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Global Market of Bauxite Ore, its Reserves, Production and Consumption Scenario vis-a-vis Sustainability of Indian Bauxite Industry

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Aluminium is the most abundant metal on the Earth, and one of the widely used metal in the world after steel. Bauxite ores are used to extract alumina and principally source of aluminium in aluminium industry. Due to fast growth of aluminium industries, mechanisations, automations and suburbanization developments, the demand of bauxite ore has increased drastically in the last few years. With the huge global demand and limited availability of high-grade bauxite reserves, now, it is the right time to develop some advanced techniques to extract alumina from low grade and medium grade bauxite ores. Also, thrust must be given towards precise exploratory work, computerised mine planning and mineral beneficiation process for better utilization of available low grade bauxite ores. Apart from this, initiatives must be taken to develop new models and dynamic approach to address the ecological, geographical, legal, technical, economically feasible and political issues for bauxite mining on sustainable basis. This paper deliberates the geographical and geological setting of bauxite ores globally, trends in ore production, and its utilization with reference to our country with an objective of fulfilling not only the needs of present generation but preservation for the future requirements as well.

Keywords: *Bauxite; reserves; production; consumption; sustainable.*

1.0 Introduction

Bauxite is a relatively high aluminium content sedimentary rocks and it is a main source of aluminium from alumina. About 90% of the industrially processed bauxites consumed for metallic aluminium production, and 10% is applied in the production of refractory and abrasive materials, clay cement and chemical products (Sampaio et al. 2008). Bauxite consists mostly of the aluminium minerals like diasporic, gibbsitic and boehmitic minerals along with other oxides of iron like haematite (Fe_2O_3) and goethite ($FeO(OH)$). The aluminous clay minerals are also associated with bauxite ore in the form of kaolinite ($Al_2Si_2O_5(OH)$) and small amounts of anatase (TiO_2) and ilmenite ($FeTiO_3$ or $FeO.TiO_2$). In addition to that it also contains several kinds of impurities like iron, titanium and silica, which directly affects the quality and quantity of aluminium. The compounds of iron and titanium are insoluble in caustic solutions and because of high percentage of these contents, more red mud is generated in the process. The silicon compounds basically present in the form of quartz and kaolin in bauxite dissolves in caustic soda used in the digestion process but bauxites comprising substantial amounts of silica have the potential to be tough to treat economically.

Geologically, there are mainly two types of bauxite, one is lateritic bauxite and another one is karst bauxites. Lateritic bauxites are basically aluminous silicate rocks however karst bauxites are aluminous silicate and inter bedded carbonate rocks. Karst bauxite has a diversified mineralogical composition as compared to lateritic bauxite as it has experienced different weathering circumstances during mineralization and comprises carbonates in the parent rock.

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But in lateritic ore, kaolinite is the main silicate mineral allied with other silicate minerals i.e., goethite and quartz. Due to difference in mineralogical composition, the lateritic bauxites are more ideal for use in the Bayer's process because it is easy to digest as compared to karst bauxites. The mineralogical composition of bauxite is given below.

Element	Bauxites
Al_2O_3	Gibbsite, Boehmite
SiO_2	Kaolinite, Quartz
Fe_2O_3	Goethite, Hematite
TiO_2	Anatase, Rutile
CaO	Calcite, Apatite

2.0 Market Scenario of Aluminium Industry

Bauxite is the primarily raw material of aluminium used to extract alumina in the Bayer's process. With the huge demand and the rapid development of the global alumina industry, bauxite consumption is rising and has reached more than 160 Mt per annum. Since the economy of India is growing consistently at a rate of 8% per year, the demand for several metals has also been increasing across the various sectors and industry segments. As a result, Indian aluminium industry is undergoing a phenomenal development. It is pleasure to know that India has the fifth largest producer of aluminium of the globe and the country has a capacity to produce more than 2.7 Mt of aluminium per annum, which is about 5% of the total aluminium production of the world.

