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A Comparative Analysis of Environmental and Social Practices in the Sugar Industries of Brazil and Southern Maharashtra, India

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

This paper reviews the worldwide sugar business, focusing on South Maharashtra in India and Brazil. The study employs a systematic approach to evaluate the environmental sustainability, as well as the social and economic impact of sugar production in these regions. Businesses are

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reassessing their tactics as people become more aware of social fairness and climate change, making the sugar industry an ideal subject for research due to its important environmental and social ramifications. While Brazil's sugar market has grown dramatically due to advances in farming methods and technologies, Southern Maharashtra continues to rely significantly on traditional agricultural practices, particularly sugar cultivation. The intent is to shed light on the contrasts between these industries by analyzing their environmental assessment methodologies, social responsibility efforts, and sustainable business practices. Furthermore, it attempts to add useful insights to the continuing discourse about promoting sustainable practices in the global sugar industry. The sugar industry has a lot of potential for growth due to its byproducts such as ethanol, biogas, and different agro-based products which further bolster the environmental sustainability potential.

Keywords: Sugarcane; environmental practices; social practices; sugar industry; comparative analysis; Maharashtra, Brazil.

1. INTRODUCTION

Sugar, a rather common ingredient, holds a very important role in the social and economic structure of the world. Sugar is a staple commodity and has played a powerful role in shaping societies globally. A variety of businesses revolve around the sugar industry hence it is characterized by complex supply chains, diverse stakeholders, and changing market trends. However, sugar industries are highly dependent on forces of nature and therefore a very challenging and dynamic area requiring constant improvements.

India and Brazil are the nations that produce the most sugar in the world. Both these regions are characterized by tropical climates and hence are suitable for huge volumes of sugarcane production (Shukla et al., 2017). Brazil, a world leader, in sugar production, has experienced tremendous growth in recent years due to the adoption of advanced agricultural techniques and technology. While, India which is known as the original home of sugar and sugarcane (Solomon, 2011) and among the major sugar producing areas is southern Maharashtra, India the industries here have also experienced a similar level of growth.However, the sugar industry is deeply involved in their traditional agricultural practices and the agro-based economy of this region is hugely dependent on sugar industries.

The sugar industry originally was an industry that only produced sugar but it has now branched into the production of alcohol, bio-fuels, bio-manures, and energy. Hence it has become a significant contributor towards various industries and is a continuously growing industry [Eggleston and Lima, Lima, 2015). Innovations in the industry further widen the variety of products produced.

Environmental concerns around the sugar industry are challenges such as deforestation, water scarcity, loss of biodiversity and waste disposal have become very pressing issues for the industry in this age of heightened awareness of climate change and sustainable development (Shivagami and Prasad 2020, Saini et al., 2022). Socially, sugar is linked to health problems such as obesity, heart disease, and diabetes. Public health initiatives are driven to reduce sugar intake, or have healthier alternatives, these factors are constantly changing consumer demand hence challenging the traditional models of the sugar industry.

The objectives of this undertaken research are (1) To Assess the Environmental Impact (2) To Examine the Resource Management Practices (3) To Evaluate the Social Responsibility Initiatives (4) To Identify the Technological Innovations (5) To Examine the Policy and Regulatory Frameworks (6) To Draw the Comparative Insights and (7) To Provide the Recommendations for Improvement.

2. WATER SUPPLY AND RESOURCES

Water is a very important resource in the sugar industry. To produce one ton of sugar approximately 1500 liters of water is required. Water is required for most of the activities concerned with sugar production like cultivation of sugar-producing crops, processing of cane to syrup, and then crystallization by steam, boiler feed, cooling towers, and sanitation (Martinelli et a., 2013).

In the sugar industry, water requirements vary with the type of industry in discussion, that is whether the industry produces only sugar or produces both sugar and ethanol. A sugar

industry without an annexed distillery unit requires more water than an industry with an annexed distillery. A continuous supply of water is necessary to keep the production process running. Despite the high demand for water in the different production stages, the sugar-energy sector has a high recycling ratio.

In India, groundwater supplies more than 80 percent of the country's residential water supply. But groundwater is running out quickly. Considering most sugar industries in India are concentrated around rural regions the water is taken from tubewells and water supply is not very dependable (Solomon, 2005). Sugar industries in southern Maharashtra face a huge water crisis as some districts face drought conditions, while some districts do have rivers such as Panchganga, Krishna, etc. that provide some relief to the industries near them. Therefore, most of the industries in the region get their supply from rivers, lakes, groundwater, and irrigation canals for a regular supply.

