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Research Article

A GIS-Based Mapping for Effective Utilization of Biomass ash in the Construction Sector

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A B S T R A C T

India is an emerging country in the world in both the agriculture and industrial sectors. The dynamic growth of these sectors causes enormous consumption of natural resources and also generates large quantities of agricultural waste which causes pollution in our ecosystem. So, it is important to manage agricultural waste generation and properly utilize waste to effectively attain some of the agenda of SDGs by 2030. The objective of the study is to reduce the generated agricultural waste and its utilization as fuel in industries. The ash emerging from these industries can be potentially used as Supplementary Cementitious Materials (SCM) in construction. To minimize natural resource consumption in the construction sector, a detailed map-based study of biomass ash carried out from crop residue generation to complete utilization in the industrial sector using GIS is carried out. The parameters of the study are crop pattern, identification of industries, ash composition, and location of cement industries. Results from the network analysis, OD analysis, and map-based study shall analyze the biomass origin to ash destination use, time involved, cost implications, and feasibility. The study on GIS-based mapping shall identify the optimum supply chain and can propose future agriculture and industrial clusters in the division. The practical framework helps to develop effective GIS network analysis to attain the shortest distance for road and rail networks which helps in the reduction of freight cost, fuel, and carbon emissions to achieve a clean and sustainable environment.

Keywords: GIS-Based Analysis, Biomass, Supplementary Cementitious Material (SCM), Proximity, Sustainability

Introduction and Literature Review

In India, agricultural waste is a significant contributor to environmental pollution, especially during the crop-burning season.[1] It has been estimated in national policy for the management of crop residue that India alone generates 500 MT residue from crops annually.[2] The burning of agricultural waste leads to the emission of greenhouse gases and other pollutants, causing severe air, water, and soil pollution in many parts of the country.[3] The increased industrialization and requirement for power generation have been at its peak. Power plant activities have led to an increase in environmental pollution, causing adverse effects on human health and the environment.[4] This has led to a need for sustainable waste management practices, including the effective utilization of agricultural waste to gain some SDGs goal of a clean climate (SDG 13), to protect life on land (SDG 15), and provide affordable and clean energy (SDG 7) for future generation.[5] It is crucial to promote the effective utilization of agricultural waste to reduce pollution and promote sustainable economic practices in the country.[6] The current scenario is to focus on utilizing alternative fuels and raw materials in cement production. In India, presently we use 2.5 % Biomass Power/Cogen fuel from the total fuel used to generate power in the industry[7] as illustrated in Figure 1.

Biomass is renewable, easily available in abundant amounts, and carbon neutral energy source. The use of agricultural biomass as an energy source can contribute to addressing the problem of managing waste from agricultural residues. Some of the concerning problems are seasonal availability, variable quality and composition, transportation and handling costs. Additional cementitious elements like fly ash, blast furnace slag, and silica fume are frequently utilised as (partial) cement replacement materials to lessen the environmental impact in the construction industry[8]. Although these materials are by-products of an industry that are not accessible everywhere, such as in developing nations. In these countries, industrial and agricultural wastes with pozzolanic behaviour offer opportunities for use in concrete production.[9] Economic opportunities in rural areas may be created by the availability of agricultural biomass.

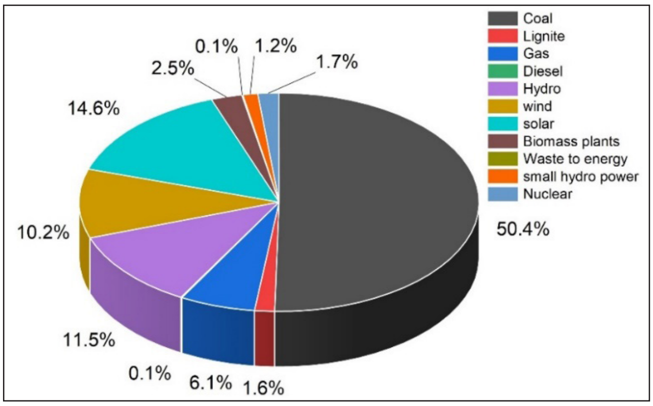

Figure 1.Percentage share of different fuels for the generation of power in India in the year 2023 (Ministry of Power)

