How Climate would likely change in future: Case study of a mine site in Kazakhstan

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Abstract

Global warming and climate change can be a threat to mining and other industries, especially those involving water supply and management, since such change could induce/amplify some climatic parameters, e.g. change in precipitation regime and temperature extremes. This study quantifies the level of climate change that may affect the development of a mine site in the northeast part of Kazakhstan, using the latest NASA NEX-GDDP-CMIP6 datasets. For this purpose, daily precipitation as well as maximum and minimum temperature for 18 global circulation models (GCMs) were analysed over three future time periods, namely 2040s, 2060s and 2080s under two shared socioeconomic pathway scenarios, i.e. SSP245 and SSP585. The period 1981-2014 was considered as the baseline period to and future climate condition compared to this period. The analysis results revealed that: (1) Both maximum and minimum temperature will increase under both SSPs in those time periods with the rate of change for minimum temperature being higher than maximum temperature. (2) The mean annual precipitation will increase by an average rate of 7% in 2040s for both SSPs and 14% and 17% for SSP245 and SSP585 in 2080s, respectively. It is also observed that summer months will experience drier condition whilst all other months will have increase in precipitation. (3) The values of 24-hr precipitation with 10-year return period will also increase under both SSP and future time period combination for most of the 18 GCMs. These predicted changes should be considered as design criteria adjustment for project water supply and water management structures.

Keywords: Climate Change, SSPs scenarios, Water Management, Mining, Kazakhstan

Introduction

With growing threat of climate change in the past few decades and exacerbation of the worst scenarios in the areas of energy, water and desertification, the pressures on natural resource management as a result of poverty has also been intensified (Deere-Birkbeck, 2009). It is believed that the risk associated to climate change is one of the most prominent threats to human societies (Hui-Min *et al*., 2021), manifested by increasing intensity, frequency and impacts of extreme weather events such as hurricanes, floods, droughts and heatwaves. Also Global Industry Standard on Tailings Management (GISTM) suggested to strengthen protections required as a result of evolving climate change impacts (ICMM, 2020).

It is widely recognised that available mining deposits are increasingly deeper and of declining ore grade. This will lead to growing demands for water as well as greater mine waste (Ruttinger and Sharma, 2016) while it is expected that climate change would increase pressure on the mining industry since more frequent droughts and floods are expected in future leading to alteration in water supply and disruption of mining operations. Climate change studies for mining projects should be adopted as a consistent approach to help mining companies identify the risks and opportunities related to the management of water resources in all stages of the mine development and closure phase (Krogerus and Pasanen, 2016).

It is essential for mining companies to consider the climate change and its impact on sustainability and cost of water and energy supplies and use decision making tools that help them optimise use of available water resources. Climate change analysis coupled with stochastic project water balance models can provide good predictions of water surplus or deficit over mine life (and closure) and so solutions/measures are prepared and costed for at early stage of project development. To address climate change, Coupled Model Intercomparison Project (CMIP) models provides the required feasible tool to predict future climate condition under the changing conditions (Farjad *et al*., 2019). CMIP6 is the latest version of the CMIPs based on IPCC's sixth assessment report (AR6).

Due to climate models' structural uncertainties, complexity in earth-atmosphere systems and finally coarse resolution of the GCMs, the application of their outputs is limited to some extent (Chen *et al*., 2021). NASA implemented a project named NASA Earth Exchange Global Daily Downscaled Projections 6 (NEX-GDDP-CMIP6) to provide downscaled historical and future projections for the period 1950 to 2100 based on CMIP6 models (Thrasher *et al*., 2022).

While the outputs of global models provide an appropriate tool for understanding future climate conditions, however very few research has been reported on using the latest NASA NEX-GDDP-CMIP6 product in Central Asia countries. The purpose of this study is to evaluate the future climate condition at a mine site located in northeast part of Kazakhstan using the NEX-GDDP-CMIP6. The change in projected average and extreme precipitation and temperature conditions in future was evaluated to provide a more in-depth information on potential future climate conditions in the region.