In comparison, Brazil is a nation that has the highest available freshwater resources, however, most of the populated regions and industrialized areas are located along the eastern coast of Brazil and they lie far away from the Amazon river basin where most of the water resources are concentrated. Also, with the deforestation of the Amazon rainforest and climatic changes water resources cannot be taken for granted and proper management is required.

Most sugar mills have implemented water conservation practices and try to save as much water as possible. The use of chemicals such as coagulants, acids, and biocides make the effluent leaving the mill highly contaminated hence industries employ effluent treatment plants (ETP) to recycle water. Charging the industries for the use of water has also proved to be a means to reduce water consumption by industries and can also help to fund projects related to rejuvenation of rivers basins and increase ground water level (Barroquela et al., 2023).

3. WASTE WATER TREATMENT

3.1 Waste Water Characterization

Wastewater from sugar factories exhibits elevated biological oxygen demand (BOD), chemical oxygen demand (COD), and dissolved solids levels. These effluents generally contain carbohydrates, nutrients, oils, fats, chlorides, sulfates, and heavy metals (Kushwaha, 2013). This effluent when released into the environment poses serious threats such as reduced soil fertility, eutrophication and reduced oxygen concentration in water bodies causing large-scale death of aquatic life due to presence of pathogens, excessive nutrients, pesticides and heavy metals (Malik, 2019).

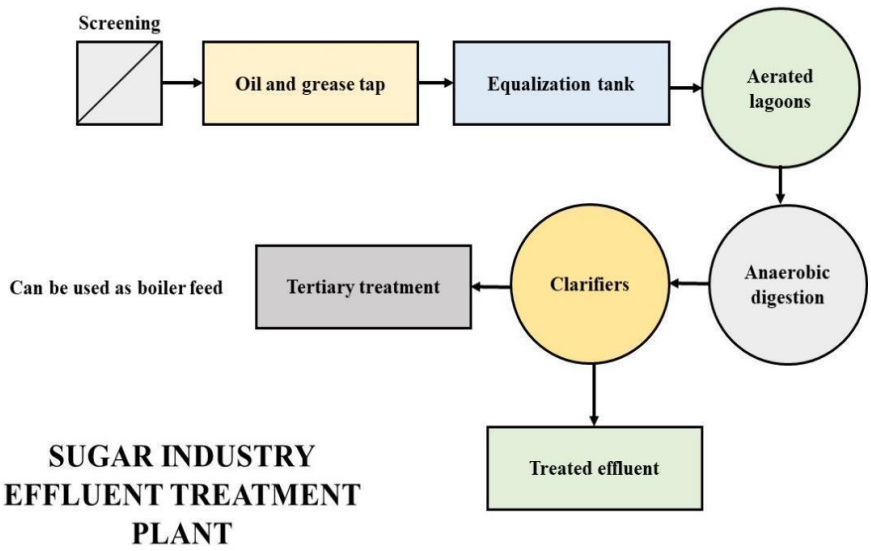

Fig. 1. A Typical effluent treatment plant

Table 1. Sugar industry wastewater characteristics

Parameter	Raw Waste Water Characteristics	Treated Waste Water Characteristics	Indian Regulatory Standards	Brazilian Regulatory Standards	References
Color	Dark brownish to brown	Whitish	-	-	(Poddar and Sahu2015)
pH	5.5-7	7-7.5	5.5-8.5	5-9	(Kushwaha, 20130
Temperature	40 ℃	<30 ℃	-	<30 ℃	(Poddar and Sahu 2015)
COD	3500-4000	300	-	-	(Poddar and Sahu 2015)
BOD for 3 days at 27c	4,641–5,103	-	100(for disposal on land) 30(for disposal in surface water)	30	(Kushwaha, 2013)
DO	1-1.5	2.5	-	-	(Poddar and Sahu, 2015)
TSS	790	100	100(for disposal on land) 30(for disposal in surface water)	100	(Poddar and Sahu, 2015)
TDS	1650	1030	2100		(Poddar and Sahu, 2015)
Oils and grease	12	9	10	10	(Poddar and Sahu, 2015)

