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Analysis of Factors Affecting on Energy Consumption: A Case Study of Kolhapur City

SWATI A. PATIL[1]*, MUKUND KULKARNI[1] and SWATI ANIL PATIL[2]

[1]Department Computer Application, Bharati Vidyapeeth University, Kolhapur, Maharashtra, India.
[2]Department of Computer Applications, Sanjay Ghodawat University, Kolhapur, Maharashtra, India.

Abstract

The impact of many factors on Kolhapur city's energy usage in 2022 will be impartially investigated in this study. As urbanization and population growth continue to accelerate in Kolhapur, understanding the factors influencing energy usage becomes increasingly critical. The city faces challenges related to energy supply, sustainability, and environmental impact. Despite the growing demand for energy, there is limited research on the specific factors that drive energy consumption in Kolhapur. This study aims to fill that gap by investigating the various determinants of energy usage in the city. To determine the various factors influencing energy use, a variety of data was gathered from the Census handbook and the Kolhapur Maharashtra Electricity Board. The findings confirm that climate, temperature, population growth, time, environmental conditions, pollution, and humidity all have statistically significant positive effects on energy usage. Notably, there is a strong positive correlation between energy consumption and the population growth rate, indicating that as the population increases, so does the demand for energy. On the other hand, the cost of natural gas and water has no effect on energy use, suggesting that other factors are more influential in determining consumption patterns.

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Introduction

The improvement of social wellbeing requires sustainable economic development. On the other hand, one of the main objectives of sustainable development is to promote a strong economy in order to generate a lot of resources to satisfy the needs of the general public and improve environmental quality.[1] Consequently, it would further protect human health and the environment. Sustainable development also attempts to offer enough energy supply to reduce the negative effects of energy consumption to positive levels, allowing customers to meet their demands while consuming less energy through better energy efficiency.

CONTACT Swati A. Patil patilswati7922@gmail.com Department Computer Application, Bharati Vidyapeeth University, Kolhapur, Maharashtra, India.

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Energy sources are defined as those that are derived from the environment and used for commercial objectives (e.g., coal mine, oil well, solar, wind, or water on turbines, etc.). One of main advantages of wind energy is that it is a renewable energy source for all countries.

One of the most important aspects of modern living is electricity. It facilitates the efficient and seamless execution of daily duties. However, a shortage of energy causes serious issues for the business and society, particularly during periods of high demand.[2,3] As a result, energy providers and smart homes must prepare for energy output and consumption, and forecasting energy demand is crucial.

Energy is regarded as the backbone of economic growth. In a developing economy with rapid population expansion, it's critical to maintain equilibrium between energy supply and emerging needs. If corrective actions are not successfully anticipated, major limitations for development activities begin to appear.[4]

Nonetheless, prior studies have shown the negative consequences of high energy consumption. Sooyoun,[5] for example, has shown that the industrial sector is often considered to be significantly more pollutant-intensive than the services sector. In a related study, Kumaran *et al*,[6] claim that excessive utilization of natural resources raises emissions of industrial pollutants. The results as industrial expansion increases, environmental quality deteriorates. The rapid urbanization, the middle class, and the increasing consumption of goods and services during a rebellion are said to have joined with creative growth to produce major negative effects that reduce the likelihood of economic advancement for the countries. Unacceptable amounts of carbon emissions are detrimental, according to study by Khan *et al*.[7]

The main objective of this study is to experimentally examine how various factors affect energy consumption in Kolhapur city over the 2022–2023 timeframe. Even though there are many factors that affect energy consumption, this study only looks at the effects of pollution, life expectancy, urbanization, and population increase. This study is different from previous research in that it takes into account a different time period and a different range of locations. Nonetheless, numerous earlier studies have looked at a variety of factors impacting the energy consumption function from different perspectives and with different bands.

