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RESEARCH ARTICLE

ANALYSIS AND EXPLORING THE IMPACT OF WEATHER FACTORS ON ELECTRICITY CONSUMPTION IN THE STATE OF BIHAR, INDIA

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ABSTRACT

This research article presents a comparison of the characteristics of power demands for the state of Bihar, India, and examines its probable relationship with the weather variable factors. In fact, weather plays a key role in alerting the power demand of any area as it completely changes the load pattern. Because of that, a lot of parameters such as voltage, frequency, and power are regulated as per the demand, making the generators very responsive during the block times so as to maintain the load. Temperature and rainfall have been found to play a very important role in regulating the demand for energy in the state. We find that the state of Bihar's power system is growing rapidly, with peak-demand increases of up to 6.6 GW due to electric heating in 2021–2022.

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INTRODUCTION

Energy consumption in emerging nations like India is predicted to skyrocket over the next several decades. Non-OECD countries (for example, India, South Africa, Brazil, and others) are expected to increase their energy consumption by 84% between 2007 and 2035 *(1)*. Also, increasing population growth and improvements in standards of living lead to an increase in the consumption of energy. Also, energy consumption, along with transportation, building construction, etc., leads to increases in greenhouse gas emissions (GHGs). Climate sensitivity is estimated to be 3 degrees Celsius for every doubling of atmospheric carbon dioxide, according to the Intergovernmental Panel on Climate Change's sixth assessment report (AR6). By the middle of the twenty-first century, the average global temperature in all of the shared socioeconomic pathways has risen above the 1.5 °C warming threshold. According to a major IPCC author, it is possible to prevent warming of 1.5 degrees Celsius, but only if the world reduces emissions by 50 percent by 2030 and 100 percent by 2050. This scenario still predicts a peak temperature of 1.6 °C between 2041 and 2060, after which the temperature will slowly go down *(2)*. These changes are largely due to the increase in anthropogenic emissions(GHGs) since pre-industrial times, caused by economic and population growth, as well as urban development that affects almost all sectors of human life, including agriculture, aviation, road transport, water resources, and energy*(3)*. In line with the current rate of urbanization, global warming and urban heat island (UHI) have been cited as two causes of increased energy demand and consumption, especially during the summer period of many tropical and subtropical cities*(4–6)*. The increase in ambient temperatures caused by global climate change in recent years has increased global energy consumption *(7,8)*. In the United States, 5–10% of the increase in urban peak demand for electricity comes with a small rise of 2–4% for every 1°C rise in daily maximum temperatures above 15-20 °C *(9)*. However, the demand for cooling or heating energy varies across climatic zones; in colder countries, where the demand for heating is high, less energy is required to heat buildings during the winter, whereas the demand for building cooling energy increases in tropical countries during the hot summer*(3,10)*. Therefore, the high ambient outdoor temperatures will have a significant impact on energy consumption by increasing the need for refrigeration and air conditioning and reducing the need for space heating*(11)*. However, climate change influences energy demand by changing heating and cooling requirements*(12–16)*. Rising temperatures are expected to have a significant impact on the energy sector as there is no alternative to cooling*(17–19)*.

Temperature is the most important meteorological determinant of electricity demand and has long been regarded as a driving force for electricity demand in the short term. A lot of literature is dedicated to analyzing these results and their application to predictions of power demands. It is not uncommon for temperatures to increase as a long-term driver and have a great impact on the electrical industry, including generation, transmission, and distribution*(*20*)*. These observations raise public awareness about energy use and the effects of climate change implications and help to generate lots of interest in better understanding energy use and its prevailing weather conditions. With global climate change and the rate of urbanization, cities will be susceptible to extreme heat events that are likely to be extremely hot days and nights, and the intensity and frequency of heat waves will increase in the future, as predicted by the IPCC*(*21*)*.

