**Climate Change Adaptation Measures for Water-stressed Thermal Power Plants in India**

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Abstract

Thermal power plants situated in water-stressed regions of India are highly vulnerable to the impacts of climate change. Reduced availability and increased temperature of cooling water can cause shutdowns or under-performance of these plants, and these issues are highly seasonal. By considering four different water-stressed regions of India, it was shown that water withdrawal increased during the summer months by nearly 24% compared to winter months. The quantification for future climate scenarios of SSP2-RCP 4.5 and SSP5-RCP 8.5 showed that there could be severe water stress for the months of December-June in the region of Rajasthan. The objective of this work is to quantify the effect of retrofits with the environmental control technologies such as flue gas desulphurization (FGD) and carbon capture and sequestration (CCS) on the water withdrawals for a representative coal-fired power plant in the region of Rajasthan. It was found that water withdrawals further increased by 300 – 3000 l/MWh. Adaptation of thermal power plants to climate change is, therefore, crucial. The choice of boiler technology, type of condenser for cooling, and type of fuel used in a thermal power plant can bring down the water withdrawals for electricity generation substantially. Hybrid cooling technology for water-stressed regions like Rajasthan and Punjab in India can reduce water withdrawal by 2000-2500 l/MWh. The ultra-supercritical boiler reduces water withdrawals by 500 – 700 l/MWh compared to the sub-critical boiler. However, capital investments are considerably higher for these technologies. Therefore, a cost-benefit analysis of the available options for the adaptation along with the provision of optimal solutions for the water-stressed power plants regionally is extremely important.

**Keywords**: water stress, thermal power plants, environmental control technologies, cooling technologies, adaptation measures

* 1. Introduction

India is the third-largest producer of electricity in the world with an annual production of 1714.8 TWh after China and the United States (Statista, 2023). Coal-fired power plants in India alone were responsible for emission of 1104 Mt CO2 which was the highest among all the sectors (IEA, 2022). These emissions are responsible for the climate change impacts such as rise in temperature, decreasing summer monsoon precipitation, an increase in the duration, intensity, and coverage of pre-monsoon season heatwaves, tropical cyclones, and droughts. Though power sector is majorly responsible for climate change, the sector itself is vulnerable to its impacts. These impacts can be infrastructural and/or operational. India particularly is vulnerable to the problem of water stress in power plants. Historically, there have been many instances of shutdowns and underperformance of thermal units due to cooling water shortages in India. Consequently, the water-power-climate nexus studies are extremely important in the states such as, Maharashtra, Rajasthan, Karnataka where most of the plant shutdowns and under-performances were reported. Taking into account such instances, uninterrupted thermal power generation with sufficient water availability is going to be very vital for future periods. Moreover, suitable adaptation measures such as hybrid cooling, efficient boiler choice; on a regional basis will be paramount.

In the previous work, we evaluated the intra-annual water withdrawal variations at the plant as well as the regional level (Shinde et al., 2023). The work focused on the states that are considered as high or extremely high water stressed. Furthermore, the work estimated the overall surface water availability for current and alternate future scenarios of a chosen region based on simple conceptual framework – Budyko. By considering this, additional water requirements because of implementation of environmental control technologies such as Flue Gas Desulphurisation (FGD), Selective Catalytic Reduction (SCR), and Carbon Capture and Sequestration (CCS) will further increase the water withdrawals. The outcome of the study will help in understanding the intra-annual water requirements for thermal power generation and increments in the water withdrawals due to the control technologies.

This manuscript is arranged as follows. Section 2 deals with materials and methods. Section 3 reports the results and key insights. The article ends with a conclusion in section 4.

* 1. Materials and methods

Considering the historical shutdowns in the region, high water stress, and the type of cooling technology used; four different states - Rajasthan (RJ), Maharashtra (MH), Uttar Pradesh (UP), and Punjab (PN) in India are chosen for the study. The cooling technology dominant in these regions is re-circulating cooling. The weather parameters and other plant-level data are then obtained for the selected regions and Integrated Environmental Control Model (IECM) is used to calculate monthly water withdrawal and consumption intensities (website: <https://tcktcktck.org/>). Further, the water withdrawal intensities are calculated for additional environmental control technologies and how the reduction in water requirements occurs with the boiler choice and cooling technologies is shown.