Material and Methods

Flow of Methodology

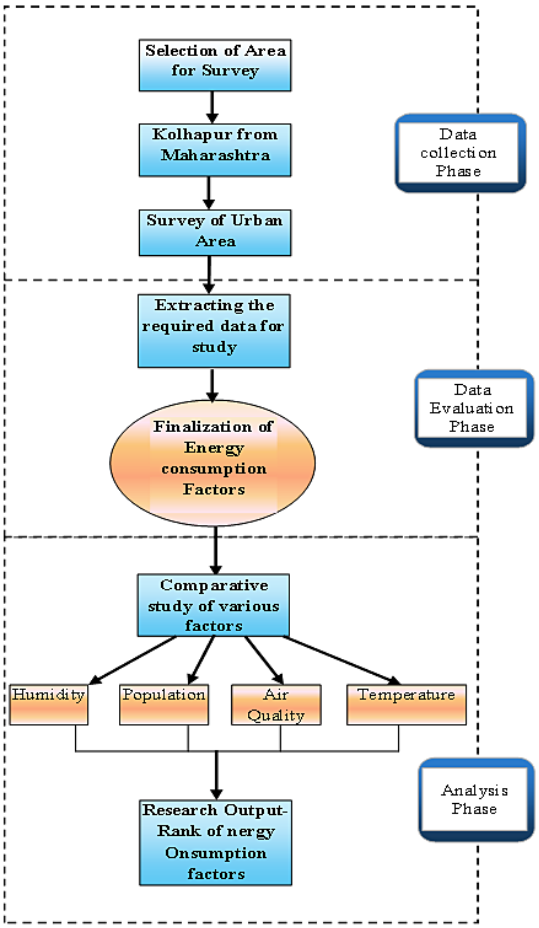

Fig. 1: Flow of Methodology

Literature Review

An important field of study is energy consumption analysis, especially in urban areas like Kolhapur City. Numerous studies have looked into the many different aspects that affect energy use, from socioeconomic factors to technical developments. The results of pertinent studies are combined in this overview of the literature to give readers a thorough grasp of the variables influencing energy use.

A substantial amount of research highlights how socioeconomic factors influence patterns of energy use Jones *et al*,[8] examined at the effects of socio-economic status, home features, and appliance use on electricity consumption in residential structures. Similar patterns may be seen in Kolhapur because of its expanding economy, according to Khalid *et al*,[9] who emphasized the impact of urbanization and economic expansion on commercial energy use in Pakistan.

Analysis of energy use has changed with the introduction of technology, especially machine learning. In his discussion of the use of machine learning for intelligent energy consumption management in smart homes, Alzoubi[10] made the argument that improvements in technology can result in more economical energy use. Similarly, Hosseini and Fard[11] showed how well machine learning algorithms forecast building electricity use, which might be used to improve Kolhapur's energy management.

The transition to renewable energy sources is another critical factor influencing overall energy consumption. Filimonova, Provornaya, Kozhevin[12] conducted an empirical analysis of factors affecting renewableenergy consumption, highlighting the importance of policy frameworks and public acceptance. Chen Y[13] further explored the factors influencing renewable energy consumption in China, suggesting that similar dynamics may be relevant in Kolhapur, especially as India pushes for greater renewable energy adoption.

Environmental factors, including air quality and pollution, also influence energy consumption. The Maharashtra Pollution Control Board report on ambient air quality[14] in Kolhapur highlights the need for sustainable energy practices to mitigate environmental impacts. Pita P[15] examined the relationship between energy consumption and CO2 emissions in Thailand, suggesting that similar studies could be beneficial for understanding the environmental implications of energy consumption in Kolhapur.

The literature indicates that energy consumption in Kolhapur City is influenced by a complex interplay of socio-economic, behavioral, technological, and environmental factors. This research focuses on localized studies that consider the unique characteristics of Kolhapur to inform policy and practice effectively.

Localized studies on energy efficiency and sustainability solutions for Kolhapur City can draw insights from global practices, emphasizing the importance of tailored approaches. This study explores community-driven initiatives, renewable energy integration, and efficient urban planning to address local challenges and promote sustainable development.

Scope of study

Kolhapur city

Located in "one of the top six districts in the state of Maharashtra with highest per capita income," Kolhapur is the eleventh largest city in the state. (March 8, 2016) is located between longitudes 740 11" 20' to 740 16" 10' east and latitudes 160 39" 3' to 160 45" 50' north. The Panchaganga River, a tributary of the Krishna River, runs alongside this city on its right bank. Kolhapur city is situated 650 meters above sea level. With an average yearly temperature of 1043 mm, a minimum temperature of 150 °c, and a high temperature of 400 °c, Kolhapur city enjoys a temperate environment.

