Revista Minelor – Mining Revue
ISSN-L 1220-2053 / ISSN 2247-8590
vol. 28, issue 1 / 2022, pp. 73-86

PAST AND PRESENT CLIMATE CONDITIONS OF EUROPEAN COAL AND LIGNITE AREAS

Alexandros I. THEOCHARIS[1], Ioannis E. ZEVGOLIS[2], Nikolaos C. KOUKOUZAS[3], Michal REHOR[4], Kristina VOLKOVA[5], David de PAZ[6], Pawel LABAJ[7], Michael BEDFORD[8], Małgorzata MARKOWSKA[9]*

[1] Chemical Process & Energy Resources Institute, Centre for Research & Technology Hellas, Athens, Greece, theocharis@certh.gr
[2] School of Mining and Metallurgical Engineering, National Technical University of Athens, Greece; izevgolis@metal.ntua.gr
[3] Chemical Process & Energy Resources Institute, Centre for Research & Technology Hellas, Athens, Greece; koukouzas@certh.gr
[4] Brown Coal Research Institute, Inc. (VUHU), Most, Czech Republic; rehor@vuhu.cz
[5] DMT GmbH & Co. KG, Essen, Germany; Kristina.Volkova@dmt-group.com
[6] Subterra Ingeniería, Madrid, Spain; dpaz@subterra-ing.com
[7] Central Mining Institute (GIG), Katowice, Poland; plabaj@gig.eu
[8] University of Exeter, Exeter, UK; M.D.Bedford@exeter.ac.uk
[9] Central Mining Institute (GIG), Katowice, Poland; mmarkowska@gig.eu

DOI: 10.2478/minrv-2022-0007

Abstract: *Weather and climate are parameters vital for the development and flourish of human activities, and they crucially affect mining activities. Coal and lignite (brown coal) mining operations can be aided by appropriate weather or stopped by an extreme weather event that might have catastrophic consequences for a mining area. The same stands for closed and abandoned coal mines, as extreme weather events can have severe consequences. This work aims to obtain a comprehensive overview of the climatic conditions by documenting and reporting them in various European coal and lignite mining regions. Specifically, the chosen regions cover Europe from the north (the United Kingdom) to the south (Greece), from the east (Poland, the Czech Republic) to the west (Spain), and through Europe's center (Germany). A climate baseline is created for the chosen regions to serve as a reference for safety assessment and for evaluating future climate changes. Initially, the general climate of each region was evaluated; additionally, an extensive climate database from 1990 to 2020 was created, including the mean annual temperature and precipitation. Mean values and general trends of increase or decrease during the last 30 years are of interest and were compared for all areas.*
Keywords: *coal mines, lignite mines, climate conditions, precipitation, temperature*

1. Introduction

Weather and climate are parameters crucial for the development and flourish of human activities. They are of utmost importance for food production, health, and well-being and critical regarding infrastructure and mining operations [1, 2, 3, 4]. As the climate changes, species and systems try to adapt and issues arise regarding the sustainability of human activities. The earth presents changes in its average temperature, seasons change and swift and extreme weather events become frequent and common. Simultaneously, other climate change impacts and slow onset events become increasingly present globally [5, 6, 7, 8, 9, 10].

Human activities such as land use and greenhouse gas emissions are often considered to impact climate [11, 12, 13, 14, 15]. Climate change and its variations caused by external forces can be partly predicted, especially globally. The sum of all human activities, considered to be external forces, can also be partially predictable [16, 17, 18, 19]. These predictions, however, can be unreliable because predictions for global

[*] Corresponding author: Alexandros I. Theocharis, PhD., Chemical Process & Energy Resources Institute, Centre for Research & Technology Hellas, Athens, Greece, contact details (theocharis@certh.gr)

population growth, future financial status, and technological advancement cannot be accurately predicted [20, 21]. Average minimum and maximum temperature, precipitation, surface wind speed and direction, humidity, cloud type, and solar radiation are the main parameters constantly monitored by many weather stations worldwide. As the climate changes, adaptation becomes more difficult and expensive.

Weather and climate crucially affect coal mining activities [22, 23, 24, 25]. Coal and lignite (brown coal) mining operations can be aided by appropriate weather (e.g. increased efficiency) or might be stopped and even provoke catastrophic consequences in the nearby areas in an extreme weather event. The same stands for closed and abandoned coal mines, as extreme weather events can have severe consequences. In numerous cases, weather events were related to problems in mining areas; the most frequent elements that cause these troubles are precipitation and temperature, wind speed and atmospheric pressure.

One of the most famous catastrophes related to coal mines is the Aberfan disaster related to a coal spoil tip in the UK in 1966. A period of heavy rain caused the spoil tip to build up high water pressures and suddenly slid downhill as slurry, causing 144 deaths. Heavy rain is connected to many incidents in European coal and lignite mining areas. It can cause severe flooding (e.g. Greece, Kardia mine, 2014); suspension of mining operations and equipment destruction (e.g. Poland, Turów mine, 2010); dam breakage (e.g. Spain, Valencia mine, 1982); and threaten the safety of the mining area and infrastructure through flooding and landslides (e.g. Germany, Concordia mine, 2019; Czech Republic, Most Basin region, 2013; UK, Tylorstown, South Wales, 2020). On the other hand, drought and extreme heat can also cause trouble, such as problems in the reclamation of abandoned mines (Czech Republic, Most Basin region, 2018) and closure of mining operations (Greece, Western Macedonia Lignite Centre, 1991). Other hazards have also been related to extreme snowfall causing impossible conditions for mining operation (e.g. Greece, Western Macedonia Lignite Centre, 2003) or abrupt atmospheric pressure drops causing dangerous gas emissions (e.g. Poland, Gliwice mine, 2014).

It becomes evident that weather events and climatic conditions are crucial for the safety of mining areas, either operating or abandoned. In that vein, this work aims to document and report climatic conditions in various European coal and lignite mining regions. In this way, a climate baseline is created for the regions' current climate conditions that can serve as a reference for current safety assessment and the evaluation of future climate changes. Specifically, the chosen regions cover Europe from the north (the United Kingdom) to the south (Greece), from the east (Poland, the Czech Republic) to the west (Spain), and through Europe's center (Germany).

The general climate of each region was evaluated based on published literature, official reports, and classification systems. Additionally, an extensive climate database from 1990 to 2020 was carried out for these mining regions; temperature and precipitation data were collected for each area. Local sources were primarily employed to obtain the needed records, such as weather stations and meteorological agencies, but global climate datasets were not excluded. Mean values of precipitation and temperature and general trends of increase or decrease during the last 30 years are of interest and were compared for all areas. Overall, the aim is to obtain a comprehensive overview of the climatic conditions in European coal and lignite mining regions.

2. Reference climate classification for the mining areas

Weather and climate are two loosely defined terms because they vary greatly, day by day and year by year. Weather is the atmosphere state defined by temperature, humidity, wind direction and speed, precipitation, and visibility. Weather is the direct result of the interaction of weather systems like high or low pressure and humidity. These systems are developing and decaying rapidly, so weather prediction for more than a week is unreliable.

Climate is commonly defined as the statistical description of various parameters like temperature, precipitation, and wind. The mean values commonly describe these parameters, while their time variability ranges from months to thousands of years. The climate varies between places, even in close proximity. The main aspects of climate variation are latitude, elevation from sea level, distance from the sea, vegetation, and the mountains' presence. Climate can also vary between years, decades, and other periods.