J. Hohn, E et al in their research, analyzed the spatial GIS distribution and amount of biomass for biomethane production and optimized the locations, sizes, and numbers biogas plants in southern Finland in the area of three regional waste management companies.[10] The agriculture and industrial sector contributes about half of the country's economic growth. Due increased production of waste causes inadequate management of waste causing the emission of Greenhouse gases like methane and nitrous oxide. Suvash Chandra Paul et al. summarize the engineering properties of concrete produced using widespread agricultural wastes such as palm oil fuel ash, rice husk ash, sugarcane bagasse ash, and bamboo leaf ash.[11] Research on cement replacement containing agricultural wastes has shown that there is great potential for their utilization as a partial replacement for cement and aggregates in concrete production. When properly designed, concretes containing these wastes have similar or slightly better mechanical and durability properties compared to Ordinary Portland Cement (OPC) concrete.

G. Athira et al investigated the availability of different ashes such as sugarcane bagasse ash, fly ash and slag in five states of India and found bagasse ash more suitable and easily available by using ArcGIS and found the greatest benefits of different states.[12] G. Athira et al investigated the availability of sugarcane bagasse ash in five major sugar-producing states and quantified using a GIS-based network analysis approach to investigate the effective utilization of biomass ash in the Maharashtra(India) construction sector to generate ease of availability, accessibility of biomass ash for industry through GIS based Analysis, optimize distance, cost of material transportation to reduce CO_2 emission and save energy and find the optimal locations for new plants were identified based on availability of biomass, using location-allocation analysis.[13]

The present research attempts to fulfill the gap of mapping and network analysis to generate an economical and shortest path network of road and rail between cement to biomass-based industries or plants In this research paper we study and analyse the availability, accessibility and optimal utilization of biomass ash for the use in the construction sector through GIS-based analysis (Höhn et al.). The different crops available in Maharashtra region were identified, the residue produced per tonne of crop generated was assessesd. The chemical composition of these crop residue ashes were reported. With the GIS-based analysis, a proximity analysis was carried out w.r.t. to the biomass industries and nearby cement plants. The analysis heped to potimize the utilization of biomass ash in terms of cost, time and distance.

Methodology

Proximity analysis was adopted among biomass ash sources, biomass fuel-based industries, and cement & biomass plants in detail. GIS (Geographic Information System) is a powerful tool that can be used to manage, analyse, and visualize spatial data. GIS can be used for a wide range of applications, including urban planning, resource management, proper monitoring of materials, and disaster response.[14] So, it is used to find out data

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regarding accessibility (GPS coordinates) and availability (quantity) of biomass collected. Data of 7141 industries was assesed from Maharashtra Pollution Control Board database, out of which 258 biomass based industries data were identified in six divisions of the Maharashtra region of India. Nagpur, Amravati, Aurangabad, Nashik, Pune and Konkan are six divisions in Maharashtra. Figure 2 shows the different steps involved in proximity analysis. The Network analysis extension in QGIS software was used to analyse the accessibility of biomass ashes in Maharashtra through road networks.[15] The origin and destination cost matrix analysis was used to find the distance to the nearest sources to cement industries.

Data Collection

There are about 25 crops grown in the Maharashtra region. For analysis purposes, 9 crops were taken based on their production (greater than 10,00,000 tonnes/yr) from the Ministry of Agriculture and Farmers Welfare[16]

Quantity of Biomass availability and their Requirement as a Fuel

Data of crops are divided based on their production and their total residue generation (Equation 1) based on their different straw/grain ratio[17] shown in Table 1.