Primary aluminium production industry in India is mainly dominated by the following firms that account for the total aluminium production of the country i.e. Bharat Aluminium Company (BALCO), National Aluminium Company (A Govt. of India Enterprises), Vedanta Limited and Hindalco Industries (subsidiary of the Aditya Birla Group). Presently BALCO has been taken over by Vedanta Limited.

Primary aluminium consumption in India increased by 16% year on year in 2010 on the back of strong growth in the electricity, transportation, industrial and infrastructure sectors. The overall consumption of aluminium is projected to be about 11 Mt by 2021. India's consumption has grown at a CAGR of 15% in the last five years, almost double the world average of 8.1%. The per capita aluminium consumption in India is just 1.3 kg as compared to about 39 kg in Germany, 28 kg in the US and 12 kg in China. The world average is 7.4 kg. The graphical representation of country-wise consumption details of aluminium is as under (Fig.1).

3.0 Worldwide Resources and Production of Bauxite Ore

The overall development of any nation is linked with industrialization, and in turn, depends on its mineral resources. India is endowed with a diverse and abundant resource of metallic and non-metallic minerals by the mother earth, which propounded it a robust industrial base. Out of 89 minerals produced in India, 4 are fuel, 11 are metallic, 52 are non-metallic and 22 are minor minerals. India's abundant mineral resources include manganese, coal, bauxite, chromite, mica, iron, monazite, titanium, limestone and salt. The other bauxite-rich nations around the globe are Guinea, Australia, Brazil, Russia, China, Vietnam and Jamaica. The worldwide distribution of bauxite ore deposits has been given in Fig.2.

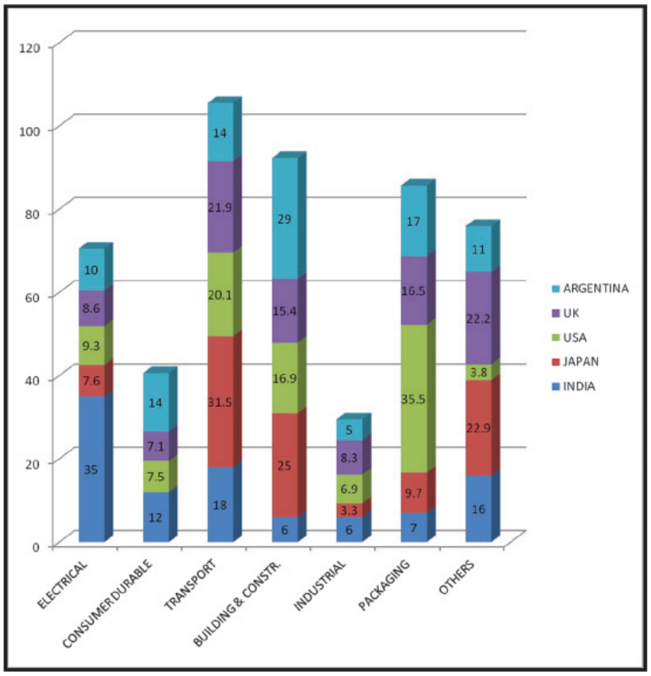

Figure 1: The worldwide uses of aluminium (SOURCES: WORLD-ALUMINIUM.ORG)

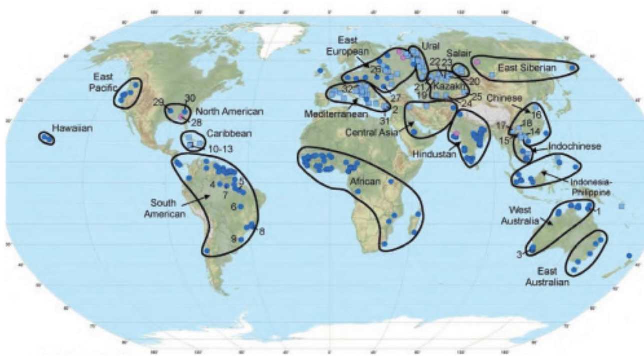

Figure 2: The worldwide distribution of bauxite ore deposits

According to USGS (2017), the estimated global mineral resources ore is 17.0 billion tonnes and bauxite ore resource is about 30.0 billion tonnes. and are located mainly in Guinea (25%), Australia (20%), Vietnam (12%), Brazil (11%), Jamaica (7%), Indonesia, Guyana, China and India (3% each). The distribution of bauxite ore reserves in different counties world-wide are tabulated and presented a pictorial view in Fig.3.