The German scientist W. Köppen presented the first quantitative classification of world climate in 1900; it has been available as a world map updated in 1954 and 1961 by R. Geiger [26, 27, 28]. The Köppen–Geiger climate classification system was employed herein as an essential reference. This system divides climates into five main groups: A (tropical), B (dry), C (temperate), D (continental), and E (polar). Table 1 summarizes the definitions for this system. The leading five groups of the system are based on the type of vegetation that grows in the area. This link between climate and plant life in a given region can also link climate change and its impact on the region's flora and fauna. Every area is additionally characterized by a second letter which corresponds to seasonal precipitation type. Finally, a third letter characterizes the summer heat from very cold to hot; summer is defined as the warmest six-month period [29].

vol. 28, issue 1 / 2022
pp. 73-86

Figure 1 shows an overview of Europe's climate, and Table 2 presents the description of the 18 areas under investigation for this classification system (Beck et al. 2018). Generally, most mining areas' climate is temperate or continental. As expected from Figure 1, mining areas in Greece and Spain present a hot-summer Mediterranean climate except for the area of Ptolemais, areas in the UK temperate oceanic, and areas in Germany, Poland, and the Czech Republic temperate oceanic or humid continental.

Table 1. Köppen–Geiger climate classification [26, 27, 28, 29]

1st	2nd	3rd
A (Tropical)	f (rainforest)	
	m (monsoon)	
	w (savanna, dry winter)	
	s (savanna, dry summer)	
B (Arid)	W (desert)	
	S (steppe)	
		h (hot)
		k (cold)
C (Temperate)	s (dry summer)	
	w (dry winter)	
	f (without dry season)	
		a (hot summer)
		b (warm summer)
		c (cold summer)
D (Continental)	s (dry summer)	
	w (dry winter)	
	f (without dry season)	
		a (hot summer)
		b (warm summer)
		c (cold summer)
		d (very cold summer)
E (Polar)	T (tundra)	
	F (eternal frost (ice cap))	

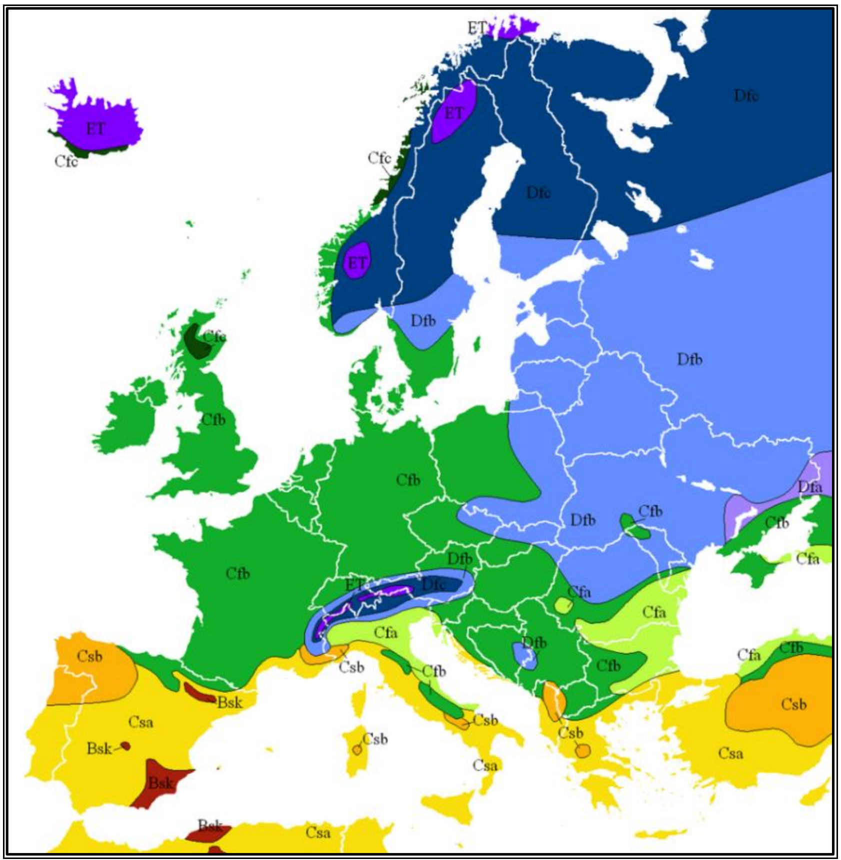

Figure 1. Köppen–Geiger climate classification in Europe

vol. 28, issue 1 / 2022
pp. 73-86

Table 2. Mining areas analyzed in Köppen–Geiger climate classification

Country	Mine location	Köppen–Geiger classification	Description of climate
Czech Republic	North-Western Bohemia	Dfb	Humid continental
Germany	NRW-Ruhr	Cfb	Temperate oceanic
Germany	NRW-Ibbenburen	Cfb	Temperate oceanic
Germany	Thuringia	Dfb	Humid continental
Germany	Saarland	Cfb	Temperate oceanic
Germany	Saxony	Dfb	Humid continental
Greece	Ptolemais	Cfb	Temperate oceanic
Greece	Megalopolis	Csa	Hot-summer Mediterranean
Poland	Klodzko	Cfb	Temperate oceanic
Poland	Katowice	Dfb	Humid continental
Poland	Lublin	Dfb	Humid continental
Spain	Sevilla	Csa	Hot-summer Mediterranean
Spain	Teruel	Csa	Hot-summer Mediterranean
UK	South Wales	Cfb	Temperate oceanic
UK	Ayrshire	Cfb	Temperate oceanic
UK	Nottinghamshire	Cfb	Temperate oceanic
UK	Yorkshire	Cfb	Temperate oceanic
UK	Durham	Cfb	Temperate oceanic

3. Climate profile and rainfall and temperature records for the mining areas

The classical period used for describing a climate is 30 years, as defined by the World Meteorological Organization. This chosen period is ideally suited for a complete climate baseline study. In the following, the baseline climate is described for the European mining areas under investigation. A climate database was created for each country's mining areas for the last 30 years (between 1990 and 2020), mainly temperature and precipitation, the most crucial climate elements of operation and reclamation issues in mines. Other elements such as snowfall and wind speed might be locally important for several areas but were not analyzed herein. Moreover, each region's climate data were processed and presented to illustrate climate records trends.

3.1. Czech Republic

The largest Czech brown coal deposit is in the Most Coal Basin area in North-Western Bohemia. This area is generally identified as the dry and relatively hot part of the Czech Republic. The climate of the North-Western Bohemia mining region is characterized as cold with warm summers and no dry seasons. The characteristic average monthly temperatures are -2°C to -3°C in January, 8°C to 9°C in April, 18°C to 19 °C in July, and 7°C to 9 °C in October. The days with precipitation vary between 90 and 100 per year. The precipitation amount from April to September is between 350 mm - 400 mm, and from October to March between 200 mm and 300 mm; overall, the precipitation varies between 550 mm and 700 mm per year.

Figure 2 presents the average annual temperature, and Figure 3 the average annual rainfall in the area. The region's climate data were obtained from the Czech Hydro-Meteorological Institute on the regional meteorological station. The analysis focuses on the area of an abandoned surface lignite mine in Kopisty. The maximum average annual temperature for 1990-2019 was 9.7°C, while the minimum 6.4°C. The annual average temperature level has a clear increasing trend of approximately 1°C in 30 years.

On the other hand, the rainfall has no apparent increase or decrease trend during this period but presents significant fluctuations. Overall, the decade 2000 to 2010 was a relatively humid period, while 2010 to 2019 was relatively dry. The maximum average annual precipitation value was 879mm, while the minimum was 378mm. The region of the Most Coal Basin is a relatively hot area compared to the Czech Republic's climate; however, during the last 30 years, no extreme rainfall events have been reported.