Residue Production = Grain Production*(Straw/Grain Ratio) Equation 1

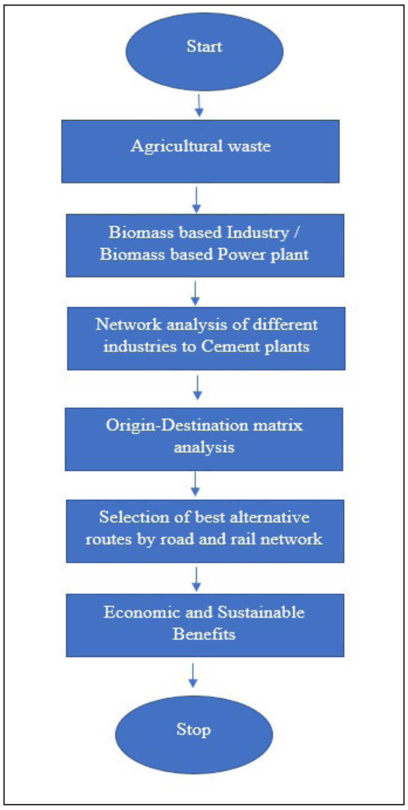

Figure 2.GIS-based analysis for data collection and analysis process

Table 1.Crops residuegenerationin Maharashtra region in the year 2019-20(welfare)

S.No	Crops	Production (Tonnes)	Area (Hectare)	Yield (Tonnes/ Hectare)	Straw/Grain ratio	Residue Generation (Tonnes)
1.	Arhar/Tur	11,96,801	13,19,102	0.91	1.5	17,95,201.5
2.	Cotton(Lint)	66,39,697	4,91,331	1.48	1.5	99,59,545.6
3.	Gram	22,40,091	20,43,208	1.10	1.6	35,84,145.6
4.	Maize	19,59,989	11,26,657	1.74	1.6	31,35,982.4
5.	Rice	28,97,433	15,52,989	1.87	1.5	43,46,149.5
6.	Soyabean	48,25,628	41,23,911	1.17	1	48,25,628
7.	Sugarcane	6,93,12,919	8,22,407	84.28	0.25	1,73,28,229.25

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8.	Wheat	17,93,440	10,56,965	1.70	1.5	26,90,160
9.	Jowar	18,64,697	23,71,472	0.79	1.7	31,69,984.9
	Total				5,08,35,027.15	

Comparison of Available Chemical Properties of Biomass Ashes

As per the criteria mentioned in ASTM C 618 and IS 3812 (Part -1), the percentage of SiO_2+Al_2O_3+ Fe_2O_3 should be greater than 70% for material to be called as supplementary cementitious material (SCM). This criteria helps to classify the material as SCM. Chemical composition of various agricultural crop residue ashes are detailed in Table 2.

Result and Discussion

A supply chain mechanism was adopted in the case of farm to biomass fuel-based industries/biomass power plant, biomass fuel-based industries/biomass power plant to cement industries for utilizing as supplementary cementitious materials to support the construction sector.

Geographical mapping distribution of industries and their fuel availability in Maharashtra Region (biomass fuel-based, cement, and biomass plant)

About 211 biomass fuel-based industries, 28 cement plants, and 19 biomass plants were located and mapped as shown in Figure 3. The location and quantity of fuel capacity of each biomass fuel-based industries were mapped with the help of QGIS. From Table 3, the Pune division has the highest number of biomass fuel-based industries (62) followed by Aurangabad division and Nashik division. Nagpur division identifies with the highest number of cement plants (11) and biomass power plants (10). However, the quantity of biomass fuel is highest at the Pune division which is followed by Nashik division and Konkan division and least by Amaravati Division of Maharashtra which has a higher encounter of sugar based biomass fuel industries due to higher sugarcane production.

Network definition and analysis from Biomass ash sources to cement plants (Figure 4 - Figure 7)

To achieve a detailed understanding of network analysis of biomass ash from cement plant, an origin-destination cost matrix (ODCM) were used as mentioned in the methodology. According to OD cost matrix analysis, the nearest biomass-based industries and plants were identified. So, on the basis of outputs from the ODCM analysis, a network analysis was done from biomass base industries and plants to cement plants where 5908 routes trips network were generated from each biomass fuel based industries to cement plants(fig 4a) for railways and(fig 5a) for roadways network and 532 routes trips network were generated form each biomass plants to cement plants (fig 4b) for railways and (fig 5b) for roadways respectively for each network and also the shortest distance was analyses through SQL query where shortest distance trips calculated for each biomass fuel industries to the nearest cement plant for railway(fig 6a) and roadways(fig 7a) networks and also same analysis done for biomass plant to cement plant for railway(fig 6b) and roadways (fig 7b) network through OD method.