Sources: - 1) Indian regulatory standards: [Environment (Protection) Amendment Rules, 2016]
2) Brazilian regulatory standards: [CONOMA Resolution 430/11, 2011]

Wastewater discharges from these industries create a significant pollution burden to the environment. Untreated effluent from the sugarcane industry poses serious environmental threats to both aquatic and terrestrial ecosystems. Also, untreated sugar factory wastewater gives off unpleasant odors when discharged into the environment (Solomon, 2016). Due to these harmful effects on the environment strict rules are imposed on the industries. Therefore, the final treated waste water generation is limited by the regulatory bodies to 200 liters of treated effluent per ton of cane crushed. The case study of environmental pollution in the Assalaya factory is a great example of water pollution being done by sugar industries (Khair et al., 2023).

3.2 Waste Water Generation Sources

The wastewater in the sugar industry comes mainly from sanitation works. Large amounts of wastewater are generated during cleaning of mill floors and combustion chamber components, including evaporators, clarifiers, exhaust systems, and materials transportation of centrifugal and water scrubbers for rotary vacuum filter cloth and regular scrubbing of lime water and sulfur dioxide production facilities. There are two kinds of water utilized in the sugar industry. Condensed hot water is in one, and cold water is in the other. In addition to being utilized for chilling purposes for numerous accessories such motors, crystallizers, cold maceration, juice dilution, lime preparation, laboratory testing, and factory equipment cleaning, cold water is also utilized for make-up, injection, and condenser water. Condensed water is warm and utilized for a variety of purposes, including massecuite dilution, oliver wash, centrifugal, molasses conditioning, maceration, juice dilution, lime and sulphate preparation, and boiler feed-water.

The barometric condensers of the multiple effect evaporators and vacuum pans need a lot of water. After cooling through a spray pond, the water is often recirculated either totally or partially. This cooling water gets polluted as it picks up some organic substances from the vapor of boiling syrup in evaporators and vacuum-pan.

3.3 Effluent Treatment Methods

While setting up an effluent treatment plant an industry must take into consideration the capacity requirement of the plant, provision for installation of flow meters at inlet and outlet of each unit, installation of real time monitoring system that measures flow rates and important parameters such as pH, COD, BOD, TSS, etc. and proper space for operation and maintenance.

The basic methods used to treat sugar factory wastewater include filtration, sedimentation, and load equalization. While, secondary treatment includes biological methods such as lagoons, aerated ponds, anaerobic treatment, and aerobic treatment in addition, sugar factory wastewater is sometimes treated using a combination of anaerobic and anaerobic treatments (Kushwaha, 2013). Generally, both areas can use conventional biological processes such as activated sludge or anaerobic digestion to break down organic matter. However, specific technologies and methods may vary depending on local conditions. In addition, economic factors may affect the adoption of a technology such as investment in advanced treatment systems or the adoption of sustainability initiatives.

In India, CPCB has provided guidelines for monitoring the waste water at the very moment water leaves the industry, a new system called "Online Continuous Effluent/Emission Monitoring System" (OCEMS) was introduced in 2014 and was made mandatory for the sugar industries. This technology uses electrode methods for measurement of pH and UV-Vis Spectro-photometry for measurement of COD, BOD and TSS (CPCB, 2016, CPCB 2016). This creates a sense of self-regulatory action for abiding to the regulatory standards set by CPCB while also keeping a track of release of pollutants (Ranjan 2021 et al.). Such technologies are ideal for keeping pollution in check. The major problem is that for profits most of the industries do not use tertiary treatment. Due to this ignorance industries generally discharge effluents that are not up to the recommended level of the respective pollution control body.

A lot of research and innovation is being done to reduce the cost of wastewater treatment as compared to the existing methods. One such idea is to develop adsorbents that can further purify the treated water after the secondary stage as the aerobic and anaerobic digesters cannot fully remove the pollutants. Also blending the effluents from both the sugar mill and distillery is another way of saving treatment costs and maintaining the quality of treated water (Fito et al., 2019).

4. ENVIRONMENTAL PRACTICES

The sugar industries are a major source of income for developing countries, it is a great boon providing income and supporting a lot of families, however it is a huge environmental burden for the locality. The sugar industry is known to give off foul smell, gas squander, strong waste and waste water. The production and processing of sugar causes severe harm to the environment and has its own consequences. Environmental practices such as disposal of effluent and waste on land and into surface water bodies, burning of sugarcane, deforestation for increasing cane production and heavy use of fertilizers and pesticides threaten the entire ecosystem (Hashem et al., 2015). Due to a lot of demand for sugar and ethanol the industry tries to expand into new areas, the study of policy and social factors affecting the expansion in area of farming land for sugarcane in the state of Cerrado are discussed in detail by Granco et al., (2015).