Over the span of more than a century, the population increased from 54,373 in 1901 to 5,49,236 in 2011. The city's modest slope, which gently decreases from south to north, gives it a distinctive physical layout. Located on the western edge of the city, the famous Rankala tank is a favourite site for both locals and tourists to the great Mahalashami temple. Kolhapur is known as "DakshinKashi" because to the famed and majestic Mahalashami temple. The national highway no. 4, which links Bengaluru and Pune, runs along the city's eastern edge.

When Kolhapur city was established as a municipal corporation on December 15, 1972, its total size was 66.82 square kilometers, and it has stayed that way ever since. Its population was less than one lakh (93,032) in 1941 and more than one lakh (136,835) in 1951, according to the Indian census. For an urban center to be recognized as a city and given the status of a Municipal Corporation, it must undergo this population expansion. The city was really granted this status in 1972. The city's population has more than doubled, from 2,59,050 in 1971 to 5,49,236 as of the 2011 census.

Discussions of combining Kolhapur city with the about 42 nearby villages had been going on since 1989. Twenty-five of the forty-two villages were eliminated on July 11, 2001, and in August 2014, the state chief minister stopped seventeen of the communities from joining together. Following the urban planning department's rejection of the proposal, the KMC then released a resolution proposing the combination of 18 villages and two industrial zones. When these villages become part of the KMC, their population will grow, increasing the amount of funding the civic body receives for development.

Experimental Approach

Data Sources

2022–2023 is the time series for the year data used in this study. The energy consumption data was collected from the Maharashtra State Electricity Board in Kolhapur. Information on the Kolhapur district can also be found in the guidebook of the Maharashtra Census Office in Bombay.[16] The e-book, which was issued by the Executive Editor and Secretary of the Gazetters department of the Government of Maharashtra, Mumbai, also contains information on Kolhapur.

Results

Sources of Electricity Generation in India

One of the world's seven largest countries, India has 1.2 billion people and a land area of 3.29 million km². Its economy, which depends on infrastructure and electrical generation, is still in its infancy. India's main electricity source is coal thermal power plants.

Despite efforts to diversify the options, particularly in the case of renewable energies, coal remains the country's primary source of electricity.[17,18]

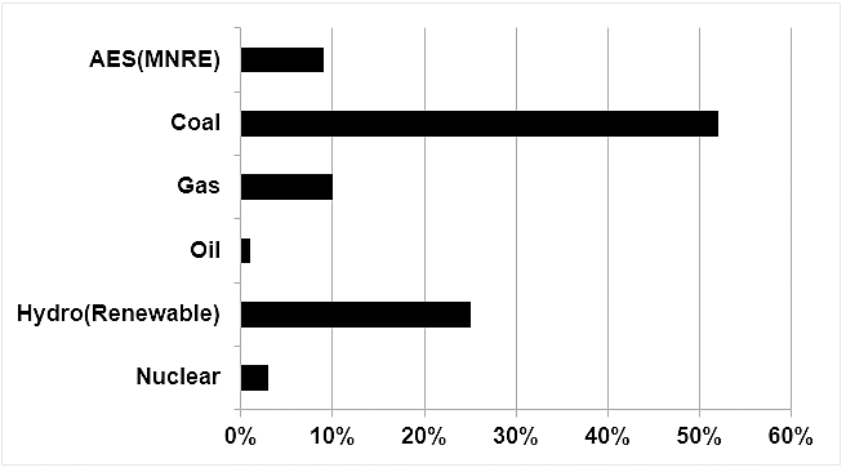

Fig. 2: Sources of Energy in India

Temperature and humidity changes in Kolhapur city from January to December 2022 in relation to peak power demand.

Table 1lists the highest and lowest temperatures, humidity levels, and electrical usage peaks. Seasonal Variations in Humidity and Temperature.

Humidity Levels

June, July, and August: These months typically experience high humidity levels, especially in many temperate and tropical regions. High humidity can create a feeling of discomfort, but it also means that the air is saturated with moisture. This can lead to a phenomenon known as "heat index," where the perceived temperature is higher than the actual temperature due to humidity. However, during these months, the need for heating is virtually eliminated, which can lead to lower overall electricity consumption for heating purposes.[19,20]

Temperature Trends

Spring (March to June): As the weather warms, the demand for power rises, mostly because more people are using air conditioners.