Relationship between ambient temperature and cooling energy requirements: Climate is recognized as a major factor in energy consumption and air temperature leads to all climatic factors as others like relative humidity, and solar radiation cannot be underemphasized*(*22,23*)*.Studies across the globe and the subtropical climates have generally shown increasing trends in temperatures and summer discomfort in the last decades, and as a result, the need for more cooling energy demand is anticipated*(*24*)*.To estimate the heating and cooling requirements at different spatial scales,degree-days are described as very simple, and effective in all other methods that are extensively used to measure the impact of climate, i.e. the severity of winter and summer conditions on heating and cooling requirements *(*16,17*)*. The increased demand from industrial, domestic, and commercial sectors are the main determinants of total electricity demand, fluctuations in Weather from hourly to seasonal scales. The seasonality of agricultural operations plays a significant role in daily and seasonal changes in electricity demand.

Load Demand patterns in the state of Bihar: The rapid increase in population and living standards, as measured by per capita Gross Domestic Product(GDP) has a significant impact on the Growth of Power Demand in developing states like Bihar*(*25*)*. There is a steady increase in mean demand and peak demand on year to year basis (shown in Figure 1.) at the rate of 5-11%(Mean Demand) in every financial year from 2016-17 to 2021-22.

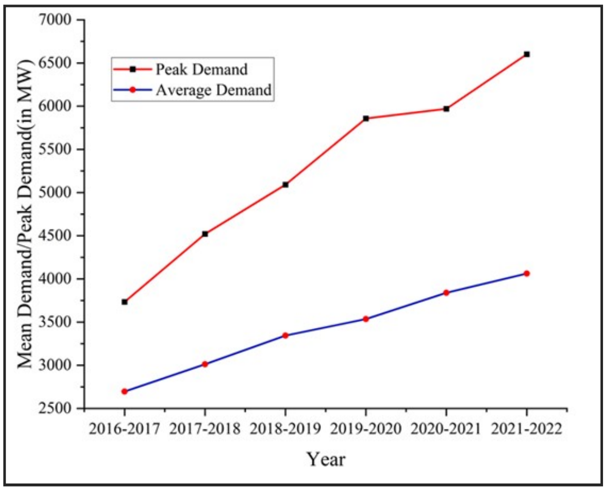


Fig. 1. Yearly variation of Mean Demand and Peak demand

The peak demand also showed an increasing trend, raising between 10.6% to 21 % in every financial year except in the year 2020-21 mainly because of COVID 19 lockdown or active Rainfall Year (Total Rainfall 1384.7 mm against the Normal Rainfall of 1167.2 mm). The steady increase in the annual mean or peak demand is primarily due to improvement in the availability of power in the state or because of the increasing penetration of the power in rural areas besides increased demand from industrial, domestic, and commercial sectors. Also, it is anticipated that longer-term growth will be impacted by the changes in weather patterns brought on by climate change.

Bihar mainly comes under the subtropical monsoon, mild and dry winter, and hot summer, with annual temperature ranges of -1°C to 49.5°C*(*26*)*. This variance has a significant impact on electricity demands. The seasonality is of Mean and Peak demands clearly shown in Fig. 2. and Fig. 3.

