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Responses in river water quality during summers with extreme weather periods in Europe

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Master thesis, 30 credits, in *Physical Geography and Ecosystem Science*

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Abstract

Europe has experienced several climate extremes during the past decades. These extreme events have increased in number and intensity and are projected to further intensify. Previous studies show that heatwaves, drought, and flood can have an impact on water quality in several ways. Drought can cause reduced dilution of nutrients, limiting oxygen availability as a result of increased water temperature, and reduced primary production are all example of such impacts which can affect many biological processes. The aim of this study was to determine the impact on water quality caused by extreme events over a wider geographical extent covering Europe and across multiple rivers. This was done by using Waterbase database, water sample data retrieved during the years 2013-2015, and climate data retrieved from Copernicus Climate Change Service. Changes in the concentration of dissolved oxygen, nitrate, phosphate and chlorophyll-a during years that experienced summer climate extremes (2013 and 2015) relative to the values of a reference year were tested statistically, and further explored through correlation and regression analyses. The nutrients and dissolved oxygen were expected to increase and decrease, respectively, with higher air temperature, especially in rivers with small catchment areas. Dissolved oxygen concentrations decreased significantly during 2013 and 2015 at mid latitudes compared to concentrations in 2014. A spearman's correlation analysis was performed to determine any driver of the oxygen concentration patterns, showing a significant correlation between temperature and concentrations and both mid and high latitudes. To visualize the results of the correlation analysis, a linear regression was performed on the relationship between temperature and concentration of dissolved oxygen and showed significant results at both mid and high latitude, though contradictory to each other. No significant differences between concentrations of neither nutrient nor chlorophyll-a and year were found. Therefore, results were only in part consistent with findings of previous studies, making an overall interpretation difficult and not straightforward. The question about the effect of climate extremes on water quality is complex and includes a variety of variables not accounted for, but potentially highly influential on the parameters used in this study. Additionally, a more geographical spread of sample locations, and a higher consistency in sampling, and increase in frequency, would allow for a more robust and precise analysis.

***Keywords**: physical geography, water quality, rivers, Europe, climate extremes, drought, heatwave, floods, dissolved oxygen, nitrate, chlorophyll-a, phosphate*

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1. Introduction

Europe has experienced several extreme climate events the last decades, which could potentially impact water quality. Several studies on extreme events following climate change, and their impact on water quality, have been published during 2000s (van Vliet and Zwolsman 2008; Zieliński et al. 2009; Orth et al. 2016; Gómez-Gener et al. 2020). Drought can cause low river water levels and flow (Zieliński et al. 2009; Orth et al. 2016), leading to less dilution of nutrients and organic pollutant concentrations and causing an increase in biological oxygen demand, which in turn results in lower concentrations of dissolved oxygen (van Vliet and Zwolsman 2008; Whitehead et al. 2009). Increase in air temperature, caused by severe or prolonged heatwaves can result in an increase of water temperature, this affects the solubility of oxygen as the solubility decreases in warmer water temperature, resulting in a decreased concentration of dissolved oxygen (Harvey et al. 2011a; Diamantini et al. 2018). Additionally, higher water temperature would also increase the biological oxygen consumption (Cox and Whitehead 2009). Low flow, long residence time, elevated nutrients and temperature following climate extremes can cause an increase in the primary production of water bodies, which could result in excessive growth of algae causing eutrophication (Hilton et al. 2006; van Vliet and Zwolsman 2008; Yang et al. 2008). However, heatwaves have also resulted in a decrease in water temperature, where the increased air temperature affects the snow melt and increase melt water causing the temperature in rivers which normally are fed by meltwater, to decrease (Sebastiano et al. 2018).

Freshwater systems across Europe are of importance for many reasons. They provide services that generate socioeconomic benefits to human societies in several ways (EEA 2018b; Jorda-Capdevila et al. 2019), such as hydro power, irrigation used for agriculture, domestic and industrial purposes as well providing opportunities for fishing and water sports (Jorda-Capdevila et al. 2019). Population growth and an accelerated extraction of the earth’s resources has put pressure on our water resources. European Environmental Agency (2918) reports that there has been a steady increase in Europe’s water demand over the last 50 years (EEA 2018b). Approximately 40% of the total freshwater usage in Europe is consumed within agriculture. This is especially the case in southern Europe (EEA 2018b), with particular exposure to extreme weather events in (EEA 2018a).

The main processes that affect water quality during droughts are similar across different rivers, but the magnitude of changes in water quality depends on catchment characteristics, river regime and human activities, which are site specific (van Vliet and Zwolsman 2008).

This is perhaps why most of the previous published studies have been carried out with focus on rivers with limited geographical extent or looking only at one or a few rivers (van Vliet and Zwolsman 2008; Zieliński et al. 2009; Diamantini et al. 2018). Although few studies have been performed at a larger scale, Laaha et al. (2017) studied the hydrological footprint of the 2015 drought in terms of both severity and spatial extent in comparison to the extreme drought in 2003, but could not cover the whole continent, and more research on impacts at this scale is needed including multiple rivers across a wider geographical extent.

The aim of this study was to determine if years with extreme weather periods, here specified as periods of drought and heatwave, during the summer period of June-August can affect the water quality across European rivers by answering the following research questions:

- How do different extreme weather periods affect water quality measured in Dissolved Oxygen (DO), Nitrate (NO3), Phosphate (PO_4^{3-}) and Chlorophyll-*a*, across rivers in Europe?
- Comparing data from years with climate extremes against a reference year, will the response in river water quality towards these events be different depending on their location based on latitude?
- Comparing data from years with climate extremes against a reference year, will the response in river water quality towards these events be different depending on catchment size?
- How do the different water quality parameters correlate with each other during extreme weather periods?

This study aims at testing the following hypotheses:

- The concentrations of dissolved oxygen will decrease during events of heatwaves and drought.
- Levels of nutrients are expected to increase, because drought results in less water entering the aquatic system which otherwise would dilute concentrations.
- Chlorophyll-a is expected to increase as nutrient increase.

The increase in water temperature and the subsequent decrease in solubility of oxygen will be high during drought event, and only groundwater will enter the aquatic system, which is known to be oxygen poor. Drought can also decrease re-aeration where water are more stagnant, or flow is reduced, which can result in a poorer concentration of oxygen (Conlan

2007). Increase in nutrients can lead to increase in primary production and result in increased levels of chlorophyll-a (Bennett et al. 2017).

Smaller catchments is expected respond to extreme weather periods at a larger extent both in concentrations of oxygen and nutrients since larger catchments responses to atmospheric signals are slower due to increased storages which could delay processes in the river network (Laaha et al. 2017).

2. Background

2.1. *Periods of extreme heat*

Europe has been subject to a series of severe hot and dry summers since the beginning of the century. Heat waves, droughts and other extreme weather events can have major environmental impact on, and cause severe stress to ecosystems and vegetation (Parry et al. 2007), threatening biodiversity (Parmesan 2006; IPCC 2014a; Ratnayake et al. 2019). It also affects humans through several socioeconomic impacts: increase in mortality, reduction in productivity of natural vegetation, crop failure, increase in air pollution, lower energy supply and electricity restriction to mention a few (Barriopedro et al. 2011; Grumm 2011; Coumou and Rahmstorf 2012; Stefanon et al. 2012; Tomczyk and Bednorz 2019). For example, the heat wave in 2003 is estimated to have caused 14,800 deaths in France alone during 9 days with extreme temperatures in August (Bouchama 2004). During that same heatwave Europe reported crop losses of approximately 12.3 billion US$, record melting of the Alps and rock fall due to permafrost thawing (Schar and Jendritzky 2004). The heat wave combined drought in 2015 caused drinking water deficiencies and crop losses. During the same heatwave the major rivers of the Netherlands experienced salt intrusion that reached tens of kilometres due to low flow affecting freshwater ecosystems (Van Lanen et al. 2016). Both the heatwave combined droughts in 2003 and 2010 led to a decrease in net CO2 uptake in ecosystems (Bastos et al. 2020). The more recent heatwave combined drought in 2018, that affected central and Northern Europe in particular, caused the largest decline in crop yields in Sweden since 1959, creating food deficiency for the cattle farmers (Jordbruksverket 2019).

Such extreme weather events are not a new phenomenon, but natural disturbances that are a part of global climate variability (Marvin et al. 2013; Ionita et al. 2017; Laaha et al. 2017; Sergio et al. 2018). However, there has been an increase over the 21st century in frequency, intensity and duration of weather extreme events (Schär et al. 2004; Coumou and Rahmstorf 2012; Perkins et al. 2012; IPCC 2014a; Houghton 2015; Ratnayake et al. 2019; Tomczyk and Bednorz 2019). Since year 2000, Europe experienced 17 of the last 18 warmest year on record, and the year 2018 was the world's fourth hottest year on record following 2015, 2016 and 2017 (EEA 2019a). Recent studies associates such heat waves, and other extreme weather events such as colds spells and flooding in Eurasia, with the Arctic Amplification (AA), the more rapidly warming of the arctic (Francis and Skific 2015a). The ongoing research focus on identifying the mechanism(s) that explain how AA could influence the large-scale circulation of the Northern hemisphere, and the possible role of anthropogenic forcing versus random natural variation. Studies show that the occurrence of several extreme weather events were associated with strong high-pressure systems, which block the zonal circulation (the jet stream's westerly winds) creating a persistent weather pattern (Stefanon et al. 2012; Francis and Skific 2015b; Pardo and Garcia 2016; Van Lanen et al. 2016; Tomczyk and Bednorz 2019). The warming of the climate and continued AA, cause changes in the Northern Hemisphere circulation pattern and as a consequence the occurrence of persistent weather pattern is expected to increase favouring increased occurrence of extreme events (Francis and Skific 2015b). However, tracing back it is difficult to know if the Arctic amplification would be the cause of any specific extreme event, but (Francis and Skific 2015b).

Extreme weather events are predicted to increase in frequency, duration and intensity as the climate keeps warming (Schär et al. 2004), and the southern and south-eastern Europe is projected to become a climate change hotspot (EEA 2017). As long as the emission of greenhouse gases increases the Intergovernmental Panel on Climate Change (IPCC) states that it is *very likely* that heat waves will occur at a higher frequency and with a longer duration and that the world will continue to warm (IPCC 2014a). A study by Stott et al. (2004) show that, despite being a natural phenomenon, human activities is likely to have doubled the risk of an occurrence of such an event, with a confidence level >90% (Stott et al. 2004). Another study by Christidis et al. (2015) found that events that would occur twice in a century in the early 2000s now are expected to occur twice a decade.

2.2. Droughts

National drought mitigation centre of Nebraska defines four types of drought: meteorological, hydrological, agricultural, and socioeconomic (NDMC 2020). Meteorological droughts, here defined by the National Oceanic and Atmospheric Administration (NOAA), is based on the length of the dry period, and the degree of dryness or rainfall deficit while the hydrological drought refers to the impact of the rainfall deficit on the water supply such as stream flow, ground water table decline or reservoirs and lake levels. Agricultural drought refers to the impact on agriculture from factors such as those above mentioned, and socioeconomic drought defined as the combined impacts of hydrological, meteorological, and agricultural drought on supply and demand on farmed goods (NOAA 2020). Both metrological and hydrological droughts have increased in frequency and severity in many parts of Europe, and in the southern parts in particular (EEA 2020). Projections are that drought conditions across Europe will continue to increase, except for central- and north-eastern parts. Again, the south of Europe is projected to have the greatest increase in drought conditions (EEA 2020). Drought is generally accepted as one of the most costly weather related natural hazard (Van Lanen et al. 2016; Ionita et al. 2017). It has major impact on both ecosystems, water quality and affects many socioeconomical factors (Hardenbicker et al. 2016; Van Lanen et al. 2016; Ionita et al. 2017). During the drought in 2003, water shortages were reported in combination with high temperature in addition to widespread losses in the agricultural sector and problems with the temperature related energy sector (Stahl et al. 2016). Additionally, as a consequence of increased water temperature and non-limited nutrients supply due to less dilution, oxygen levels could decrease to a level that poses a threat to invertebrates and fish (Conlan 2007). Drought can cause low flow and low river water levels (Zieliński et al. 2009; Orth et al. 2016) which will impact water quality by reduced dilution of concentrations of nutrients and organic pollutant and causing an increase in biological oxygen demand, which in turn results in lower concentrations of dissolved oxygen (van Vliet and Zwolsman 2008; Whitehead et al. 2009). Increase in river water temperatures has been reported during conditions of drought in many rivers (Mosley 2015), and a higher water temperature would increase the biological oxygen consumption (Cox and Whitehead 2009) decreasing dissolved oxygen concentrations. Additionally, low flow, long residence time, elevated nutrients and temperature following drought can cause an increase in the primary production of water bodies, which could result in excessive growth of algae causing eutrophication (Hilton et al. 2006; van Vliet and Zwolsman 2008; Yang et al. 2008).

2.3. Water quality and the response to extreme weather

Water quality is defined in terms of physicochemical characteristics, e.g. the concentration of different constituents such as nutrients, oxygen, organic matter and toxicants, but also physical properties like water temperature (Nilsson and Renöfält 2008). Several of these constituents in the freshwater of Europe will be affected by climate change (IPCC 2014a, b) and by extreme events such as heat waves (Hannah and Garner 2015). This is observed in previous published studies, which presented indications of climate related mechanisms, both short and long term, that had direct impact on water quality (van Vliet and Zwolsman 2008; Hrdinka et al. 2012; Hannah and Garner 2015). Biological processes and water quality parameters, such as dissolved oxygen, are affected by changes in water temperature, however studies covering extreme events and the immediate response in water temperature are sparse (Hannah and Garner 2015).