Table 1: Kolhapur City peak power demand with temperature and humidity

Sr. No	Month	Humidity (in MUS)	Peak Demand	Min Temperature (in ºC)	Maximum Temperature (in ºC)
1	January	45	64.55983	14.2	30.92
2	February	41	65.58295	15.5	34.77
3	March	40	72.57671	19.62	34.61
4	April	49	73.01285	24.67	39.59
5	Mays	62	76.96687	23.73	37.24
6	June	83	74.07304	25.84	36.69
7	July	89	71.23935	24.3	29.5
8	August	89	69.87016	21.4	25.3
9	September	85	67.80365	21.2	26.9
10	October	72	72.53676	20.8	29.1
11	November	54	63.99293	19.3	29.0
12	December	46	65.91544	17.6	29.6

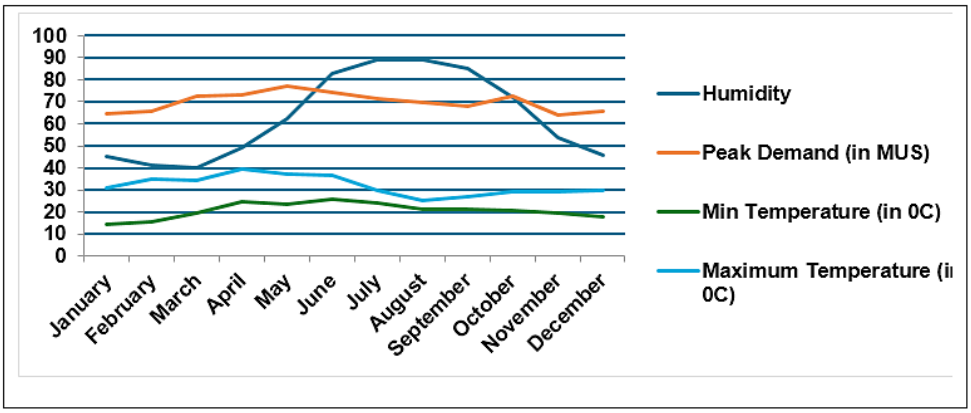

Fig. 3: Comparison of Energy Demand with temperature and humidity

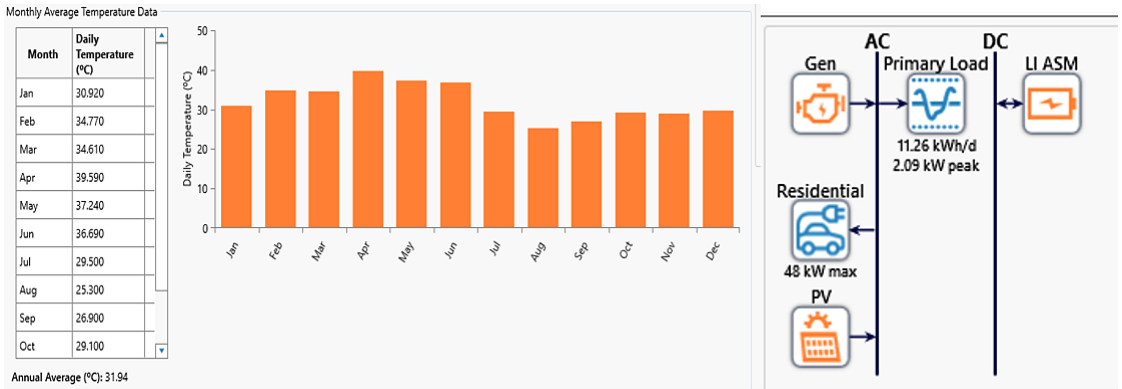

Fig. 4: Energy Demand with Max temperature (HOMER Software)

Peak Demand

In October, Kolhapur experiences the highest demand for power.

Figure 2 is the comparison study shows that when humidity increases, peak electricity demand falls. As a result, it is evident that June, July, and August has the highest levels of air humidity and, as a result, use less electricity. Although high humidity during the summer might lower the need for heating, it can also raise the need for cooling, which results in a large amount of electricity being used.[21] On the other hand, as temperatures increase and fall throughout the transitional months, needs may fluctuate. October frequently sees the highest power usage because of the simultaneous need for heating and cooling.

