extreme ones. Periods for which daily, systematic information from weather diaries is available have correspondingly denser assignments (see also Glaser & Riemann 2009).

The information covers the German area well (Fig.1). All written sources were processed according to the methods used in historical climatology (Pfister 1999, Brazdil et al., 2005, Glaser 2013).

[Fig. 1: Spatial distribution of information in tambora.org]

All records in tambora.org are numerically coded, comprising spatial, temporal and content aspects. In addition to the coded events, the original text quotes are also included in the database so that the overall context and the coding can be retraced for each record. Revised and supplemented precipitation indices are available from 1500 to 1995 (Glaser 2013, Glaser & Kahle 2019).

Additionally, there are early precipitation measurements and derived drought indices from 1800 onward (Erfurt et al. 2019).

The information in tambora.org is coded, especially the spatial, temporal and content aspects are classified into numerical codes. The information relevant for the analysis of dryness and drought events, in particular the temperature and precipitation information are completely available from 1500 onwards as seven-level monthly indices (Fig. 2). In addition, hydrological extremes, in particular high and low water as well as phenological hints are available. In addition to the drought events there are many descriptions of the impacts on the environment and society. In addition to the coded events, the original text quotes are also included in the database so that the overall context and the coding can be traced at any time. The sources of drought are extremely varied and differentiated. For example, in the 123 sources for the Drought Year 1540, 41% of the data refer to agriculture, 17% to water, 11% to health, 10% to forest fires, 8% to soil and 8% to the environment and ecosystem. Basically, outstanding drought events are documented by particularly many and differentiated sources. Particularly well-documented events of the century include 1540, 1503 and 1534, 1615 and 1616, 1669 and 1684, and 1718 and 1719, 1834, 1842, 1865 and 1893, 1921, 1949, 1959, 1976, 2003 and 2018.

[Fig. 1: Spatial distribution of all records referring to Central Europa in *tambora.org* since 1500 (blue), precipitation, dryness and drought records (red), and impacts and consequences (green).]

The data relevant for the analysis are consistently available from 1500 onwards as classified monthly hygric indices using a seven-level scale (PI) (Fig. 3).

The monthly PI reveals a differentiated picture of drier and wetter periods since 1500.

In general, a particularly large number and higher differentiation of sources document outstanding drought events. One example is the drought year 1540, where 41% of the 123 sources refer to agriculture, 17% to water, 11% to health, 10% to forest fires, 8% to soil and 8% to environmental and ecosystem issues. Other ouitstanding drought events are in the 16th century the droughts of 1534, 1536, 1540 and 1590. In the 17th century 1615, 1616, 1632, 1635, 1669, 1684 and 1685 had been described as exeptional dry. The same for 1718, 1719, 1742 and 1749 during the 18th century. While in the 19th century, the years 1834, 1842, 1858, 1865 and 1893 are reported as drought years. For the 20th century this was the case in 1921, 1949, 1959 and 1976 and finally in the 21st century in 2003 and 2018.

The second, modern data set used for the analysis consists of the official precipitation data for Germany from 1881 onward. These values, recorded, averaged and provided by the DWD (Deutscher Wetter Dienst, the official German Weather Service) from the national official network stations, respresent the area of modern-day Germany. This study also draws upon the official drought categories D0-D4 and their definitions by the DWD (2019).

In addition, from 1881 onward the official precipitation data for Germany can be used. From 1800 onward early precipitation measurements and derived drought indices are available (Erfurt et al. 2019) as well as the revised and supplemented precipitation indices from 1500 to 1995 (Glaser 2013, Glaser & Kahle 2019).

[Fig. 2: Summary of the monthly precipitation index (PI) for Germany from AD 1500-2018]

3 Methods

The conceptual design of the analysis is given in Fig.2. It illustrates the single steps and the workflow as a whole. Each individual step is described in the following subchapters in detail.

[Fig. 2: Conceptual design of the analysis, illustrating the workflow and the single steps deriving the specific indices and their relations]

3.1 Derivation of the monthly Precipitation Index (PI) since 1500

The hygric indices (PI) were derived from the written evidence of the *tambora* sources via semantic profiles, a method well established in historical climatology (Glaser 1991, 1996, 2013, Glaser & Riemann 2009, Pfister 1999, Brazdil et al., 2005). Therefore, direct hygric indications as well as the descriptions of impacts and consequences are hierarchically ordered according to their intensity and assigned to the appropriate index value. A seven-scale index scheme, ranging from -3 to +3 with index 0 representing the average situation, has proven to be appropriate for the classification of historical records (Glaser 1991, 1996, Glaser & Riemann 2009, Glaser 2013).

Direct descriptions mostly refer to the absence of rain or the corresponding lack of clouds. In many cases, the duration is also indicated. The documents related to specific consequences describe effects on harvest results, the phaenological and ecological situation, but also hydrological consequences and impacts on economy, society, and their reactions. This correlates very well with the definitions of meteorological, agrarian, hydrological, groundwater and socio-economic drought in modern classifications (NDMC 2018).

Generally, extreme events are represented by a larger number of sources in historical documents. Such information also spans wider areas, especially if the records refer to droughts. Additionally, the information is more detailed and quite often severe events are compared to previous ones. Such long-term memories persist across generations.

The hierarchical class assignment and its typical indicators for the precipitation indices (PI) -1 to -3 are presented as follows:

Index -1 is indicated by descriptions of a beginning rainfall deficit. There are often indications of higher damages relating to the harvest of rain-sensitive products such as hay, vegetables and other garden products.

Index -2 relates to a longer duration of lack of precipitation, prolonged heat and dryness. Average crop losses for main crops are reported as well as low water levels in smaller bodies of water and reduced spring fills. Heat stress on plants, premature leaf discoloration and the death of plant parts are observed, also dry cracks in soils, occasional forest fires and the impairment of infrastructure, for example related to shipping and water mills.

Index -3 represents extreme dryness revealing a chain of effects: After a prolonged period of dryness and heat, the agrarian consequences include severe crop losses and even harvest failures as well as emergency slaughteries due to fodder shortages. If the dryness lasts for weeks, several months or even seasons, there are integrating effects that correpond to reports like low water levels in greater lakes, ponds and larger river systems as well as the drying up of springs and wells. In addition, reports of excessive water shortage and the appearance of "hunger stones" are common. Ecological impacts include a generally visible heat stress of the vegetation, premature leaf discoloration and the withering of plants. In addition, dry cracks in soils, dust veils, dust storms and effects of wind erosion are indicated. There are diverse descriptions of a shift of the phaenological phases, e.g. early flowering, ripening and harvest, but also expression like “wine of the century” indicate dry years. The same is true for reports of forest fires and fish kills. The impairment of infrastructure, especially the termination of shipping and the failure of mills are frequently mentioned socio-economic impacts. The direct consequences for human health and well-being are also documented, e. g. through indications of heat stress and death, increased death rates, the outbreak of epidemics, diseases and hunger crisis due to a lack of food. In addition, the reports include price increases and speculations.

Documented authorities´ reactions range from restrictions and regulations on water access or rationing to the declaration of a state of emergency. Societal reactions like supplications, processions, pilgrimages, increasing irrational explanations and interpretations are quite common. The sources also report begging, moving around in order to seek for food, riots and protests, theft, looting, robbery and social excesses. These integrating effects allow conclusions to the preceding months, and in many cases, the exact dates of meteorological droughts are indicated by the name day of saints.

The indexing process is similar to modern classifications and definitions of drought categories. Such modern drought catgories also take into account the descriptions of impacts and societal consequences and reactions (McKee 1993, NDMC 2018).

Weather diaries with daily records exist for 60 years from the period 1500 to 1800 also on precipitation days (Glaser 1996, Glaser 2013). These records are compared with modern precipitation data on a monthly scale, enabling a comparison of numerical rainfall data with the classified written evidences, which serves as an additional verification of the index levels.

For the numerical records since 1800, we used a classification scheme based on normal distribution, index „0“ reflecting the monthly average with a plus/ minus 0.75 –fold standard deviation. Index „-1“ ranges betwen -0.75 and -1.5 standard deviation, Index „-2“ between -1.5 and -2.25 fold standard deviation and „-3“ below -2.25 standard deviation. The positive indices refer to the appropriate positive ranges. The period 1951-1980 was chosen as reference period. These numerically derived indices were combined with the hermeneutically derived ones.
The positive hygric index correponds to the humid and wet situations and is derived in the same manner. The summary of the monthly PI for Germany from 1500 onward is given in Fig. 3. The data is available via Glaser & Kahle (2019).

[Fig. 3: Summary of the monthly precipitation index (PI) for Germany from AD 1500-2018]

3.2 Derivation of historical pathways and drought categories

The consequences and effects of drought on environment and society recorded in historical sources resemble the structure also observed by recent approaches (Glaser et al. 2016, Brazdil et al. 2016): A precipitation deficit is followed by specific pathway. It first appears on the agricultural, then the hydrological and finally the socio-economic level - a development reflected by modern drought definitions (Nash et al. 2019, Erfurt et al. 2019).

Numerous studies on droughts with an explicitly historical perspective have been presented in recent years, for example by Gil Guirado et al (2019), Brazdil et al. (2018, 2019), Erfurt et al. (2019). A wide range of content and methodological aspects was taken up and implemented. The spectrum ranges from analyzes of outstanding individual years (Wetter et al., 2014), the derivation of regional time series in different climatic zones (Noone et al 2017, Kiss 2017, Dobrovolný et al., 2018, Nash et al., 2019), to the focus on effects (Glaser et al., 2017).

The study presented here examines the extent to which the seven-level historical index scale can be linked to existing, recent quantitative drought classifications. It will also be analyzed to what extent a quantitative estimate of the historical reconstructions can be obtained and, if a comparison with modern developments is possible. The starting point are the parameters and criteria used in the Drought Severity Classification (NDCM) 2018) or the Drought Index of the German Weather Service (DWD 2018). These include drought indices derived from measured data, such as the SPI, the SPEI and the Palmer Drought Severity Index, as well as the assessment of the severity of droughts in the form of drought categories. In addition, effects and consequences are described in short blocks of text. These follow the criteria used in the general drought classifications of an agricultural, then hydrological and finally socio-economic drought. These descriptions and categories include duration information.