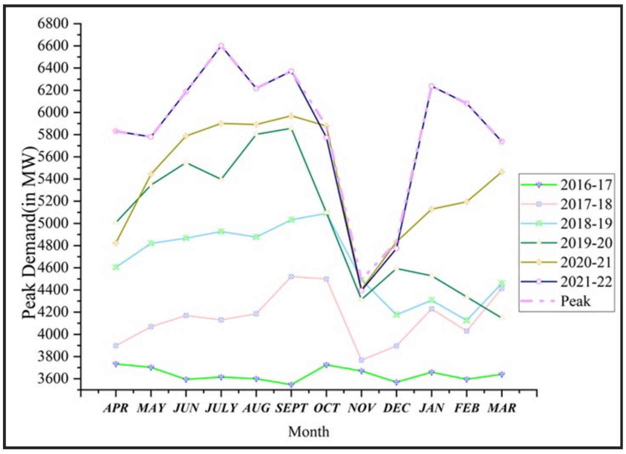


Fig. 2. Seasonality of Mean Demands in the state of Bihar

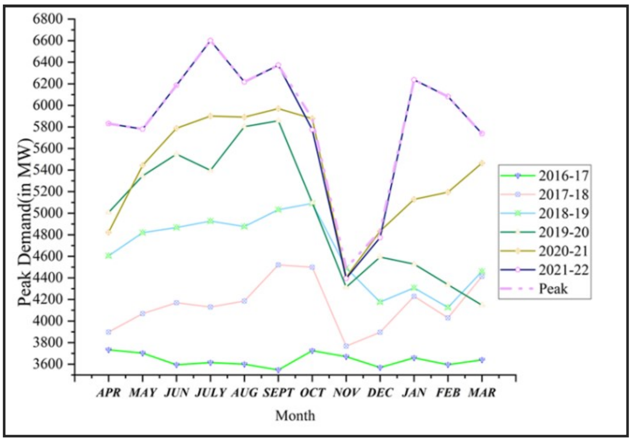


Fig. 3. Seasonality of Mean Demands in the state of Bihar

The Mean power demand has a very clear seasonal pattern with the lowest demand registered in November or December. This is primarily on account of the cessation of agricultural activities during the leading agrarian season (June to October) and reduced demand for space cooling due to a decrease in temperatures. There is a slight increase in the demand in January, probably because of increased use for domestic and space heating purposes as January is the coldest month in the state, with minimum temperatures dropping to below 10 degrees Celsius in many parts of the state. Demand generally remains low till March.

With the increase in temperatures from April, the demand also starts increasing; it reached a peak in August/September. From April to June, the increase in demand is primarily due to use for space cooling and increased use for agricultural purposes during the peak of the main agricultural season. Intra-seasonal modulations in demand seem to be related to rainfall patterns. There was a significant dip in power demand during July 2019 (and also a minor dip in July 2017) as July 2019 recorded the highest Rainfall of 418.5 mm, followed by July 2017 (379.9mm). Rainfall in July 2016 and 2018 was 356.4 and 291.5 mm, respectively.

Diurnal variation of mean power across the state of Bihar, India(shown in Fig. 4) seems to be regulated by the seasonal variation in Temperature with four distinct categories. The mean demand for November and March shows a similar pattern which represents the one month of post and Pre-Monsoon has similar characteristics. Also, Monsoon(JJAS) has similar characteristics. Similarly, Winter usually onset in December, So December, January, and February have similar characteristics in diurnal variations of mean demand. Within this broad pattern, winter months(DJF) register a strong bi-modal demand pattern with low Demand in the early morning (2000 UTC to 00 UTC); the Demand starts rising after that and reaches the peak at 0200 to 0300 UTC in the morning, primarily on account of space heating and domestic use. It decreases afterward, reaching minima around 0900 UTC. A steep increase in demand is noticed again from 1100 UTC reaching its maximum values around 1200-1300 UTC. This increase seems to be dominated by street lightning, domestic use, and space heating. Reduced domestic consumption brings the demand down from 1700 UTC to 2100-2200UTC. The Monsoon(JJAS) has a strong peak in the 1400-1600 UTC with a secondary rise in the 0700-0900 UTC. April, May, and October have a similar pattern to monsoon with reduced loads and a strong peak at 1300-1500 Utc bit earlier than the Monsoon pattern.