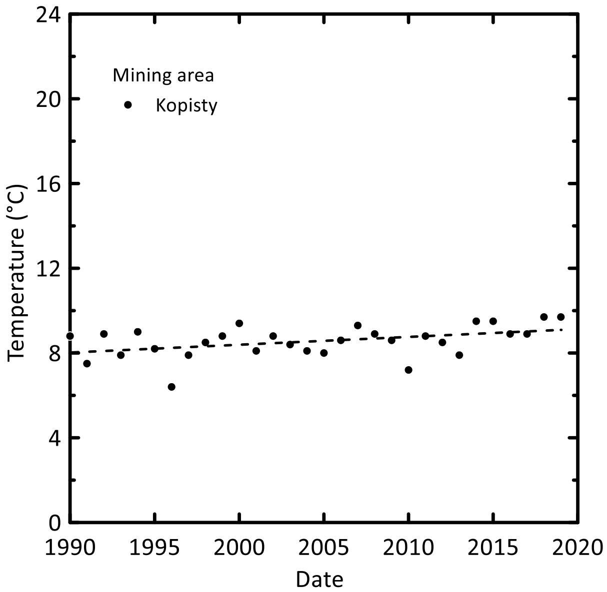

Figure 2. Mean annual temperature
for Kopisty Czech mining area

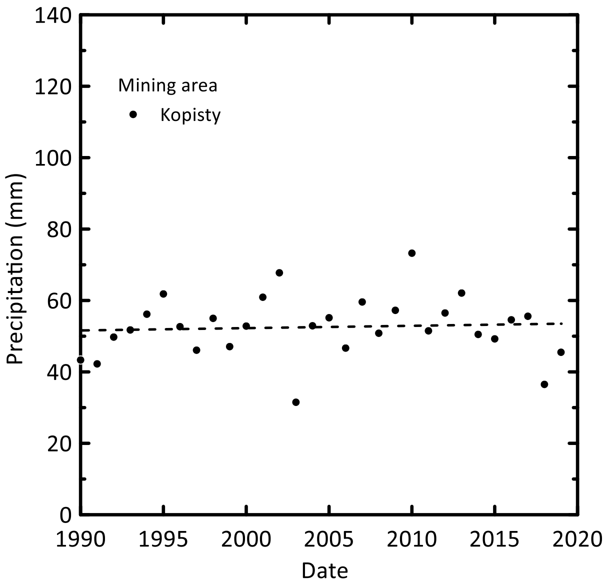

Figure 3. Annual rainfall
for Kopisty Czech mining area

3.2. Germany

Germany belongs to the warm temperate climate region of the middle latitudes. Predominant western winds bring thermally moderate and humid air masses from the North Atlantic, contributing to the Central European precipitation regime. The oceanic influence, characterized by the Gulf Stream, ensures relatively mild winters and not too hot summers. The continental influence in Germany increases to the east.

Climate data from five different regions were analyzed: Ruhr and Ibbenbüren (in North Rhine-Westphalia), Saarland, Thuringia, and Saxony. The climate in North Rhine-Westphalia is similar to that of Central Europe. It is a predominantly maritime area with cool summers and mild winters. The warm, moderate rain climate generally leads to average temperatures below 22°C in the warmest month and above -3°C in the coldest month. At the same time, there is always sufficient precipitation, and extreme weather events are rare. Phases with a continental influence lead to more extended periods of high air pressure, higher temperatures, and dry summers with weak winds from the east to the southeast. The distinct structure of reliefs leads to a general division of climatic conditions in this area [30]. Weather conditions from west to south-west mainly characterize the weather patterns. Thus, the air masses accumulate on the mountains' south/west slopes, leading to higher precipitation in the high altitudes and lower precipitation in the lower altitudes [30].

The Ruhr and Ibbenbüren areas are both located in Westphalia Bay. Due to the relatively short distance and a small difference in altitude, the climatic conditions in these areas are comparable. The average annual temperature between 1990 and 2018 was around 10.5°C in Ruhr and 10°C in Ibbenbüren. For both regions, in the winter months (December to February), the lowest average monthly temperature (average temperature of the individual months from 1990 to 2018) was 3C°; the highest average monthly temperature was during July and August between 18°C to 19°C. The average annual precipitation from 1990 to 2018 was 826 mm per year in Ruhr and 753 mm per year in Ibbenbüren. In both areas, the lowest average monthly precipitation (average precipitation of the individual months from 1990 to 2018) was in April, with around 46 mm for Ruhr and 43 mm for Ibbenbüren. The highest average monthly precipitation in Ruhr was recorded in August and December with about 82 mm and in Ibbenbüren in July and August with 75 mm to 76 mm.

In Saarland, the average annual temperature was 10°C and varied in the same range as in North Rhine-Westphalia. The average annual precipitation in Saarland from 1990 to 2018 was about 908 mm. Here, the lowest average monthly precipitation of 50 mm was recorded in April. In December, the highest average monthly precipitation occurs with about 110 mm. The minimum average monthly temperatures were 2°C to 3°C from December to February and the highest 18°C to 19°C from July to August.

Thuringia has a complex surface structure; thus, the terrain strongly influences the region's climatic conditions. The average annual temperature is 8.6°C. The lowest average monthly temperatures were between 0°C and 1°C from December to February, while the highest of 18°C in July and August. The middle heights represent the largest area of Thuringia and have an average annual precipitation of 713 mm [31]. The lowest average monthly precipitation was in April with 43 mm and the highest in July with 88 mm throughout the region.

vol. 28, issue 1 / 2022
pp. 73-86

Saxony's climate is strongly continental influenced, as the continental influence increases towards the east of Germany. This influence leads to lower annual precipitation compared to the rest of Germany. A significant factor of the climatic conditions is the varying topography, and the location and the height of the measurements play a significant role [32]. The temperature shows an average annual temperature of 8.5°C. From December to February, average monthly temperatures between -0.2°C and 0.6°C are the lowest, whereas, in July and August, average monthly temperatures between 17°C and 18°C are the highest. The average annual precipitation was around 740 mm from 1990 to 2018. In February and April, the lowest average monthly precipitation was 43 mm and 44 mm. July shows the highest average monthly precipitation with 93 mm.

Figure 4 presents the annual temperature and Figure 5 the annual precipitation level for the reference period for the five major German mining areas. These areas all show a slight increase in temperature over the last thirty years of less than 1°C on average. Ruhr presents the highest temperature levels while Saxony the lowest and temperatures of Saxony have the most significant fluctuation. On the other hand, a decrease in average precipitation can be observed almost for all German coal mining regions examined over the last thirty years. The only exception is Saxony, presenting practically a constant average precipitation, however, having significant variability. Simultaneously, extreme precipitation events have increased, and the months with very low precipitation rates (not presented herein).