~~In the further analysis, the modern descriptions and drought categories are to be related to the historical ones. For this purpose, pathways and corresponding drought categories are derived from the historical sources. Likewise a historical precipitation index (HPI).~~

~~**Determination of modern SPI and mapping of recent drought categories**~~

~~The modern SPI1-SPI12 was calculated from the official precipitation values for Germany 1881 - 2018 (Tab.1, first column). The drought categories and the characterization of the droughts as well as the duration and the description of the consequences were taken over from the scheme of the DWD (DWD 2018).~~

~~**Derivation of historical pathways and drought categories**~~

~~The descriptions of the consequences and effects of drought on the environment and society used in the historical sources follow a structure very similar to recent approaches (Freiburger Zeitung 1834, Pfaff 1846, Brooks & Gkasspole 1922, DWD 1947a, b, Dürr 1986, Glaser et al 2016, Brazdil et al 2016, Nash et al 2019, Erfurt et al 2019). With the duration of the precipitation deficit, cascade-like effects first appear in the agricultural, then the hydrological and finally the socio-economic droughts, as they are also expressed in the drought definitions.~~

These time- and intensity-related chain of ~~cascade~~ effects can be derived from the historical sources as characteristic pathways: First of all, the absence of rain and first signs of dryness and a beginning drought ~~in historical sources~~ are usually described very precisely in historical sources. Often these are provided with time information, especially duration, beginning and end of drought effects. Very often information is given on the phenological phases, ~~in~~ particularly the prematurity of flowering, but also ~~the~~ field cropping and harvest dates (Freiburger Zeitung 1834, Pfaff 1846).~~.~~ With increasing drought, the consequences for agriculture like~~, in particular~~ crop damages and crop failures, ~~in the main crops and failures~~ especially in rain-sensitive horticultural products and hay, are described. As the drought progresses, both the number of descriptions and the differentiation ~~of messages~~ increase, including~~:~~ emergency slaughters for lack of food and the use of~~evidence of~~ emergency reserves~~crops prove the increase~~. At this stage, descriptions ~~Descriptions~~ of the water balance also appear frequently: ~~situation are added at this stage:~~ low water levels in waterbodies, subsidence of spring discharges, drying up of small wells. Effects on the environment such as forest fires, fish dying, algae blooms and various forms of soil degradation such as deflation and dry cracks complete the picture (Brooks & Gkasspole 1922, DWD 1947a, b, Dürr 1986). The explanations are now also supplemented by indications of ~~problems with the~~ infrastructure problems, ~~in~~ particularly regarding ~~the problems with the~~ low water levels and the ~~mill~~ operation of mills. ~~Also, h~~Health consequences are also recorded, including an increased mortality following the outbreak of epidemics, often due to poor water quality. Harvest losses lead to price increases and subsequently to hunger (Nees & Kehrer 2002). ~~such as heat stress and heat death as well as increased mortality from the outbreak of epidemics, often due to poor water quality, are reported. Harvest losses lead to price increases and with further increase to hunger.~~ Religious rites such as prayer services for rain or processions, but also official measures such as water rationing are taken. If the drought persists, the conditions described become more acute. In the historical context, especially after famine crises and epidemics, there are social excesses such as looting, robbery, persecution of minorities and excluded groups of people as well as emigration and migration (Glaser et al., 2017, 2018). Fortunately, these are lacking in the modern context in Europe after 1950. However, ~~the~~ extreme droughts in the post-war period 1947 and 1949 were also accompanied by protests and strikes as a result of the special circumstances ~~in the post-war period 1947 and 1949~~ (DWD 1947a, Nees & Kehrer 2002, Erfurt et al., 2019, Brazdil et al., 2016).

These chains of effects reflecting the duration of a drought period are understood as pathways. Their grades were also classified as drought categories (see last column of Tab. 1). As these are very similar to descriptions of the consequences and implications of modern classifications, it is possible to parallelize them on a hermeneutical basis.

These cascade effects over the duration of the drought and dryness, which also follow the classical definitions of drought, are understood as pathways and their grades can be classified as drought categories. These are shown in the last column of Table 1 (Table 1).

Because the pathways and drought categories are very similar to descriptions of the consequences and implications of modern classifications, it is possible to parallelize them on a hermeneutical basis.

3.3 Determination of modern SPI and mapping of recent drought categories

The modern Standardized Precipitation Index (SPI) was calculated from the official precipitation values for Germany 1881 - 2018 provided by the DWD, Climate Data Center (2019), using the package 'SCI' (Gudmundsson & Stagge 2016, Stagee et al. 2015, 2016). The different SPIs were calculated for the corresponding time periods of one to twelve months as SPI1 to SPI12.

The drought categories D0-D4 and the characterization of droughts as well as the duration and the description of the consequences were also taken over from the scheme of the DWD (DWD 2018), see Tab.1, first to forth column.

3.4 Derivation of the Historical Precipitation Index (HPI)

In order to put the drought and drought -related patterns in the overall framework of hygric development, the next step was to include the positive hygric indices. These represent humid and wet conditions at month scale.

The derivation of the HHistorical Pprecipitation Iindex (HPI) is based on the monthly Precipitation Indices (PI). We calculated the HPI as the sum

of the PIs of the corresponding number of the relevant months. This was done for time windows from one to twelve months in order to map the accumulative effects of dryness and lack of rainfall, analogous to the SPI. For example, HPI3 of June results from the sum of the PIs April to June. We included also positive values for humid and wet conditions.

from the monthly precipitation indices (PI) - including the positive deviations - is analogous to the SPI as the sum of the corresponding number of months of the period 1881-1996. The strength of the statistical relationship and its shape are shown in Figure 3.

3.5 Correlation of the Historical Precipitation Index (HPI) with the modern SPI

To compare the HPI with the modern SPI, a correlation analysis for the overlapping period 1881-1996 was applied. The results show a very high correlation of 0.65 to 0.74 between SPI and HPI. The correlation reveals a high connectivity between the two parameters (HPI vs SPI). The strength of the statistical relationship and its shape are shown in Fig. 4. There is also an obvious connectivity between the specific inclination and the duration. Therefore, we introduced a duration dependent compensation factor.

[Fig. 43: Strength and shape of the relationship between SPI and HPI 1881-1996 for the duration of one to twelve months]

To integrate the duration effect, this derived compensation factor was used. The comparison of the accumulated values allows the identification of a factor dependent on the number of months, which we used to adjust the scaling (Fig. 5).

The results show a very high correlation of 0.65 to 0.74 between SPI and HPI!

If one compares the accumulated values, then a factor dependent on the number of months results (Fig. 4)..

[Fig. 54: Duration and scale factors of the relationship between SPI and HPI for the duration of one to twelve months]

We solved the equation and applied the following inverse function to map the class boundaries given in SPI values (see Tab.1, column 1) to HPI values (Tab.1, column 5).

The calculation of the HPI class limits is done from the SPI class limits according to the formula:

$$HPI_i = SPI_i \cdot i^{\frac{1}{\sqrt{3}}}$$

3.6 Derivation of HSPI time series from 1500

In a further step the compensation factors were applied to the Historical Precipitation Index (HPI) since 1500 to derive the Historical SPIs (HSPIs). Examples of the transformed HSPIs are shown as HSPI3, HSPI6 and HSPI12 (Fig. 6).

[Fig. 6: HSPI3, HSPI6 and HSPI12 for Germany since 1500 for the duration of three, six and twelve months]

3.7 Derivation of the Historical Drought Index (HDI) and comparison with the Modern Drought Index (MDI)

For the determination of the Historical Drought Index (HDI), we stepwise interpolated the classes linearly defined in Tab. 1, using the negative SPIs with different durations (Fig. 7). These were compared with the Modern Drought Index (MDI) of the DWD for the calibration phase 1881-1996. The correlation of $r^2 = 0.48$ underlines the strength of the relationship between the two variables.

[Fig. 7: Comparison of the Historical Drought Index (HDI) and the Modern Drought Index (MDI) for Germany 1881-1991]

We also used this approach to calculate the last 500 years.

3.8 Synopsis of SPI, HPI and numerical as well as hermeneutic drought categories

To synthesize and compare the different numerical indices, drought categories and hermeneutic classifications, we compiled the modern SPI, the historical and modern drought categories (HDI & MDI), duration classes, recent descriptions and the HPI as well as the historical description of consequences and impacts in Tab 1.

The starting point are the parameters and criteria used in the Drought Severity Classification (NDCM) 2018) or the Drought Index of the German Weather Service (DWD 2018). These include drought indices derived from measured data such as the SPI as well as the assessment of the severity of droughts in the form of drought categories. These follow the criteria used in the general drought classifications of an agricultural, hydrological and socio-economic drought and include information on duration. In addition, we described the effects and consequences in short text blocks.

The synopsis of recent SPI, drought categories, duration, recent descriptions and the HPI as well as the description of the historical consequences and impacts are summarized in Table 1 (Tab 1).

Tab. 1.: Synopsis of SPI and HPI and numerical and hermeneutic drought categories

SPI Acc. DWD (2018)	**Drought-Categories** **(HDI & MDI)** Acc. DWD (2018)	**Duration months** Acc. DWD (2018)	**Recent descriptions of the effects and consequences as well as the duration** Acc. DWD (2018)	**HPI** (Historical Precipitation Index)	**Historical descriptions of effects and duration**
-0.1 to -0.99 (SPI1, SPI2)	almost normal (slight dryness) D0	1-2	short-term dryness	0 to -1.5 (HPI1, HPI2)	low rainfall, heat and drought, possible first consequences for agriculture and yields
-1.0 to -1.49 (SPI1, SPI2)	moderate drought D1	1-2	meteorological drought: one to two months drier than usual	-1.5 to -2.5 (HPI1, HPI2)	lower crop impact on main crops, failures in rain-sensitive horticultural products and hay, better wine quality
-1.5 to -1.99 (SPI2 - SPI4)	severe drought D2	2-4	agricultural drought: two months and longer dry, crop losses	-2.5 to -4.5 (HPI2 - HPI4)	crop losses on main crops, emergency slaughter for lack of food, prematurity phenological phases, drying up springs, low water levels, mill arrest, forest fires, problems with water supply, heat deaths, measures of the authorities, price increases, hunger, religious rites
-2.0 to -2.99 (SPI4-SPI10)	extreme drought D3	4-10	hydrological drought: from four months, groundwater and level affected	-4.5 to -12 (HPI4 - HPI10)	crop failures, emergency slaughterings, strong premature phenological phases forest fires, fish dying, algal blooms, soil erosion drying of springs and wells, low water levels of large rivers, hunger stones, heat deaths, epidemics, price increases and speculation, measures of the authorities, hunger, religious rites, increasing irrational explanations

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-3.0 to -4.0 (SPI10-SPI12)	extra-ordinary drought D4	> 10	socio-economic drought: from one year, water shortage slows down producing economy	-12 to -36 (HPI10 - HPI12)	...begging, moving about, searching for food, food substitution, robbery, plunder, murder, emigration and emigration, social excesses (Century-events)

This table is of manyfold uses for cross validation and comparisons of modern and historical Indices, as well as comparisions of hermeneutic descriptions with numerical indices, shortcutting calculations and conversions.