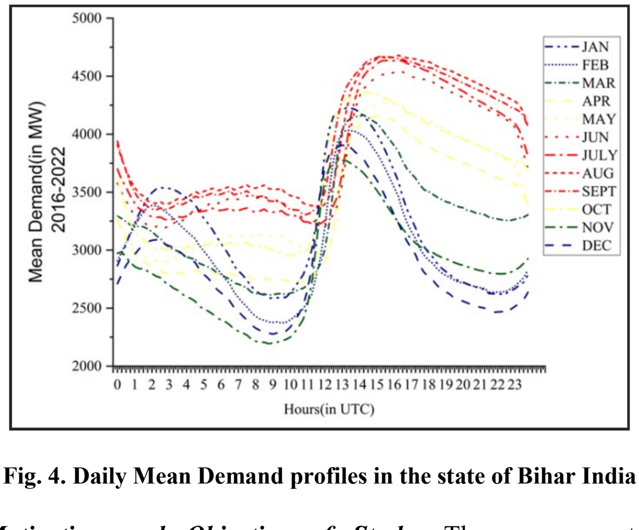


Fig. 4. Daily Mean Demand profiles in the state of Bihar India

Motivation and Objective of Study: The power sector significantly depends upon weather variability on all time scales, including the diurnal variation of meteorological parameters. Effective utilization of weather forecasts in planning and management of demand and supply of electricity is a crucial factor for economically profitable operations. Added to this is the higher dependence of non-conventional power sources like wind and solar power on accurate and timely access to current weather situations and forecast weather.

The present study is an attempt to understand the dependence of power generation and consumption on prevailing meteorological conditions at different time scales. Since a huge investment is required for the planning and operation of a power project, even a minor improvement in efficiency by utilizing a better weather forecast will have a very large, long-term economic gain. Such studies on the dependence of the power sector on current weather parameters have been somewhat limited in the country, and the present study is likely to fill some gaps in the current level of understanding.

As electricity consumption has been and is likely to continue to be driven by household and agricultural consumption, their dependence on meteorological parameters is likely to show an increasing trend. High-impact weather also affects the demand and supply balance time and duration of heavy to very heavy rainstorms Flooding has also been used in the study to demonstrate the negative impact of such a phenomenon, including the impact on distribution network infrastructure. Finally, the two sets of data were used to find the various correlations between mean temperature and demand, peak temperature and demand, and the role of rainfall events in on-demand variation. In the end, these diagnostic studies help predict how much power will be needed based on the weather now and in the future.

METHODS

Study Area: The study areas were the jurisdictions of two power distribution companies(namely NBPDCL and SBPDCL) in Bihar, India. The state of Bihar stretches from 24° 20'N to 27° 31'N latitude and 83° 20 "E to 88° 18'E longitude. The state has a mean altitude of about 150 metres with mainly subtropical monsoon and tropical savanna climates with four distinct seasons.

The Obtained Data: Temperature and rainfall measurements were performed at the different meteorological stations in the state of Bihar. The daily station data recorded at the different weather stations across the state has been maintained by the local office of the India Meteorological Department. Weather data from across the state, such as temperature (more than 15 stations) and rainfall (more than 400 stations), have been converted into a daily summary of the temperature and rainfall of the state of Bihar representative weather data. The data on the power consumption was taken from the State Load Dispatch Centre, Govt. of Bihar, on a scale of every 15 minutes. Weather data for the period April 2016 to March 2022 and power consumption data have been taken to analysethe study. The data taken is shown in Fig. 5. This 15-minute data was then utilized to arrive at hourly, daily, monthly, and seasonal power demand, which correlates with the weather variables of the same scale. The observed meteorological data generated by the local India Meteorological Department has been used to find a possible correlation between demand for power and prevailing meteorological conditions. While the long-term steady variation in demand is linked with the economic well-being of the country, the short-term fluctuations from hourly to seasonal scales are mainly governed by fluctuations in weather conditions and the seasonality of agricultural operations. The diurnal variation in demand, average and monthly demand, and yearly peak and average demand were calculated using the demand data log.