Table 2.Chemical composition of crop residue ashes (% by mass)

Major Chemical Composition (%)	(SiO_2)	(Al_2O_3)	(Fe_2O_3)	(CaO)	Sources
Pigeon pea stalk	11.3	6	8	53.10	[18]
Cotton stalk	51.1	9.4	3.8	12.3	[19]
Rice straw ash	65.92	1.78	0.2	2.4	[20]
Corn cob ash	21.9	3.6	4.6	64.3	[21]
Rice husk ash (RHA)	88.32	0.46	0.67	0.67	[22]
Soybean husk ash	17.3	2.5	3.08	45.8	[23]
Sugarcane bagasse ash	72.7	5.3	3.9	8	[24]
Wheat straw ash	67.34	6.44	4.36	10.60	[25]
Sorghum Straw	1.46	0.06	0.04	0.30	[26]

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Table 3.Availability of biomass fuel in six study divisions in Maharashtra

S.No.	Divisions	Biomass fuel-based industries	Total Biomass used by industries as a fuel(MT/D)	Ash Generated biomass fuel-based industries (MT/D)	Cement Plants	Biomass Plants
1.	Amaravati	5	793.62	20.661	3	1
2.	Aurangabad	52	32,688.77	501.8462	1	4
3.	Konkan	21	5,472.638	128.9871	4	0
4.	Nagpur	25	5,248.4	201.153	11	10
5.	Nashik	46	63,814.43	1085.021	3	3
6.	Pune	62	56,928.27	613.35	6	1
Total		211	1,64,946.128	2,551.018	28	19

[MT/D – Million tonnes per day]