Derivation of SPI time series from 1500

Since the drought arises over the intensity and duration of the precipitation deficit and are used for the evaluation of SPIs of different duration (see Table 1, first column), in a further step the monthly precipitation index (PI) from 1500 were summed up to HPIs 1-12 and transformed into SPIs (Fig. 5). Shown are SPI3, SPI6 and SPI12.

[Fig. 5: Historical SPI3, SPI6 and SPI12 for Germany since 1500]

Derivation of the Historical Drought Index (HDI) and comparison with the Modern Drought Index (MDI) from 1881

In a next step, for the determination of the Historical Drought Index (HDI), the classes defined in Table 1 were stepwise interpolated linearly. These are shown in Figure 6 and compared with the MDI of the DWD for the calibration phase 1881-1996. The correlation of r = 0.478 underlines the similarity or strength of the relationship between the two variables.

[Fig. 6: Historical Drought Index (HDI) vs Modern Drought Index (MDI)]

This approach was used to calculate the last 500 years. To include not only dryness and drought aspects humidity has also taken into account for the analysis by including the positive hygric indices as a Historical Wet Index (HWI). Its derivation was analogous to the class boundaries of the drought categories. The dominating effects of the HDI and the HWI are combined into the Historical Humidity Index (HHI). The monthly results are shown in Figure 6, along with the frequency-filtered signals for 1 and 5 years (Fig.7).

[Fig.7: Historical Humidity Index (HHI) for Germany from 1500]

3.9 Derivation of the Historical Wet Index (HWI) and Historical Humidity Index (HHI)

To include not only dryness and drought aspects, humidity has also been considered in the analysis by including the positive hygric indices as a Historical Wet Index (HWI). Its derivation was analogous to the class boundaries of the drought categories. The dominating effects of the HDI and the HWI are combined into the Historical Humidity Index (HHI). The monthly results are shown in Fig. 8, along with the frequency-filtered signals for 1 and 5 years (Fig.8).

[Fig. 8: Historical Humidity Index (HHI) for Germany since 1500. The upper part represents the monthly HHI from January to December for each year and the overlayed filtered five-year low pass (black line). The lower part indicates the low-pass values represented as colored schemes for five years and one year]

3.10 Identification of extreme drought years since 1500

To identify and quantify the most outstanding extreme droughts over the centuries we compiled the different years according to the strength or intensity of the derived indices. All months with a HHI below the value -0.5 were selected and periods of consecutive dry month were clustered. For each of these periods, the minimum HHI value, its sum and its beginning, end and duration as well as the HHI average were calculated. As usual in such compilations, the rankings of the top-century-events vary somewhat, according to the different indices and categories and their underlying calculations - weighting duration and intensities in different ways (see also Erfurt et al. 2019).

In addition to the calculations, the chains of effects extracted from the written hermeneutic evidence were used to confirm extreme events. These are characterized by detailed evidence, emphasizing strong impacts on agriculture, forestry, water circle and water supply as well as socio-economic effects like rising prices and hunger. Additionally, ecological effects were considered, e.g. wildfires, algae bloom, fish kills and soil erosion. There is also evidence about the societal contextualisation, especially about the societies´ coping and adaptation strategies, which reveal their vulnerability and resilience capacity.

These aspects have changed through the ages: In the agrarian-feudal age, societies coped with drought very differently than during the industrialisation period when, for instance, migration became an option. There was also a great shift in the past 100 years: While the extremely vulnerable societies during and in the aftermath of the First and Second World Wars were severely affected by droughts, the consequences could be coped with during the modern episodes of 2003 and 2018 (Erfurt et al. 2019).

Tab. 2: Table of outstanding drought periods since 1500 for Germany, in relation to different indices

	Longer context of dryness		**Selected Indices**			**Reference based on treerings (after Cook et al. 2015)**
Year	**Start**	**End**	**HHI min**	**HSPI.6**	**HSPI.12**	**Cook DE scPDSI**
1503	Apr 1503	Aug 1503	-2.56	-2.03	-0.26	-5.54
1522	Apr 1521	May 1522	-4.00	-3.69	-3.81	-0.17 (SE: -1.4)

1540	May 1540	Mar 1541	-4.00	-5.35	-3.59	-2.94
1567	Apr 1566	Jan 1568	-2.99	-2.36	-2.48	-2.13
1590	Mar 1590	Mar 1591	-4.00	-4.02	-3.81	-3.03
1615	Jan 1615	Mar 1617	-3.81	-3.69	-3.81	-1.91 (1616: -3.79)
1632	Mar 1630	May 1633	-3.31	-2.69	-3.15	-1.71
1635	Mar 1634	Apr 1635	-3.78	-3.35	-3.59	-3.36
1669	May 1669	Feb 1670	-3.15	-3.69	-3.15	-3.30
1681	Jul 1680	Sep 1681	-3.59	-3.03	-3.59	-3.13
1706	Jun 1705	Jul 1707	-4.00	-4.35	-4.47	-2.07
1719	May 1719	Dec 1719	-3.00	-3.69	-2.26	-3.81
1800	Nov 1799	Jan 1801	-3.98	-3.69	-3.58	-3.06
1803	Mar 1802	Oct 1803	-3.59	-3.69	-3.58	-3.73
1814	Dec 1813	Jan 1816	-3.54	-3.36	-3.37	-0.51 (N: -2.4)
1834	Feb 1834	Feb 1835	-3.73	-3.69	-3.37	-2.76 (1835: -4.44)
1842	Jan 1842	Jan 1843	-3.49	-3.69	-3.15	-3.06
1858	Feb 1857	Oct 1858	-3.00	-2.69	-2.92	-4.64
1864	Dec 1863	Jan 1866	-3.37	-2.36	-3.37	-2.53
1893	Mar 1893	Mar 1894	-4.00	-4.69	-3.37	-4.17
1921	Oct 1920	Feb 1922	-3.49	-3.36	-3.37	-5.57
1947	May 1947	Oct 1947	-2.46	-2.36	-2.04	-3.96
1949	Jun 1949	Mar 1950	-2.99	-2.69	-2.48	-1.6
1963	Jun 1962	Jun 1963	-2.92	-2.69	-2.70	+0.37
1976	Mar 1976	Aug 1976	-2.56	-2.36	-1.82	-4.06
2003	Mar 2003	Dec 2003	-2.47	-2.33	-1.76	-1.36

2018	Feb 2018	Feb 2019	-3.35	-3.46	-2.26	-

To visualize the outstanding single drought years, we also derived a „yearcloud“of classified years since 1500. It supports the comparison of the related extreme droughts to minor ones through time, especially between the modern and historical period.

[Fig. 9: "Yearcloud" of classified years since 1500. The average intensity is reflected by the color scheme and duration (month) by font size.]

As can be seen, outstanding drought events have appeared in all centuries since 1500. Many of them are well known and already described in the literature for Germany and neighboring regions of Central Europe like the droughts of 1540 (Wetter et al. 2014), 1590, 1622, 1631/32, 1706, 1719 (Glaser 2013), or the ones in 1834 and 1921 (Erfurt et al. 2019) or 1842 (Brazdil et al. 2019).

4 Results, discussion and conclusionResults and discussion

The article presents different index-based reconstructions of monthly and yearly drought time series for Germany since 1500. The reconstructions are based on historical records from the virtual research environment tambora.org as well as modern instrumental records. Written documents are also taken into account to analyse the climatic effects and consequences on environment and society. These chain of effects reflect very strongly the common accumulating effects of modern definitions of drought types. Therefor they are also comparable to modern drought categories (McKee 1993, NDMC 2018).

At first, a seven-scale index scheme is used to deduce a monthly Precipitation Index (PI) since 1500. This method is well established in historical climatology (Glaser 1991, 1996, 2013, Glaser & Riemann 2009, Pfister 1999, Brazdil et al., 2005). Hygric indications as well as the descriptions of impacts and consequences, here referred to as chain of effects are hierarchically ordered according to their intensity and assigned to the appropriate index value. The process is similar to modern classifications and definitions of droughts. In difference to modern drought-indices like SPI, SPEI or PDSI derived from modern instrumental records, these classifications directly take into account the descriptions of impacts and societal consequences and reactions (see also Erfurt et al 2019).

The derivation of the historical precipitation index (HPI) from the monthly precipitation indices (PI) - including the positive deviations - is the sum of the corresponding number of months of the period 1881-1996, analogous to the SPI. We calculated the HPI for time windows from one to twelve months in order to map the accumulative effects of dryness and lack of rainfall as well as for humid and wet conditions. The derived Historical Precipitation Index (HPI) is correlated with the Standardized Precipitation Index (SPI). A calibration factor had been calculated and applied to derive the Historical Standardized Precipitation Index (HSPI). In this sense, the HSPI reflects the longer rainfall deficits and dryness in a more comparable way to modern statistical approaches. Finally, a Historical Drought Index

(HDI) and a Historical Wet Index (HWI) are derived from the hygric indices seperately. Both are combined for the Historical Humidity Index (HHI).