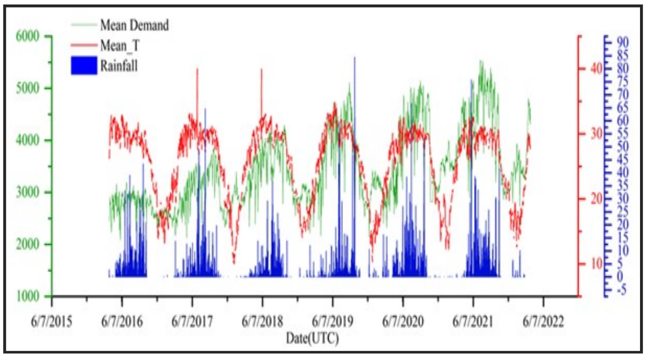


Fig. 1. Mean Demand Data and Weather Parameter on the same scale during the studied period

The distribution functions of weekdays and weekends have similar probability distribution functions. (Shown in Fig.6.). This indicates that total power has no significant industrial contributions. Also, it indicates that the state mainly has residential and agricultural contributions to power demand and consumption.

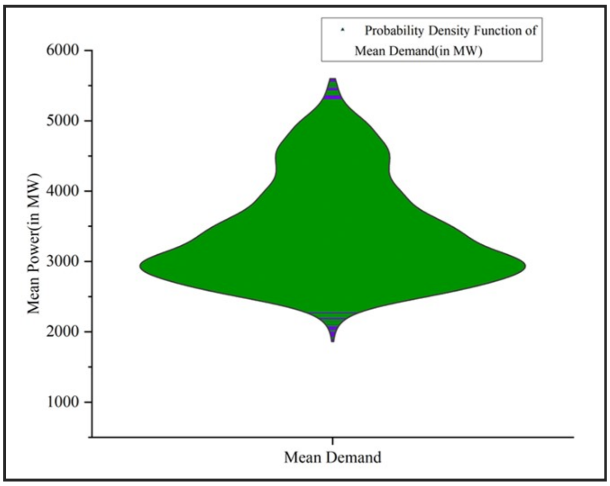


Fig. 6. The Probability Distribution function of Mean Demand for the state of Bihar(2016-17 to 2021-2022)

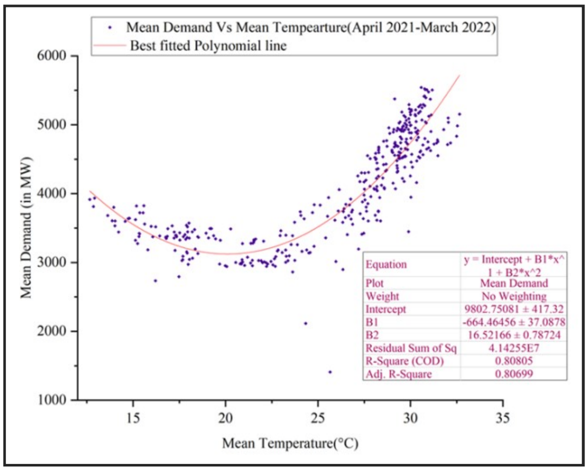
METHODOLOGY

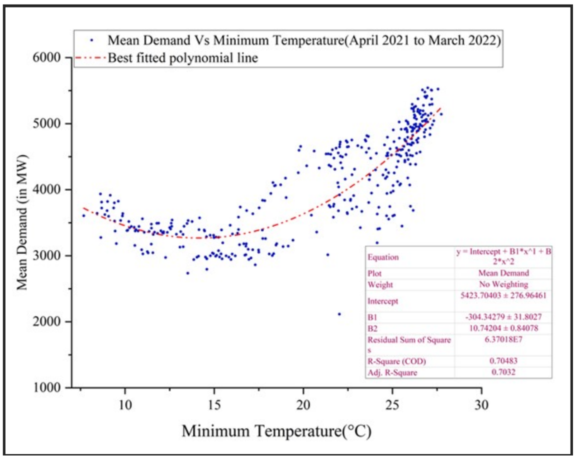
High impact weather also affects the demand and supply balance time and duration of heavy to very heavy rainstorms. Flooding has also been used in the study to see the adverse impact of such phenomenon, including that on the infrastructure of the distribution network. Finally, the two sets of data were used to find the various correlations between mean temperature and demand, peak temperature and demand, and the role of rainfall events in on-demand variation. These diagnostic studies eventually help in forecasting the power demand based on current and forecast weather conditions.