*2.1 Integrated Environmental Control Model (IECM)*

IECM allows the user to configure the plant to be modelled for a variety of pollutant control technologies and types of power plants. IECM also includes a set of major cooling technologies, including once-through cooling, wet towers, and air-cooled condensers (ACCs) for dry cooling. The water models in the IECM are based on the mass and energy balances to estimate water use, energy penalties, and costs of cooling systems (Zhai et al., 2011). The*IECM 11.5 version* is used as it allows the selection of India as the location for analysis. The plant-level data and India-specific fuel data are obtained from the literature and the Indian coal-data directory is created in IECM (Nagarkatti & Kolar, 2021). The weather parameters such as ambient air temperature (°C), mean ambient air pressure (MPa), mean relative humidity (%), and mean annual precipitation (cm/year) are also the inputs to the model and are discussed in the subsequent section.

*2.2 Climate projections*

For future projections, the temperature and precipitation data are obtained from the World Bank’s open access climate model - ‘Climate Change Knowledge Portal’ (CCKP) specific to the chosen region for the period 2020 - 2039 (The World Bank Group, 2021). The data are based on CMIP-6 (Coupled Model Inter-comparison Project phase-6) viz. a standard experimental framework for studying the output of coupled atmosphere-ocean general circulation models, administered by the World Climate Research Program (WCRP).

The monthly relative humidity (Rh) for the current scenario is calculated using the ambient temperature and dew point temperature data for all the regions between the period 2011 and 2020 (Shinde et al., 2023). The climate models only estimate future ambient temperature. The intra-annual variation of Rh in the future is unknown. Hence, regression models are developed correlating T and Rh for their simplicity. Two different regression models are considered for monsoon (June-July-August-September) and non-monsoon months (Shinde et al., 2023).

*2.3 Estimation of overall surface water availability: Current and Future*

Budyko framework is used to calculate current as well as future water availability for the Shared Socio-economic Pathway (SSP) - Representative Concentration Pathway (RCP) of SSP2-RCP 4.5 and SSP5-RCP 8.5 climate scenarios. SSP2-RCP 4.5 represents ‘middle of the road scenario’ which spans the warming of 4.5 W/m2; caused by the activities under certain assumptions of population, economic growth, and other factors such as fossil fuel usage, energy demands etc. On the other hand, SSP5-RCP8.5 is referred as ‘high emission scenario’ or ‘pessimistic scenario’ which may cause global temperature rise of 3 to 5 °C (<https://www.carbonbrief.org/>). Further, Budyko’s hypothesis states that the ratio of mean annual transpiration to mean annual precipitation is controlled by the ratio of mean annual potential evapotranspiration to mean annual precipitation as stated by Eq. 1.

$$\frac{E}{P}=f\left(\frac{E\_{P}}{P}\right) (1)$$

Fu’s functional equation is used to enhance the Budyko model for concerned local region and to account for different surface types; where a single parameter ω can be calibrated against local data as per Eq. 2 (Zhang et al., 2001; Arora, 2002).

$$\frac{E}{P}=1+ \frac{E\_{P}}{P}-\left[1+\left(\frac{E\_{P}}{P}\right)^{ω}\right]^{\left(\frac{1}{ω}\right)} (2)$$

where $E$ is actual evapotranspiration$, E\_{P} $is potential evapotranspiration, $P$ is precipitation, and ω is the single value parameter.

*2.4 Water withdrawal intensities of environmental control and other cooling technologies*

Based on the feasibility studies, coal power plants in India are required to install FGD systems to reduce SOx emissions. Various elements of the FGD system require water such as the wash system of the mist eliminator, the absorber system, the limestone grinding and slurry preparation system, and the gypsum de-watering system. This means additional water would be required in the power plants. The additional water requirements will increase substantially with the implementation of CCS to curb the CO2 emissions and limit the global warming. The anthropogenic water footprints are anticipated to be doubled with the deployment of CCS technology (Brandl et al., 2017). Hence, water withdrawal for typical Indian coal plant for different control technologies, the boiler types, and other cooling technologies such as hybrid cooling are evaluated for a 650 MW subcritical coal plant with an average ambient temperature of 29 °C and average Rh of 50%. The mean annual precipitation is considered as 50 cm/year. These conditions are representative of RJ region of India. Rest of the parameters are kept at default in the IECM.

* 1. Results and Discussion

In this section, we will discuss the results of water withdrawal and consumption based on IECM and increase water withdrawals of control technologies. Further, water savings with other cooling technologies will be highlighted.