The reconstructed monthly HHI for Germany since 1500 clearly reveals the annual structures of dryness and wetness. It allows to easily identify dry months and longer periods of dryness and droughts. In total, the synopsis reveals the generally high variability of dryness and wetness through time. Additionally, the time series clearly show that not only summer, but also winter precipitation deficits occur. In this context, it is noticeable that in comparison to the analysis of summer droughts comparatively few studies on spring, autumn or winter droughts are available. The same can be stated for the humidity aspect. An exception is, for example, Pfister et al. (2006) with the analysis of hydrological winter droughts of the last 450 years in the Upper Rhine area.

To highlight the mid-term development, a 5-year frequency low-pass filter was applied. It emphasizes a somewhat higher variability in the first 150 years (1500 until 1650), including a very remarkable contrast between the dry period 1630-1635 and the moist phase 1646-1651. This represents the most striking mid-term change of the last 500 years. The moist phase 1692-96 and the dry period 1740-1744 are also striking variations. In addition, more dry months occurred in the period 1750 to 1911, as in the period after 1911. In the last few decades no striking trends have occurred, except for the most recent accumulation of extremes. Seen from this point of view, no comparable development to the anthropogenic temperature trend can be observed. This also corresponds to the findings of Sheffield et al (2012) and Spinoni et al. (2015). According to their analyses, drought frequency is increasing in southern Europe, with a reverse trend observed in northern Europe.

Even if the derived HHI shows some remarkable changes and a high variability on the 5-year scale, there is an extensive stationarity of annual humidity as expressed by the HSPI in the long-term 500-year perspective. In opposition to that there are remarkable shifts and seasonal trends on the longer scale, for instance winter humidity has increased while summer precipitation has decreased slightly during the last 150 years. There are also sections with comparable seasonal shifts and trends like an increase in winter humidity between 1590 and 1725 and in summer humidity between 1540 and 1690, as well a decrease in winter humidity between 1725 and 1800.

In order to further interpret the internal structure of this time series, a Fast Fourier Transformation was applied to the Historical Humidity Index (HHI) 1500-2018. This results in striking recurrence cycles at 22, 37 and 58 years. The same results can be found in the underlying indices, e.g. the HSPI. The curves and structures are also very similar to those of Dobrovolny et al. (2015) and Mikšovský et al. (2019), which were reconstructed for the neighboring Czech lands.

~~**Documentary Data**~~

~~The written sources on which the analyzes are based and the derived seven-step monthly precipitation indices (PI) for Germany, allow differentiated statements about the climatic causes and the development of dryness and droughts in Germany since 1500. The consequences and impacts on the environment and society can also be reconstructed very well. The information of the droughts is differentiated and very detailed. In many cases information is available about the temporal structure, in particular the onset, the end and the development. They are thus similar in content to other Central European historical sources (Pfister 1999, Brazdil et al., 2019).~~

~~**Pathways**~~

The contextual ~~contentual~~ differentiation of ~~the~~ source material allows the derivation of ~~enables in particular to derive~~ pathways from the causes of ~~dryness and~~single drought events to ~~and~~ their consequences and impacts. These are ~~very~~ strongly coupled with the intensity and duration of the precipitation deficit~~tency~~. The agrarian, then the hydrological and finally the socio-economic consequences are presented in a progressing ~~cascade~~ chain of effects. Structurally, they correspond to today's drought definitions and ~~drought~~ classifications. The descriptions of impacts and consequences and the derived pathways of historical events are in most cases comparable ~~very similar~~ to recent events (Erfurt et al 2019, Blauhut et al. 2016, Glaser et al. 2016, 2017, 2018, Brazdil et al. 2016, 2019 or Nash et al 2019). ~~so that~~Therefore, a parallelization is possible.

These statements apply to the pathways itself, but not to resilience and the underlying adaptation strategies~~adaptation manners or resilience~~. Obviously, these have developed over the centuries~~, these have become~~ due to changes in ~~the~~ social structures, ~~the~~ assets and~~,~~ technical possibilities ~~and thus the adaptation~~ (Glaser et al. 2018, Camenisch & Rohr 2018, Camenisch et al. 2014). In the historical context, for example, water-driven mills play a key role in food security. Due to a lack~~ing~~ of water, horse mills or hand mills were set into operation. In today's context, on the other hand, the lower energy production of hydropower plants, or the shutdown of nuclear power plants due to ~~at~~ low water or at high water temperatures plays a major role (DWD 1947a,b, Loßnitzer 1947, BNN 1947a,b, DWD 1949a,b, BNN 1949a,b, Erfurt et al. 2019). In addition, ~~Also~~ within the historical period, i.e. before the establishment of the official measuring network from 1881, the social and technical possibilities and structures changed. From 1800 onward, the dominant agricultural-feudal structures were gradually replaced by the industrial revolution, also involving ~~. There were also~~ new possibilities for adaptation, ~~:~~ e.g. ~~such as an~~ improved infrastructure, better technical equipment such as pumps, more expertise and better hygiene and social welfare measures. The striking emigration waves of the 19th century from Germany to North America, which were also ~~repeatedly~~ triggered by drought events, can be seen as another new adaptation option (Glaser et al 2017). Additional ~~Added to this were~~ innovations were~~such as~~ the advent of the insurance industry (Kiermayr-Bühn 2009) or institutional reactions~~. Also the reactions of institutions~~ in the modern age, ~~-~~ understood as governance ~~- can be seen in this context~~. Examples are the DWD's establishment of the heat warning system in 2005 as a result of the extreme summer of 2003 (Matzarakis 2016) with its unexpectedly large number of heat deaths or the implementation of a new 2019 drought index after the extreme year of 2018 (DWD 2019).

Nonetheless, there are many similarities between the recent and historical chain of effects. This~~pathways that~~ justifies~~y~~ the parallelization~~ing~~ of past and historical drought categories, ~~through the cascade effects. This~~ combining~~ation of~~ hermeneutic criteria with empirically derived indices.

In Tab.1 we synthesized an evaluation scheme to relate historical descriptions with the corresponding modern descriptive ratings and selected numerically derived indices. This enables the direct comparison of historical derived indices and classified descriptions with current assessments of drought events according to NDMC (2018) and the German Weather Service (DWD 2018, 2019).

~~represents an intrinsic and unique value.~~

~~Overall, a stringent evaluation scheme was derived, which comes very close to the current assessments of drought events such as the NDMC (2018) or the German Weather Service (DWD 2018, 2019).~~

~~Outstanding single years~~

The comprehensive data collections and derived time series~~in tambora.org~~ also enable to identify outstanding and correspondingly well-documented events of the centuries.

, as given in the one-year filtered time series. The written evidence often allows differentiated statements about the underlying climatic causes and in many cases information is available about the temporal structure, particularly the onset, the end and the course of droughts. They are thus similar in content to other Central European historical sources (Pfister 1999, Brazdil et al. 2019). The written evidence covers not only the climatic development but also the impacts and consequences as well as the responses and adaptation strategies of societies. This allowed the application of the concept of pathway analysis, especially for extreme drought events, which in turn served as baseline for the derivation of the evaluation scheme (Tab.1).

The most outstanding drought events occurred in the 16th century in 1590 and 1540, but also in 1536. In the 17th century, this is the case in 1615 and 1616 and during the striking sequence 1630-1635, 1669 and 1685. Outstanding droughts occurred during the 18th century in 1706, 1718 and 1719, 1742, and 1749; in the 19th century in 1834, 1842, 1865 and 1893; in the 20th century in 1921, 1949 and 1959; and finally in the 21st century in 2003 and 2018. Many of these extremes are not only confirmed in other papers (Koppe & Jendritzky 2014, Cook et al. 2015, Glaser et al. 2018, Erfurt et al. 2019), but have also been identified in neighbouring regions (Doornkamp et al. 1980, Hémon et al. 2003, Poumadère 2005, Cook et al. 2015, Wetter et al. 2014, Brazdil et al. 2019b).

These are 1540, 1503 and 1534; 1615 and 1616, the striking sequence 1630-1635, 1669 and 1684, and 1718 and 1719, 1834, 1842, 1865 and 1893, 1921, 1949, 1959, 1976, 2003 and 2018. Many of these extremes are not only confirmed in other papers, but have also been identified as such in neighboring regions (Doornkamp et al. 1980, Hémon et al. 2003, Poumadère 2005, Koppe & Jendritzky 2014, Cook et al. 2015, Wetter et al. 2014, Glaser et al. 2018, Brazdil et al. 2019b, Erfurt et al. 2019). As expected with drought, the large-scale structure is also evident.

In general, the method itself is transferable whenever the relevant regions allow the application of the SPIs. The results and conclusions presented in this article refer to the spatial outline of modern Germany, which shows homogeneity for this approach.

Long-term development

In order to be able to examine the long-term development quantitatively and, above all, to achieve a connection to the modern age, various indices have been derived. The modern SPI1-SPI12 was calculated from the official precipitation data for Germany 1881 - 1996. The strengths and weaknesses of the SPI are now widely discussed in literature (Briffa et al 1994, Cook et al 2015). Its wide distribution and simple calculation as well as the ability to connect to the historical period are the reasons why it was used here - and not the more complex scPDSI, as used for example by Cook et al. (2015) or Mikšovský (2019).

The reconstructed SPI for Germany from 1500 onward show high variability on the one hand, and extensive stationarity in the long-term perspective on the other. However, variability is slightly higher in the first 150 years, while it has been reduced over the last 100 years. Also noticeable spikes occur in the SPI time series, which show significant droughts. Medium-term changes characterize, for example, the section 1890 to 1920. Prominet is the increase of 1630 - with the conspicuous sequence of drought years 1630-1635 up to the maximum 1646-1651 followed by a series of wet and humid years. Noteworthy is also the sinking or lack of heavy rainfall since the 1980s. The curves and structures are also very similar to those of Dobrovolny et al. (2015) and Mikšovský et al. (2019), which were reconstructed for the neighboring Czech Lands.

All in all, interesting conclusions about the development of SPIs and droughts in Germany since 1500 can be drawn from the reconstructed time series. To evaluate the quality, the Historical Drought Index (HDI) was correlated with the Modern Drought Index (MDI). The very good correlation of r = 0.75 proves the strength of the relationship.