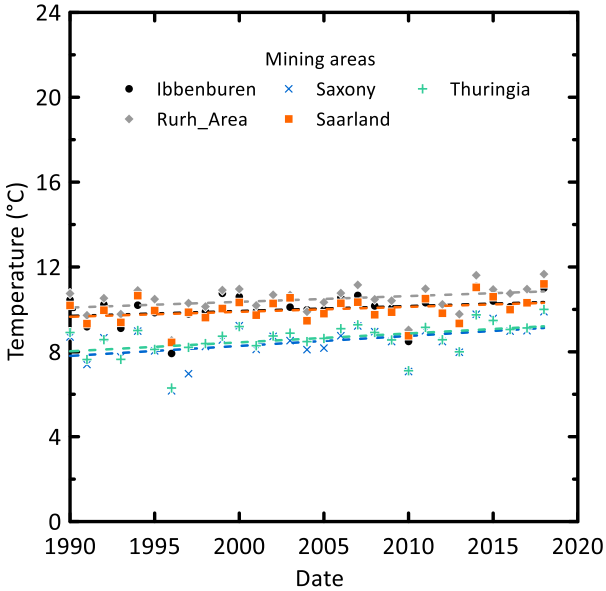

Figure 4. Mean annual temperature for German mining areas

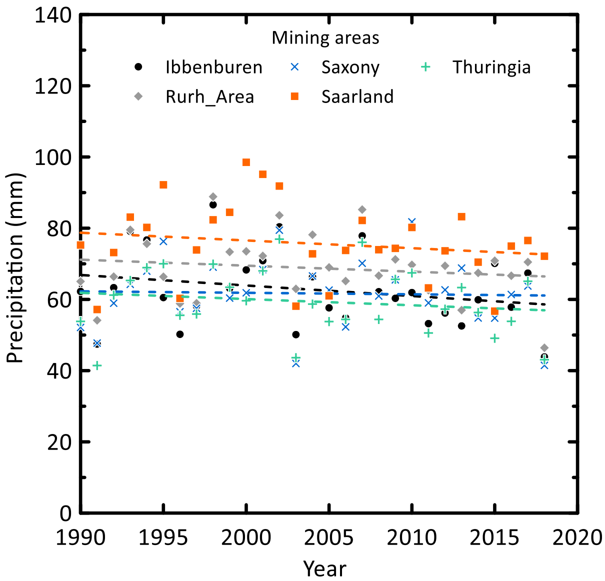

Figure 5. Mean annual rainfall for German mining areas

3.3. Greece

The terrain of Greece has significant variations because 80% of the total surface is mountainous, and only 20% of it is arable land. The climate of Greece also has variations but, for the most part, is Mediterranean with mild, rainy winters and warm, dry summers [33, 34]. The majority of mining areas are in two regions that were examined herein, Western Macedonia and Peloponnese. Ptolemais is part of the Western Macedonia Lignite Centre in the Kozani-Ptolemais area in northern Greece and Megalopolis is in the Peloponnese area, southern Greece. They present different climate characteristics, the one having a temperate oceanic climate and the other one hot-summer Mediterranean.

The climate of Western Macedonia is more similar to continental Europe; that is attributed to the fact that western Macedonia is the only landlocked region of Greece, and 82% of the terrain is mountainous and semi-mountainous [34, 35]. Rainfalls in the plain areas range from 600-800 mm, while they can reach 1400mm in the mountainous areas. Due to mountainous terrain and highlands alternations, the north winds result in lower temperatures and several snowfalls per year compared to neighbor central Macedonia and Epirus. Western Macedonia has a moister climate than western Greece despite the lower levels of rainfall due to the combination of the mountainous terrain and its several lakes [36].

The climate of Ptolemais is classified as Cfb (temperate oceanic climate), with intense winters and mild summers with a very low average annual number of dry days [37]. There are 108.3 rainfall days throughout the year, with August being the driest month with 5.1 days of rainfall and 30mm of rain. November is the

vol. 28, issue 1 / 2022
pp. 73-86

wettest month, with 10.7 days of rainfall and 60.3 mm of rain precipitation. The average annual temperature is 11.5°C, with the coldest month being January with an average high temperature of 6.1°C and the coldest month being January with an average temperature of -1.2°C. The geographical location and the terrain morphology are responsible for significant seasonal temperature differences. The lowest recorded temperature in Ptolemais was 1963 at 600m elevation at -28°C [36, 38].

On the other hand, the climate of Megalopolis is categorized as Csa in the Koppen-Geiger classification with hot summers and mild winters [37]. The average temperature is 14.9°C, with August being the hottest month with an average of 23.1°C and January being the coldest month with 7.2°C. Most rainfall days were during the fall and winter, with annual precipitation of 800mm. The driest month of the year is July, with average rain precipitation of 9mm and the wettest month is December with 147mm of rain precipitation.

Figure 6 and Figure 7 present the temperature and rainfall recorded by the Hellenic National Meteorological Service (data provided upon request). Ptolemais has higher mean monthly rainfall and slightly lower mean monthly temperature than Megalopolis. There is a visible trend of a long-term increase in average temperature for both Greek mining regions, having an average increase of more than 1°C. On the other hand, rainfall presents an increasing trend during the period under investigation, especially during the last decade (2010-2019).

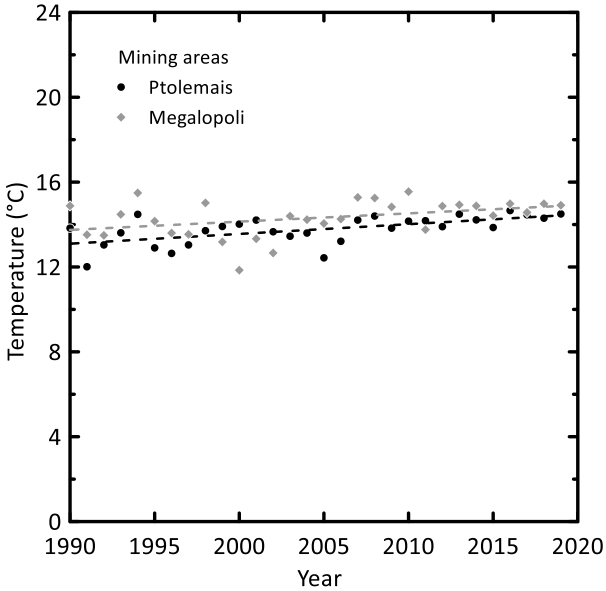

Figure 6. Mean monthly temperature for Greek mining areas

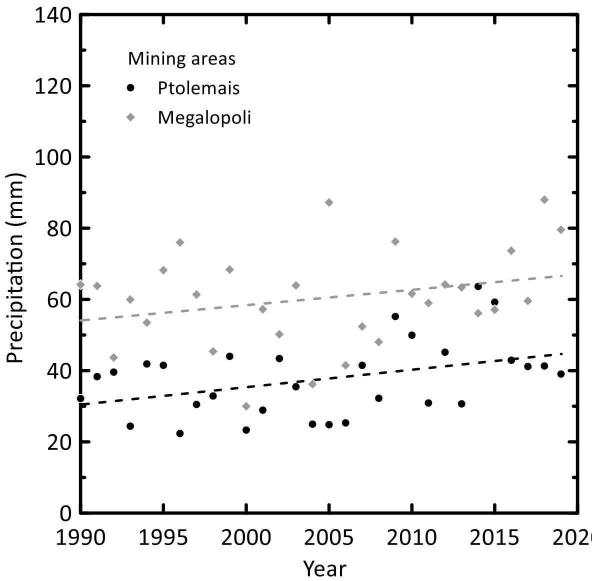

Figure 7. Mean monthly rainfall for Greek mining areas

3.4. Poland

Climate data from the three major Polish mine areas were analyzed: the Upper Silesia area, the Lower Silesia area, and the Lubelskie Coal Basin area in Lublin. The climate of Upper Silesia widely corresponds to Central European weather conditions. Frequent migration of air masses with various physical properties gives the climate a temporary character. It has both oceanic and continental climate features. For over 60% of the year, polar sea air flows into the region from the west. During winter, it promotes thaws and causes large cloud cover, as well as rain and snow. In the summer, there is cooling combined with an increase in cloudiness and, as a consequence, precipitation. For about 30% of the days of the year, the region receives polar-continental air masses from Eastern Europe and Asia. Arctic air is in the described area for about 6% of the days in the year. It comes from northern Scandinavia and the region of Greenland. The air from the Mediterranean region is recorded for only 2% of days a year, rarely reaches Upper Silesia. In such cases, there is rapid warming in winter and periods of very hot weather in summer. During the remaining 2% of days, air flows in from other regions.