*3.1 Water withdrawal and consumption*

Water withdrawal necessarily represents water abstracted from nearby resources such as lakes, rivers to the power plants. On the other hand, water consumption represents evaporation losses of water during the cooling process. We found that intra-annual water withdrawal lied in the range of 2500 - 4600 l/MWh for the current scenario whereas future scenarios withdrawal intensity ranged between 2500 – 5400 l/MWh for all the regions. In the summer months, the withdrawal intensity increased by as much as 24% compared to winter months. This change was particularly observed in the state of Punjab. Water consumption range was found between 1700 and 2200 l/MWh for all the regions in current and future scenarios. The water withdrawal intensities of current and future scenarios were then used to evaluate average monthly gross water withdrawal for overall thermal power generation on sub-annual basis. It ranged between 5 Million m3 (MCM) to 56 MCM (Shinde et al., 2023).

It was shown by using Budyko framework how the overall surface water availability for the state of RJ decreased by almost 49% compared to current one which caused the intra-annual deficiencies in the months of Dec-June for the future scenarios of SSP2-RCP 4.5 and SSP5-RCP 8.5 (Shinde et al., 2023). Moreover, the water availability in the state of MH is decreased by 39.14% in SSP2-RCP 4.5 and 41.35% in SSP5- RCP 8.5 compared to current one.

*3.2 Water withdrawals by control technologies*

Some of the retrofitting technologies commonly used in a coal thermal power plants are – Electrostatic Precipitator (ESP), Selective Catalytic Reduction (SCR), FGD and CCS. The SCR is used to reduce the NOx emissions from the coal power plants. As we moved from the base plant to the CCS system retrofits; the water withdrawals went on increasing. Table 1. shows the water withdrawal increments with these technologies. It could be observed that as we went on adding the environmental control technologies from SCR to CCS, the water withdrawal rose by 17 – 2700 l/MWh. However, as we moved from sub-critical to super-critical and ultra-supercritical boiler technologies; the overall plant operation water withdrawals reduced by 700 – 1500 l/MWh. Nevertheless, apart from climate change-driven increased water withdrawals; these additional quantities must also be satisfied in order to facilitate the working of the power plant. Wet FGDs are considered to be more efficient historically. Dry FGDs require lower capital costs as there is no need of water treatment as no liquid waste is generated. However, operating costs are higher due to reagent viz. expensive. For the cooling requirements of FGD, de-mineralized water is required.

Hybrid cooling essentially does cooling by water when it’s hot and by air when it’s not. It can also use the combination simultaneously. When hybrid cooling method was chosen in IECM for the same parameters above, it was found that the water withdrawal dropped to 1047 l/MWh whereas the water consumption was 609.2 l/MWh. These numbers were without the implementation of environmental control technologies. Still, it could be seen that significant water can be saved as compared to the wet cooling tower. However, it comes with the higher costs and significant penalty in the plant efficiency.

The uninterrupted power supply is crucial for country’s social, economic, and industrial development. The output, efficiency, and financial viability of power generation could be affected because of climate change. As of now, there is no policy to phase out old coal power plants in India. Moreover, it is stated by the government that no coal power plant will be phased out before 2030 given the expected rise in the electricity demand (Ministry of Power, 2023). Therefore, water withdrawal is only going to increase in the near future. Retrofitting or usage of less water-intensive cooling technologies can play a major role in significant water savings. Further, choice of boiler technology can lead to improved efficiency and water savings.

* 1. Conclusion

The water withdrawals for thermal power generation in the water stressed regions of India increased substantially compared to current situation as a result of climate change. The greatest intra-annual rise was observed in the state of Punjab where withdrawal in the month of June was nearly 24% higher than that of winter month of January. Overall withdrawal rates of UP were greatest because of actual higher withdrawal rates of non-compliant plants. The withdrawals increase with the addition of control technologies such as FGD, CCS by 17 – 2700 l/MWh. The hybrid cooling without consideration of environmental control technologies can reduce the water withdrawals significantly to 1047 l/MWh.

At a broader level, this work strongly emphasized the need to perform detailed region specific intra-annual assessment to ensure sustainability of the thermal power sector. Further, the regional adaptation measures such as alternative cooling technologies and water resources could be proven to be a solution to reduce the water withdrawals. Future work can include evaluation of long-term water needs and availability along with economic analyses of control technology options.

**Table 1.** Water withdrawals for different environmental control technologies (l/MWh)



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