In order to assess not only the negative hygric events and thus the drought and dryness, but also the positive hygric events, humid and wet events were included. For this purpose, the monthly precipitation indices (PI) of the historical precipitation index (HPI) were used to form the sum of the corresponding number of months, analogous to the SPI. The very good correlations are a conclusive measure of the strength of the statistical context and the quality of the approach. This also applies to the Historical Drought Index (HDI) and the Historical Wet Index (HWI). Both indices have been combined into the Historical Humidity Index (HHI).

The monthly HHI reveals very well the annual structure of individual drought and dry events and clearly shows that not only summery, but especially winter precipitation deficits but also marked positive deviations occurred. It is noticeable that in comparison to the analysis of summer drought comparatively few studies on the winter droughts are available in literature. An exception is, for example, Pfister et al. (2006) with the analysis of hydrological winter droughts of the last 450 years in the Upper Rhine plain. This also applies to the transition seasons.

The medium-term development is presented as a 5-year course. He emphasizes the somewhat stronger eruptions in the first 150 years, especially the great contrasts of the dry period 1630-1635 and the damp phase 1646-1651. This represents the most striking vibration of the last 500 years. The damp phase 1692-96 and the dry period 1740-1744 are also striking. Also, in the period 1750 to 1911 basically more dry months occurred, as in the period after 1911. In the last few decades no striking trends occur - only the most recent extremes accumulate. Seen from this point of view, no comparable structure to the anthropogenic temperature trend can be observed. This also corresponds to the findings of Sheffield et al (2012). Spinoni et al. (2015) confirm this indirectly. According to their analyzes, the drought frequency is increasing in southern Europe, and a reverse trend can be observed in northern Europe. Moreover, they rightly refer to the different methodological approaches.

In order to further develop the internal structure of this time series, the Historical Humidity Index (HHI) 1500-2018 carried out a Fast Fourier Transformation. This results in striking recurrence cycles at 22, 37 and 58 years.

5 Outlook

The elaborations make it clear that there have been significant changes and outstanding individual events concerning dryness and drought events. Of course, the question arises about the reasons and causes. Explanations are given by solar and volcanogenic forcing, which in fact help to understand individual events and phases. At the same time, however, questions of internal variation of the climate system have to be discussed, such as the teleconnections likewise the NAO + and NAO- or connections with the ENSO phenomenon. Nonetheless, today the question of the recent anthropogenic increase in greenhouse gas emissions and a possible increase in drought events and their long-term consequences is of interest. Are there any relevant trends that will show up in the future?

Increasingly, there is also the question of the social impact and long-term developments, especially regarding the effects of climate changes on human history . Such questions are usually answered using multiproxy approaches (Brazdil et al. 2019, Mikšovský et al. 2019, Büntgen et al. 2010, 2011). In how far the methodical and content-related insights presented in this study can be integrated into . How have climate changes affected human history? Especially in multiproxy approaches such questions are answered (Brazdil et al. 2019, Mikšovský et al. 2019, Büntgen et al. 2010,2011). How the methodical and content-related insights presented here can be integrated into these questions will be the subject of future analyzes.

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Abbreviations, developed and used in the text

PI: Precipitation Index (-3 .. + 3) (Integer)
SPI : Standard Precipitation Index
HSPI : Historical Standard Precipitation Index
HPI: Historical Precipitation Index (-15 ... +15):
MDI: Modern Drought Index, DWD drought Index, 5-scale, derived from SPIs
HDI: Historical Drought Index, 5-scale drought index, derived from HPIs
HWI: Historical Wet Index, analogous to HDI for positive hygric indices
HHI: Historical Humidity Index (-5…+5) (HDI Combines & HWI)

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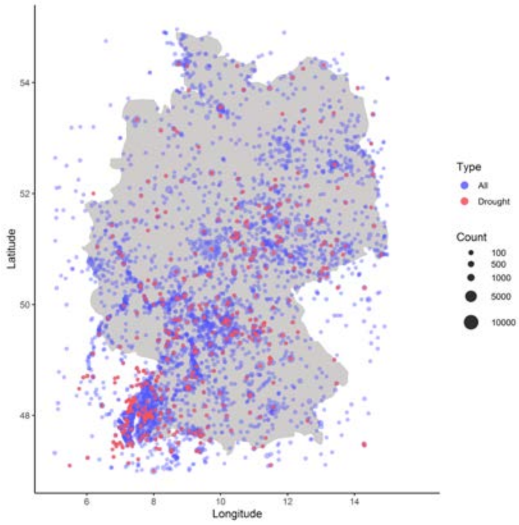
This study was carried out within the interdisciplinary research project DRIeR. The project is supported by the Wassernetzwerk Baden-Württemberg (Water Research Network), which is funded by the Ministerium für Wissenschaft, Forschung und Kunst Baden-Württemberg (Ministry of Science, Research and the Arts of the Land of Baden-Württemberg). The authors like to thank Mathilde Erfurt for support in providing the SPI data series for Germany (1881-2018, data source: DWD).

Figures


Type
All
Drought
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100
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Latitude
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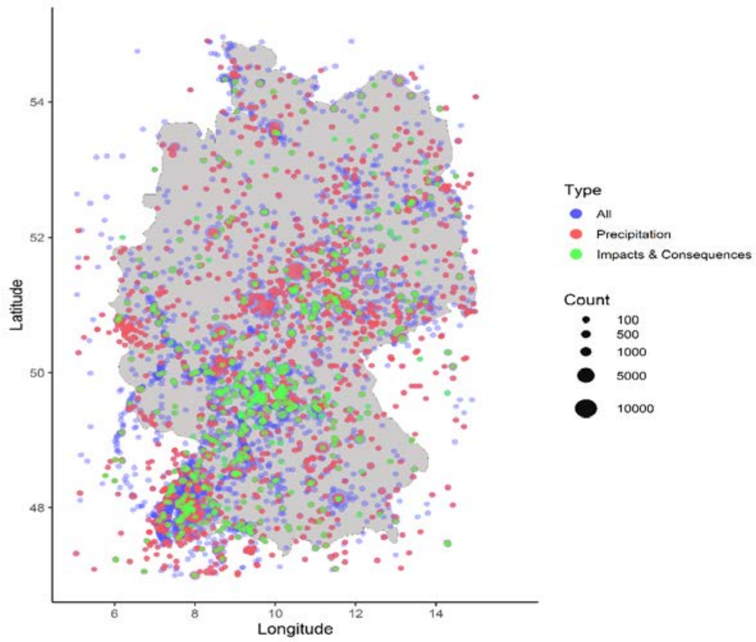
Type
All
Precipitation
Impacts & Consequences
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5000
10000
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Longitude
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Fig. 1: Spatial distribution of

all records referring to Central Europa in *tambora.org* since 1500 (blue), precipitation, dryness and drought records (red) and impacts and consequences (green).

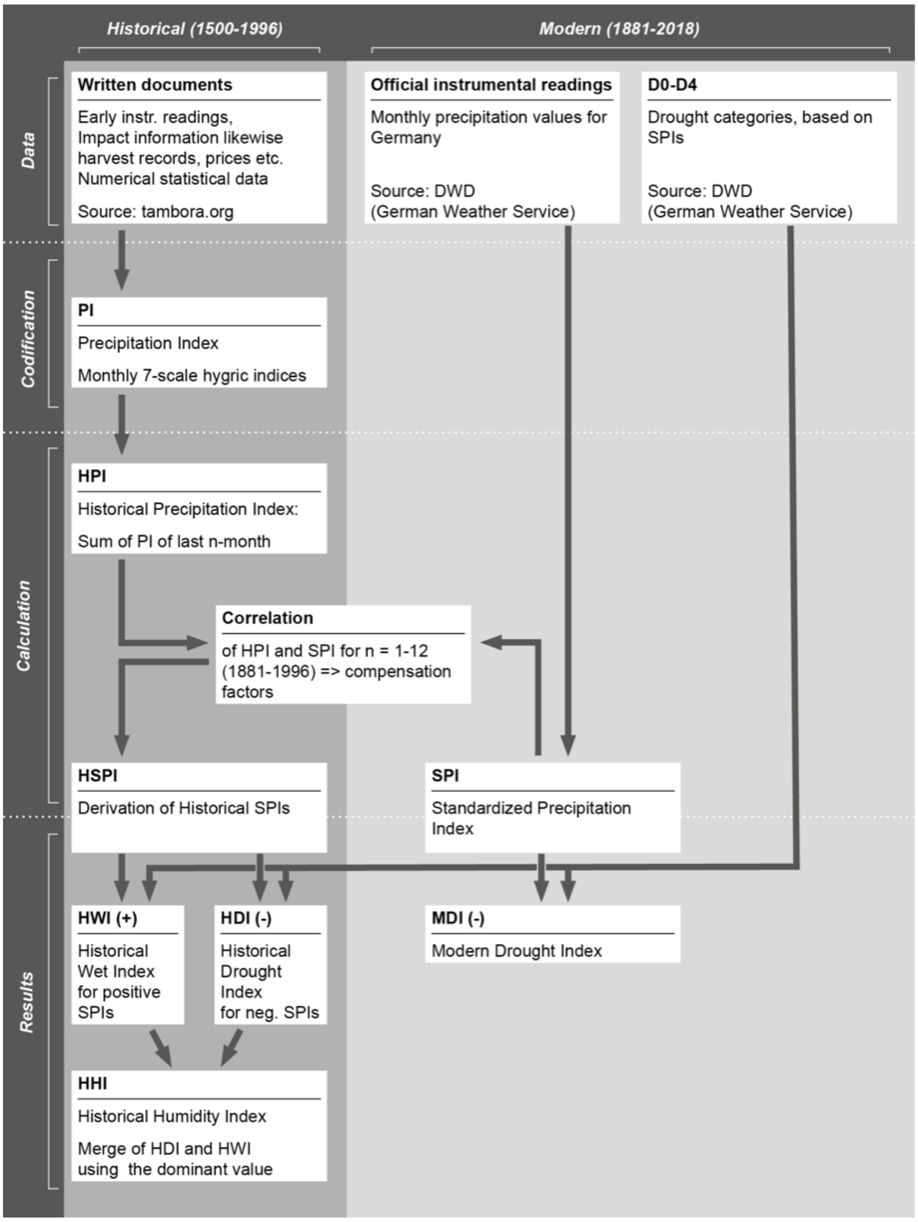


Fig. 2: Conceptual design of the analysis, illustrating the workflow and the single steps deriving the specific indices and their relations

information in tambora.org

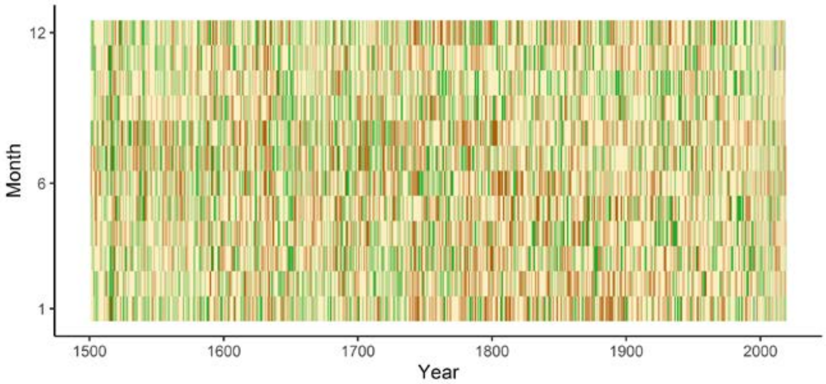


Fig. 32: Summary of the monthly precipitation index (PI) for Germany from AD 1500-2018