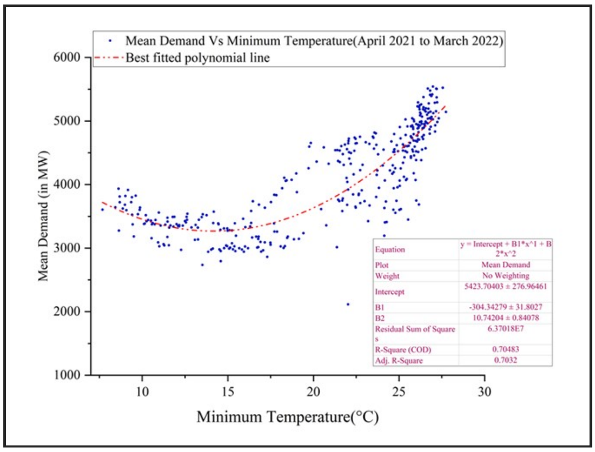
RESULTS AND DISCUSSION

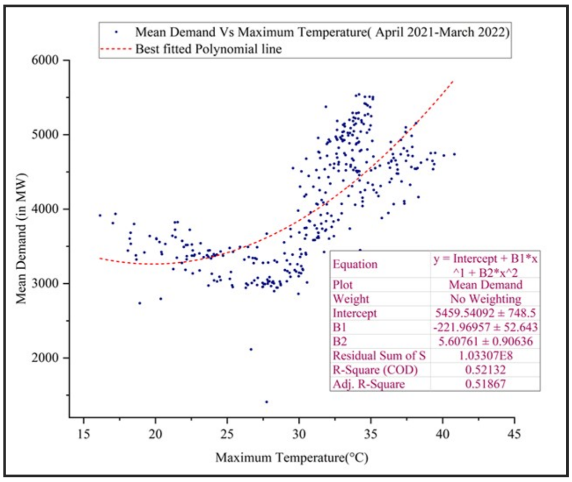
This study is the first step in figuring out how the weather might affect the electricity needs of the state of Bihar.