Changes in both climate, and climate extreme events, can alter the hydrological system by changes in precipitation patterns and the melting of snow and ice. These changes in runoff indicate changes in the flow volume, which defines dilution of concentrations and residence time (Cox and Whitehead 2009). Additionally, changes in water levels and already mentioned changes in temperature – are all factors affecting water quantity and quality. Drought can potentially increase the concentration of nutrients, which is one of the major factors together with higher water temperature, to cause eutrophication (Yang et al. 2008). By reducing dilution, drought will have an impact on organic pollutant concentrations with increased biological oxygen demand, which will reduce the concentration of dissolved oxygen (Cox and Whitehead 2009). Furthermore, river water temperature, which is highly influenced by air temperature, is another major factor influencing water quality as it regulates many biological processes in a river system (Harvey et al. 2011b; Hannah and Garner 2015; Osman et al. 2018) and directly affects the concentrations of dissolved oxygen (van Vliet and Zwolsman 2008; Whitehead et al. 2009). Increase in water temperature could increase primary production and phytoplankton growth rates, which can worsen eutrophic conditions (Hilton et al. 2006) that in turn affect concentration of oxygen (Nguyen et al. 2016). When organic material decomposes, dissolved oxygen is consumed, causing deficient levels of concentration (Yi-Fan et al. 2020). Additionally, higher river water temperature increases the rate of chemical reactions. This results in a decreased concentration of dissolved oxygen, due to the increase of oxygen demand (Cox and Whitehead 2009; IRMA 2017). In addition, the solubility of oxygen decreases with an increase in temperature (Harvey et al. 2011b; IRMA 2017). The combined effect of increased oxygen demand and decreased solubility can result in a reduced biodiversity and overall productivity (IRMA 2017). The process of eutrophication has become a global environmental problem (Yang et al. 2008). During conditions of excessive concentrations of nitrate and phosphate, caused by decreased dilution during drought, increased input from human activities, or brought by flood water from terrestrial sources, slow current velocity, adequate temperature and microbial activity and biodiversity eutrophication may occur rapidly (Yang et al. 2008), and such conditions are a known problem (excessive nutrient load, increased water temperature) and may increase with future climate change.

Floods can also affects rivers and its ecosystems by excessive concentrations of organic and inorganic matter brought by the flood water, which could reduce primary production due to increased turbidity and sedimentation where light cannot penetrate (Nilsson and Renöfält 2008) and by that affect concentrations of dissolved oxygen.

However, it could also be a positive feedback as the added nutrients by the flood could increase primary production. Pollutants could also be brought with the water from floods (Nilsson and Renöfält 2008).

Many indicators of water quality vary naturally - dissolved oxygen varies daily through respiration and photosynthesis (Morgan et al. 2006) – or it varies with weather and variation in water flow through dilution of concentrations and turbidity, potentially having an impact on photosynthesis (Nilsson and Renöfält 2008).

Trough pollution caused by human activities, flow regime modifications and water extraction, the European freshwater has been under pressure for a long time and have affected eco systems negatively (Whitworth et al. 2012; Grizzetti et al. 2017), and freshwater systems in particular (Nilsson and Renöfält 2008). Major European rivers have increased in temperature by 1 to 3 °C (EEA 2016) and are projected to further increase in temperature and decrease in flow – affecting the river water quality further (van Vliet et al. 2013) by reduced concentration of dissolved oxygen, increase in nutrient concentration worsening many already polluted rivers in Europe, affect biological processes and in severe cases cause increase in algae bloom events. Though EEA in 2018 published the report “*European waters — Assessment of status and pressures 2018*”, which estimated that 40% of Europe’s surface water bodies are in good or high ecological status, although coastal waters and lakes are doing better than transitional waters and rivers. Significant decrease in the average nitrogen concentration is reported from 32% of the river monitoring stations throughout Europe, while a significant increase has occurred for 14% of the monitoring stations (Eurostat 2012). Despite the improvement in the state of water quality over the past decade, excessive concentrations of nutrients are still a problem for many European rivers (EEA 2019b), and even with both nitrate and phosphate decreasing in parts of European freshwater, the process of eutrophication is still an issue (Ibisch et al. 2017; Matthew et al. 2018). The process of eutrophication in rivers are less studied compared to the process of eutrophication in lakes which is rather well understood, since its more complicated due to its dynamic nature (Hilton et al. 2006).

2.4. *Description of water quality parameters*

In this study, four different water quality parameters were focused, and they include dissolved oxygen, phosphate, nitrate, and chlorophyll a. In Table 1, the concentrations of these parameters are presented where values are within the range of a good quality in terms of river water following the Environmental Protection Agency report from 2017 on water quality (Trodd and O'Boyle 2018) and using the thresholds for chlorophyll-a by Tryggvadotter (2006) in the report "indicator for algae bloom in the coastal zone" since no defined values for rivers were found.

Table 1. Chosen parameters and their concentrations in a river with different conditions of quality. The changes in concentration for these parameters are used to determine changes in water quality between years with summers experiencing extreme events and a reference year. The thresholds for nitrate and phosphate are taken from the Environmental Protection Agency report from 2017 on water quality (Trodd and O'Boyle 2018) and threshold values for chlorophyll-a was taken from the report "indicator for algae bloom in the coastal zone" (Tryggvadotter 2006). However, the threshold for chlorophyll-a is focused on the coastal waters but used as indicators of quality in rivers for this thesis.

	High	Good	Stress	Hypoxic/Polluted
Dissolved oxygen (mg/L)		>8	<4	<2
Nitrate (mg N/L)	<4	<8	8-37.5	37.5-50
Phosphate (mg P/L)	<0.025	<0.035	0.035-0.25	>0.25
Chlorophyll-*a* (um/L)	<1.5	1.5-3	3-5	>5

These four variables interact with each other through different processes. Excessive concentrations of nutrients and increasing water temperature can increase the growth of algae and oxygen is consumed (Hilton et al. 2006). Additionally, the increase of algae and plants at water surface could limit how far the sunlight is able to reach (Grizzetti et al. 2011) and therefore influence the growth of plants and algae at lower part of water (Hilton et al. 2006; Grizzetti et al. 2011).

2.4.1. *Dissolved Oxygen (DO)*

For living organisms in aquatic environments oxygen is an essential chemical compound (Harvey et al. 2011b; IRMA 2017), and therefore one parameter indicating water quality in this study. This is supported by a study by Kannel et al. (2007) in which four different water quality indices (WQI) to classify river quality was used, the indices considered 18, five and one water quality parameters. Dissolved oxygen and the index named WQI_{min}, which considers 5 parameters (temperature, pH, dissolved oxygen, electrical conductivity and total suspended solids), coincided in 90% and 93% of the samples, making dissolved oxygen a good parameter to use as indicator of water quality (Kannel et al. 2007). Concentrations of dissolved oxygen vary daily and seasonally and are dependent on location and water depth (Morgan et al. 2006). During night time, respiration consumes dissolved oxygen (Morgan et al. 2006) while oxygen during daytime enters the water as a product from photosynthesis, or through aeration (EPA 2020). In lakes, climate change is projected to change the stratification, by timing and by its duration, and decrease in the thermocline thickness (Zhang et al. 2015). In lakes, the dissolved oxygen depth profile is greatly dependent on the thermal stratifications pattern, which means that climate change could ultimately lengthen the period of dissolved oxygen stratification, as the oxygenated surface waters are isolated from the hypolimnetic water (bottom water, poor in oxygen) (Zhang et al. 2015). During this time, the bottom water can be depleted of oxygen (Zhang et al. 2015). This is not applicable for small fully mixed rivers, but the depth profile of dissolved oxygen in larger rivers has to be considered, as the sampling depth could affect the results and their interpretation. The concentration of dissolved oxygen in a healthy river lies somewhere in the range of 8-12 mg/L, whereas concentrations lower than that have reported effects on freshwater ecosystems (Harvey et al. 2011b).

2.4.2. Nitrate

Nitrate is essential for photosynthesis and primary production. It is also a common chemical fertilizer in modern farming practice and has long been known to be the cause of excessive nitrate concentrations across Europe (Ibisch et al. 2017; Trodd and O'Boyle 2018). High levels of nitrate can contribute to the process of eutrophication, leading to excessive algal growth - oxygen consumption and biodiversity affected (Grizzetti et al. 2011; Ibisch et al. 2017; Trodd and O'Boyle 2018; Poikane et al. 2019). Nitrate is negatively and significantly correlated with temperature, and highly positive correlated with oxygen concentration (Kempe et al. 1991). In the global nitrogen budget denitrification is a sink of nitrate, and can help to control the excessive amount if added nutrients (Sybil 1988). Denitrification is the microbial process where nitrate and nitrite is reduced to gaseous forms of nitrogen (Skiba 2008). If water temperatures are high enough for bacterial denitrification to occur, dissolved nitrate can function as additional source of oxygen during respiration (Kempe et al. 1991).

2.4.3. *Phosphate*

Elevation in levels of phosphate can originate from agriculture, wastewater, or runoff from urban areas (Trodd and O'Boyle 2018). An increase in phosphate, e.g. due to reduced dilution, can decrease the levels of dissolved oxygen through increased algae growth and large aquatic plants resulting in eutrophication (Trodd and O'Boyle 2018). Previously, phosphate was considered to be the “limiting nutrient” for freshwater, as its availability controls primary production. However, studies now show both nitrate and phosphate being able to limit primary production (Poikane et al. 2019), and the limiting role can vary seasonally and temporal between nitrate and phosphate (Grizzetti et al. 2011). Naturally, phosphate is found in small concentrations, as such sensitive to small increases which negatively affects water quality.

2.4.4. *Chlorophyll-a (Chl-a)*

Chlorophyll-a is produced by algae and is required for plants grow, also giving plants their green colour. An increase in algae plant growth, due to excessive nutrients, can cause a decrease in DO in the bottom waters during the decomposition process (Grizzetti et al. 2011). Higher water temperature favours an increase in the growth rate of algae, which could in extreme cases cause eutrophication (Hilton et al. 2006). One major factor causing eutrophication is high water temperature, however more is needed for this process to take place, such as excessive concentrations of nutrients. Algae biomass is often measured as chlorophyll-a, which in a study by Neal et al. (2006) showed a strong negative correlation with the base flow index (BFI). Rivers with high BFI generally has a stable flow, with very few events of low flows, while river with low BFI indicate a flashy flow regime and high variability in flow (Neal et al. 2006). The relationship is stronger during low-flow periods, indicating the importance of residence time for planktonic growth (Neal et al. 2006).

2.5. *Previous studies on water quality response to extreme weather events*

A study on the possible impact of floods and drought on water quality in Czech Republic from 2011 recorded significant increase in surface water temperature during the drought in 2003 (Hrdinka et al. 2012). Chlorophyll-*a* concentrations were unchanged and a small decrease in oxygen were recorded and related to increased water temperature (Hrdinka et al. 2012).

In a study by Cox and Whitehead (2009) the aim was to investigate the effect of climate change on dissolved oxygen in the river Thames. The river drains 9948 km^2 of central southern England. A model named O^2 (described in detail in Cox and Whitehead, 2009) was used to simulate different emission scenarios and how the following consequences affect the river water (Cox and Whitehead 2009). The emission scenarios used were derived from the UKCIP02 report, which presents four scenarios of future climate change for the United Kingdom (Hulme et al. 2002). During dry years the river Thames was subject to drought, but the general water quality is good, with occasional low concentrations of dissolved oxygen (Cox and Whitehead 2009).

Another study performed by van Vliet and Zwolsman (2008) on the river Meuse in France showed similar main processes having an impact on water quality for different rivers during drought. It also showed that the magnitude of the change in water quality depends on catchment characteristics, river regime and human influences inside the catchment area (van Vliet and Zwolsman 2008). Water quality was measured using 24 parameters divided into four groups: General water quality variables, Nutrients, major elements, and heavy metals and metalloids. Generally, the results showed that rivers with a higher increase in temperature and limited stream capacity for dilution had a lower quality while those with a relatively high discharge changed less in quality during the summer (van Vliet and Zwolsman 2008).

Another study used the drought in 2015 to analyse how to best manage future events like drought (Van Lanen et al. 2016). The impacts of the drought lasted into 2016, such as losses in crop yield, livestock farming as well as degradation of water quality (Van Lanen et al. 2016) . Algae blooms and oxygen deficits were reported in Germany, Slovakia, and European Russia. Record low stream flow was recorded as a response to high temperatures, extremely low precipitation and higher than normal evapotranspiration (Van Lanen et al. 2016).

Hilton et al. (2006) preformed a study on eutrophication in rivers where interaction between nutrients, light penetration and water velocity were discussed. They presented a conceptual model of the development of eutrophic conditions where rivers mechanisms were included such as retention time, velocity, light penetration, nutrient levels and limiting nutrients (Hilton et al. 2006). The proposed model was consistent with a number of observations from eutrophic rives. The model differentiated between rivers with long and short retention times as they respond differently when exposed to excess nutrients (Hilton et al. 2006). Thus, eutrophication would not only be caused by excessive nutrient concentrations, but also be dependent on other hydrological factors. It was suggested that eutrophication is likely to express itself in two different forms depending on river characteristics such as deep rivers with long hydraulic residence time, and rivers with short retention time (Hilton et al. 2006).

Many of these studies have a limited geographical extent, focusing on a single river, or few rivers, or study the response of a single or a few water quality parameters. Studies with a broader approach are sparse, which is the motivation for this thesis.

3. Data and methods

3.1. Data sources

3.1.1. Climate data

Climate data were derived from Copernicus Climate Change Service. The dataset consists of spatially interpolated daily temperature and precipitation data (accessible from: https://surfobs.climate.copernicus.eu/dataaccess/access_eobs.php). The used data were E-OBS, a gridded dataset covering the land of Europe with a spatial resolution of 0.1 degree and data span from 1950 to December 2018. The daily mean temperature is measured at the surface in degree Celsius, covering 24 hours per time step, typically at a height of 2 meters. The precipitation data are measured in millimetre, and classified as total amount of rain, snow and hail measured as the height of the equivalent liquid water in a square meter (Copernicus 2020).