Data and Methods

As mentioned above, the case study site selected for assessing the future climate condition based on different emission scenarios, is located in the northeast part of Kazakhstan (Figure 1). Based on historical data, the air temperature variability in the region is high, ranging from −14.9°C in winter (December-January-February) and +22.3 °C in the summer (June-July-August). The average annual air temperature is 4.1 °C with a mean annual precipitation of about 270mm/year.

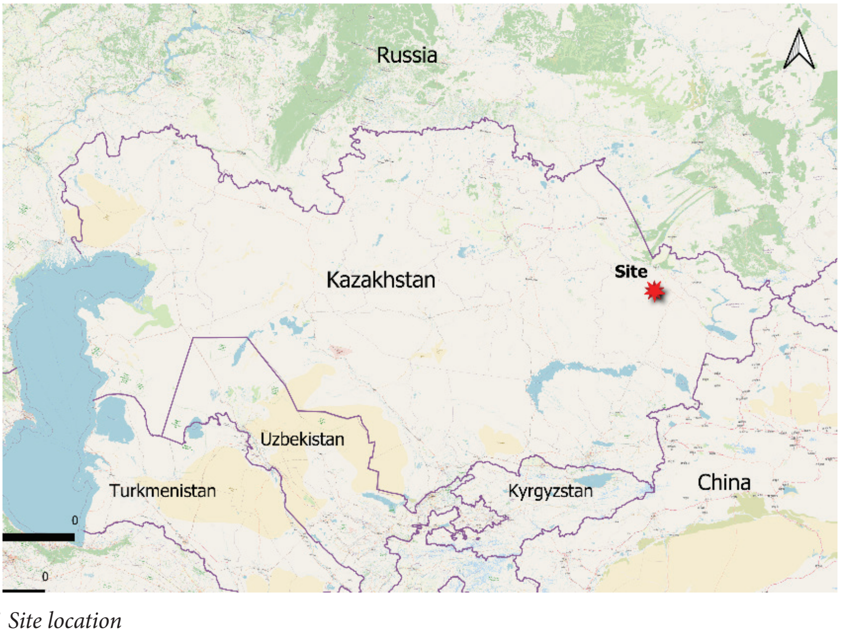

***Figure 1** Site location*

In this study, climate change for the site is assessed based on global circulation models (GCM) from NASA's NEX-GDDP dataset. Such data set is compatible with Phase 6 of the Coupled Model Intercomparison Project (CMIP6). The statistical downscaling algorithm used is a daily Bias-Correction–Spatial Disaggregation (BCSD) method (Thrasher, 2022). The NEX-GDDP-CMIP6 dataset spans the entire globe with a 0.25° (≈25 km) spatial resolution for the periods from 1950 through 2014 (historical) and from 2015 to 2100 (climate projections). Under the latest IPCC Assessment Report, AR6, two scenarios following the Shared Socioeconomic Pathway (SSP) framework where defined (SSP2-4.5 and SSP5-8.5) and are included in the analysis. Scenarios SSP245 and SSP585 shows an additional radiative forcing of 4.5 and 8.5 W/m2 representing the intermediate and high limits of the climate change projections, respectively. To reduce uncertainty in climate projections, an ensemble of GCMs' outputs is used to obtain a spectrum of possible future outcomes. The climate change studies usually take the following steps: (1): Historical data review to have a more transparent picture of the climate condition at the study site. (2) Downloading downscaled outputs of available GCMs at the site location from NEX-GDDP-CMIP6 datasets and comparing the outputs of GCMs with observed values for the baseline period. If required, bias-correction of the GCM outputs should be carried out. (3) Analysing time series of variables for interested time horizons in future under different climate change scenarios and assessing the rate of change compared to the baseline period.

To have a better projection of future climate condition, the observed data at the mine site were used to bias-correct the outputs of GCMs using quantile delta mapping (QDM) method. Finally, the effect of climate change on (1) Mean annual precipitation (MAP) as well as monthly precipitation, (2) maximum and minimum temperature at monthly time scale and (3) 24-hr precipitation with 10-year return period have been evaluated.

Results and Discussion

The change in minimum and maximum temperature at monthly scale has been calculated and the results are presented in Figure 2. This Figure is based on median temperature from all 18 models used in this study.