The average annual temperature of Upper Silesia is between 7°C and 8°C. The highest average monthly temperatures occurs in July in the range of 14-16°C and the lowest in January between -2°C and -4°C. The highest average annual maximum temperature varies between 12°C and 13°C, and the average minimum from below 1°C to above 4°C. The average annual precipitation sums are in the range of 700-800 mm. During the year, summer rainfall predominates over winter, and their distribution refers to average annual rainfall. The lowest average monthly rainfall in July did not exceed 60 mm and was recorded near the northern border of the Upper

Silesian Coal Basin. On average, in the central part of the region, monthly rainfall is between 80 and 100 mm in July. The distribution of precipitation in January is generally similar to that of July, with the difference that the average monthly precipitation sums are reduced. The minimum rainfall does not exceed 40 mm.

The climate of Lower Silesia is Central European, with the influence of oceanic weather conditions. The maximum temperature occurs from July to September, around 19 ° C, while the minimum temperature is from January to February, approximately -5°C; the average annual temperature is 7°C. Moderate cloud cover occurs in autumn and winter, and violent thunderstorms often accompany precipitation. Average annual precipitation sums are within 500-600 mm. Maximum precipitation occurs in July and minimum in February. High rainfall, moderate average annual temperatures, the specific location, and relative height of the terrain create favorable conditions for flora and fauna.

Atmospheric fronts are the main factor influencing the weather changes in the Lubelskie Coal Basin area. Most days with fronts are observed in November and December and the least in June and August when the weather is more stable. The region is characterized by an average annual air temperature of 7.3 ° C, with the lowest average monthly temperature in February −4.0°C, and the highest in July, 18.2°C. Temperatures below 0°C appear from December to March, while hot days above 25°C occur from April to September. About 560 mm of precipitation is recorded in the area annually, distributed unevenly throughout the year. The highest monthly sums occur in July, 77 mm, while the lowest precipitation is in January, 29.6 mm. Generally, rainfall varies through seasons in both intensity and duration. Winter and autumn are usually long-lasting, while summer is shorter and more intense and is often accompanied by storms (on average 25-30 storms per year).

Figure 8 and Figure 9 present the climatic conditions -temperature and rainfall- in the three major Polish mine areas. The highest mean temperature is in Upper Silesia, the lowest in Lower Silesia, and all three regions show an apparent temperature rise. The average annual temperature is increased around 1°C on average for the three Poland mining areas from 1990 to 2019. The precipitation in the three Poland mining areas is highly variable, with significant fluctuations. Upper Silesia presents the highest mean precipitation with a trend to decrease. At the same time, Lower Silesia and Lublin have a similar mean annual precipitation that remained practically unchanged over the last thirty years.

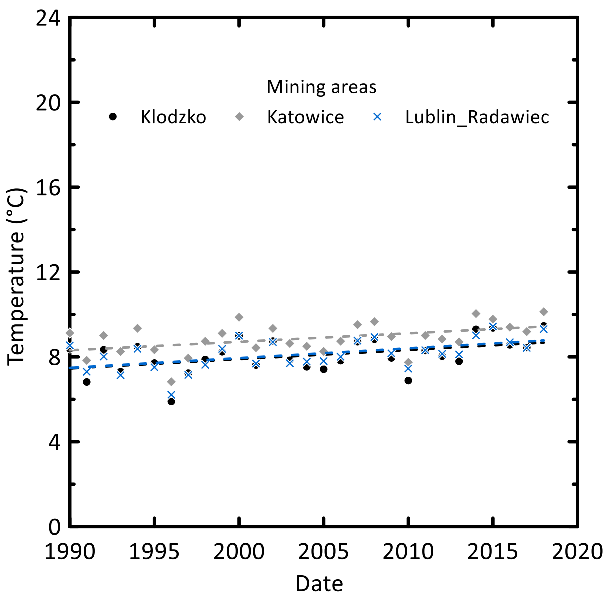

Figure 8. Mean annual temperature for Polish mining areas

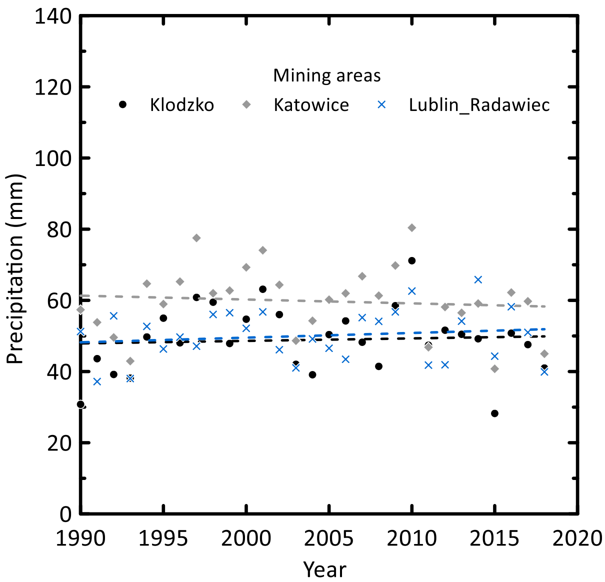

Figure 9. Annual rainfall for Polish mining areas

3.5. Spain

The climate of Spain is enormously varied due to its complex topography and geographical location, presenting significant spatial differences in the annual average temperature and the average annual precipitation range. To this, high inter-annual climate variability is added and the remarkable breadth of extreme daily values. Thus, the annual rainfall variability can increase by over 30% in the Mediterranean regions and the Canary archipelago. Moreover, the sequence of consecutive days without rain can reach over four months in the southern half. This climatic variability year-on-year is largely conditioned, particularly for rainfall, by the circulation patterns of the atmosphere in the Northern Hemisphere, particularly by the North Atlantic Oscillation.

vol. 28, issue 1 / 2022
pp. 73-86

During the twentieth century, particularly since the 70s of that century, temperatures in Spain have increased overall, with a magnitude somewhat higher than the planet's global average. This increase has been particularly pronounced in winter. Precipitation during this period has tended down, especially in the southern part and the Canary Islands. This trend corresponds, in part, with an increase in the North Atlantic Oscillation index.

Figure 10 and Figure 11 present the climatic conditions in the mining areas of Teruel and Seville in southern Spain. The mean annual temperature is higher in Seville than in Teruel, and it is almost around 8°C. In both Spanish mining areas, the mean annual temperature presents an apparent increase, which is more profound in the area of Teruel. Furthermore, Seville's precipitation level is higher than in Teruel and presents more significant fluctuations. Nevertheless, the mean annual precipitation remains practically constant in both mining areas, slightly increasing from 2000 onwards.