3.1.2. Water quality data

Data of samples from different water bodies were derived from Waterbase database developed by the European Environment Agency (EEA). The data set includes time series of organic matter, nutrients, hazardous substances, data on biological quality elements and other chemicals from the years 1960 to 2019. Samples from ground water, rivers and lakes (RW, LW, GW) were downloaded by the sampling parameters: dissolved oxygen (mg/L), nitrate (mg P/L), phosphate (mg P/L) and chlorophyll a (µm/L). Dissolved oxygen concentration was used instead of oxygen saturation, which had limited number of samples over time. River water temperature data was not included in this study, but of importance due to its impact on water quality (van Vliet and Zwolsman 2008; Whitehead et al. 2009; Harvey et al. 2011a; van Vliet et al. 2013; Hannah and Garner 2015; Osman et al. 2018). Since air temperature is one of the main drivers of water temperature, changes in average air temperature will be used as an indicator for changes in river surface water temperature. Rivers with lower summer discharge are generally more sensitive to drought than rivers with higher summer discharges, such as rivers fed by snowmelt (van Vliet and Zwolsman 2008). With the purpose to keep rivers with similar climate and catchment size within the same group, river sample data were divided into three groups depending on latitude and catchment size.

3.1.3. Catchment data

Catchment area was derived from the Global Drainage Basin Database (GDBD) developed at Centre for Global Environmental Research (Masutomi et al. 2007). The database consist of six GIS data collections: drainage basin boundary data, river network data, discharge gauging station data, natural lake data, dam lake data, and flow direction data, but only the drainage basin boundary data was used in this thesis (accessible from: https://www.cger.nies.go.jp/db/gdbd/gdbd_index_e.html). Metadata available in *User's manual* is accessible at CGER (Masutomi et al. 2009).

3.2. River catchment size and latitude differences

The quality parameters were divided into three different groups to explore any increase or decrease in response to weather extremes for different environmental characteristics. To study whether rivers are more sensitive to extreme changes in weather depending on geographical location each parameter were divided into group of latitudes roughly separating northern (>55° N), central (45-55° N), and southern Europe (<45° N) with the purpose to keep northern, central and southern Europe separate. The data was also divided into three groups depending on catchment area, to explore whether its size could have any effect on the magnitude of potential impacts from periods of extreme weather.

3.3. Time span

To specify the temporal extent for this research extreme weather events were chosen through published literature of past events, ultimately following the IPPC and WMO on reported heat waves (WMO 2011; Seneviratne et al. 2012). There are several drought and heat wave periods in Europe since the beginning of 2000. Among some of the most severe climate events are the heatwave combined drought in 2003, the "Russian heat wave" in 2010, the heat wave combined drought in 2015 and more recently during 2018, affecting northern Europe especially hard. Due to data limitations, some of the severe heatwaves that happened earlier than the year 2000 could not be included in this thesis (number of data samples, Table 2). The number of samples increased greatly after 2011 for almost every parameter, but data from 2018 and forward were not yet reported. This left a limited number of years to be used for analysis. The years 2013 and 2015 both experienced extreme weather periods during the summer and was used in this analysis, while 2014 will be used as reference year. The time span could be problematic since impacts from severe weather events could last into the following year such as reported by Van Lanen et al. (2016), however the years of 2016 and 2017 were not suitable as reference years due to both experiencing weather events at some time during the period of interest, and not enough water quality data was available for years prior to 2013 across all parameters.

During the summer in 2013 a series of heat waves affected Europe, the central and southern parts in particular. Austria experienced three heatwaves with a total of 27 days during the summer, and the average maximum temperature anomalies from their mean value were measured close to 10 degrees (Lhotka and Kyselý 2015). The maximum temperature was recorded on 8th of August and measured 40.5 °C (Lhotka and Kyselý 2015). Additionally, Austria experienced one of the largest flood events in the past two centuries early in June (Blöschl et al. 2013). The flood affected several parts of Central Europe and Southern and Eastern Germany in particular (Merz et al. 2014). High soil moisture caused by a strong rainfall anomaly in May was combined with intense rainfall during 31 May and 4th of June set off the flood event (Merz et al. 2014).

In the summer of 2015, exceptionally high temperatures were measured in many parts of Europe with daily maximum temperatures 2°C higher than the seasonal mean (1971-2000) in larger parts of western Europe, and 3°C higher than seasonal mean for eastern parts of Europe (Ionita et al. 2017). Four times over the summer there were episodes of heat wave associated with persistent blocking events. At the same time, there was a rapidly developing drought, one of the worst recorded, which peaked in August affecting eastern Europe especially (Ionita et al. 2017). The duration of the heat wave varied depending on location, in some places it started in late June and lasted about 30 days, while at other European areas it lasted about ten days into August (Russo et al. 2015). Compared to the drought combined heatwave during 2003, the extreme event experienced during 2015 were not as spatially extensive and had contrasting response where the climate became wetter in the north and south while more severe conditions north of the alps and parts of central Europe (Laaha et al. 2017).

3.4. Data processing

From the Waterbase database the parameters used in the study were extracted using R Studio: dissolved oxygen, nitrate, phosphate, and chlorophyll-*a*. Coordinates for each sample site were downloaded separately from Waterbase and added to the data set. Samples with no coordinate data were excluded. Dividing data into parameter and subgroups was done using Excel. Maps over site sample locations was created using ArcMap.

3.4.1. Groups by catchment

To divide all the parameter sample data into groups based on catchment area, the samples site coordinates were imported into ArcMap. The catchment areas were extracted using the Global Drainage Basin database and imported into excel. With no accepted general size limits for river size classification (SMHI 2012) the three groups were defined by equal amount of percentile per category and catchment size group is therefore dependent on number of rivers included, and could change if the number of rivers included in the study changed. Figure 1 show the distribution of sample site locations of dissolved oxygen for each catchment group (Figure 1, Divided by catchment). The distribution is similar across all parameters except for France which sampled both nitrate, phosphate, and chlorophyll. The catchment range are presented in Table 2.

Table 2. Table of the catchment size ranges within each group of percentile for each parameter. The original unit were m^2but converted in excel to km^2 by multiplying m^2 with 0,00001.

	Catchment	**Area min km^2**	**Area max km^2**
Dissolved oxygen	1	190 km^2	3100 km^2
	2	19200 km^2	34680 km^2
	3	35700 km^2	246310 km^2
Nitrate	1	6 km^2	1828 km^2
	2	1835 km^2	3238 km^2
	3	3239 km^2	246310 km^2
Phosphate	1	6 km^2	1891 km^2
	2	1896 km^2	3312 km^2
	3	3316 km^2	246310 km^2
Chlorophyll-a	1	6 km^2	1785 km^2
	2	1822 km^2	3109 km^2
	3	3112 km^2	246310 km^2

3.4.2. Groups by latitude

As no other study has the same large-scale approach, these latitude divisions were determined with the aim to roughly separate southern, central, and northern Europe, to keep rivers with similar environmental characteristics in the same group to analyse. Using Excel, the data was divided into latitude groups by 45° south, 45-55° and 55N° north as seen in Figure 1 (Groups divided by latitude). The distribution of samples between the different parameters were similar to those in Figure 1, where dissolved oxygen is used as an example, apart from all nutrients being sampled across France.

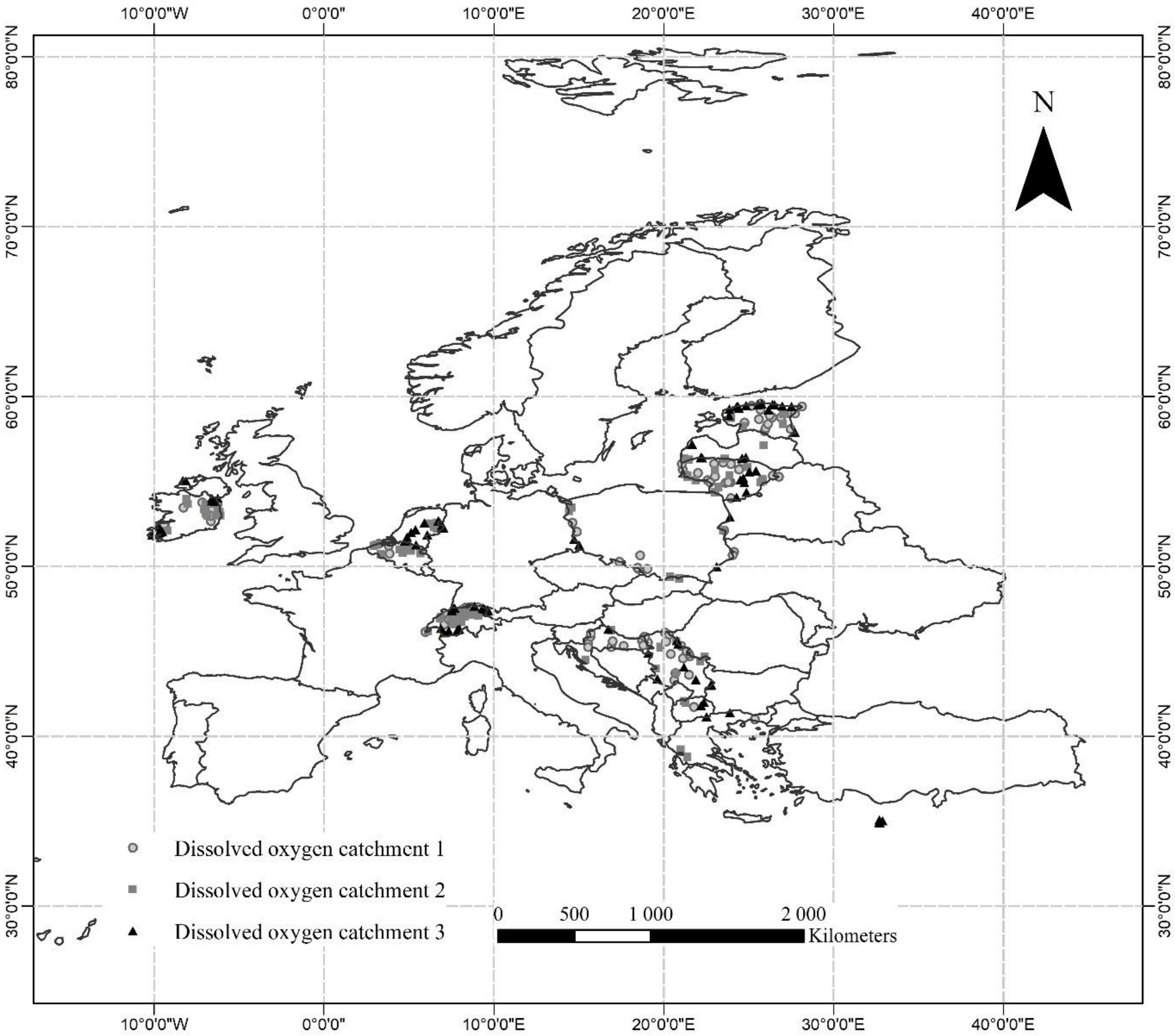

Figure 1. The map represents sample site locations for dissolved oxygen divided by catchment size. It is used as an example to visualize the distribution of sample locations at 45°N, 45-55°N and 55°N. Nitrate, phosphate, and chlorophyll-a all had similar distribution of sample locations apart from samples taken in France. The location of the monitoring sample sites are similar to those sites divided by latitude.

3.4.3. Climate Data

The climate data was downloaded from Copernicus and processed using R Studio and Excel. Temperature and precipitation data were extracted for each year using the coordinates from each sample site location in R. With Excel, the time span used for this analysis were extracted. Since few stations collected samples including all of those used for this analysis, climate data needed to be extracted for every parameter within the latitude and catchment groups.

3.5. *Statistics*

Statistics were performed using SPSS, R Studio and data processing using Excel. The samples data for each parameter were tested for normal distribution and homogeneity in SPSS. To see how the data were spread and a statistical summary of each parameter, clustered boxplots were made in SPSS. The data showed a skewed distribution for all nutrients, while dissolved oxygen had normal distribution. The non-parametric test Mann Whitney were used determine any significant difference between the years with climate extremes and the reference year for groups of nutrients. A paired t-test was performed on the groups of dissolved oxygen to determine any significant difference. The p value had to be <0.05 to be considered significant for both statistical tests and were done in SPSS. Drivers of any changes in concentration of the chosen variables were analysed by performing the Spearman‘s Rank Correlation analysis on the climate data and parameter concentration following the method of Morgan et al. (2006) for correlation analysis. This correlation analysis was chosen due to the skewed, and characteristics of the data (Diamantini et al. 2018). To further investigate any relationship between climate data and parameter concentration data, a regression analysis was performed for selected parameters.

4. Results

The amount of collected samples varied between the different parameter and years (Table 3). A large amount of data was lost when selecting only recurrent stations which sampled every year due to no consistency in frequency of sampling, and there was a great variation in numbers of samples/month, which limited the analysis to concentrations of monthly means for every parameter. Any clear pattern could therefore not be attributed to the average daily climate data, so it was instead calculated as the monthly average and the total average of the period June-August. Close to every subgroup had data with skewed distribution, both negative and positive.

Table 3. Summary of the number of samples for each parameter, year, and catchment (left table) and latitude (right table). Samples of Chlorophyll-a har sparse, especially at higher latitude where a total of 35 samples were collected during the period Jun-Aug under 3 years. DO and chl-a were sampled prior to 2011, and number of samples were less than 20 for all years before 2010.