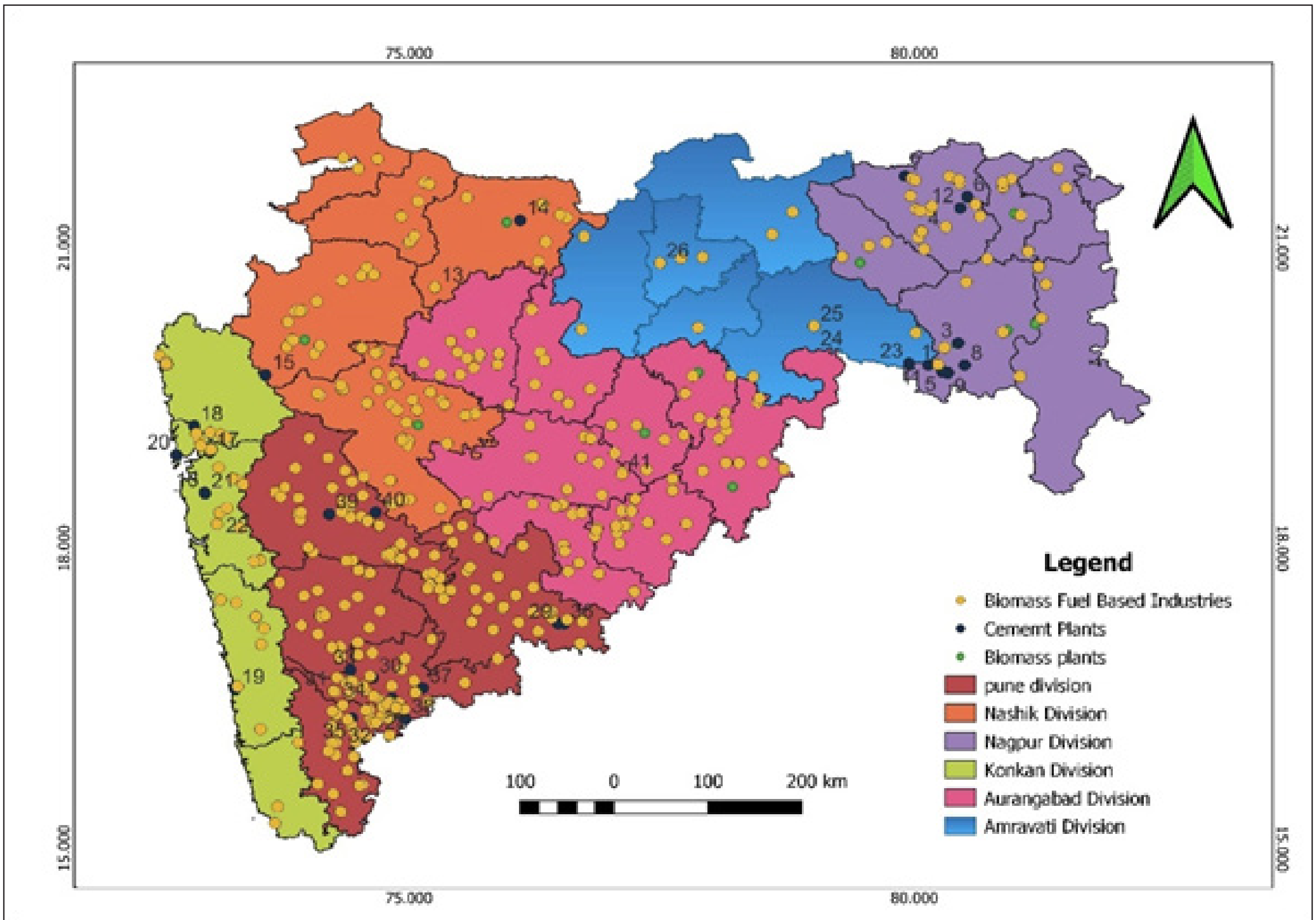

Figure 3.Geographical distribution of Cement plants, Biomass plants, and Biomass-based industries in Maharashtra, India

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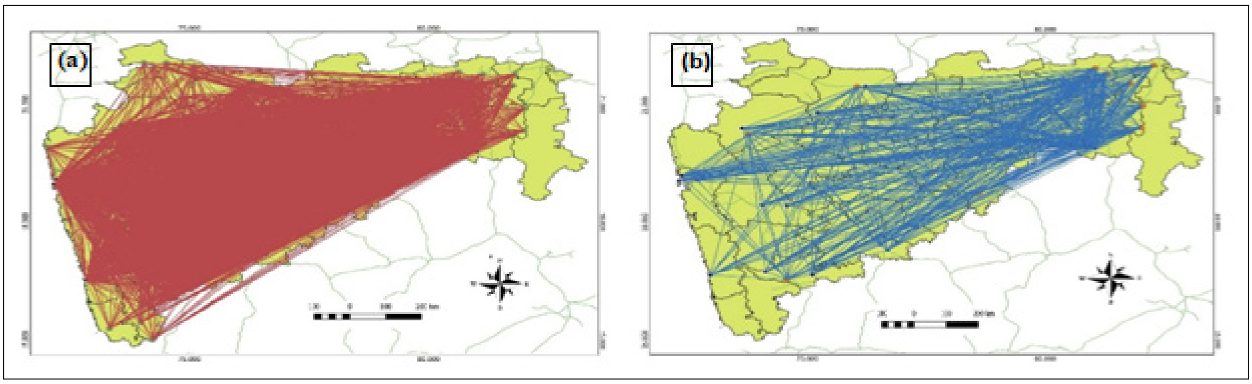

Figure 4.Network analysis through OD Matrix for Railways Network (a) Biomass fuel-based industries to Cement Plant (b) Biomass plant to Cement plant