The results suggest that whilst both maximum and minimum temperatures will increase over the future periods the rate of increase is higher based on the pessimistic SSP585 scenario compared to the moderate scenario of SSP245. Also, the increase in temperature is higher in the far future period, i.e. 2080s compared to middle (2060s) and near (2040s) periods. The number of freezing days (days with average temperature bellow zero) will also decrease especially in March and then April and November which means less freezing condition is expected to happen during these months at the mine site (results not shown). Significant change in freezing periods and air temperature can have defining consequences on the development of projects that would rely on water sources such as glaciers or groundwater baseflow that feeds streams/rivers/lakes.

For precipitation, almost all climate models for both SSP scenarios and all future time periods predict an increase in annual precipitation (Figure 3). The only exceptions are MPI-ESM1-2-HR (all cases) and ACCESS-ESM1 over 2040s for SSP245 and 2040s and 2060s for SSP585 scenarios which show less precipitation in future compared to the baseline period. The median increase in MAP in 2040s will be approximately 5.9% and 7.9% based on RCP245 and RCP585, respectively. On the other hand, and at monthly time scale, the results suggest that July and August will experience decrease in precipitation over all time periods and SSPs whilst SSP585 shows June will also experience less precipitation over 2080s (Figure 4). All other months will experience increase in precipitation with the SSP585 causing more increase compared to SSP245 in those months.

Finally, the change in precipitations with 24-hr duration and with 10% annual exceedance probability (10-year return period) was also assessed, as illustrated in Table 2. Again, it can be seen that except a few GCMs, SSP and time horizons (e.g. CMCC-CM2-SR5 in most combination of SSPs and time horizons and FGOALS-g3 for both SSP245 and SSP585 in 2080s), in most of the cases the 24-hr precipitation

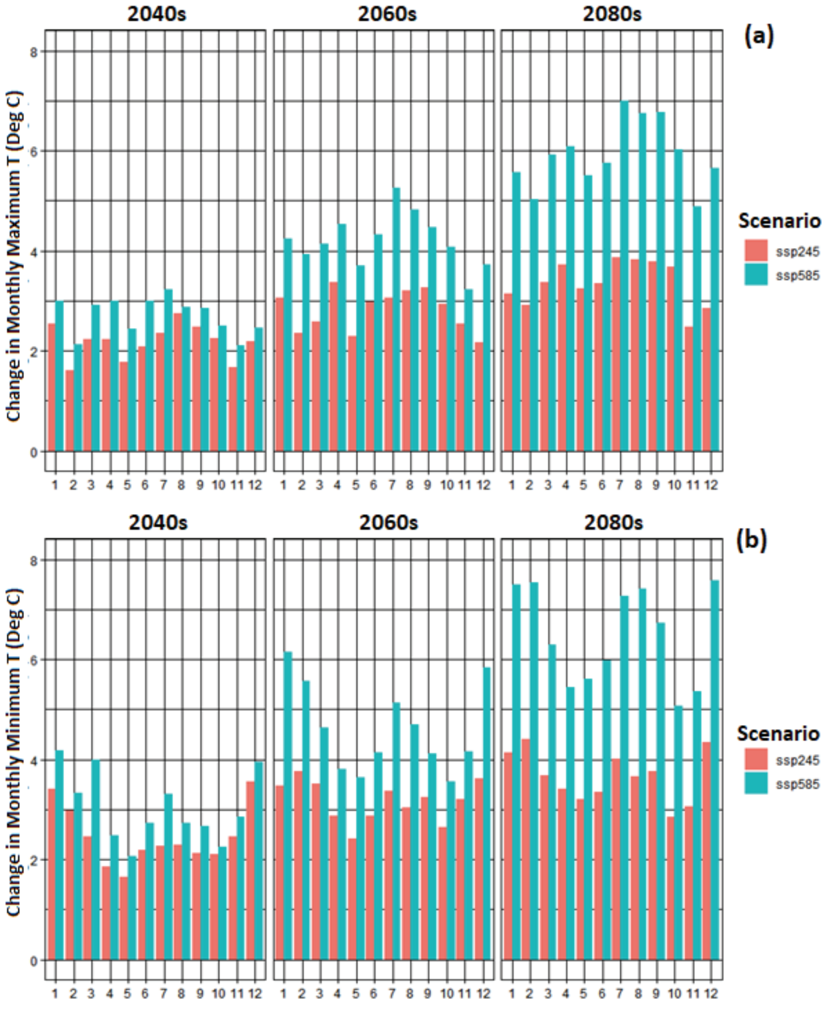

Figure 2 Change in monthly maximum (a) and minimum temperature (in Day) over future periods