Catchment		2013	2014	2015	Latitude		2013	2014	2015
	1	131	127	128		<45 °N	38	41	36
Dissolved Oxygen	2	126	124	122	**Dissolved Oxygen**	45-55 °N	269	262	260
	3	137	130	124		>55 °N	87	78	78
	1	26	27	24		<45 °N	12	12	12
Nitrate	2	18	16	18	**Nitrate**	45-55 °N	42	41	42
	3	14	14	14		>55 °N	9	9	9
	1	18	18	17		<45 °N	11	10	10
Phosphate	2	27	24	25	**Phosphate**	45-55 °N	46	43	25
	3	22	20	20		>55 °N	10	9	8
	1	11	12	13		<45 °N	5	6	5
Chlorophyll-a	2	13	18	18	**Chlorophyll-a**	45-55 °N	28	34	35
	3	9	10	9		>55 °N	11	8	7

4.1. Analysis of groups by latitude

Dissolved Oxygen

Figure 2 show a descriptive summary of dissolved oxygen samples for 2013-2015 grouped by year and latitude. Concentrations of dissolved oxygen did not show large variation between the latitude groups. The median value was similar between the years, and all latitudes had years with outliers.

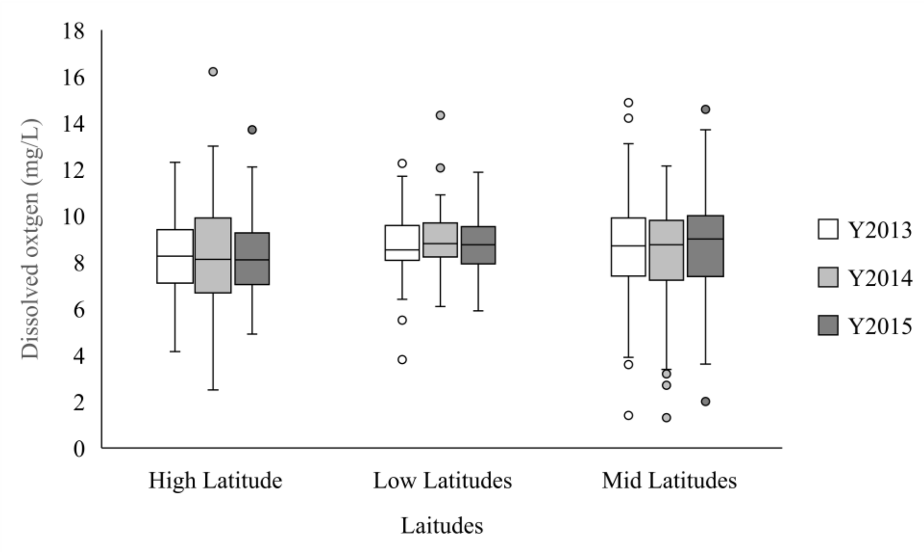

Figure 2. Clustered boxplot of dissolved oxygen by year by latitude. High latitudes represent 55° N, 45° N and mid latitude 45-55°N. Boxes show median +/- one quartile and whiskers represent the minimum and maximum values.

Table 4 shows the average values for dissolved oxygen, temperature and precipitation during June-August in the years 2013-2015 at low, mid, and high latitudes. The average concentration showed no significant difference between years at neither low nor high latitude. However, at mid latitudes, the concentration during year 2014 were significantly lower than during 2013 (paired t-test, n=262, p=0,004). Additionally, the concentration during 2015 were significantly higher than during 2014 (paired t-test, N=260, p=0,012), despite being a year both warmer and drying compared to the reference year.

Table 4. Table of average concentrations for Dissolved Oxygen (mg/L), temperature (C°) and precipitation (mm) during Jun-Aug 2013-2015 divided by latitude. Precipiation in presented in total precipitation for the period and in monthly average in brackets.

Latitude		**2013**	**2014**	**2015**
	DO concentration	8.85	8.87	8.84
<45°N	Temperature	25.48	24.36	24.62
	Precipitation	0 (0)	45,9 (0.03)	0,80 (0.0005)
	DO concentration	8.52*	8.43	8.63*****
45-55°N	Temperature	18.73	17.75	20.03
	Precipitation	61535,4 (2.49)	96393,3 (3.90)	46993,4 (1.99)
	DO concentration	8.16	8.32	8.30
>55°N	Temperature	17.82	16.59	16.88
	Precipitation	5405,8 (2.18)	6761,9 (2.72)	4225,4 (1.70)

*Note. *p < .05; ** p < .01*

Looking at difference-by-site monthly average dissolved oxygen concentrations and climate data relative to the reference year (Figure 3), the average concentration decreased throughout the studied period of the summer at the lower latitude, while being more varied at mid and high latitudes (Figure 3). With the exception for June and July at low and high latitude respectively, the average air temperature in 2015 were above that of 2014.

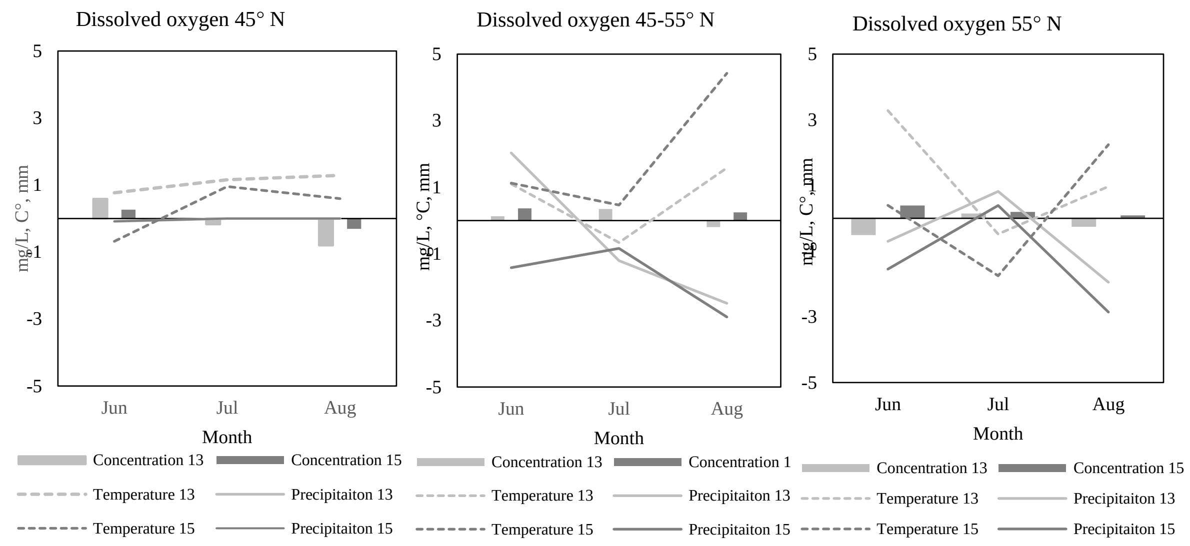

Figure 3. Each graph shows difference-by-site in monthly average concentration of DO (mg/L), temperature (C°) and precipitation (mm) relative to 2014 mean for latitude 45 °N (N=37), 45-55°N (N=260) and 55°N (N=37). Differences were calculated by subtracting the average values of the reference year from the average values of the warm years. Numbers in legend represent the years 2013 and 2015. Positive values show a higher value relative to the reference year.

A Spearman's Rank correlation was performed using the data for June-August for the years 2013-2014. The result showed low significant negative correlation between dissolved oxygen and temperature for the mid latitudes (Table 5) where average air temperature during 2013 and 2015 were higher than the reference year, except for June 2013 (Figure 3). Additionally, there was a significant positive correlation between dissolved oxygen and temperature at high latitudes. The correlation analysis in which all years were merged, were stronger than when performed by year, which could possibly indicate that it is the between year variability that drives the correlation.

Table 5. Results of Spearman's Rank Correlation analysis including all years of Dissolved Oxygen, temperature and precipitation for the period of June-August, 2013-2015, divided by latitude. p-values equal to, or below 0,05 were considered significant. Numbers presented in the table are the correlation coefficient r_2.

Temperature	**Latitude**	**Temperature**	**Precipitation**
	<45	0.127	-0.162
Dissolved oxygen	45-55	-0.14*	-0.018
	>55	0.271**	-0.027

*Note. N =1157. *p < .05; ** p < .01*

For latitudes with significant correlation between concentrations of dissolved oxygen and temperature a regression analysis was performed to investigate whether temperature could significantly predict concentrations of dissolved oxygen. At both mid (F(1,274)=13,13, *p* = <0,001) and high latitudes (F(1,246)=14,21, *p* = <0,001), the model was a significant predictor of concentrations of DO, however in a contrasting way (Figure 4).

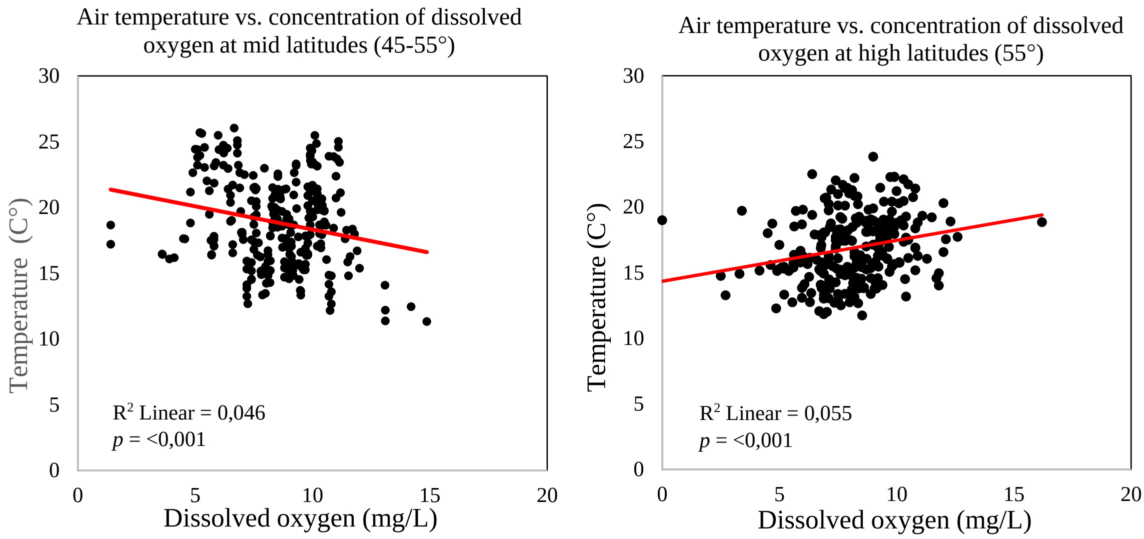

Figure 4. The result of the regression analysis for mid and high latitudes carried out in SPSS. The results showed that the model was a significant predictor of do concentration.

Nitrate

Figure 5 presents descriptive summary for nitrate samples during the years 2013-2015 grouped by latitude. Concentrations of nitrate highly varied between the latitudes, where high latitudes had lower sampled concentrations compared to mid- and southern latitudes. The median value varied between the year within each latitude group, and there was a difference in the spread of the distribution between the latitudes, at mid and low latitudes in particular.

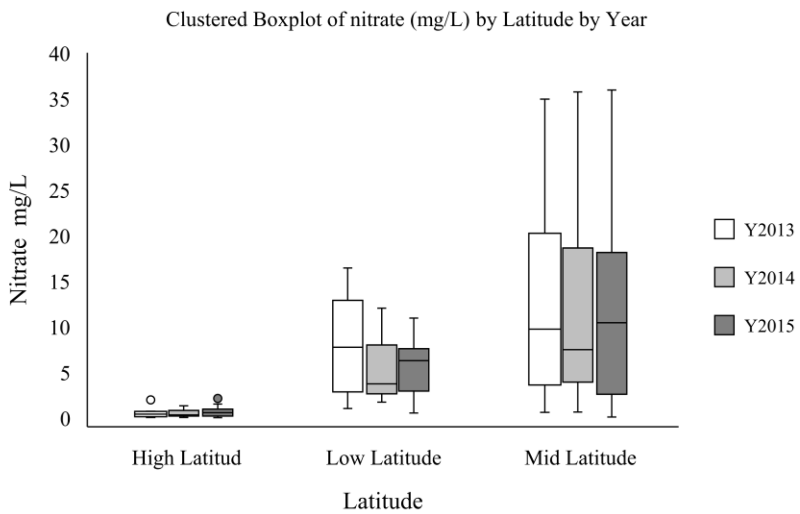

Figure 5. Clustered boxplot of Nitrate by year by latitude. High latitudes represent 55° north, low 45° south and mid latitude 45-55°. Boxes show median +/- one quartile and whiskers represent the minimum and maximum values.

Average nitrate concentrations, and average climate data are presented in Table 6. At mid latitudes, all years had average concentrations of nitrate above threshold value for good quality (Table 1). A Mann-Kendall test was carried out to determine any significant difference between the years at each latitude. There was no significant difference between the years at any of the latitude groups.

Table 6. Average values of Nitrate concentrations (mg N/L), temperature (C°) and precipitation (mm) during the period Jun-Aug for years 2013-2015. Precipiation in presented in total precipitation for the period and in monthly average in brackets.

Latitude		**2013**	**2014**	**2015**
	Nitrate concentration	7.78	5.42	5.54
<45° N	Temperature	24.82	24.28	25.37
	Precipitation	63,3 (0.09)	285,9 (0.39)	116,3 (0.16)
	Nitrate concentration	13.65	12.71	11.37
45-55° N	Temperature	18.71	17.5	19.67
	Precipitation	9491,6 (2.46)	18836,6 (4.87)	11556,9 (2.99)
	Nitrate concentration	0.52	0.53	0.772
>55° N	Temperature	13.4	13.8	12.0
	Precipitation	2370 (2.86)	2470,2 (2.98)	2409,1 (2.91)

*Note. N =1157. *p < .05; ** p < .01*

Looking at monthly difference-by-site nitrate concentration and climate data relative to the year 2014 there were no clear patterns (Figure 6). Due to limited number of samples, no significance test was performed on monthly differences in concentration between the years at any latitude group. However, data was sufficient with site groups merged and a paired t-test was performed but showed no significant difference between the years.