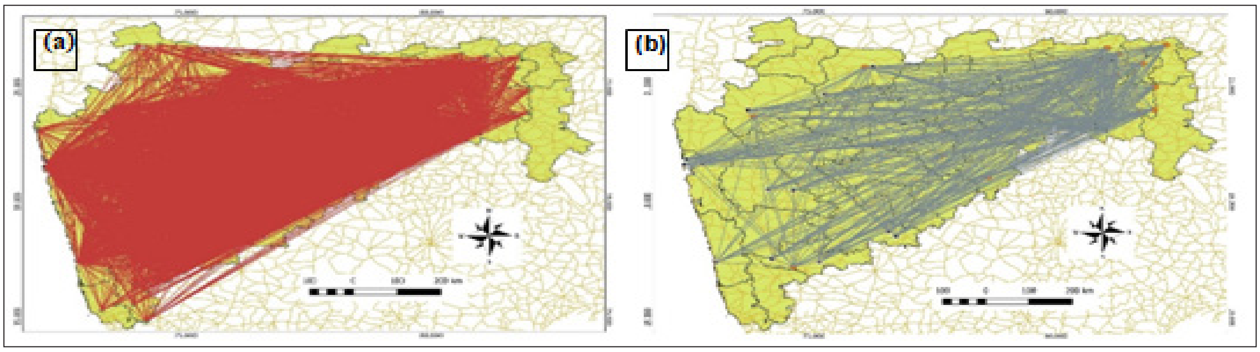

Figure 5.Network analysis through OD Matrix for Roadways Network (a) Biomass fuel-based industries to Cement Plant (b) Biomass plant to Cement plant

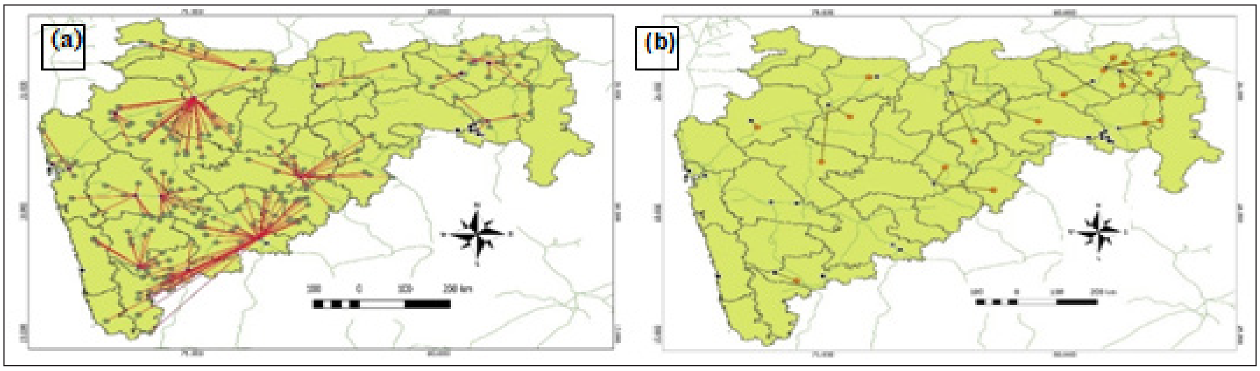

Figure 6.Shortest railway distance calculated through SQL from cement plants (a) Biomass fuel-based industries to Cement Plant (b) Biomass plant to Cement plant