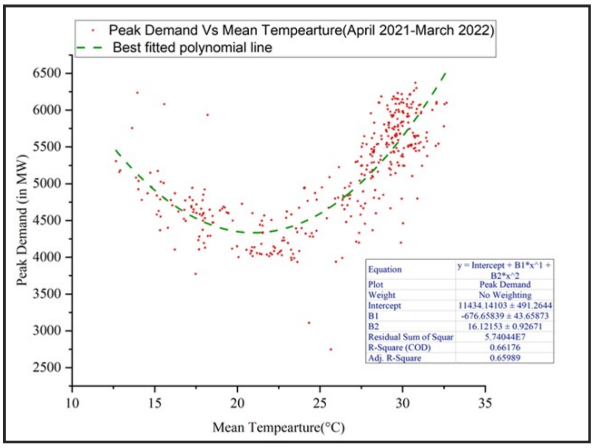
Relationship between Power Demand and weather variables (Temperature): The impact of temperature on power demand and consumption is studied using 210358 observations of 15-minute log data from April 2016 to March 2022 of the power demand and consumption data for the state of Bihar, India. This data is converted into hourly, daily, and monthly scales for further study based on the rules of averaging. Also, the same scale of weather data was taken from the India Meteorological Department for analysis. India has a greater number of hot and humid days as compared with cold and chilly days. This often increases the peak load at the same time, stressing power system components. Thermal limits on the elements are more restrictive during the summer. The correlation between maximum, minimum, and mean temperatures with peak and mean demand was calculated(shown in Fig.7). The analysis of coefficients of correlation indicates that it has the highest correlation with the temperature in recent years as compared with 2016-17. Also, all the months have a positive correlation with the temperature, except the months of winter (December, January, and February). For most of the year in the state of Bihar, the lowest peak demand is experienced at the mean temperature of 21°C, the maximum temperature of 25°C, and the minimum temperature of 15°C. Similarly, at a mean temperature of 20 °C, a maximum temperature of 23 °C, and a minimum temperature of 15 °C (As shown in Fig 7.), the lowest mean demands occur.This backs up the fact that electric cooling is used more often as a response to temperature in emerging economies. This suggests that energy consumption responses to lower temperatures may be very different in these areas than in Europe and North America. Power demands (Mean and Peak) increase over time from 2016-17 to 2021-22, and the coefficient of correlation becomes more robust with weather variables (e.g., temperature, rainfall, etc.). Also, for cooling purposes, with the lower correlation between maximum temperature and demand as compared with the mean temperature, it can be inferred with a fair amount of confidence that maximum temperature does not influence the power demand, thereby indicating that the larger population of the state may not be using space cooling devices like air conditioners or air coolers. The correlation coefficient of 0.60 indicates the power usage for cooling purposes. Also, for heating purposes, the mean temperature best fitted the curve as compared to the minimum temperature. This corroborates the findings that the state's larger population may not be using space heating devices like room heaters etc. Thus, household temperature responses in the emerging economy more commonly include electric heating, suggesting that energy consumption responses at lower temperatures may be substantially different in these regions than in Europe and North America *(1)*. The demand pattern is somewhat in contrast with another finding in respect of Delhi, where it has been estimated that air conditioning might be accounting for up to 60% of the total load on peak summer days in Delhi*(27)*. As per the study conducted by the Centre for Policy Research and Prayas, a Delhi household consumes an average of 250 to 270 units of electricity, which is on par with the power consumption of an average household in Germany. Significantly, this high consumption is partially attributed to high ownership of cooling devices like air-conditioners (12% of total households) and air-coolers (70%), and partially due to tariff subsidies in Delhi. This leads us to another finding that, depending upon the availability and affordability of a household in a state power pattern is primarily utilized in the lighting purposes of household followed by cooling purposes, and then only for heating purposes. According to the Bihar Economic Survey of 2020–21 *(28)*, the average number of hours of power in the state has gone up from 6–8 to 20–22 in rural areas and from 10–12 to 22–24 in cities.

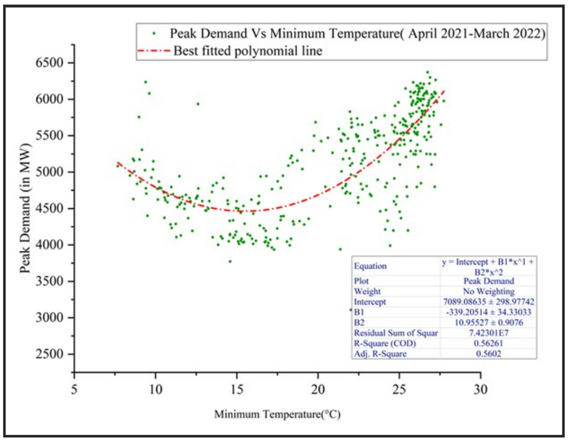












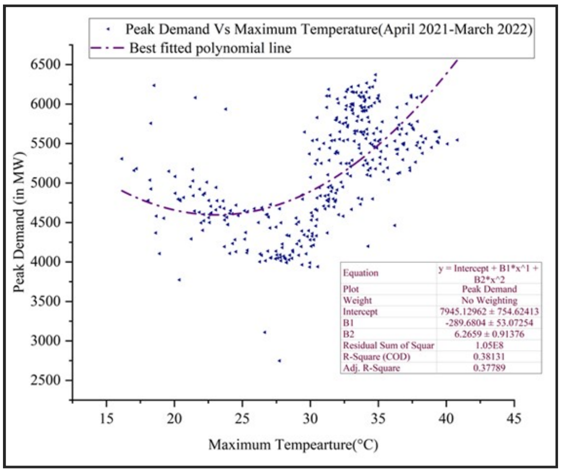


Fig. 7. Peak and mean(average) demand as a function of temperature extremes and averages are graphically represented.