The government of India promotes the growth of agriculture of sugarcane for the development of the region, however it is very water consuming and the overproduction leads to lower rates of sugarcane which causes distress to the environment as well as farmers (Bandyopadhyay et al., 2020). The Indian industry faces a lot of issues due to the highly irregular pattern of rainfall over the recent years which reduces the sugar production significantly damaging the economic structure of the industry. The yield of sugarcane is also expected to decrease with time according to Cobb-Douglas production function model (Jyoti and Singh 2020).

In Brazil the sugar-energy and bioethanol sector is expanding rapidly and to meet the raw material demands, the land under agriculture of sugarcane is increasing. There was criticism in the past regarding deforestation to obtain land for agriculture, the situation is changing now with a decline of deforestation from a 10-year average of 19,500 km2 year−1 through 2005 to 5843 km2 in 2013 (Nepstad et al., 2014). The increase in productivity of the industry is a solution to this problem as it may reduce pressure on land use for sugarcane agriculture (Danelon, et al. 2023). Sugarcane is seen as a bioenergy crop in Brazil and hence a lot of study is done over the sustainability of sugarcane production in Brazil making it the top producer of sugarcane in the world (De Oliveira Bordonal, 2018, FAO, 2023).

The influence of external and internal pressures leads the industries towards implementation of environmental strategies and practices which gives the industry some relief considering the regulatory standards for sugar industries. Although many efforts and a lot of care is taken to reduce the environmental damage caused, sugar industries still fail to provide a consistent good record (Dornfeld et al., 2021). Overall, Brazil and South Maharashtra see steady improvements in environmental practices in their sugar industries, driven by a combination of regulatory requirements, market demands and technological innovations. Collaboration and knowledge sharing among stakeholders including government departments, industry associations and research institutes plays an important role in accelerating the transition towards a safe and sustainable industry.

5. SOCIAL PRACTICES

The sugar industry is an economical backbone for developing areas as it provides new opportunities for overall growth of the region. Sugar industries are dependent on manpower and community support as they are labor intensive and in turn, have to work for overall community development hence, they are expected to engage in community engagement initiatives, evaluation of labor practices, and investment in local infrastructure development.

Social practices in the sugar industry in Brazil are crucial for evaluating community participation, management practices, and social responsibility policies (Vian et al., 2018). The sugar industry provides a very positive impact on the immediate locality as well as surrounding areas, as the quality of living improves with a rise in job requirements and at higher wages which lowers unemployment in adults and as an effect also improves the literacy rate of the locality under consideration according to studies (Zieliński et al., 2022).

In Southern Maharashtra, India, sugar industries are a very significant economic contributor. The sugar industries in India are mostly concentrated in the rural areas of the country, therefore it is a great help in economic development of the area (Solomon, 2005). The sugar industries in Maharashtra, India, are generally operated by politicians or are operated jointly by the public and private sectors and they are supported by government incentives (Lalvani, 2008). Due to the close ties of the industry with government the

industry faces a paradox, the government implies policies such as incentivizing the sugar production and meanwhile, the government also spends billions on subsidizing the sugar prices for domestic market (Lee al., 2020).

The sugar industry is a seasonal industry in both India and Brazil, hence the workers that are hired in the industry are also temporary and are fired after each season forcing them to return to their place of origin causing mass migration (Moraes Silva et al., 2014). Brazilian industry has been criticized for being involved in practices such as labor entrapment where the workers were being taken away under false pretexts. Another issue concerned with sugarcane harvesting is that most of the sugarcane grown in India is grown by small scale farmers, this poses a great challenge for the use of modern agricultural techniques and technology (Solomon, 2016).

6. COMPARATIVE ANALYSIS

The Brazilian sugar industry is a good example of active community participation, it aims to solve the local problems and improve the existing conditions along with the local people. The industry invests large amounts in education, healthcare and within the industry to develop a sense of social reliability and build a strong network. Such efforts show that the industry has an excellent social commitment. The industry faced a lot of criticism in the past over fair labor conditions but it has now improved significantly. In comparison, the industry in South Maharashtra shows similar commitments in terms of social networking. The industry in Southern Maharashtra engages in social activities such as solving regional problems, for example, finding a solution on water supply and as most industries are co-operative in this region a lot of investment goes into development of public infrastructure. This industry is very closely linked with labor welfare practices such as fair wages, good working conditions and providing living conditions.