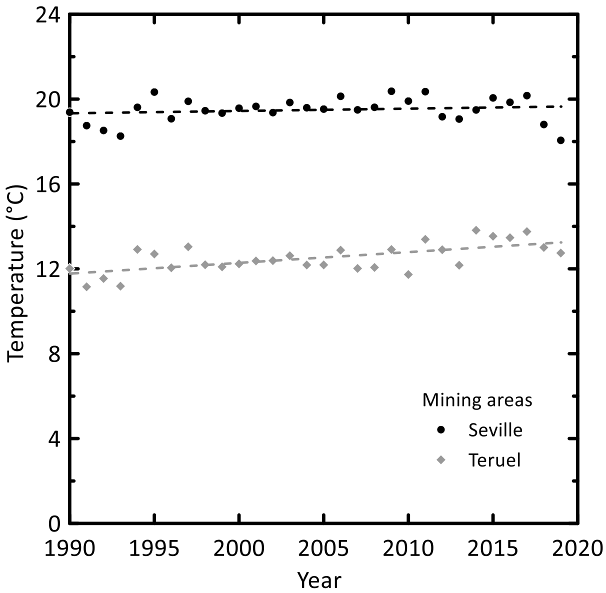

Figure 10. Mean annual temperature for Spanish mining areas

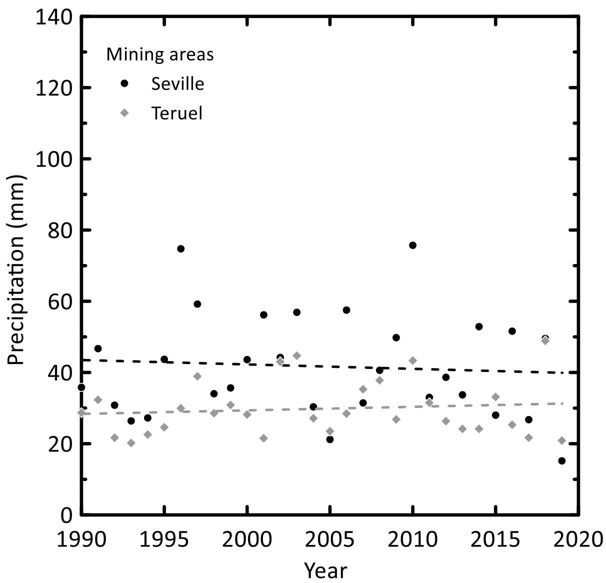

Figure 11. Annual rainfall for Spanish mining areas

3.6. United Kingdom

The following sections refer to five of the UK's former coal-mining regions of South Wales, Ayrshire, Nottinghamshire, Yorkshire, and Durham. South Wales coalfield is in southeast Wales and has an oceanic (maritime) climate; it presents cloudy, windy, wet, but mild weather. Localized differences exist due to various conditions on and near the coastline. The average annual temperature near the Wales coasts varies from 9.5°C to 11°C, with the lower values occurring away from the coasts. In winter, temperatures are influenced mainly by the surrounding sea, and February is usually the coldest month. The mean daily minimum temperatures vary from above 0°C in the higher parts to 3 or 4°C around the coast; July is usually the warmest month. Precipitation comes mainly as rainfall, and its intensity varies widely, with the highest average annual heights recorded on the way from Snowdonia to the Brecon Beacons. In the wettest area of Wales, the average annual rainfall exceeds 3000mm. In contrast, places along the coast present annual rainfall height of less than 1000mm. Notice that significant daily rainfalls with more than 50mm height occur every two years.

The Ayrshire coalfield is in the mid-latitude western part of Western Scotland. Similarly to South Wales, this region has a crucial maritime influence, showing in the temperature range. However, in this case, winds from the sea are the decisive part rather than the surface temperature. The annual mean temperatures in Ayrshire vary in a very narrow range, from 9.5 to 9.9°C. Average annual rainfall range from 1000mm in the upper valley and along the coasts to over 3500mm on the higher parts. Rainfall varies seasonally, with October to January being the wettest months; nevertheless, the rainfall is generally well-distributed throughout the year.

The Nottinghamshire coalfield is in the northeastern part of the Midlands in England. The average annual temperatures vary from 8°C to just over 10°C. Extreme events such as winter frosts and very hot summer days are sporadically observed, particularly in the south and east. January is the coldest month - mean daily minimum temperatures from below 0°C to 1.5°C - and July is the warmest month - maximum daily temperatures exceeding 22°C. The region is relatively dry for the UK standards. The wettest areas are along

vol. 28, issue 1 / 2022
pp. 73-86

the Welsh border, with an annual average of over 800mm. On the other hand, the South and East Midlands are the driest - being more covered - with less than 600mm per year. Extended rainfalls lasting for many days have led to widespread flooding, especially when soils are near saturation (mainly winter or early spring).

The Yorkshire and Durham coalfields are in North East England. Notably, the Yorkshire coalfield develops at West Yorkshire, South Yorkshire, and North Yorkshire, in the southern part of the region; the Durham coalfield is in the County Durham mid-latitude eastern part of the region. The average annual temperature depends on the height above sea level, with a decrease of about 0.5°C for every 100 meters; the average annual temperature ranges from 8.5°C to 10°C. January is the coldest month, and the mean daily minimum temperature ranges from 0.5°C to 2°C, depending on altitude and coast distance. The maximum temperature ranges from 21.5°C in South Yorkshire to less than 17°C in the mountains (during the summer). Extreme heat has been reported in various cases in July or August. The average annual rainfall exceeds 1500m on the upper part of the Pennines hills and mountains. The annual rainfall decreases to less than 600mm by descending towards the east, as this coast is one of the UK's driest parts. While rainfall is generally well distributed throughout the year, a seasonal pattern exists. Thunderstorms might occur from May to September, peaking in July and August. The heaviest UK rainfalls are typically associated with these summer thunderstorms.

The UK Met Office provided the data analyzed herein. Figure 12 shows that South Wales has the highest temperature level while Durham has the lowest of the UK mining regions. In the last thirty years, the average annual temperature level in these regions is 8.3°C to 11.8°C and appears a minor trend towards increasing; however, this trend is less than 0.5°C on average. Figure 13 presents the rainfall for the five UK regions. Aryshire displays the highest rainfall levels while Nottinghamshire has the lowest ones. In Ayrshire, South Wales, and Durham, the precipitation tends to increase. In Yorkshire and Nottinghamshire, the average rainfall has been practically at the same level for thirty years.

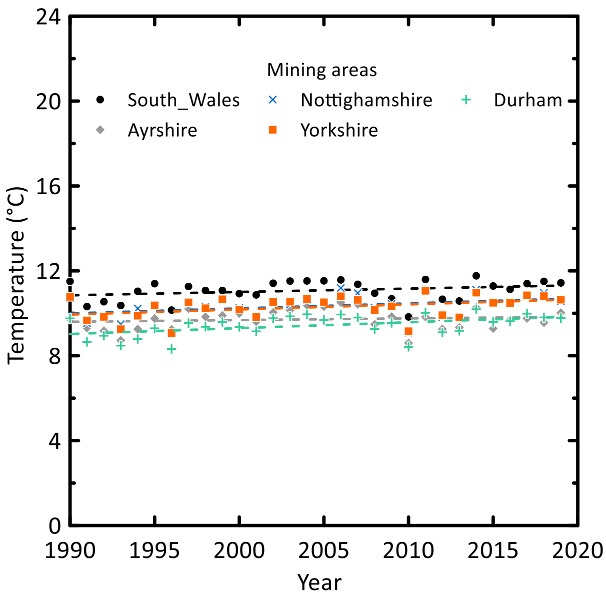

Figure 12. Mean monthly temperature for UK mining areas

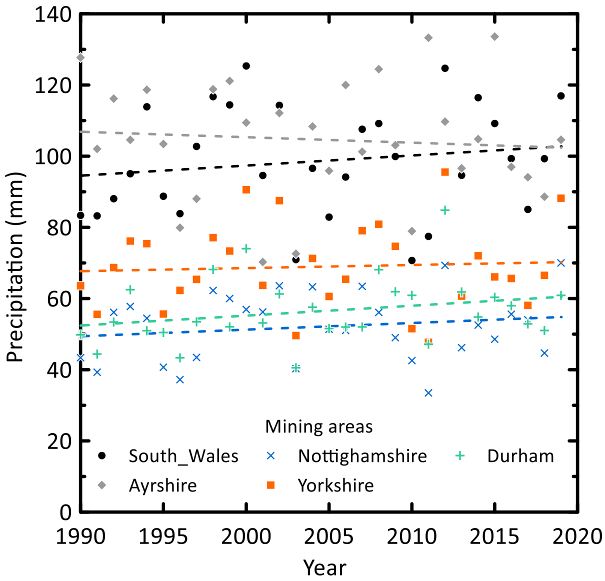

Figure 13. Mean monthly rainfall for UK mining areas

4. Conclusions

In this work, past and current climate and weather conditions are analyzed for European mining areas. These areas cover in large all corners of Europe from north to south and from east to west. More specifically, mining areas in the Czech Republic, Germany, Greece, Poland, Spain, and the UK were investigated. The analysis is based on climate classification, local and global reports of climate conditions during the past decades, and precipitation and temperature records for the past 30 years (the reference period for climate description). Based on these data, the climate profile of each area can be established, and the conditions that affect the most mining operation and reclamation are examined, i.e. temperature and precipitation.