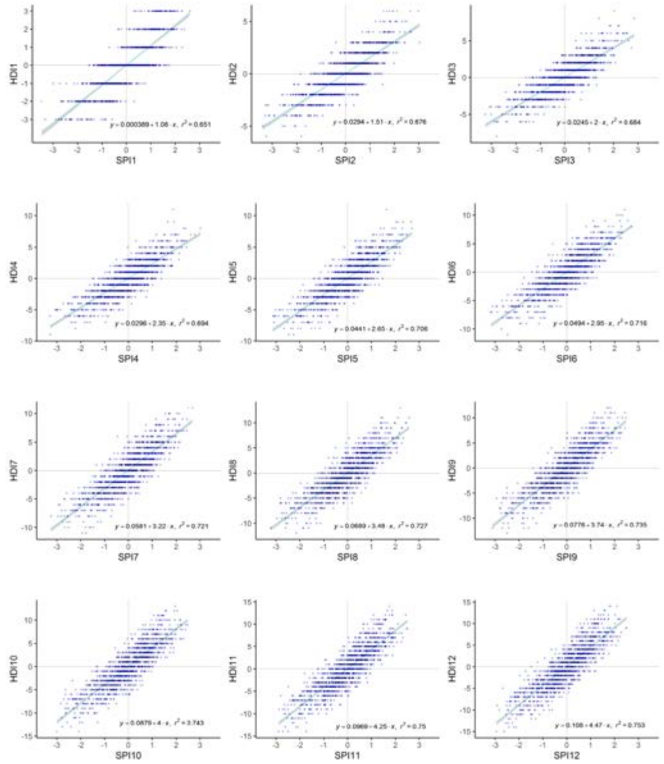
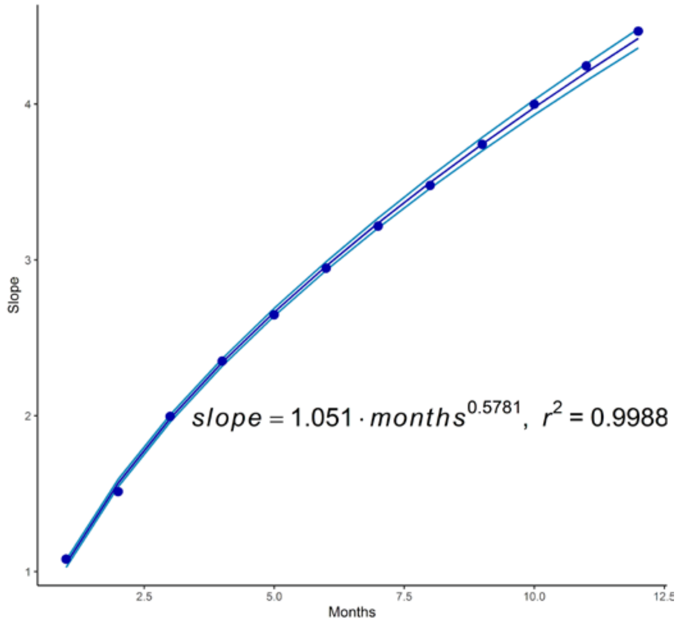


Fig. 43: Strength and shape of the relationship between SPI and HPI 1881-1996 for the duration of one to twelve months

Months	Slope
1	1.0802
2	1.5127
3	1.9957
4	2.3506
5	2.6475
6	2.9465
7	3.2167
8	3.4780
9	3.7417
10	3.9986
11	4.2452
12	4.4677



$$SPI_i = HPI_i \cdot i^{-\frac{1}{\sqrt{3}}}$$

Fig. 54: Duration and scale factors of the relationship between SPI and HPI for the duration of one to twelve months

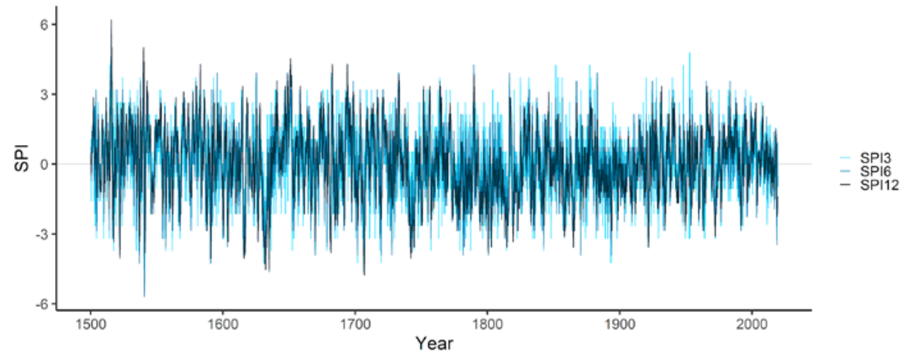


Fig. 65: Historical HSPI3, HSPI6 and HSPI12 for Germany since 1500 for the duration of three, six and twelve months

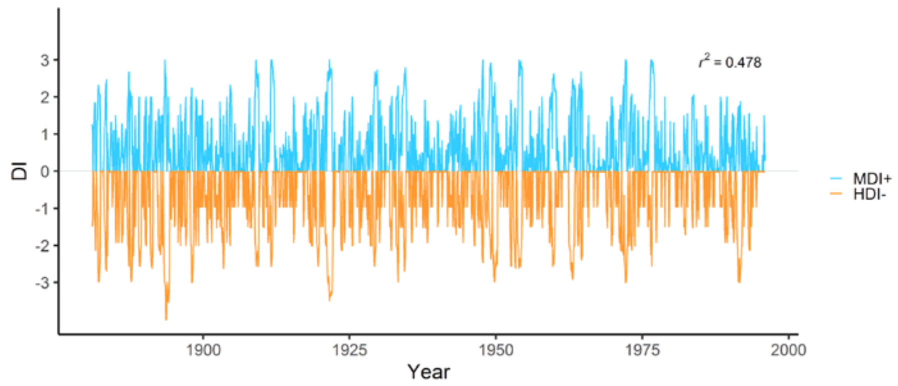


Fig. 76: Comparison of the Historical Drought Index (HDI) and the Modern Drought Index (MDI) for Germany 1881-1991Historical Drought Index (HDI) vs Modern Drought Index (MDI)

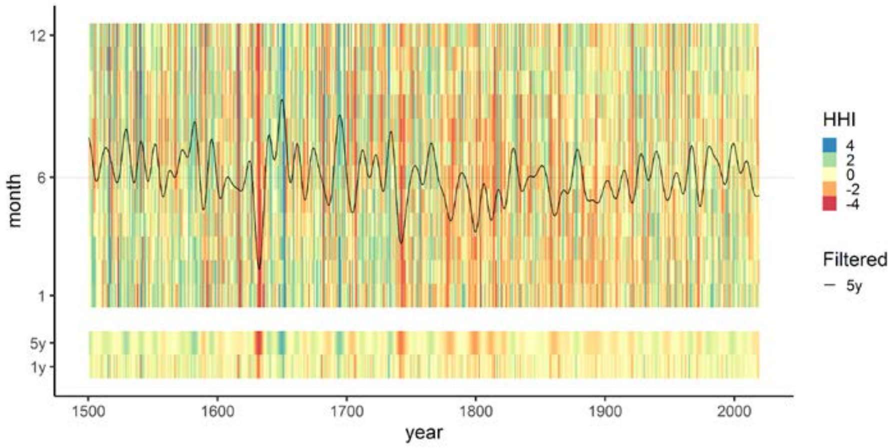


Fig.8~~7~~: Historical Humidity Index (HHI) for Germany

since 1500. The upper part represents the monthly HHI from January to December for each year and the overlayed filtered five-year low pass (black line). The lower part indicates the low-pass values represented as colored scheme for five years and one year

~~from 1500~~

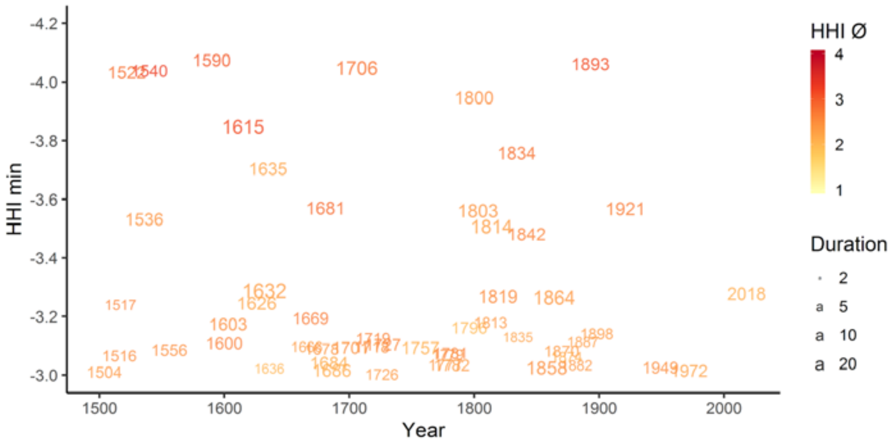


Fig. 9: “Yearcloud” of classified years since 1500. The average intensity is reflected by the color scheme and duration (month) by font size.