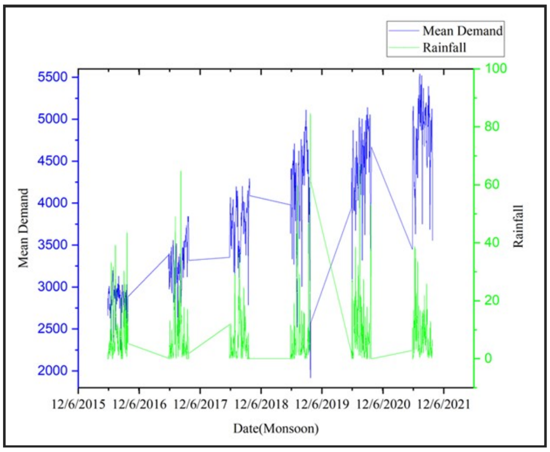


Fig. 8. The Rainfall and Power Demands are negatively correlated for the Monsoon Season, 2016-2021(JJAS).

Variation with Extreme Weather Events (Rainfall): A number of natural disasters have struck the state of Bihar. Extreme weather, such as heavy rain leading to flooding, intense lightning, thunder squalls, heat waves, and cold waves, frequently affect Bihar, one of the most hazardously prone states in India.

Table A.1. Shows a list of alphabetically ordered acronyms that appear in this paper

Acronyms	Full Name
SBPDCL	South Bihar Power Distribution Company Ltd.
NBPDCL	North Bihar Power Distribution Company Ltd.
IMD	India Meteorological Department
SCADA	Supervisory Control And Data Acquisition
BSPHCL	Bihar State Power Holding Company Ltd.

There is a short-term impact on the electricity network's demand and supply chain from all these extreme weather occurrences. However, the severe downpour spell reduced the time scale to only a few days. The longer period of rainfall is associated with the greatest fluctuation, which influences both home and agricultural consumption.

Between 2021 and 2022, the months of September (r=-0.68), June (r=-0.70), July (r=-0.62), etc., have the highest coefficients of correlation between daily mean power consumption and demand and daily rainfall. According to the latest research, the power sector benefits greatly from precise precipitation and extreme event forecasts (initial conditions of power). Fig.8 presents the negative relationship between mean demand and rainfall throughout the on soon Season (2015-

CONCLUSION

Bihar's economy is mostly dependent on the agricultural sector. Based on data analysis, it appears that lighting of households, air conditioning, and agricultural uses account for the bulk of the state of Bihar's electrical needs, Because the probability distribution of electricity demand/consumption is independent of the days of the week. Energy consumption per person is a key indicator of economic growth. Efficient planning can be improved by any research that examines the demand-supply pattern and the factors affecting it.

Based on the observed datasets a distinct seasonal and diurnal pattern was established in the present investigation. These studies have the potential to greatly aid power production and distribution businesses and grid management in optimizing power generation in light of present and forecasted weather conditions, thereby reducing operational costs and increasing efficiency. The BSPHCL relies heavily on the predictions and nowcasts released by the India Meteorological Department Patna in order to maximize efficiency based on the analysis.

Data Availability: Data can be shared after the request.

Compliance with Ethical Standards: The authors declare that the research was conducted without a commercial or financial relationship that could be interpreted as a potential conflict of interest.

Appendix A. Acronyms: Table A.1 shows a list of alphabetically ordered acronyms that appear in this paper.

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