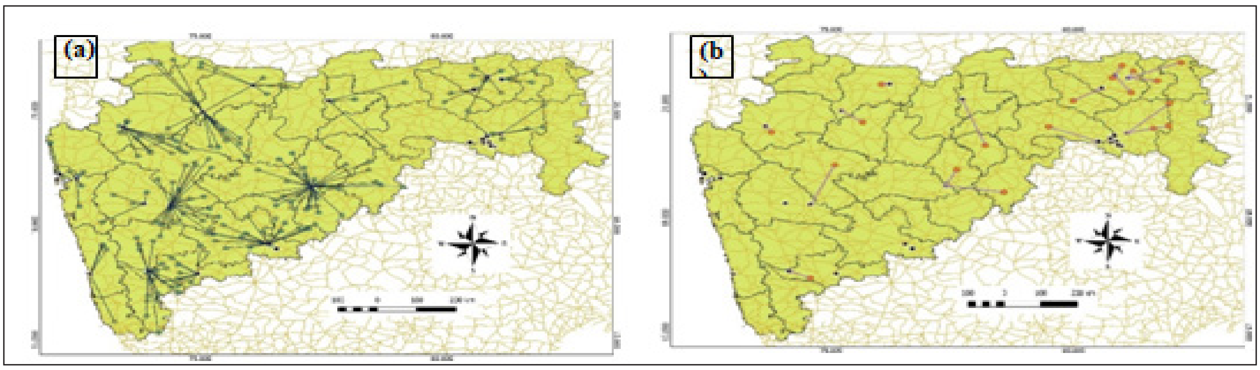

Figure 6.Shortest railway distance calculated through SQL from cement plants (a) Biomass fuel-based industries to Cement Plant (b) Biomass plant to Cement plant

The economic analysis of SCMs depends on the distances they have to be transported. The analysis was done based shortest distance from cement plants to biomass-based industries and plants to save in distance, fuel, cost, and carbon dioxide when biomass ash is used as SCM. The Table 4 and Table 5 shows the best alternative for cement plants in terms of cost and sustainability benefits by selecting the shortest routes for cement plants in terms of biomass-based industries and plants through roadways and railway network analysis. For roadways network analysis, out of 28 cement plants, two cement plants (CP-6 & CP-13) have a better alternative in switching source to Biomass plant to cement plant in terms of proximity. So, the total saving in terms of distance, fuel, cost, and CO_2 are 2224.185 km, 556.0463 litres, Rs 52824.39 and 1490.204 kg respectively.

For railway network analysis, out of 28 cement plants, four cement plants (CP-6 CP-11, CP-13, & CP-14) has a better alternative in switching source to Biomass plant to cement plant in term of proximity. So, the total saving in terms of distance, fuel, cost and CO2 are 3016.807 km, 12067.23 litres, Rs 1146387 and 108.6051kg respectively.

Table 4.Cost and sustainability benefits of cement plants in terms of roadways transportation

Cement Plants (CP)	Biomass-based industries(BBI) (km)	Biomass plant(BP) (km)	Better Alternative	Saving in distance (km)	Fuel Saving (litres)	Cost Saving (Rs)	CO_2 emission reduction (Kg)
1	2.298	88.01	BBI	85.712	21.428	2035.66	57.42704
2	21.641	107.353	BBI	85.712	21.428	2035.66	57.42704
3	36.798	73.832	BBI	37.034	9.2585	879.5575	24.81278
4	11.272	35.096	BBI	23.824	5.956	565.82	15.96208
5	17.073	102.784	BBI	85.711	21.42775	2035.636	57.42637
6	8.467	8.444	BP	0.023	0.00575	0.54625	0.01541
7	17.074	102.786	BBI	85.712	21.428	2035.66	57.42704
8	13.49	49.021	BBI	35.531	8.88275	843.8613	23.80577
9	17.068	102.779	BBI	85.711	21.42775	2035.636	57.42637
10	10.901	96.613	BBI	85.712	21.428	2035.66	57.42704
11	14.59	27.38	BBI	12.79	3.1975	303.7625	8.5693
12	34.779	55.326	BBI	20.547	5.13675	487.9913	13.76649
13	43.613	14.026	BP	29.587	7.39675	702.6913	19.82329
14	14.291	28.714	BBI	14.423	3.60575	342.5463	9.66341
15	10.008	177.839	BBI	167.831	41.95775	3985.986	112.4468
16	7.368	167.759	BBI	160.391	40.09775	3809.286	107.462
17	84.542	188.163	BBI	103.621	25.90525	2460.999	69.42607
18	13.714	176.097	BBI	162.383	40.59575	3856.596	108.7966
19	42.781	79.936	BBI	37.155	9.28875	882.4313	24.89385
20	39.19	124.902	BBI	85.712	21.428	2035.66	57.42704
21	7.715	127.836	BBI	120.121	30.03025	2852.874	80.48107
22	16.254	200.826	BBI	184.572	46.143	4383.585	123.6632
23	25.465	224.045	BBI	198.58	49.645	4716.275	133.0486
24	43.791	64.764	BBI	20.973	5.24325	498.1088	14.05191
25	13.312	43.625	BBI	30.313	7.57825	719.9338	20.30971
26	20.887	154.409	BBI	133.522	33.3805	3171.148	89.45974
27	16.258	114.368	BBI	98.11	24.5275	2330.113	65.7337
28	25.973	58.845	BBI	32.872	8.218	780.71	22.02424
	Total per trip			2224.185	556.0463	52824.39	1490.204