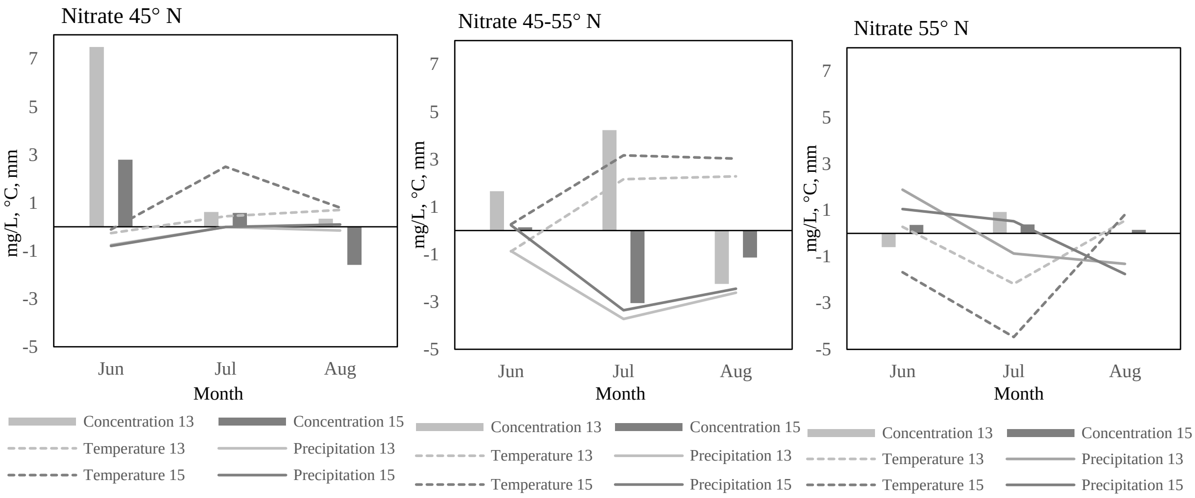

Figure 6. Each graph show difference-by-site in monthly average nitrate concentration (mg N/L), temperature (°C), and precipitation (mm) relative to the 2014 values, for latitude 45 ° N (N45, N=12), 45-55° N (N455, N=41) and 55° N (N55, N=9). Differences were calculated by subtracting the average values of the reference year from the average values of the warm years. Numbers in legend represent the years 2013 and 2015. Positive values show a higher value relative to the control year. No significance test was performed between the month, within any latitude groups.

Phosphate

Descriptive summary of phosphate for the years 2013-2015 grouped by latitude are presented in Figure 7. The distribution of samples of phosphate concentration were skewed, and medians similar between the years and latitude group, but the spread of distribution is larger for the mid and lower latitude which also has increased number of outliers.

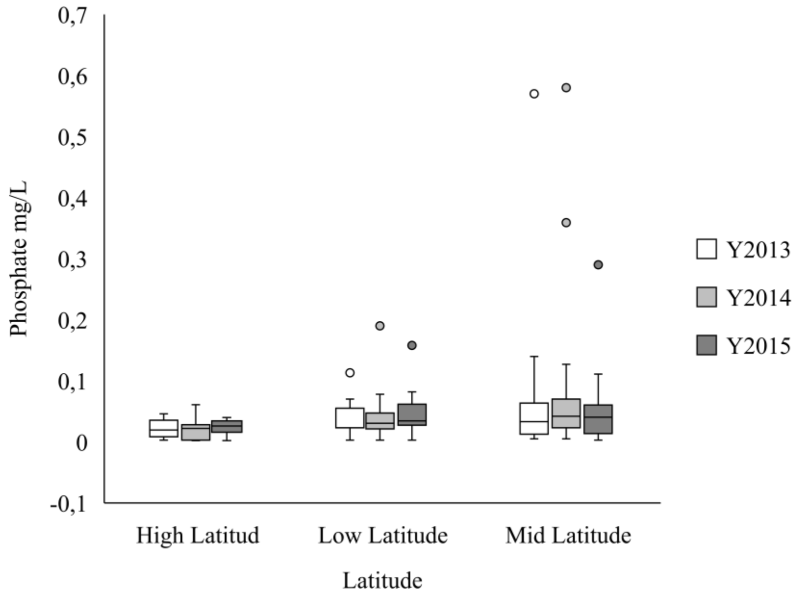

Figure 7. Boxplot of phosphate concentrations (mg P/L) by year and latitude range. High latitudes represent 55° N, low 45° N and mid latitude 45-55 °N. Boxes show median +/- one quartile and whiskers represent the minimum and maximum values.

Average phosphate concentration, temperature and precipitation are presented in Table 7. Both lower and mid latitudes had average concentration of phosphate that exceeded the threshold value of good quality for all years (Table 1). A Mann-Whitney analysis were performed to determine any significant difference between the years at the specified latitudes, however the results showed no statistically significant difference.

Table 7. Averages of concentrations of Phosphate (mg P/L), temperature(C°) and precipitation (mm) data during the period Jun-Aug for years 2013-2015. Precipiation in presented in total precipitation for the period and in monthly average in brackets.

Latitude		**2013**	**2014**	**2015**
<45° N	Phosphate concentration	0.040	0.047	0.048
	Temperature	22.33	21.26	22.60
	Precipitation	1670,4 (1.65)	2191,8 (1.95)	1511,3 (1.49)
45-55° N	Phosphate concentration	0.055	0.068	0.073
	Temperature	17.96	17.20	18.65
	Precipitation	7346,2 (2.00)	14938,4 (4.06)	8180,2 (2.23)
>55° N	Phosphate concentration	0.022	0.024	0.023
	Temperature	14.12	14.72	12.83
	Precipitation	2727,5 (2.96)	2401,8 (2.61)	2950,8 (3.21)

*Note. N =1157. *p < .05; ** p < .01*

Concentrations in phosphate varied between the months (Figure 8). High average concentration compared to reference values in June and July, compared to below reference values in June for mid and high latitudes before they increased during July. All latitudes show decrease in average concentration during August. The average precipitation was above the reference values for all latitudes except for during July 2013. Average air temperature however was below reference values for every latitude group and month except for July for 2013 while average air temperature during 2015 varied monthly. No significance test was performed on monthly difference within the latitude groups, due to limited number of samples. However, data was sufficient with site groups merged and a paired t-test was performed, but showed no significant difference between the years,

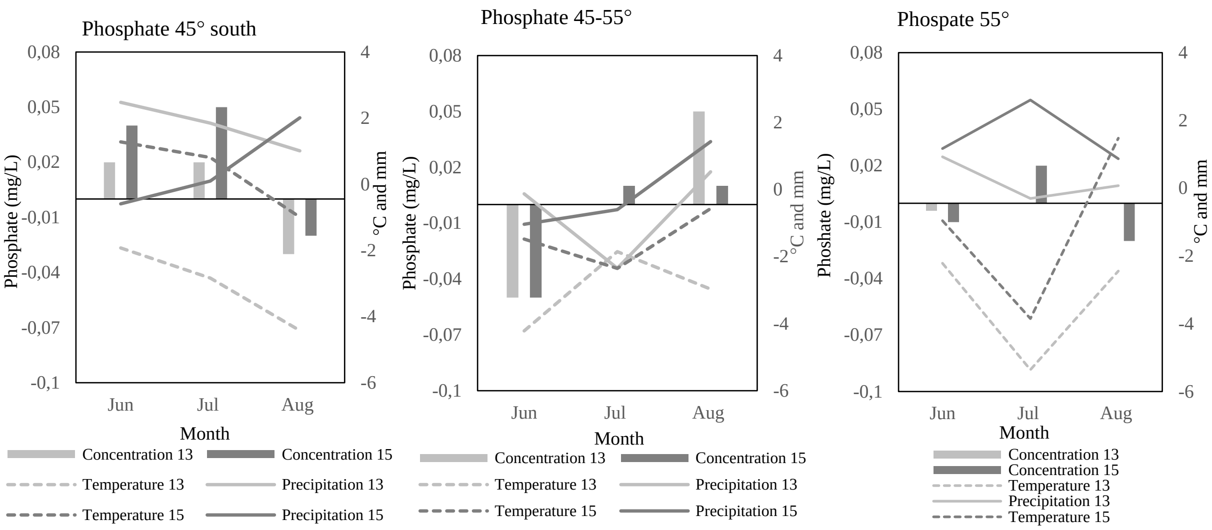

Figure 8. Each graph show difference-by-site in monthly differences in concentration of phosphate (mg P/L), temperature (°C), and precipitation (mm) relative to the 2014 values for latitude 45 °N (N45, N=10), 45-55° N (N455, N=44) and 55° N (N55, N=9). Differences were calculated by subtracting the average values of the reference year from the average values of the warm years. Numbers in legend represent the years 2013 and 2015. Positive values show a higher value relative to the control year.

Chlorophyll-a

Statistical summary for Chlorophyll-a concentrations for the years 2013-2015 grouped by latitude are presented in Figure 9. At high latitude there is a high variability compared to low and mid latitudes, and a big difference in maximum and minimum values. Samples of concentration of chlorophyll-a showed higher variability than the other parameters, outliers were present in every catchment and year. The distribution was right skewed for all samples at mid and high latitudes during 2014 and 2015. The number of samples were few compared to the other parameters (Table 2).

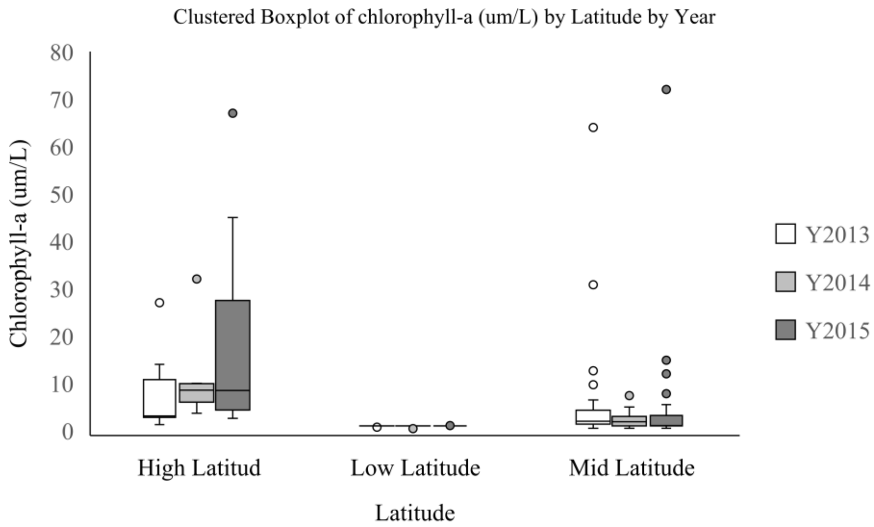

Figure 9. Clustered boxplot of Chlorophyll-a concentration by year by latitude. High latitudes represent 55° north, low 45° south and mid latitude 45-55°. Boxes show median +/- one quartile and whiskers represent the minimum and maximum values.

Total average of Chlorophyll-a concentration and climate data during Jun-Aug are presented in Table 8. Concentrations of Chlorophyll a were high during 2015 for the lower and mid latitude, and at higher latitudes during 2014. Samples for Chlorophyll-*a* were few, with only 8, 10 and 13 during Jun, Jul and Aug at higher latitudes. The Mann-Whitney test showed no significant difference between any of the years.

Table 8. Averages of Chlorophyll-a concentration (um/L), temperature (C°), and precipitation (mm) for the period June-August, 2013-2015. Precipiation in presented in total precipitation for the period and in monthly average in brackets.

Latitude		**2013**	**2014**	**2015**
<45° N	Chlorophyll-a concentration	0.95	0.93	1.02
	Temperature	24.24	23.49	24.19
	Precipitation	11 (0.03)	82,2 (0.22)	4,4 (0.01)
45-55° N	Chlorophyll-a concentration	6.21	3.53	4.66
	Temperature	19.14	18.36	20.84
	Precipitation	6005,4 (1.87)	100017,4 (3.11)	6464,7 (2.01)
>55° N	Chlorophyll-a concentration	8.37	11.40	20.26
	Temperature	17.90	17.65	16.84
	Precipitation	1637,1 (1.62)	2649,7 (2.62)	1519,1 (1.50)

*Note. N =1157. *p < .05; ** p < .01*

Differences in average monthly concentrations of chlorophyll-a relative to the concentrations during 2014 are presented in Figure 10. Average chlorophyll concentrations during 2013 and 2015 where high in relation to 2014 values during every month at high latitudes. The temperature averages where close to 2014 values but increased during August, while precipitation were below 2014 values for both June and July. Additionally, concentrations during 2015 were also high compared to 2014 values at mid latitudes for all months despite low average temperature compared to 2014 though average precipitation also were low compared to 2014 values. No significance test was performed on monthly difference within the latitude groups, due to limited number of samples. However, data was sufficient with site groups merged and a Mann-Whitney significance test was performed but showed no significant difference between the years.