Overall, three climate types are found in these areas, humid continental (in the Czech Republic, Germany, and Poland), temperate oceanic (in Germany, north Greece, Poland, the UK), and hot-summer Mediterranean (in Greece and Spain). Each type has characteristics generally defining the climate of the mining area.

vol. 28, issue 1 / 2022
pp. 73-86

In the Czech Republic area, the characteristic average monthly temperatures are -2°C to -3°C in January, 8°C to 9°C in April, 18°C to 19 °C in July, and 7°C to 9 °C in October. The precipitation amount from April to September is between 350 mm - 400 mm, and in October to March between 200 mm - 300 mm; overall, the precipitation varies between 550 mm - 700 mm per year.

In Germany, climate data from five different regions were analyzed: Ruhr and Ibbenbüren (in North Rhine-Westphalia), Saarland, Thuringia, and Saxony. The average annual temperature is around 10.5°C in Ruhr and 10°C in Ibbenbüren. In Saarland, the average annual temperature is 10°C, in Thuringia 8.6°C, and in Saxony 8.5°C. The average annual precipitation is 826 mm per year in Ruhr and 753 mm per year in Ibbenbüren. Furthermore, it is 908mm in Saarland, 713mm in Thuringia and 740mm in Saxony.

Two Greek mining areas were analyzed Ptolemais (in the north) and Megalopolis (in the south). In Ptolemais, the mean annual temperature is 11.5°C, with August being the driest month with 30mm of rain and November the wettest month with 60.3 mm of rain. In Megalopolis, the average temperature is 14.9°C, with August being the hottest month with an average of 23.1°C and January being the coldest month with 7.2°C. Most rainfall days are during the fall and winter, with average annual precipitation of 800mm.

Climate data from the three major Polish mine areas were examined: the Upper Silesia area, the Lower Silesia area, and the Lubelskie Coal Basin area in Lublin. The average annual temperature of Upper Silesia is between 7°C and eight °C, and the average annual precipitation is700-800 mm. In Lower Silesia, the average annual temperature is 7°C, and the average annual precipitation is 500-600 mm. Lublin region is characterized by an average temperature of 7.3°C and precipitation of about 560 mm.

Temperatures in Spain have increased during the last decades, with a magnitude somewhat higher than the planet's global average, an increase particularly pronounced in winter. Precipitation during this period has tended down, especially in the southern part. Two mining regions of Spain were investigated, Teruel and Seville. Teruel has an average annual temperature of 12°C and Seville of 19°C, while the average annual precipitation varies from 200mm to 600mm for both regions.

Five of the UK's former coal-mining regions were examined: South Wales, Ayrshire, Nottinghamshire, Yorkshire, and Durham. The average annual temperature in Wales (in lower heights) ranges from 9.5°C to 11°C, but the higher values are observed mainly towards the coasts. Rainfall in South Wales varies extensively, with an average annual from 800mm to 1500mm. The annual mean temperature in Ayrshire is influenced mainly by the winds from the seas and ranges around 9.5°C, and the average annual rainfall ranges similarly to South Wales. The Nottinghamshire coalfield is in the northeastern part of the Midlands in England. Mean annual temperatures over the region vary from 8°C to just over 10°C and average annual precipitation from 480mm to 720mm. Yorkshire presents an annual mean temperature of 9°C -11°C and Durham 8°C -10°C. Durham has a slightly larger annual precipitation than Nottinghamshire, while Yorkshire has higher precipitation of 720mm-1080mm per year.

Overall, in all mining areas, the average temperature increased during the past 30 years from 1°C to 2°C. This trend is evident in all cases. However, the precipitation presents several trends. In most cases, the average annual precipitation remains practically constant. Nevertheless, in some cases, precipitation decreased, such as in most German mining areas, one in Poland, one in Spain, and one in the UK. Finally, only in few cases average precipitation presented a clear, increasing trend, mainly in Greek areas.

Acknowledgements

This work has received funding from the European Union's Research Fund for Coal and Steel under the project TEXMIN grant agreement No 847250.

References

[1] **McGuirk M., Shuford S., Peterson T.C., Pisano P.** 2009
Weather and Climate Change Implications for Surface Transportation in the USA. WMO bulletin, 2009. 58(2): p. 85

[2] **Tromp S.W.** 1972
Influence of Weather and Climate on the Fibrinogen Content of Human Blood. International Journal of Biometeorology, 1972. 16(1): p. 93-95

[3] **Smith K.** 1993
The influence of Weather and Climate on Recreation and Tourism. Weather, 1993. 48(12): p. 398-404

[4] **Ivanov S.L., Ivanova P.V., Kuvshinkin S.U.** 2019
Weather Conditions as a Factor Affecting the Performance of Modern Powerful Mining Excavators. Journal of Physics: Conference Series, 2019. 1399: p. 044070

[5] **Oreskes N.** 2004
The Scientific Consensus on Climate Change. Science, 2004. 306(5702): p. 1686-1686

[6] **Masson-Delmotte V., Zhai P., Pörtner H.-O., Roberts D., Skea J., Shukla P.R., Pirani A., Moufouma-Okia W., Péan C., Pidcock R., Connors S., Matthews J.B.R., Chen Y., Zhou X., Gomis M.I., Lonnoy E., Maycock T., Tignor M., Waterfield T.** 2018
IPCC, Global Warming of 1.5°C. An IPCC Special Report on the Impacts of Global Warming of 1.5°C above Pre-Industrial Levels and Related Global Greenhouse Gas Emission Pathways, in the Context of Strengthening the Global Response to the Threat of Climate Change, Sustainable Development, and Efforts to Eradicate Poverty, Editor. 2018, World Meteorological Organization: Geneva, Switzerland. p. P. 32

[7] **Shukla P.R., Calvo Buendia E., Masson-Delmotte V., Pörtner H.-O., Roberts D.C., Zhai P., Slade R., Connors S., van Diemen R., Ferrat M., Haughey E., Luz S., Neogi S., Pathak M., Petzold J., Portugal Pereira J., Vyas P., Huntley E., Kissick K., Belkacemi M., Malley J.** 2019
IPCC, Climate Change and Land: an IPCC Special Report on Climate Change, Desertification, Land Degradation, Sustainable Land Management, Food Security, and Greenhouse Gas Fluxes in Terrestrial Ecosystems, J.S. Editor. 2019, In press

[8] **The Intergovernmental Panel on Climate Change** 2014
IPCC, Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. 2014, Geneva, Switzerland. p. P. 151

[9] **European Commission** 2013
An EU Strategy on Adaptation to Climate Change. 2013, COM (2013) 216 final: Brussels