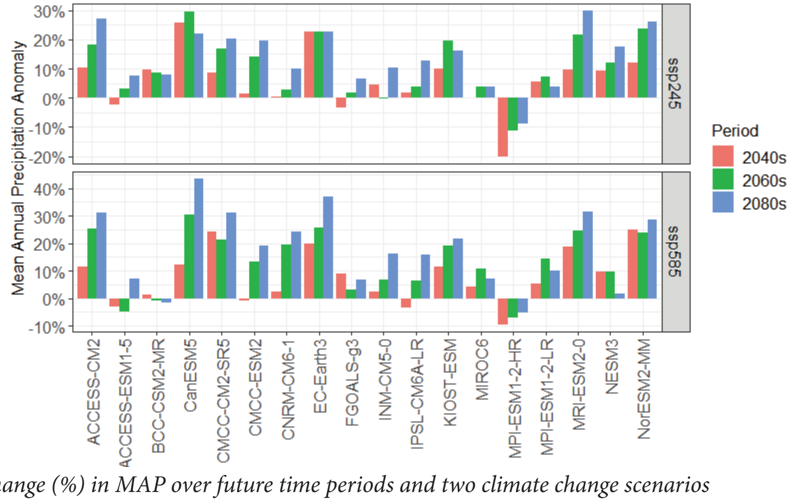

Figure 3 Rate of change (%) in MAP over future time periods and two climate change scenarios

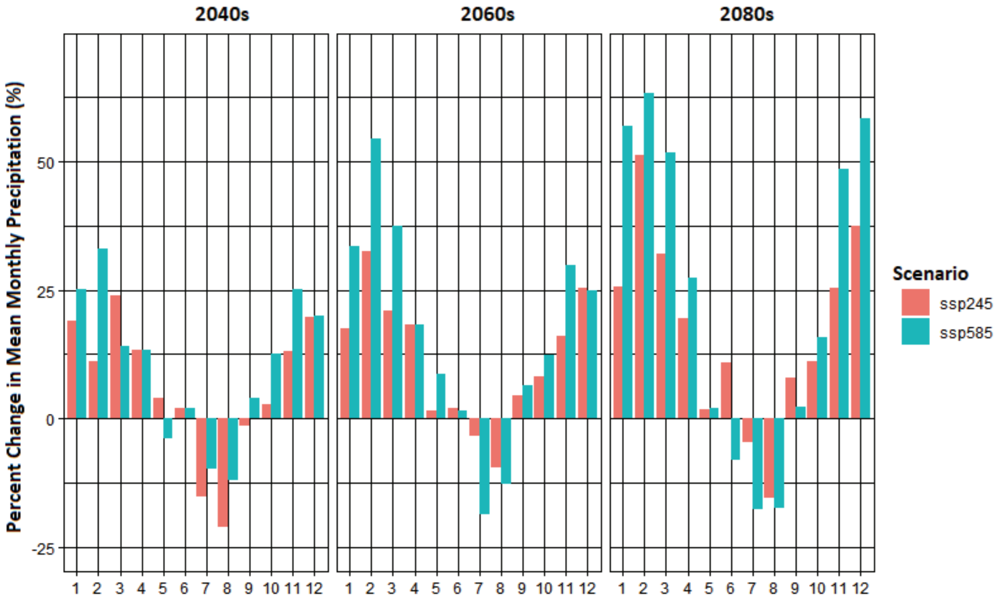

Figure 4 *Rate of change in monthly precipitation over future time periods and different SSPs based on median of all GCMs used in this study*

with 10-year return period is predicted to increase at the site.