Both the regions face environmental problems like water scarcity, deforestation for agricultural purposes, and disposal of generated waste. In Brazil, water scarcity arises due to population concentration as most of the industries are located near regions such as São Paulo, Minas Gerais, and Paraná this creates a huge load on water resources in the area. In comparison, in Southern Maharashtra, the irregular rainfall pattern during the recent years is the main cause of water scarcity, furthermore the districts such as Solapur., face drought conditions making it harder to sustain agricultural practices as well as regular water supply in industries. Most of the irrigation potential is being diverted to sugarcane cultivation which leaves less water for agriculture of other agricultural sectors (Lee et al., 2020).

7. SUSTAINABILITY AND OPPORTUNITIES FOR THE SUGAR INDUSTRY

The global sugar prices are known to be very volatile and are influenced by certain factors in the producing and consuming countries, especially in India; intervention of government policies in the distribution between exports and domestic stocks of sugar and limitation for ethanol production cause a very significant impact on the overall dynamics of the industry globally (Hashem et al., 2015). As India and Brazil are the two major sugar producing countries in the world, they are also the price setters for the world market. The countries have their own set of categories that they excel in producing, India has a great future in the export of raw cane sugar, glucose syrup and chemical sucrose; similarly, Brazil has scope in sustainable ethanol production (Sheetal et al., 2020).

Despite being a major industry and economic backbone to several regions the sugar industry faces quite a few challenges, these challenges are created by internal factors, external factors, regulatory limitations and environmental factors. The Sugar industry is completely dependent on the harvest of the crops which is dependent on climatic factors as well as agricultural techniques of the region. The poor working conditions of small-scale farmers and low wages of field workers is an alarming concern for the social image of the industry.

As sugar is a staple ingredient and has a huge demand, the sugar industry is a rapidly growing industry globally and hence a lot of research and development has to be done for sustainability of the industry. Along with production of sugar and ethanol, several new byproducts are being researched such as ethyl acetate, crotonaldehyde, 1,3-butanediol, flavor and fragrance ingredients (Eggleston and Lima 2015). Efforts are being made on valorization of sugar industry waste, these make the sugar industry a sustainable and profitable industry. The reuse of wastes such as bagasse, press mud and cane trash provides an additional

source of income for the sugar industries as well as reduces the burden on the environment by leaving less waste material. Sugarcane bagasse is a lignocellulosic feedstock, and hence all potential uses of lignocellulosic feedstock are relevant for bagasse as well. Products such as 2G bioethanol, biobutanol, biohydrogen, biogas, sugar alcohols, and organic acids like lactic acid succinic acids are a major area of interest in the valorization of sugarcane bagasse (Meghana and Shastri, 2020).

Similarly, reuse of waste products such as the use of bagasse as a low-cost adsorbent (Brandão et al., 2010) and its fibers can be used as adsorbent for removal of heavy metals (Khoo et al., 2018). The major application of bagasse is as a source of energy in sugar industries as it provides 98% of power required in the industry (Dantas et al., 2013). Similarly, the waste water from the sugar industry can be reused by treating the waste water to an extent and using it to irrigate the sugarcane fields which does help in improved growth of the sugarcane crop (Rais and Sheoran, 2015). Further-more, irrigation with treated wastewater minimizes the use of traditional chemical fertilizers, increases the soil organic matter, improves soil's physical and chemical properties, enhances soil fertility, and helps to build a good soil ecosystem and carry out sustainable sugarcane production (Damodharan and Reddy, 2012).

8. CONCLUSION

This study gives a comparative view of the environmental and social practices in Brazil and South Maharashtra's sugar industries and reveals the prevailing issues in both regions. The issues such as waste disposal and water scarcity emphasize the importance of sustainable development in the industry as the resources will get depleted even more in the near future. The need for collaborative research and knowledge exchange for future growth and sustainability along with economic profits is highlighted in this study. The sugar industry has a lot of potential for growth due to its byproducts such as ethanol, biogas, and different agro-based products which further bolster the environmental sustainability potential.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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