[10] **Ackerman F., Staunton E.** 2008
The Cost of Climate Change: What We'll Pay if Global Warming Continues Unchecked. 2008, Natural Resources Defense Council

[11] **Bonan G.B., Pollard D., Thompson S.L.** 1992
Effects of Boreal Forest Vegetation on Global Climate. Nature, 1992. 359(6397): p. 716-718

[12] **Simmons C., Matthews H.** 2016
Assessing the Implications of Human Land-Use Change for the Transient Climate Response to Cumulative Carbon Emissions. Environmental Research Letters, 2016. 11(3): p. 035001

[13] **Brovkin V., Sitch S., Von Bloh W., Claussen M., Bauer E., Cramer W.** 2004
Role of Land Cover Changes for Atmospheric CO2 Increase and Climate Change during the last 150 Years. Global Change Biology, 2004. 10(8): p. 1253-1266

[14] **Pongratz J., Reick C., Raddatz T., Claussen M.** 2010
Biogeophysical versus Biogeochemical Climate Response to Historical Anthropogenic Land Cover Change. Geophysical Research Letters, 2010. 37(8)

[15] **Jia G., Shevliakova E., Artaxo P., Noblet-Ducoudré D., Houghton R., House J., Kitajima K., Lennard C., Popp A., Sirin A.** 2019
Land-Climate Interactions, in *Climate Change and Land: an IPCC Special Report on Climate Change, Desertification, Land Degradation, Sustainable Land Management, Food Security, and Greenhouse Gas Fluxes in Terrestrial Ecosystems* J.S. Editor. 2019. p. 131-247.

[16] **Almazroui M., Islam M.N., Saeed S., Saeed F., Ismail M.** 2020
Future Changes in Climate over the Arabian Peninsula based on CMIP6 Multimodel Simulations. Earth Systems and Environment, 2020. 4(4): p. 611-630.

[17] **Boudiaf B., Dabanli I., Boutaghane H., Şen Z.** 2020
Temperature and Precipitation Risk Assessment Under Climate Change Effect in Northeast Algeria. Earth Systems and Environment, 2020. 4(1)

[18] **Driouech F., ElRhaz K., Moufouma-Okia W., Arjdal K., Balhane S.** 2020
Assessing Future Changes of Climate Extreme Events in the CORDEX-MENA Region Using Regional Climate Model ALADIN-Climate. Earth Systems and Environment, 2020. 4(3): p. 477-492

[19] **Hamdi, R., Kusaka H., Doan Q.V., Cai P., He H., Luo G., Kuang W., Caluwaerts S., Duchêne F., Van Schaeybroek B., Termonia P.** 2020
The State-of-the-Art of Urban Climate Change Modeling and Observations. Earth Systems and Environment, 2020. 4(4): p. 631-646

[20] **Krishnamurthy V.** 2019
Predictability of Weather and Climate. Earth and Space Science, 2019. 6(7): p. 1043-1056

[21] **Slingo J., Palmer T.** 2011
Uncertainty in Weather and Climate Prediction. Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences, 2011. 369(1956): p. 4751-4767

[22] **Northey S.A., Mudd G.M., Werner T.T., Jowitt S.M., Haque N., Yellishetty M., Weng Z.** 2017
The Exposure of Global Base Metal Resources to Water Criticality, Scarcity and Climate Change. Global Environmental Change, 2017. 44: p. 109-124

[23] **Locke P., Clifton C., Westra S.** 2011
Extreme Weather Events and the Mining industry. Engineering and Mining Journal, 2011. 212(3): p. 58

[24] **Mason L.M., Unger C., Lederwasch A.J., Razian H., Wynne L.E., Giurco D.** 2013
Adapting to Climate Risks and Extreme Weather: A Guide for Mining and Minerals Industry Professionals. 2013, National Climate Change Adaptation Research Facility: Gold Coast

[25] **Pearce T.D., Ford J.D., Prno J., Duerden F., Pittman J., Beaumier M., Berrang-Ford L., Smit B.** 2011
Climate Change and Mining in Canada. Mitigation and Adaptation Strategies for Global Change, 2011. 16(3): p. 347-368

[26] **Geiger R.** 1954
Klassifikation der Kli-mate nach W. Köppen, in *Landolt-Börnstein – Zahlenwerte undFunktionen aus Physik, Chemie, Astronomie, Geophysikund Technik*. 1954, Springer: Berlin. p. 603-607

[27] **Geiger R.** 1961
Überarbeitete Neuausgabe von Geiger, R.: Köppen-Geiger/Klima der Erde. (Wandkarte 1:16 Mill.). 1961, Gotha: Klett-Perthes

[28] **Köppen W.** 2000
Ersuch einer Klassifikation der Kli-mate, vorzugsweise nach ihren Beziehungen zur Pflanzen-welt. Geographische Zeitschrift, 1900. 6: p. 593-611, 657-679

[29] **Köppen W., Volken E., Brönnimann S.** 2011
The Thermal Zones of the Earth According to the Duration of Hot, Moderate and Cold Periods and to the Impact of Heat on the Organic World (Translated from: Die Wärmezonen der Erde, nach der Dauer der heissen, gemässigten und kalten Zeit und nach der Wirkung der Wärme auf die organische Welt betrachtet, Meteorol Z 1884, 1, 215-226). Meteorologische Zeitschrift, 2011. 20(3): p. 351-360

[30] **LANUV (Landesamt für Natur, Umwelt und Verbraucherschutz Nordrhein-Westfalen / State Office for Nature, Environment and Consumer Protection North Rhine-Westphalia)** 2010
Climate and Climate Change in North Rhine-Westphalia - Data and Background - Technical Report 27, in *Technical Report*. 2010

[31] **TMUEN, Thüringer Ministerium für Umwelt, Energie und Naturschutz** 2017
Facts about climate change in Thuringia. 2017

vol. 28, issue 1 / 2022
pp. 73-86

[32] **LfULG (Landesamt für Umwelt, Landwirtschaft und Geologie / Saxon State Office for Environment, Agriculture and Geology)** 2013
Compendium Climate - Saxony in Climate Change 2013

[33] **Eleftheriou D., Kiachidis K., Kalmintzis G., Kalea A., Bantasis C., Koumadoraki P., Spathara M.E., Tsolaki A., Tzampazidou M.I. Gemitzi A.** 2018
Determination of Annual and Seasonal Daytime and Nighttime Trends of MODIS LST over Greece - Climate Change Implications. Science of the Total Environment, 2018. 616-617: p. 937-947

[34] **Stournaras G., Skourtos M., Kontogianni A., Yoxas G., Nastos P.** 2011
The Environmental, Economic and Social Impacts of Climate Change in Greece. 2011, Bank of Greece

[35] **Tselepidakis I., Theoharatos G.** 1989
A Bioclimatic Classification of the Greek Area. Theoretical and Applied Climatology, 1989. 40(3): p. 147-153

[36] **Feidas H., Karagiannidis A., Keppas S., Vaitis M., Kontos T., Zanis P., Melas D., Anadranistakis E.** 2014
Modeling and Mapping Temperature and Precipitation Climate Data in Greece Using Topographical and Geographical Parameters. Theoretical and Applied Climatology, 2014. 118(1-2): p. 133-146

[37] **Beck H.E., Zimmermann N.E., McVicar T.R., Vergopolan N., Berg A., Wood E.F.** 2018
Present and Future Köppen-Geiger Climate Classification Maps at 1-km Resolution. Scientific Data, 2018. 5.

[38] **Gofa F., Mamara A., Anadranistakis M., Flocas H.** 2019
Developing Gridded Climate Data Sets of Precipitation for Greece Based on Homogenized Time Series. Climate, 2019. 7(5).