The City's Population Distribution

Population, economy are main factors affecting energy consumption.[22,23] The overall height, roof area, surface and relative compaction have the greatest impact on energy consumption of buildings.[8,11]

The first noteworthy feature is the division of the city's municipal wards. These wards were created a number of years ago, but they haven't been updated since 2001. Of the city's five ancient wards, the E ward is the biggest and most vast, taking up more than 60% of the entire area. Ward C is the smallest and most crowded, making up only 2% of the entire facility.

Database

The current investigation is based on secondary sources. The secondary data was collected from the Kolhapur Municipal Corporation publications, periodicals, the District Gazetteer, and the 1961–2011 District Census Handbooks. A percentage has been used to represent the population growth rate.

Ward-Wise Density of Population

Kolhapur's ward system was altered in 2001. There A, B, C, D, and E were the five wards until 2001. In 2001, all five of these wards were converted into seventy-two new ones.[24] Kolhapur City had 77 wards as of 2011. In other words, five wards were added in 2011. The 77 wards' total area is calculated in hectares (ha) to determine their density. Owing to their tiny size, we discovered that the population density is higher than the ward's actual population when we converted the wards' area from square kilometers to hectares. Consequently, the ward area in hectares has been taken into account while calculating the population density.

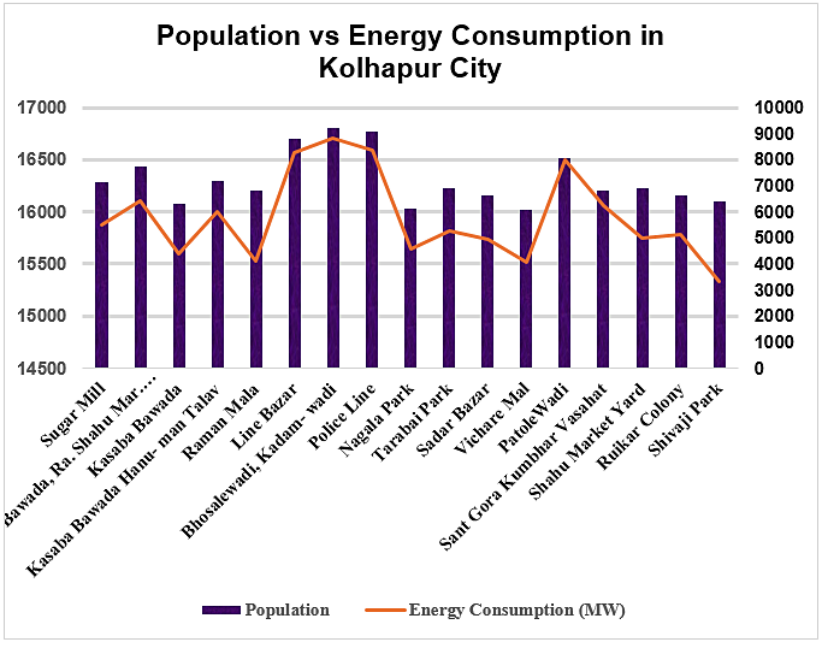

Fig. 5: Population vs Energy Consumption in Kolhapur city

Six wards in the city have a population density of over 600 people per hectare, according to figures from the 2011 census. Sukrawar Gate, PadmarajeUdyan, Yadav Nagar, Kholkhandoba, Vicharemal, and Daulat Nagar are the wards in question. Each of the four wards had between 450 and 600 inhabitants per hectare. These wards are NathaGoleTalim, Bazar Gate, Chandreswar, and Commerce College. The population density of the twelve wards ranged from 300 to 450 persons per hectare. These wards include Rajarampuri, Phirangai, DudhaliPavelean, BinduChowk, Panjarpol, Sadar Bazar, PanchgangaTalim, KasabaBawada, Shahu Bank, and Khari Corner. There are between 150 and 300 persons per acre in sixteen of the city's wards, according to records. Vikram Nagar, Subhash Nagar, Pratibhanagar, Treasury Office, TararaniVidyapeeth, MahalaxmiMandir, Shidarth Nagar, Kanan Nagar, Mangeshkar Nagar, Neharu Nagar, Line Bazar, and ShahupuriKumbharVasahat are the names of these wards. The remaining thirty-nine city wards had a population density of fewer than 150 persons per hectare.