Editor Decision: Reconsider after major revisions (01 Feb 2020) by Günter Blöschl
Comments to the Author:
The two reviews provide useful suggestions for strengthening the paper. I consider the paper interesting but more methodological detail is needed in order for the reader to understand what has been done. There are also a number of inconsistencies. I recommend that the authors address all comments of the two reviewers. The responses to the reviews seem to be an appropriate path to follow.

Additionally I have the following observations:

1. More detail on the data is needed. What is 'information' exactly? Are these 280000 pieces of information all relating to droughts – how many places, years?

Actually there are 330.000 coded records in tambora.org for Central Europe as represented as blue dots in Fig. 2.. The 54.000 records, indicating precipitation and specific information regarding dryness and droughts are given in red. Additional 12.600 records, which describe the impacts and consequences of dryness, drought and lack of precipitation, likewise water shortages, low water levels of larger rivers, fish kills, forest fires, emergency slaughteries, crop failures, or prayer for rain etc. are given in green. All in all the information covers large parts of Central Europe. The southwest and the center as well as the eastern parts of Germany are particularly well depicted, but also the larger river systems such as the Main, Rhine and Elbe. The spatial distribution also refers to the cultural, political, economic and religious centers such as Nuremberg, Cologne, Leipzig, Erfurt, Hamburg and Mainz as well as other larger cities and monasteries. The coastline respectively the harbour locations likewise Hamburg, Lübeck and Rostock are also well represented.

The temporal coverage is very good, i.e. there has been information for every month since 1500. Basically, the average and inconspicuous months are less documented than more extreme ones. Periods for which daily, systematic information from weather diaries are available have correspondingly denser assignments (see also Glaser & Riemann 2009).

How did you get the monthly indices of Fig. 2?

The hygric indices had been derived from the written evidence of the sources via semantic profiles, a method well established in historical climatology (Glaser 1991, 1996, 2013, Glaser & Riemann 2009, Pfister 1999, Brazdil et al., 2005). In such semantic profiles, the direct hygric hints as well as the descriptions of the impacts and consequences are hierarchically ordered due to their intensity and assigned to the appropriate index value. The process is similar to modern classification and definitions of droughts, which beside different drought-indices likewise SPI, SPEI, PDSI oder scPDSI derived from modern instrumental records also take into account descriptions of impacts and societal consequences and reactions (McKee 1993, NDMC 2018).
A seven-scale index system, ranging from -3 to +3 has proven appropriate for the classification of historical records (Glaser 1991, 1996, Glaser & Riemann 2009, Glaser 2013).

Generally, extreme events are represented in historical documents by a larger number of sources. Such information is also spanning wider areas, especially if the records refer to droughts. Additionally the information is more detailed. Often severe events are compared to previous ones. Such long-term memory persisted across generations.

Direct descriptions mostly refer to the absence of rain or the corresponding sky coverage and the lack of clouds. In many cases, the duration is indicated, too. The documents related to the specific pathways and consequences describe the effects onto harvest results, the phaenological and ecological situation, but also the hydrological consequences and the impacts onto economy and society and their reactions. This correlates very well with the definitions of meteorological, agraian, hydrological, groundwater and socio-economic drought in modern classificatioons (NDMC 2018).

The evaluation scheme for the hygric-index is ranging from -3 to +3.

Index 0 represents the average situation.
Index -1 is indicated by description of deficits of rainfall. There are often indications of less impairment of the harvest of rain-sensitive products such as hay, vegetables and other garden products.
Index -2 increased number of indications of lack of precipitation, prolonged heat and dryness. Average crop losses for main crops are reported as well as low water levels in smaller bodies of water, reduced spring fills. Heat stress on plants, premature leaf discoloration, death of parts of plants is quite obvious, also dry cracks in soils, occasional forest fires. Impairment of infrastructure, for example shipping and water mills.
Index -3, representing extreme dryness revealing a chain of effects as follows: Extreme dryness is indicated by large numbers of records of prolonged dryness and haet, caused by lack of rainfall. The agrarian consequences are severe crop losses and even harvest failures, emergency slaughteries due to lack of feed.
If the dryness lasts for weeks, several months and seasons, there are integrating effects that correponds to reports likewise low water levels in greater lakes, ponds and larger river systems as well as drying up of springs and wells. Also reports of excessive water shortage and the appearance of "hunger stones" are common. The ecological impacts refer to generally visible heat stress of the vegetation, premature leaf discoloration and the withering of plants. In addition, dry cracks in soils, dust veils and dust storms and effects of wind erosion are indicated. There are plentiful descriptions of clear premature of the phaenological phases likewise flowering, ripening and harvest, but also “wine of the century”. Reports of forest fires and fish kills are also common. The impairment of infrastructure, especially the termination of shipping and the failure of mills are reported as socio-economic impacts. The direct consequences for human health and well-being are also documented: Indications of heat stress, heat death, and increased death rate, outbreak of epidemics, diseases and due to lack of food hunger crisis. The scenarios also include price increases and speculations. Authorities reacted with restrictions and regulations on water access or rationing. Finally there are the adoption of special regulations and the declaration of a state of emergency.
Societal reactions as supplications, processions, pilgrimages, increasing irrational explanations and interpretations are quite common. Also begging, moving around for food seekers, riots and protests, theft, looting, robbery and social excesses.
These integrating effects allow conclusions to the preceding months. In many cases the exact date of such a meteorological drought is indicated by the name day of saints.
The positive hygric index correponds to the humid and wet situations and are derived in the same manner.

In addition, for 60 years oft he period 1500-1800, precipitation days are given from daily weather diary entries (Glaser 1996, Glaser 2013). Such high resoluted daily entries are compared with modern precipitation data on a monthly scale. This enables a comparison of numerical rainfall data with the classified written evidence on a monthly scale and can be regarded as an additional verification of the index levels.

For the numerical records since 1800, we used a classification scheme based on normal distribution. Index „0“ reflects the monthly average with a plus/ minus 0.75 –fold standard deviation. Index „-1“

ranges betwen -0.75 and -1.5 standard deviation, Index „-2" between -1.5 and -2.25 fold standard deviation and „-3" below -2.25 standard deviation. The positive Indices refer to the appropriate positive ranges. The period 1951-1980 was chosen as the reference period. These numerically derived indices were combined with the hermeneutically
derived ones.

I would not expect there is information in every singly month of the past 500 years.

There are records for all months since 1500 due to the Gutenberg revolution (printing machineries, distribution of paper production as well as the increase in writing and reading abilities…), before 1500 this is not the case.

The derivation of PI is completely missing, yet essential for understanding the paper.
The derivation is now described in detail above. Also the data information.

2. CP has an open data policy. Please deposit data in a public repository
https://www.climate-of-the-past.net/about/data_policy.html

The data are already available via

https://www.re3data.org/search?query=tambora

and assets for code and data are added to the article:

Temperature and Hygric Indices for Central Europe since AD 1500 G. Rüdiger and M. Kahle
https://doi.org/10.6094/tambora.org/2019/c493/csv.zip

climdata/drought2019: Reconstructions of Droughts in Germany since 1500 M. Kahle and R.Glaser
https://doi.org/10.5281/zenodo.3405167

3. Fig. 3 is difficult to understand (in fact the figure captions are generally too short). Is each point a year, averaged over Germany? And if so, how?

We enlarged the captions.

Each point represents a month and the average over Germany.

We added a new conceptual figure which clarifies the derivation and relations of the introduced indices very well.

4. Fig. 4 and the associated methods are unclear to me. They need a full description. Even though I do not know the details of the method, the correlation of 0.99 does not look right.

We reworked and reorganized the chapters and subchapters for each single step, so that – together with the new conceptual design - the calculations and their relations to each other should be clear.

0.99 is not the correlation of single months, but the correlation oft he relation bewteen SPI and HPI for durations of 1 to 12 months. It proofs, that summerizing PIs are equivalent to the calculation of SPIs.

5. Correlations HDI-MDI is r=0.478 in line 191 but r=0.75 in line 273.

The relevance of these correlations are difficult to assess unless the basis of the data becomes clearer. Have any systematic data been used in the historic data set? It would be good to demonstrate by a recent drought example how the documentation based data set compares with precipitation measurements.

You are absolutely right …the correlation coefficient is r=0.48

Please address the comments of the reviewers and my observations and submit a revised paper.

The manuscript "Reconstructions of droughts in Germany since 1500" focuses on the calculation of various indicators for droughts since 1500 based on the historical climate and environmental database tambora.org. Specifically a Historical Precipitation Index(HPI) is calculated and correlated with the SPI index. Additionally, a Historical Drought Index (HDI) and a Historical Wet index (HWI) are derived. Information on the long term development and dynamics of droughts is scarce and consistent long time-series are hardly available. However, the analyses of drought time series is highly relevant and important in the context of climate change and its impacts. For the development of sustainable risk management strategies for droughts it is important to know how droughts developed over time, and which drivers influenced their temporal dynamics to draw conclusions for the future. Thus, the research question dealt with and the objective of manuscript are innovative and highly relevant. However, I see the following major problems which require substantial re-writing of large parts of the manuscript as well as additional analyses during the revision. Thus, I suggest major revision (or even reject with an invitation to re-submit):

Answer: The authors thank rev1 for the general statements and comments! In the meantime, we revised the whole article along the suggestions; we also added a new conceptual viewgraph to highlight the analytical work-flow and reorganized the whole article along this concept.

1) The development, i.e. calculation of all presented indicators is not provided. It therefore remains rather unclear what their specific meaning and their advantages and disadvantages are.