Conclusion

Kazakhstan is ranked sixth in the world in terms of estimated mineral resources, and mining and metallurgy are key industries that make considerable contribution to Kazakhstan GDP. On the other hand, most of Kazakhstan is in arid and semi-arid climate with limited water resources, and the origin of the rivers used for water supply being in neighboring countries. Despite the risk of water supply shortage in near future, from

Table 1 *Percent change in 24-hr precipitation with 10-yr return period based on different GCMs**

period	2040s		2060s		2080s	
RCP	SSP245	SSP585	SSP245	SSP585	SSP245	SSP585
ACCESS-CM2	16.6	13.2	17.9	16.5	13.7	20.6
ACCESS-ESM1-5	13.5	10.8	23.2	10.7	20.9	19.2
BCC-CSM2-MR	19.2	11.6	17.9	9.6	13.7	4.5
CanESM5	4.8	3.9	7.5	11.4	8.5	19.8
CMCC-CM2-SR5	0.9	1.4	1.5	-2.6	6.9	15
CMCC-ESM2	-3.6	-9.1	-4.2	-5.4	-2.4	4.1
CNRM-CM6-1	-3.3	-3.9	8.4	6.3	17.7	5.7
EC-Earth3	17.9	20.3	18.2	17.3	24.7	13.2
FGOALS-g3	6.6	-4.1	6.4	-8.7	-8.7	-8.3
INM-CM5-0	-1.2	1.9	0	7.1	9.6	9.5
IPSL-CM6A-LR	9.8	-0.3	0.7	5.8	13.9	22.7
KIOST-ESM	15.9	4.6	20.4	5.7	8.7	10.7
MIROC6	-3.2	-1.6	-6.4	1.8	2.1	-0.8
MPI-ESM1-2-HR	8.5	9.1	14.8	11.1	6.2	9.9
MPI-ESM1-2-LR	6.5	6.8	3.1	6	6.5	10.6
MRI-ESM2-0	11.4	7.3	8.9	14.5	12.8	24.8
NESM3	-1.5	1.9	-0.4	2.6	-0.5	-5.2
NorESM2-MM	2.6	14.5	5.2	3.4	5.6	8.8

SRK's experience only a few projects have conducted studies to evaluate the future climate condition as a result of global warming and climate change.

In this research, the climate change effects on precipitation and temperature at a mine site in the northeast part of Kazakhstan were evaluated using the latest IPCC Assessment Report, AR6 Socioeconomic Pathway-Representative Concentration scenarios, namely SSP245 and SSP585.

The downscaled outputs of 18 global circulation models (GCMs) were bias corrected using observed historical values, then used to evaluate how maximum and minimum temperature as well as precipitation would likely change in three future periods, namely 2040s, 2060s, and 2080s.

The results showed that the maximum and minimum temperature is very likely to increase in future periods based on all climate models and both SSP245 and SSP585 scenarios. More increase in temperature is expected based on SSP585 in all future time periods and more increase in the far future period, i.e. 2080s compared to other two periods under both SSP scenarios. For minimum temperature, the increase will be more in winter months, i.e. in January, February and December which means less freezing hours/days are expected in the light of climate change. such predicted change is significant considering the fact that aquifer recharge and highest river flows in Kazakhstan is mainly due to snowmelt. Also this warmer climate means freeze-thaw cycles (FTCs) will increase leading to more freeze-thaw induced landslides which are one of the major geohazards especially on grasslands (Yang *et al*., 2022).

For precipitation, the average annual increase will be around 7% under both SSP245 and SSP585 in 2040s whilst under SSP245 and SSP585 in 2080s an increase of up to 14% and 17% is to be expected, respectively. At seasonal time scale, winter, spring and autumn months show increase in precipitation under most SSP and future time period combinations, whereas it is expected to have drier summer months, i.e. July and August. This could have significant consequences as under current condition the summer is the wettest season in this region with high temperature. Therefore, the analysis results suggest that climate change will alter the precipitation regime in the area, and this should be considered in the mine design and cost implication, especially in relation to water supply and management.

Finally, the results of the analysis of 24-hr precipitation with 10-year return period suggest an average increase in precipitation ranging from 4% to 10% for SSP585/2040s and SSP585/2080s scenario/future period combination. This predicted increase in precipitation and resulting runoff should be considered in the design of infrastructures, e.g. tailing facilities and diversion channels.

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