As per the ward wise Population, Area and Energy Consumption of Kolhapur City in year 2016, the graph above, which shows Kolhapur City's energy consumption by ward, indicates wards with larger populations typically use more electricity. The main reason for this is that as the population grows, so does the need for different electrical services, such as lighting, heating, cooling, and powering appliances. The combined impact of several homes and businesses can greatly increase overall energy usage in densely populated areas.[25]

Impact of Pollution and Environment on Energy Consumption

One out of every nine deaths worldwide is caused by poor indoor or outdoor air quality, making air pollution one of the largest environmental risks to human health. According to estimations from the World Health Organization (WHO), 92% of people on the planet reside in areas where local air pollution levels are higher than WHO guidelines.

Cardiff University is a public research institution situated in Cardiff, Wales. Established in 1883 under the name University institution of South Wales and Monmouthshire, it became a foundation institution of the University of Wales in 1893.

This institution reported on September 24, 2024, that rising power use in residential structures has been associated with higher pollution levels, with daytime increases primarily responsible for this increases.[26,27] As pollution levels rose, commercial buildings needed more electricity. People tend to remain indoors and travel less when air pollution is high, according to Dr. Pan He of Cardiff University's School of Earth and Environmental Sciences. As a result, overall electricity usage rises due to increased appliance use, heating, cooling, and lighting.[28,29]

Following Table shows the air quality index and consumption of energy a per Maharashtra Pollution Control Board report. It indicated that if AQI is highest than energy consumption is increased by default. For the AQI, there are six groups. All of these categories imply various kinds of health concern. Additionally, each group has a unique color. Because of the color, people can immediately and readily determine whether the air conditions in their neighborhoods are approaching dangerous levels.[30] From 0 to 50 the condition of the air is sufficient, and the possibility of air pollution is little to nonexistent. 51 to 100 range air is of a suitable quality. Some individuals, however, may be at risk, more those who are especially allergic to air pollution and other variables.

Table 3: Energy consumption and air quality

Sr. No.	Month	AQI	Energy consumption
1	January 23	53.875	64.55983
2	February 23	52.75	65.58295
3	March 23	52.75	72.57671
4	April 23	47.88	73.01285
5	May 23	50.5	76.96687
6	June 23	48.375	74.07304
7	July 23	37	71.23935
8	August 23	49	69.87016
9	September 23	51.44	67.80365
10	October 23	54.12	72.53676
11	November 23	57.63	63.99293
12	December 23	54.875	65.91544