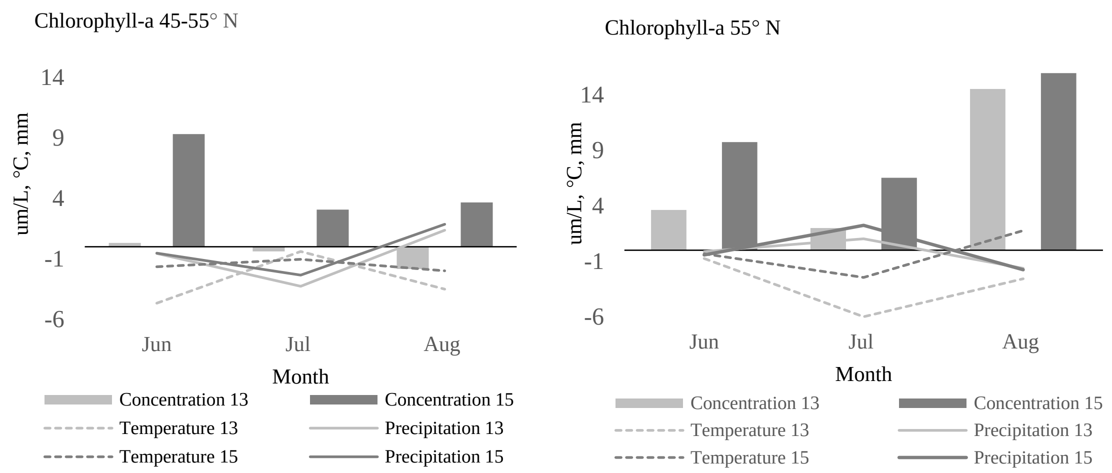

Figure 10. Each graph show difference-by-site in monthly differences in concentration of chlorophyll-a (ug/L), temperature (°C), and precipitation (mm) relative to the 2014 values for latitude 45-55°N (Chlorophyll-a 4555°N, N=35) and 55°N (Chlorophyll-a 55°N , N=7). Differences were calculated by subtracting the average values of the reference year from the average values of the warm years. Numbers in legend represent the years 2013 and 2015. Positive values show a higher value relative to the control year.

4.2. Analysis of groups by catchment

Dissolved Oxygen

A statistical summary of the DO data for catchment is presented in Figure 11 There is little variation in concentration between or within catchment groups, and hey all have similar spread of distribution and all catchment groups had outliers.

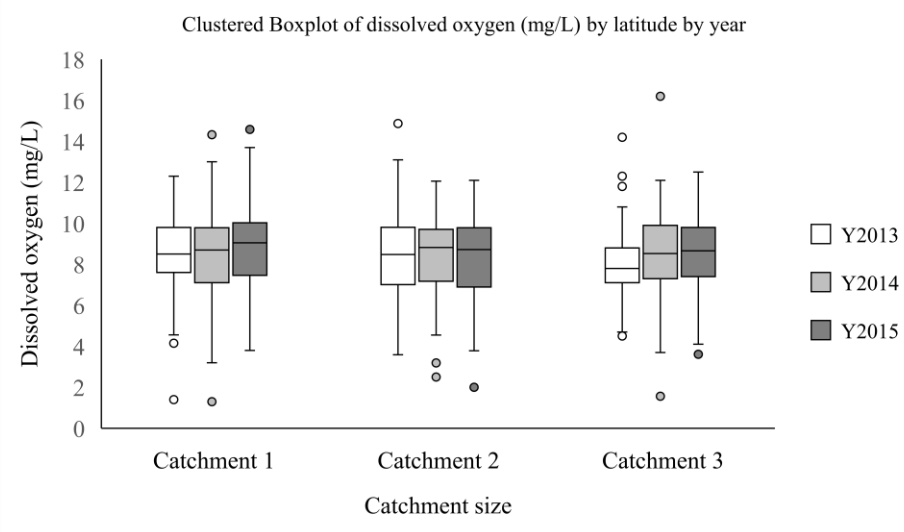

Figure 11. Clustered boxplot of Dissolved Oxygen concentration by catchment by year. Catchment size represent the three groups rivers were divided by using percentiles. Boxes show median +/- one quartile and whiskers represent the minimum and maximum values.

Total average of DO concentration and climate data during Jun-Aug are presented in Table 9. Little difference in average concentration of DO at all catchment size groups with the exception of year 2015 at catchment size 1, however the paired t-test showed no significant difference between any of the years and catchment size.

Table 9. Dissolved Oxygen concentration (mg/L), temperature (C°), and precipitation (mm)

averages for the period June-August, 2013-2015. Precipiation in presented in total precipitation for the period and in monthly average in brackets.

Catchment Size		**2013**	**2014**	**2015**
	DO concentration	8.47	8.49	8.88
1	Temperature	19.52	19.01	19.89
	Precipitation	18229,8 (1.68)	23672,2 (2.18)	14390,7 (1.33)
	Catchment 2			
	DO concentration	8.45	8.42	8.33
2	Temperature	16.96	16.60	16.49
	Precipitation	22388,9 (1.96)	28298,9 (2.48)	23166,5 (2.03)
	Catchment 3			
	DO concentration	8.50	8.46	8.52
3	Temperature	17.80	17.31	17.24
	Precipitation	24133,7 (1.94)	30956,7 (2.49)	25065, 9 (2.02)

*Note. N =1157. *p < .05; ** p < .01*

Monthly difference-by-site is presented in Figure 12. No clear pattern was visible between climate data and concentration of DO. Though rivers with larger catchment appeared to have more stable monthly variation, with decreased average as each month passed during 2015 despite average temperature and precipitation show larger variations. A paired t-test was performed to determine if there was any significant difference between the months for each latitude, however the test showed no significant differences.

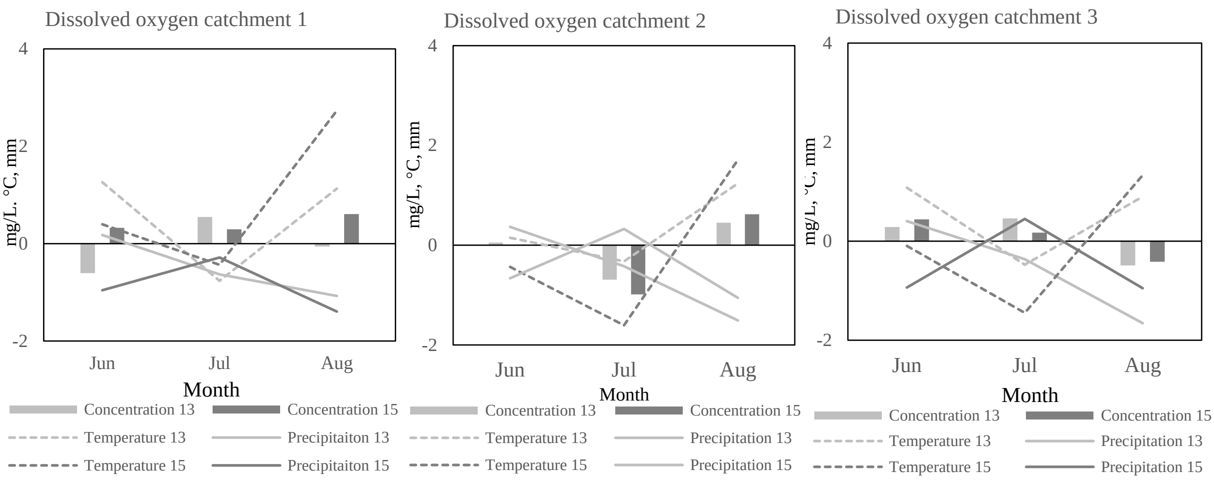

Figure 12. Monthly difference-by-site in concentration of dissolved oxygen (mg/L), temperature (°C), and precipitation (mm) relative to the 2014 values for the three catchment sizes. Differences were calculated by subtracting the average values of the reference year from the average values of the warm years. Numbers in legend represent the years 2013 and 2015. Positive values show a higher value relative to the control year.

Nitrate

A descriptive summary of the nitrogen concentrations samples is presented in Figure 13. Unlike samples of nitrate divided by latitude, all samples of nitrate for the different catchment groups had a left skewed distribution. There was high variability across all sample groups.

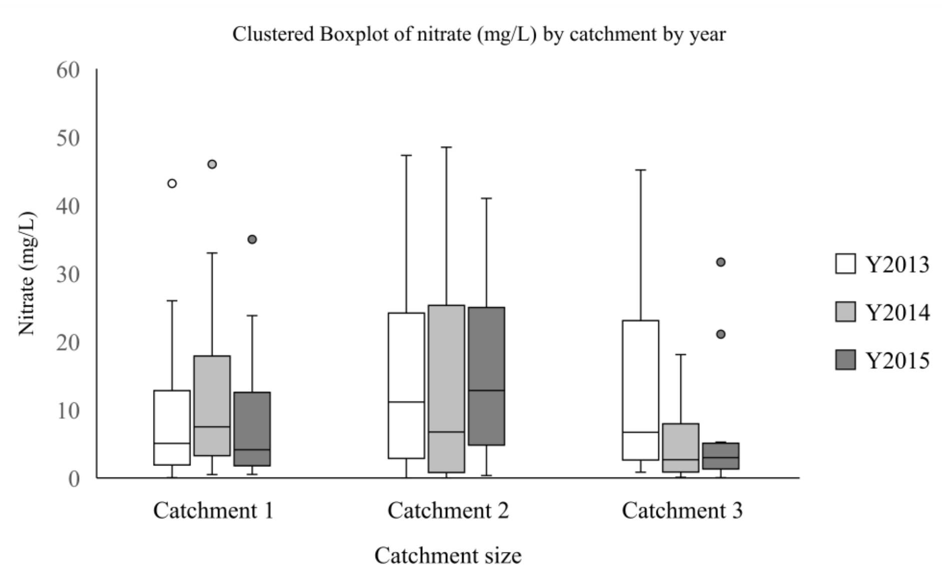

Figure 13. Clustered boxplot of Nitrate concentration samples by catchment by year during the period Jun-Aug, 2013-2015. Catchment size represent the three groups rivers were divided

by using percentiles. Boxes show median +/- one quartile and whiskers represent the minimum and maximum values.

The average Nitrate concentrations and climate data during Jun-Aug are presented in Table 10. Rivers at catchment sizes 1 and 2 have high average concentration of nitrate compared to the threshold value, while rivers with larger catchment sizes only exceed the threshold value in year 2013 (Table 1). Between year variation is high at all catchment groups, however the Mann-Whitney analysed showed no significant difference between any of the years at any catchment size.

Table 10. Nitrate concentration (mg/L), temperature (C°), and precipitation (mm) averages for the period June-August, 2013-2015. Precipiation in presented in total precipitation for the period and in monthly average in brackets.

Catchment size		**2013**	**2014**	**2015**
Size1	Nitrate concentration	9.27	11.35	8.03
	Temperature	15.55	15.65	15.03
	Precipitation	7215,7 (3.14)	9269,1 (3.97)	8080,4 (3.51)
Size 2	Nitrate concentration	15.78	14.44	16.20
	Temperature	16.57	16.31	16.54
	Precipitation	4794 (2.89)	6992 (4.22)	5771 (3.48)
Size 3	Nitrate concentration	12.44	5.31	6.03
	Temperature	15.47	15.65	14.78
	Precipitation	3953,4 (3.07)	4711,8 (3.66)	4666,6 (3.62)

Average nitrate concentrations, and average air temperature were below the reference values during June-July, before increasing to higher levels of average concentration and temperature in August relative to the reference values at catchment size 1 (Figure 14). At larger catchments, variations are more cluttered, with large variations between the months. No significance test was performed on monthly difference within the latitude groups, due to limited number of samples. However, data was sufficient with site groups merged and a Mann-Whitney significance test was performed but showed no significant difference between the years.

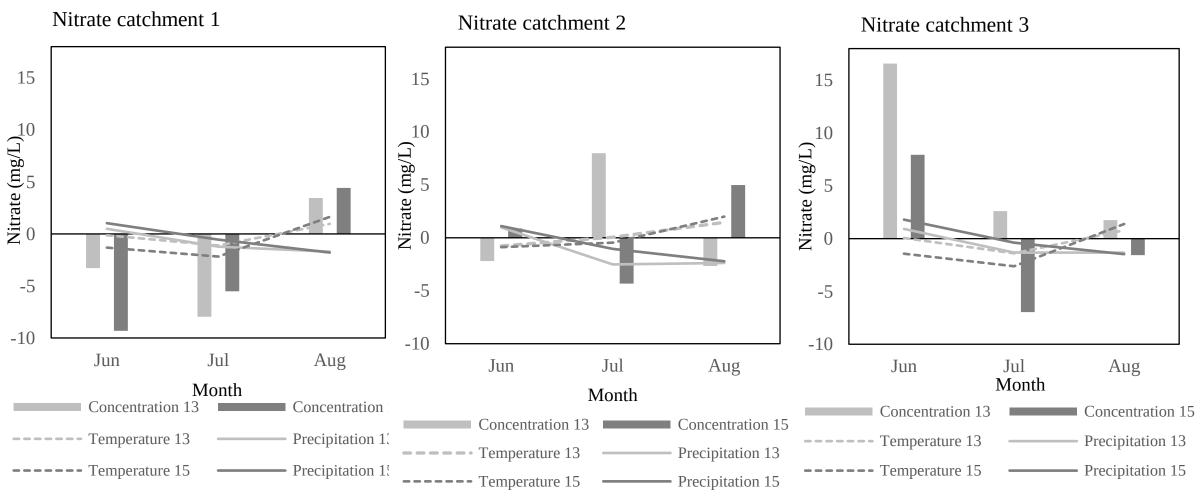

Figure 14. Difference-by-site in monthly differences in nitrate concentration (mg N/L), temperature (°C), and precipitation (mm) relative to the 2014 values for Nitrate catchment size 1, Nitrate catchment size 2 and Nitrate catchment size 3. The size ranges for each catchment is presented in Table 1.

Phosphate

Statistical summary for Phosphate concentrations samples during 2013-2015 grouped by catchment sites are presented in Figure 15. All data sets have a positive skewed distribution, and high variability due to outliers. Median values are similar between the years and all catchment sizes have outliers.