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Cement plants (CP)	Biomass-based industries(BBI) (km)	Biomass plant(BP) (km)	Better Alternative	Saving in distance (km)	Fuel savings (litres)	Cost saving (Rs)	CO_2 emission reduction (kg)
1	30.478	95.309	BBI	64.831	259.324	24635.78	2.333916
2	28.475	84.323	BBI	55.848	223.392	21222.24	2.010528
3	30.478	80.558	BBI	50.08	200.32	19030.4	1.80288
4	14.585	42.339	BBI	27.754	111.016	10546.52	0.999144
5	24.891	80.739	BBI	55.848	223.392	21222.24	2.010528
6	12.632	11.712	BP	0.92	3.68	349.6	0.03312
7	24.889	80.737	BBI	55.848	223.392	21222.24	2.010528
8	11.85	52.09	BBI	40.24	160.96	15291.2	1.44864
9	24.894	80.743	BBI	55.849	223.396	21222.62	2.010564
10	30.951	95.781	BBI	64.83	259.32	24635.4	2.33388
11	33.814	32.893	BP	0.921	3.684	349.98	0.033156
12	2.739	97.803	BBI	95.064	380.256	36124.32	3.422304
13	31.711	14.462	BP	17.249	68.996	6554.62	0.620964
14	47.383	45.432	BP	1.951	7.804	741.38	0.070236
15	8.413	167.387	BBI	158.974	635.896	60410.12	5.723064
16	8.646	172.656	BBI	164.01	656.04	62323.8	5.90436
17	124.519	168.594	BBI	44.075	176.3	16748.5	1.5867
18	14.96	181.961	BBI	167.001	668.004	63460.38	6.012036
19	22.99	87.821	BBI	64.831	259.324	24635.78	2.333916
20	43.013	107.843	BBI	64.83	259.32	24635.4	2.33388
21	14.703	147.289	BBI	132.586	530.344	50382.68	4.773096
22	5.004	497.8	BBI	492.796	1971.184	187262.5	17.74066
23	14.125	515.053	BBI	500.928	2003.712	190352.6	18.03341
24	36.079	83.07	BBI	46.991	187.964	17856.58	1.691676
25	32.738	63.356	BBI	30.618	122.472	11634.84	1.102248
26	30.612	258.205	BBI	227.593	910.372	86485.34	8.193348
27	10.636	299.564	BBI	288.928	1155.712	109792.6	10.40141
28	10.199	55.612	BBI	45.413	181.652	17256.94	1.634868
	Total per trip			3016.807	12067.23	1146387	108.6051

Conclusions

Effective agricultural waste management strategies can help reduce the negative impact of agriculture on the environment and construction sector, such as soil degradation, water pollution, and greenhouse gas emissions. Following are the conclusions of the study using GIS analysis. Maharashtra was the second largest sugarcane producing state in India it was later verified the probability of encountering sugar industries was higher in comparison to other industries So sugarcane residue generation will also be higher (1,73,28,229.25 tonnes) when compared to other biomass ashes. It was found that proximity and network analysis of biomass fuel-based and cement plants has greater benefits cheaper when compare to network analysis of biomass plants and cement plants. It was found greatest savings in terms of distance, cost and reduction in carbon footprint based on different modes of transportation through network analysis. The practical framework is done in terms of transportation materials using roadways and railways through network analysis and shortest distances in terms of convenience was analyzed through SQL for different origin and destination. GIS analysis can help to monitor and manage these clusters of agriculture and plants over time, by providing real-time information on the status of the industry, the environment, and the local community, road, and railway network. This information can be used to inform decision-making, identify areas for improvement, and promote sustainable development.

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