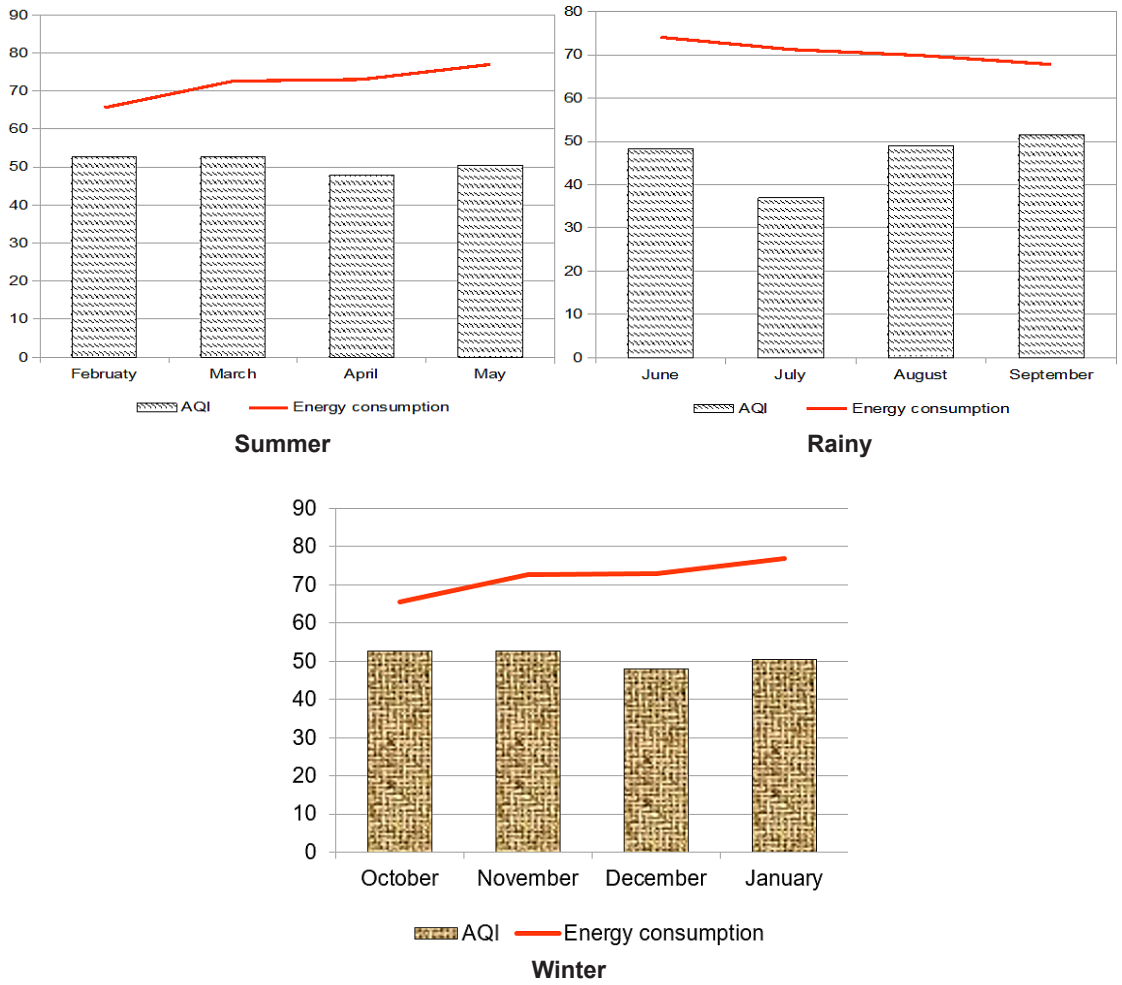

Fig. 6: The relationship between energy consumption and air quality

Above study highlights a clear relationship between air pollution levels and energy consumption across different seasons. The rainy season tends to have lower pollution levels and reduced energy use, while summer experiences higher pollution and energy demand due to cooling needs. Understanding these dynamics is crucial for developing effective policies aimed at reducing air pollution and promoting sustainable energy practices. By addressing the interconnectedness of these factors, cities can work towards a healthier environment and a more sustainable energy future.

Discussion

Therefore, the study's findings have policy implications that give priority to expanding the energy supply in order to attain a higher degree of economic growth and sustainable development.

Even though October has the biggest demand, the need for power increases as the temperature rises, as it does from March to June. Peak electricity demand decreases when humidity rises.

According to the city's energy consumption by ward, the wards with the highest population use more electricity. Energy demand is therefore strongly dependent on population.

Compared to the winter and summer, air pollution is higher during the summer and lower during the rainy season. As a result, energy consumption fluctuates just as much as air pollution.

Conclusion

The purpose of this study was to investigate the factors affecting the use of electric energy. This study

determined the primary factors affecting Kolhapur city's electricity consumption. It was discovered that the external environment (geography, temperature, and humidity) had an equivalent effect on electricity consumption as did the seasons, population growth, and air quality. Furthermore, this study found that temperature and time factors had the biggest effects on the city's energy use. Overall, we concluded that the most effective elements influencing city energy use are time, temperature, population, and environment.

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Conflict of Interest
The authors do not have any conflict of interest.

Data Availability Statement
The manuscript incorporates all datasets produced or examined throughout this research study.

Ethics Statement
This research did not involve human participants, animal subjects, or any material that requires ethical approval.

Informed Consent Statement
This study did not involve human participants, and therefore, informed consent was not required.

Author Contributions
- **Ms. Swati Patil:** Conceptualization, Data Collection, Writing - Original draft.
- **Dr.MukundKulkarni:** Visualization, Methodology.
- **Mrs. Swati Anil Patil:** Writing, review & editing.

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