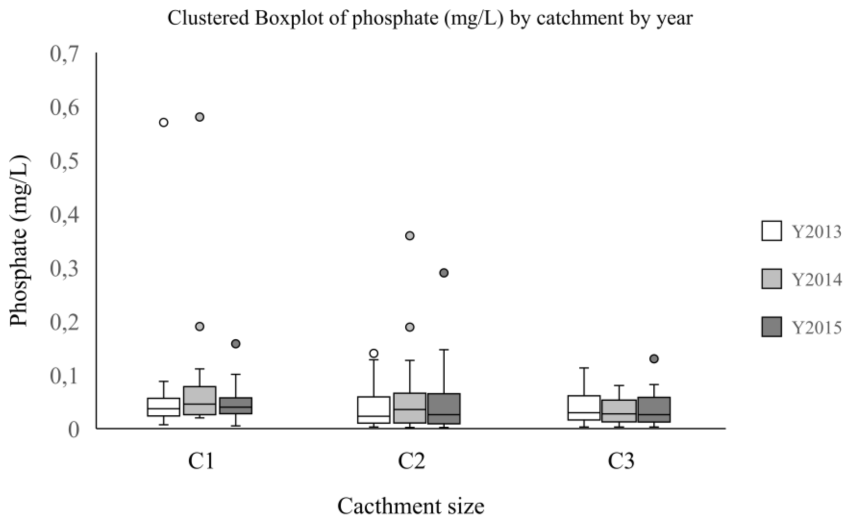

Figure 15. Clustered boxplot of Phosphate concentration (mg P/L) samples by catchment by year during the period Jun-Aug, year 2013-2015. Catchment size represent the three groups rivers were divided by using percentiles, where C1 is catchment size group 1, C2 catchment group size 2 and C3 catchment size group 3. Boxes show median +/- one quartile and whiskers represent the minimum and maximum values.

The average concentration of phosphate and average climate data are presented in Table 15. At all catchment groups and year, average concentration is above the threshold value of good condition (Table 1). The values differ at a higher degree at smaller catchment compared to the larger rivers in catchment group 3, however the Mann-Whitney analysis showed no significant difference between any of the catchment groups and years.

Table 11. Phosphate concentration (mg/L), temperature (C°), and precipitation (mm) averages for the period June-August, 2013-2015. Precipiation in presented in total precipitation for the period and in monthly average in brackets.

Catchment size		**2013**	**2014**	**2015**
Size 1	Phosphate concentration	0,068	0.085	0.049
	Temperature	15,61	16.00	15.07
	Precipitation	5888,9 (3,56)	6416,7 (3.87)	6821,4 (4.12)
Size 2	Phosphate concentration	0,040	0.058	0.053
	Temperature	16,93	16.50	17.21
	Precipitation	6387,7 (2,67)	9303,8 (3.89)	7491,2 (3.13)
Size 3	Phosphate concentration	0,040	0.035	0.037
	Temperature	15,75	15.80	15.47
	Precipitation	6278,2 (3,15)	7819,4 (3.86)	6428,8 (3.18)

Figure 15 shows the difference-by-site in monthly averages of concentration, temperature, and precipitation. While average air temperature was warmer during 2015 for all catchment groups, average precipitation was mainly lower and concentration fluctuated between the months. The largest differences are seen at catchment size 1, however there was no samples from July. No significance test was performed on monthly difference within the latitude groups, due to limited number of samples. However, data was sufficient with site groups merged and a Mann-Whitney significance test was performed but showed no significant difference between the years.

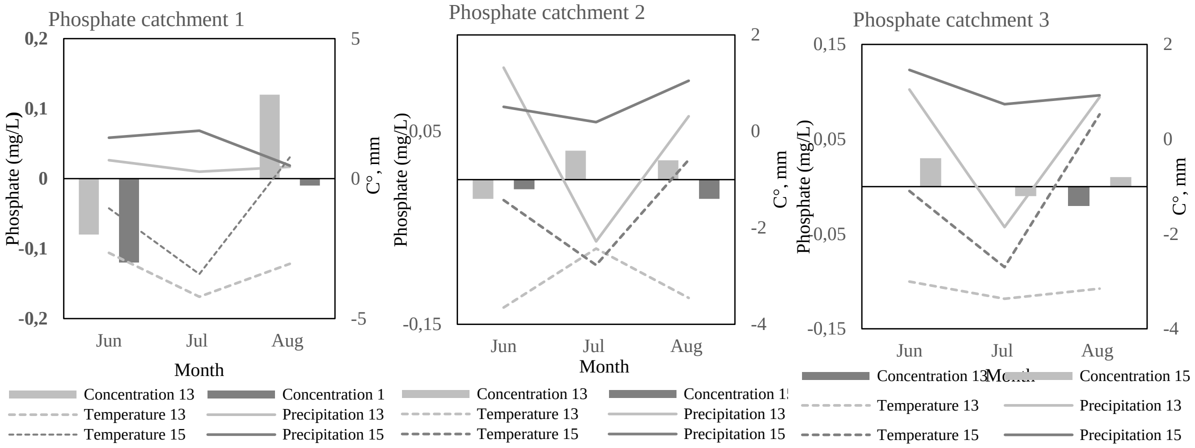

Figure 16 Each graph shows the difference-by-site in monthly differences in concentration of phosphate (mg/L), temperature (°C), and precipitation (mm) relative to the 2014 values for Catchment size 1 (P1, N=17) , Catchment size 2 (P2, N=24), and Catchment size 3 (P3, N=20). Note that the graph P1 in the figure has a different scale than P2 and P3.

Chlorophyll-a

A statistical summary of Chlorophyll-a samples divided by catchment is presented in Figure 17. Samples of concentration of Chl-a showed higher variability than the other parameters, which is caused by few very high samples, also seen in other studies (Yi-Fan et al. 2020). Outliers were present in every catchment and year. Few stations sampled chlorophyll-a continuously, and less data were available for any analysis (Table 2)

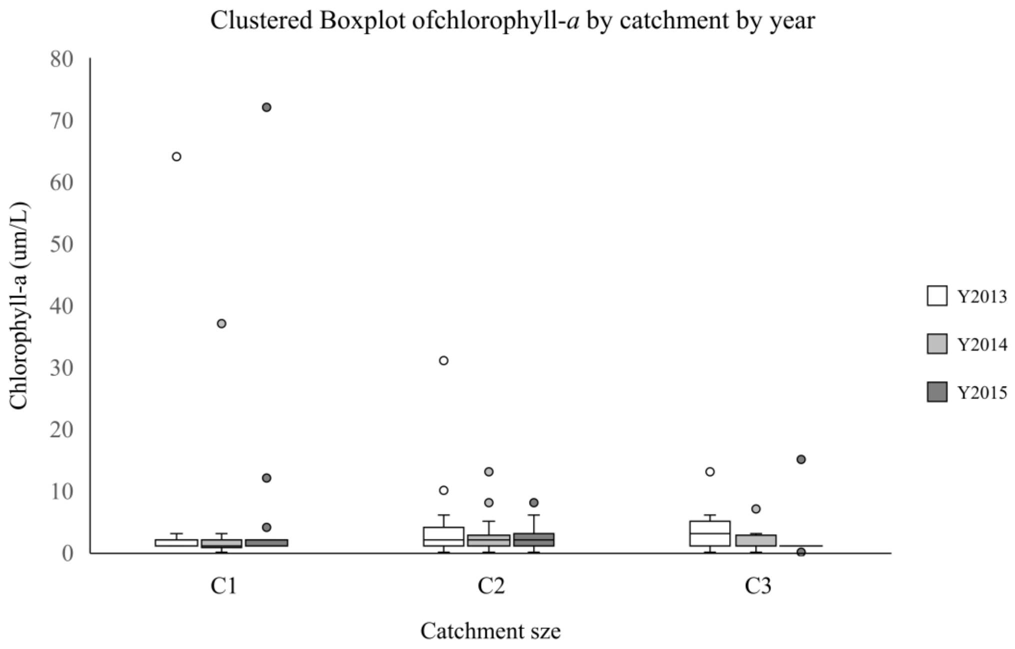

Figure 17. Clustered boxplot of Chlorophyll-a concentration samples by catchment by year during the period Jun-Aug, 2013-2015. Catchment size represent the three groups rivers were divided by using percentiles, where C1 is catchment size group 1, C2 catchment group size 2 and C3 catchment size group 3. Boxes show median +/- one quartile and whiskers represent the minimum and maximum values.

A summary of the total average concentrations of chlorophyll is presented in table 12. The Mann-Whitney significance test showed that there was significant higher concentration during 2013 (MR=130, N=145) than 2014 (MR=112, N=100) with a p-value of 0,045 at catchment 1, while no significant difference between either years at catchment size 2 and 3.

Table 12. Chlorophyll-*a* concentration (ug/L), temperature (C°), and precipitation (mm) averages for the period June-August, 2013-2015. Precipiation in presented in total precipitation for the period and in monthly average in brackets.

Catchment		2013	2014	2015
	Chlorophyll-a Concentration	2.55	2.48	2.22
Size 1	Temperature	19.81	19.18	20.52
	Precipitation	1585,4 (1.57)	2588,4 (2.56)	1861,9 (1.84)
	Chlorophyll -a Concentration	2.41	2.75	2.79
Size 2	Temperature	18.79	18.16	19.21
	Precipitation	2562,7 (1.55)	4830 (2.92)	2674,1 (1.61)
	Chlorophyll -a Concentration	2.46	2.14	2.54
Size 3	Temperature	17.95	17.53	18.64
	Precipitation	1495,9 (1.63)	2384,2 (2.59)	2062,3 (2.24)

Looking at monthly difference-by-site at catchment 1, monthly concentration during 2013, and 2015 in particular, differ from the reference value (Figure 18). While average temperature during 2013 and 2015 mainly lies below reference value, the average precipitation is above the values of reference year. No significance test was performed on monthly difference within the latitude groups, due to limited number of samples. However, with site groups merged data was sufficient and a Mann-Whitney significance test was performed but showed no significant difference between the years.

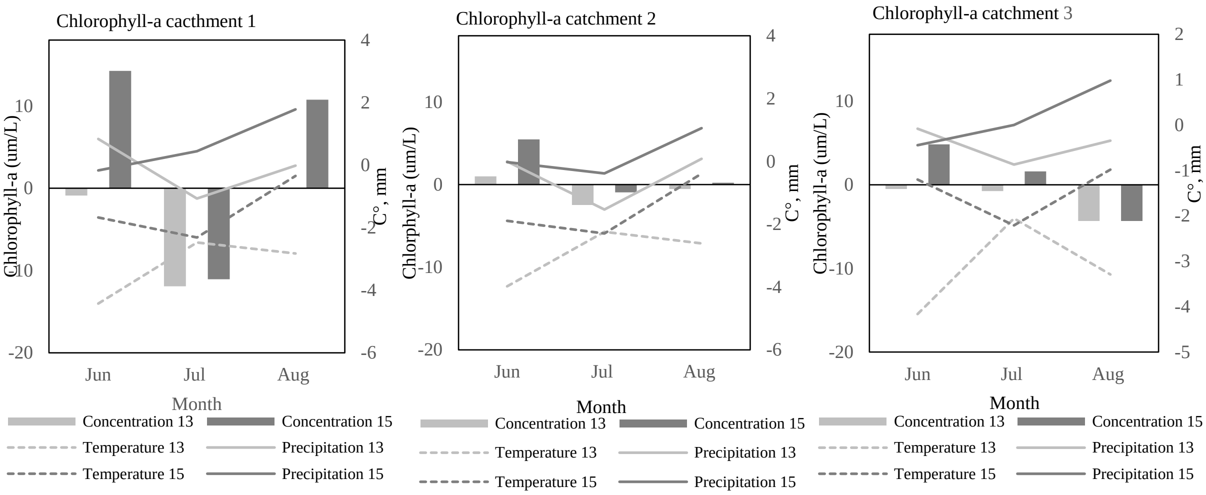

Figure 18. Each graph show the difference-by-site in monthly differences in concentration (mg/L), temperature (°C), and precipitation (mm) relative to the 2014 values for Catchment size 1, Catchment size 2, and Catchment size 3.

A Spearman’s correlation and a regression analysis was performed to determine and driver of the changes in concentration at catchment size 1, however neither showed any significant results.

5. Discussion

The aim of this thesis was to study if, and how, extreme weather periods affected the water quality in Europe's rivers. The results were not straightforward, only in part consistent with previous studies, complicating interpretation.

5.1. Analysis divided by latitude group

The concentrations of dissolved oxygen were expected to decrease during years with extreme weather periods of heat waves and drought, regardless of latitude, but rather in relation to temperature increases. In this study, highest average air temperature for the groups divided by latitude did not correspond to the lowest concentration of dissolved oxygen. However, for the high and low latitudes, the highest concentration of dissolved oxygen occurred during the period in 2014, when average air temperature was low. Neither of the two years with extreme weather periods had significantly different concentration compared to the reference year, despite lower monthly average and total precipitation. This is not consistent with previous studies which reports significant decreases in concentration of dissolved oxygen during drought (van Vliet and Zwolsman 2008; Zieliński et al. 2009). At lower latitude only small changes in concentration were seen between the years studied. At high latitudes the average air temperature is highest during 2013, and the average concentration of dissolved oxygen is lower, although not significantly. In previous studies even small decrease in concentrations, significant or not, were mainly driven by increase in water temperature (Hrdinka et al. 2012). Since air temperature is one of the main driver of river water temperature (Hannah and Garner 2015) future projections of intensified heat waves is worrying. However, at mid latitudes, the concentration of dissolved oxygen was highest during 2015, despite highest average air temperature and lowest average precipitation of all years. When breaking down the data to monthly mean anomalies relative to the 2014 mean, one can see that the average concentration during both 2015 and 2013, was higher in June and especially in 2015 despite a higher average air temperature compared to 2014 (Figure 3), which is contradictory to previous studies.