Answer: We added a new view graph to highlight the whole workflow and especially to present the calculation of all presented indicators precisely (see Figure 2 in the revised MS). We reorganized the relevant paragraph and added the meaning and advantages of the used indicators. We referred to the well introduced modern indices (SPI, Drought Classes of the DWD), which are widely known and used. The historical derived Indices are related to these to get the opportunity to calibrate, connect and compare these.

It would be interesting to know, if all indicators are based on the seven-level monthly indicators for temperature and precipitation, which are included in the tambors.org database from 1500 onwards, or if additional data and information included in the database has been used.

Answer: We used the seven class hygric index from tambora.org, but also the given information (written evidence) of the impacts on agriculture, forestry, water balance, ecology and socio-economic effects.

The development of the Historical Precipitation Index seems to be the key result of the manuscript, however, its development is described in one sentence only (lines 161-163). More detailed information is necessary here. The advantages and disadvantages of the developed indicators should be discussed.

Answer: We see the HPI, which is equivalent to the modern SPI, as a key issue, but also as a stepping stone for the derivation of the HSPI (Historical SPIs). This is now much clearer in the new introduced concept figure.
The whole structure of the workflow, which is described in the sub-paragraphs 3.1 to 3.9 is much clearer now and more informative.

2) I don't think that the droughts always affected whole of Germany in the same way. Thus, I doubt, that the indicators are continuously representative for whole of Germany. However, no information is given on spatial situation, how many stations are included in the calculation of the SPI, how are these distributed, how was the spatial aggregation undertaken? How representative for Germany is the HPI? How was spatial distributed information dealt with?

Answer: Figure 1 describes the spatial distribution of the historical information. The distribution of the given historical information covers large parts of modern Germany and neighboring regions very well.

The modern reference data are taken from the official integrated DWD data for Germany. There were no separate or additional calculations done at this stage.

3) It is additionally unclear for what the presented drought indicators can be used and what analyses can be based on the developed time series.

Answer: The presented drought reconstruction is the attempt to connect the historically derived with the modern indices and categories. Their use is the same as the modern ones, an evaluation of drought in the long-term development.

The calculation of these indicators should be complemented with analyses of the time series and their interpretation. It is quite strange, that the results and discussion section is rather a review and quite descriptive text only loosely connected with the indicators described in the methods section. I suggest to rewrite the results section completely. It should present analyses of the developed indicators and time-series and their interpretation.

Answer: We see that this was obviously not clear in the given MS. For this we followed the suggestion and we completely re-wrote this paragraph and re-organized it.

We added trend evaluations and discussed the main long-term, mid-term and yearly variations. We also added the seasonal shifts and discussed it.

4) Also the outlook section is only very loosely connected to the rest of the manuscript. I suggest to completely re-write this chapter. It should rather contain ideas of how to further analyze the developed indicators and/or how these can be analyzed in combination with other drought information. Maybe, a conclusions section would be more relevant.

Answer: We re-wrote and re-organised also the whole section.

Further comments:

Introduction Lines 20-23: These statements should be underpinned with references.

Answer: We added references

Lines 28-30: Statements could be more specific. Long-term reconstructions of what? Why are long term reconstructions necessary from comprehensive risk assessments? Century long time-series are not really necessary for comprehensive risk assessments, rather for temporally dynamic risk assessments.

Answer: We deleted this paragraph, as risk assessment is not in the focus of this article.

Lines 41-46: the statements should be underpinned with references.

Answer: We added (and moved) the relevant references.

Lines 47-53: It would be interesting to know, which drought indices are characterizing which drought type. If this is introduced in the introduction, this could be picked up later on for the new indices presented in the study, so that it becomes clearer for what the different indicators can be used.

Answer: We refer to different indices as usual in this context. But we decided to use the SPI, because this can be derived with the historical information. We added a short comment on this.

Line 65: Please clarify to which phases you refer here. This is rather unclear.D ata It is not fully clear to me, if all information/data described in this section is used for the analyses of the manuscript, maybe some more information which data/information has been used for what might be helpful.

Answer: As now outlined in the text and the conceptual view graph, the modern period refers to 1881-2018 while the term historical is related to 1500-1996.

Lines 98-101 This paragraph fits better into the introduction.

Answer: We followed the kind advice.

Lines 117-118. The equation for the calculation of the SPI should be provided or more detail how it has been calculated and on which data specifically.“Official precipitation values for Germany” is not specific. How many stations? Daily values? Spatial aggregation etc. Or was the SPI calculated already and available in the database. This becomes not fully clear here.

Answer: We used the already existing SPI values and drought categories as provided by the DWD. The spatial aggregation etc. was done by the DWD. We think more specification is not needed here, because the references are given.

Line 182-183: It remains unclear how the monthly PIs were summed up to the HPIs and how these were transformed into SPIs. Is the MDI available in the database tambora.org?

Answer: We described it more clearly ion the re-written MS. The code is also available on the Copernicus Homepage under “Assets”.

Lines 188-190 it is not clear to me how the HDI was calculated on basis of the HPI. Please elaborate on this and explain better.

Answer: We added a more specific description. Together with the conceptual view graph it should be clear now.

We thank the rev.2 for the helpful comments and corrections very much!

This manuscript is a general approach to study of droughts in historical dimension, using a large database. Different indices are implemented with overlapping to instrumental data period with more complete indices availability. Historical dimension of drought is faced with a correct approach, considering it’s a complex phenomena not easy to identify and evaluate in historical time, where not all information already is available for researchers. Justification of research is also well focused, with scientific and social preoccupation becase of increasing frequencies and severities of present drought events. Definition of droughts. Authors describe from a general and integrated point of view. Avoiding conceptual problems. Correct references, and historical approach, where conceptual definitions are not so easy. A complete conceptual development could take too pages. Context of manuscript, working on historical dimension, don’t justify so detailed conceptual analysis. Use of large database avoid the massive reference of sources and data previously available for this analysis. Bibliography is updated and complete. Absolutely adjusted to proposed research. Figures are well displayed and helps to understand results of manuscript. This manuscript, is a first analysis to show potential developments of historical droughts using quantitative and quantified information.

GENERAL ASPECTS + Title is too short. A subtitle could complete definition of pro-posed analysis.

Right. We have now a longer subtitle added

Table 1. Very interesting proposal. Putting in relation drought duration with drought severity seems logic and useful to study drought in historical time, where information about definition and development of indices is not so

complete and detailed as we would like. But, just a question about it. For a large natural region, as Germany or Central Europe, proposed table of criteria of classification is enough? Area under study is enoughly coherent or homogeneous to use only one system of criteria? Authors consider it would be possible application of similar method to be applied in different natural regions? Have they explored on this matter? Extension of this method to a larger spatial scale would be a good research path. Potential application of this method in other regions seems very useful. Authors could suggest any consideration about it?

This is indeed a crucial question, we discussed within the author team several times – there are different natural landscape types- true – But we decided to adjust our approach to the existing modern DWD concept, in which the whole of Germany is represented by one indicator as pointed out in table 1. It is a question of spatial scaling.

Concerning method proposed for indexing drought phenomena, manuscript show a single construction of index. Related with previous questions. All information available for Germany is reduced to one index with proposed method. Authors consider this only index is representative of drought variability for all Germany? On the other hand, it exist any wheighting process or statistical method to generate this index considering different climatic contexts? All information is considered in a similar way or level? Any clarification about it would be useful.

As pointed out in the previous paragraph, we adjusted our approach to the modern existing drought index – to find a comparable one dimensional representation. But analyzed and used a highly resoluted monthly time scale. The focus on the time means, that we could refer to the duration and the strength which is necessary to derive the chain of effects and the socio-economic dimension.
The method itself is transferable, whenever SPI makes sense for the relevant regions - the results and conclusions in this article refer to modern Germany.

Line 206. "The consequences and impacts (of drought) on the environment and society can also be reconstructued very well". This matter has increasing interest. In-tegrated approaches for natural and social dimension of hydroclimatic extremes. But authors only mention this potential in one sentence. It could be possible additional description of these potentialities, under point of view of authors? Sources, density and diversity of available information... For example, what oppinion about complementary sources, as economic (taxation records, tithes, market oscillations of prices... or other related aspects, as records about water resources. Any consideration about this dimension of drought impacts, would be interesting to reinforce sentence of line 206.

We have now a differentiated explanation in paragraph 3.2. where we describe the historical pathways and drought categories in detail, especially the chain of effects.

Section "Outstanding single years". Lines 244-252. A more detailed description or analysis was expected. A short relation of years with drought, not chronologically ordered, with no clear explanation about severity or duration of respective drought characteristics. Please, could you explain into text what characteristics or reasons justify for every date singularity of drought recorded? Why these years are "outstanding"?. What they have in common? Any figure about characteristics of singularity: duration? Extension?, severity? any combination of magnitudes? Considering important dimension of database tambora.org, manuscript could include a more detailed analysis about extraordinary drought events? It would be an excellent opportunity to exchange knowledge of these events to other colleagues, promoting comparative analysis in different spatiotemporal scales.

We reorganized this paragraph, explained the character of single years more detailed and even added a new derived view graph for better understanding and visualization.
There is also now a table containing the list of extreme events as derived using the different indices.

SPECIFIC ASPECTS+ Lines 128-129, 152, 214, 239.

Definition and use of concept of "cascade effects"(as impacts of droughts). Term is clear, but it could be improved with a more adjusted concept? Could be possible change "cascade" by "cumulative" effects? In fact, acascade is water flowing downstream, meanwhile impacts of drought are increasing byaddition in the same place. On the other hand, use of water-related phenomena, whendrought is an important absence/shortage of water..... it seems even ironic!

This is indeed very funny, but an often cited concept, because the duration of dryness is leading to different drought types (agrarian, hydrological and socio-.economic). We also used the term “Chain of effects” as well as “pathway”, which makes it somewhat clearer.

Line 166. Exclamation sign. Better final point.
Absolutely right. Done.

Lines 167-168. Unclear. Please, complete or clarify sentences.

We reworked these sentences – and made it clearer and more understandable.

Line 172. Formula doesn’t appear clearly showed in text. May be by any editing prob-lem. A black dot covers partially final part of formula.

This is indeed an editing problem, which does not appear in the original MS.

Line 265. "Prominet" by "prominent"

We corrected and rewrote the whole paragraph.