However, this analysis was based on the three summer months, and did not account for any weather or water quality conditions prior to that period. The year 2015 was the second warmest year on record at the time, although with great variation across Europe (WMO 2015). Samples were taken in Switzerland (mainly at mid latitude), where several rivers are fed by of meltwater from the Alps (Williamson et al. 2019). Among them, the river Rhine, which upper part receives meltwater from the Alps, and has its highest discharge in June-July

(Kempe et al. 1991). During the heatwave combined drought in 2003, the inputs of cool water from glacier or snowfield meltwater decreased the water temperature in some European rivers (Sebastiano et al. 2018). An unusual warm spring in some places of Europe during 2015 (WMO 2015) could have increased the inputs of cool water, just as during the summer in 2003, decreasing water temperature as increased volumes of meltwater would enter the rivers (Williamson et al. 2019) and by that favour a higher concentration of dissolved oxygen. Since no hydrological data was included it is not possible to know for certain that the increase during 2015 is a result of increased input of cold meltwater, however important to mention this possible cause and effect. Additionally, high flow velocities can improve oxygen concentrations through mixing or turbulence (Hrdinka et al. 2012). The results from the regression analysis showed that the model could significantly predict the changes in concentration based on changes in air temperature, despite the spread of sample locations: with increasing air temperature, concentrations of dissolved oxygen at mid latitudes should decrease. Since concentrations increased during these years with extreme weather periods in this study, including hydrological data would allow the investigation whether of melt water would affect river temperature and by that concentration of dissolved oxygen. At high latitudes however, the results show the opposite of that of mid latitudes, and concentration of dissolved oxygen increases with temperature, which was neither the expectation nor results of previous studies.

During the years with heatwave and drought, nutrients were expected to increase in concentration. Though this was the case in some cases, there was no significant difference between neither 2013 nor 2015 and 2014 and no clear pattern.

Despite the severity in the heat wave during 2015, it was not as spatially extended as e.g. the heatwave during 2003, this was noticeable in the northern Europe, which a cooler summer average normal (Herring 2014) and the average air temperature was lower than both 2013 and 2014 for all the nutrient sample site locations. This could affect the results as rivers within the cooler area of northern Europe are included in the study, and the catchment size study in particular as it does not exclude these sample sites, however this is not the case in the latitude group as northern latitudes are separately divided.

Except for nitrate, both chlorophyll-a and phosphate were highest in average concentration during 2014, which had the highest average air temperature. Although no statistically significant difference between the years, it can still affect the ecology of a river. The dynamic nature of rivers complicates the impact nutrient enrichment might have, but during low flow, such as during severe drought, small changes in nutrient concentrations can have major ecological impact on a river (Newman 2005). The impact on nutrients during droughts differ between different studies, with observed increases as well as decreases in concentration (Mosley 2015). Small changes in concentrations during warmer years could be explained by reduced input of nutrients from the catchment. However, in a review of the potential impacts of climate change on surface water quality by Whitehead et al. (2009), the effect of lower stream flow, as a result of drought was studied, and the result were reduced dilution, and hence higher concentration. The study used the river Thames as an example when Phosphorus increases during summer months as a direct consequence of reduced dilution. The increase in organic nutrients would also result in an increase in biochemical oxygen demand (BOD) and decrease dissolved oxygen. This is not consistent with the findings of this study, however, results showed

showing indicative rather than conclusive results, as phosphate concentrations were highest in concentration during 2015 for the lower and mid latitudes, but not significantly higher. Average air temperature was highest the same year combined with low average precipitation. However, for the high latitudes, phosphate concentrations were highest during 2014, which also has the highest average air temperature and lowest average precipitation. Since the collected parameters were sampled from different locations, correlating, and comparing concentrations of dissolved oxygen and nutrients would not be relevant. Since these parameters are influenced by each other, it could affect concentrations (Whitehead et al. 2009; Hrdinka et al. 2012) during drought and perhaps show a more clear result. Concentrations of chlorophyll-a had outliers with high values during every year at mid and high latitudes, also seen in other studies such as Yi-Fan et al. (2020). These high measurements could be indications of plankton blooms in the rivers (Kempe et al. 1991).

Extreme weather events can impact water quality by reducing dilution of nutrients, limiting availability of dissolved oxygen, reducing primary production, ultimately affecting many biological processes. The central parts of Europe had significant differences in dissolved oxygen concentrations between the warm years and reference year, while concentrations of nutrients differed between years, but not significantly. However, as mentioned, the extent of the drought combined heatwave event during 2015 did not include northern parts of Europe, where average temperature for June-August were below the 1950-2015 reference period (Orth et al. 2016). While it was dryer in some parts of the Nordic countries, there was increased precipitation in the eastern parts (Orth et al. 2016). This is consistent with a low average air temperature at >55°N latitude for all parameters, while the average precipitation varied, and thus at high latitude 2015 should perhaps not be seen as a warm year.

5.2. Analysis divided by catchment group

The expectations that concentrations of water quality at rivers with smaller catchment would be more strongly affected by climate were could not be seen in the results of this study. Though between year variation in average concentration could more often be the case at smaller catchment, no significant difference between the years were found. High concentrations of dissolved oxygen were associated with high average air temperatures at both the smaller and mid catchment sizes, though no significant difference. Similar to dissolved oxygen in rivers at mid-latitudes, samples were taken at rivers which could be subject to meltwater input. A high input of cooler meltwater and the increase in flow could influence the river temperature despite the increased average air temperature (Williamson et al. 2019). However, to study any influence of meltwater relative to catchment size, the rivers need to be specified to which catchment size group they fall under in addition to include river water temperature data.

The larger catchment (group 2) showed highest concentrations during the years of climate extremes, not consistent with previous studies, but with no hydrological data further investigation is limited and no conclusive reason for this can be made. The largest catchment group had the highest average air temperature corresponding with the lowest average dissolved oxygen concentration, opposite of what was expected. Since water temperature data were not available, and climate data restricted to Jun-Aug, the discussion remains hypothetical. Such as a delayed response of water characteristics following changes in the atmospheric conditions when a river is much bigger. No data prior to the period June-August has been considered, and a cooler than normal spring could possibly affect the river temperature going into the summer in 2013.

For the nutrients, there was a more consistent pattern between average climate data and concentrations. The highest average air temperature, or the combination with low average precipitation, coincided with in increased concentration for all nutrients at close to all catchment groups. Increased temperature and low precipitation has a direct impact on stream flow. Whitehead et al. (2009) found that phosphate concentration increased during summer months, when the river water flow was lower, and less water volume could reduce the capacity to dilute the concentrations. Additionally, several other studies found increasing concentrations during years of drought (van Vliet and Zwolsman 2008; Yang et al. 2008; Hrdinka et al. 2012). However no significant difference between neither nutrients nor chlorophyll-a was found. Phosphate concentrations at catchment group 2 however, are different. High concentration of phosphate was found during 2014, where average air temperature was low but average precipitation high. Increase in rain, or heavy rainfall, could increase concentration of nutrients as it is washed from agricultural or forested areas.

Moreover, neither dissolved oxygen concentrations within catchment groups nor latitude group, coincided with highest average air temperature. Diamantini et al. (2018) studied the drivers controlling water quality for three large European river basins and found that temperature was the more important driver rather than flow (Diamantini et al. 2018). With the assumption that air temperature is an indicator of water temperature, the results of this study is inconsistent with those of Diamantini et al. (2018).

The findings of this study (latitude and catchment) were only partially consistent with other studies with a more site-specific approach. Dissolved oxygen was more sensitive when divided by latitude rather than catchment size, which was not expected. Similar results were found at both latitude and catchment groups when looking at the other parameters. The question of possible impacts of climate extremes on water quality is complex. To be able to answer this question properly, further variables needs to be included and more data available across a larger geographical extent, such as hydrological data and river water temperature. In the attempt of doing a more geographically extensive study, including as many rivers as the data allowed ultimately ending up with too little data, the results became unclear. However, recurrent for nutrients within latitude and catchment groups were the high concentration often coincided with higher average air temperature and lower average precipitation, alone or in combination. Variations of concentrations of dissolved oxygen were harder to interpret, with high concentrations during high temperature averages, and low concentration during low averages, as well as high concentration during low average air temperature. Much more data is necessary to carry out a study of this scale. Both as increased number of water samples for the chosen parameters as well as including other factors such as hydrological data. Additionally, the number of factors – environmental conditions and hydrological data, which should be included in such a study, due to the complicity of the question of river response to extreme climate periods are many and would require a study much larger and the scope of this one.

5.3. Limitations of this study

There were few samples from all four parameters prior to the year 2013 and 2015. By not being able to include earlier years with severe periods of climate extremes such as 2003, 2006 and 2010 limited the study, moreover, using 2014 as reference year could be affected by any impacts lasting from the previous years, however due to data limitations in water quality data, no earlier time period could be used as reference. The years with extreme weather periods were not as pronounced as data was processed and the extreme events did in some cases get lost as the area of the study increased.

Additionally, for the years chosen for this analysis, the sampling site locations were inconsistent throughout the period. A high number of sample data was lost when only selecting yearly recurrent sampled rivers and the data became in part insufficient to carry out this study. This also made comparisons between different parameters within one subgroup (e.g. lower latitudes) difficult since samples did not originate from the same site location. Since these parameters are highly affected by each other, such comparisons and analyses could have strengthened interpretations of any result. River water temperature was not included, instead, air temperature was used as a proxy. Water temperature data are available in Waterbase and should have been included to be able to statistically test any potential correlation between dissolved oxygen and water temperature, biological processes affecting nutrients and air temperature.

Furthermore, the Waterbase database did not report the exact time of sampling, which affects concentration for e.g. dissolved oxygen since it fluctuates throughout the day. Therefore, it was assumed that all samples were taken during daytime. However, for concentrations of dissolved oxygen, the number of samples used to calculate mean values for some of the parameter was larger, strengthening that the result when different hours of sampling may be evened out.

Hydrological factors such as retention time and river streamflow are strong contributors to changes in water quality and such data were not included due to the limited time for this study (Hilton et al. 2006; Nilsson and Renöfält 2008; Yang et al. 2008). Though climate data can give indications on some hydrological influences, such hydrological data could strengthen the analysis, perhaps clarifying results. The exact location along a river from which a sample was taken, can also have an influence on the amount of concentration e.g. close to point source or downstream a river. This is not taken account for in this study, but the number of samples used to calculate means were assumed to even out differences of sampling locations of the river.

The amount of data in the Waterbase database is large, and the overall processing was very time consuming. As the data processing progressed, disadvantages of the method used for this thesis became clear. The thought of dividing the rivers by latitude, the aim was to keep rivers with similar environmental conditions within each latitude group as well as study if there would be differences in river response to periods of severe climate keeping the amount of data manageable. However, the sample data were unevenly distributed across Europe, and when only selecting recurrent samples stations, even more so, and the data then became insufficient for such approach. Additionally, this roughly drawn divisions became too general with the final data used for analysis and the thought of keeping rivers grouped by similar environmental conditions was carried out with a too simple approach.

With this set of data, the method for another study should therefore be constricted to include fewer rivers or reducing the geographical extent. However, the data reported in Waterbase database is increasing and hopefully becomes more frequent and a study with a more wide geographical extent could be carried out in the future.

Conclusions

The aim of this thesis was to study the impact of climate extremes on river water quality. Concentrations of dissolved oxygen divided by latitude were significantly higher during 2013 and 2015 compared to 2014 at mid latitudes. This was not the expectations prior to this study as high temperature and low precipitation which would decrease concentrations of dissolved oxygen. The Spearman's correlation analysis showed a low significant correlation between temperature and concentrations at both mid and high latitudes. Furthermore, the regression analysis could significantly predict the concentration of dissolved oxygen depending on temperature at both mid and high latitude, though contradictory results to previous studies. That complicates the interpretation at high latitudes where concentration increases with increasing temperature, which is not what was expected nor the results of previous studies. To draw any conclusions from these results data such as hydrological data and water temperature in particular needs to be included in the study.

No statistically significance was found between years, nor ant distinct pattern for neither nutrients nor chlorophyll-a at both groups divided by latitude and groups divided by catchment. The lack of consistent patterns or significant results throughout most of the analysis made interpretation and any conclusion difficult. The analysis suffered from uneven sample sizes and inconsistent sampling when using the Waterbase dataset; samples from one station did not cover all four parameters which made comparisons impossible, and ultimately for some parameters, there were insufficient amount data in some years.

Concentrations of dissolved oxygen showed no significant difference between any of the years at neither catchment size category. Higher nutrient concentrations were often associated with the years that experienced drought, although not statistically significant. In central Europe, where the impact was perhaps the most prominent in this study, several rivers (e.g. river Rhine and river Danube) are fed by melting water from glaciers (Huss 2011). The question of the effect of climate extremes on water quality is complex and includes a variety of variables not accounted for in this study but highly influential on the studied water quality parameters.

To be able to strengthen the analysis, making results more clear, hydrological data needs to be included to account for its effect on water temperature and physical properties in addition to more water quality data. Waterbase is a great source of data covering many parts of Europe, however, to be able to increase the geographical extent of a study such as this one, and perform analysis across several water quality variables there has to be an increase in sample locations to cover larger parts of Europe, and a higher consistency of sampling. The method used was chosen based on a high volume of data available such as from the Waterbase database. However, as the data processing progressed, data limitations became clear for a geographically wider study, and the method suffered from this changed data availability ultimately not being suitable with the final processed data. Moreover, the realization of the effort required to conduct a study at this scope, and the necessary hydrological data needed to be included, goes beyond the scope of this thesis.

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