In the last couple of years, the demand and production of bauxite ore have increased manifold. Fig.4 shows the consistent growth of the worldwide production of bauxite ore from 219 Mt in the year 2010 to 303.8 Mt in the year 2017

The country-wise production of bauxite ore during 2010-2017 is presented in Table 1. From the figure, there is significant improvement in bauxite ore production from 2010 to 2017 except little bit decline in 2016 as compared to 2015. The highest producer of bauxite ore in the world is Australia, followed by Brazil, China, Guinea and India.

		(In '000 tonnes)
	World total	30000000
1	Guinea	7400000
2	Australia	6000000
3	Vietnam	3700000
4	Brazil	2600000
5	Jamaica	2000000
6	China	1000000
7	Indonesia	1000000
8	Guyana	850000
9	India	830000
10	Russia	500000
11	Greece	250000
12	Saudi	210000
13	Kazakhstan	160000
14	Malaysia	110000
15	USA	20000
16	Other	3200000

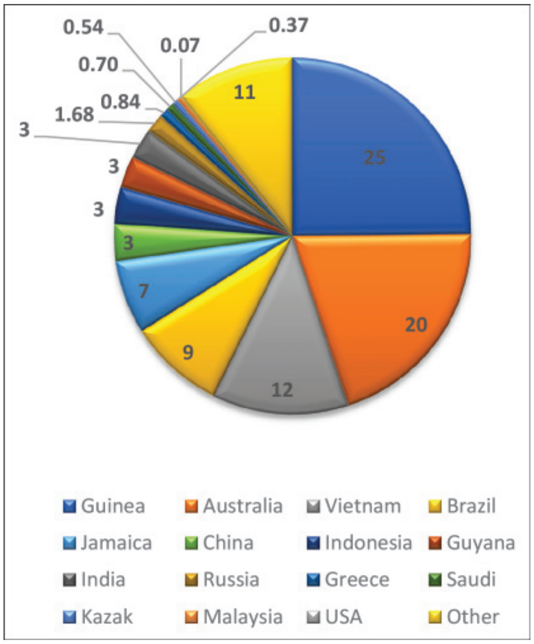

Figure 3: World reserves of bauxite (By Principal Countries) Source: Mineral Commodity Summaries, 2019.

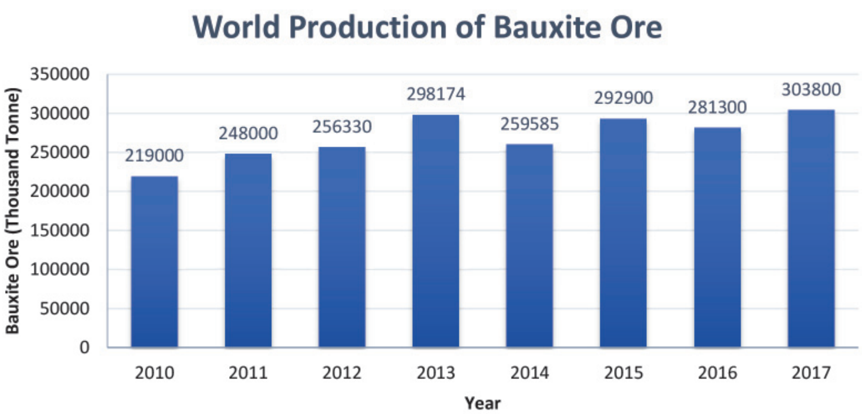

Figure 4: World production of bauxite ore

4.0 Resource and Production of Bauxite Ore in India

4.1 Bauxite Ore Resource in India

As per National Mineral Inventory (NMI), Indian Bureau of Mines database and based on United Nations Framework Classification (UNFC), the total bauxite reserves/resources in India as on 1st April 2015 is 3896 Mt These resources include 656 Mt reserves and 3,240 Mt remaining resources. Fig.5 shows the locations of major minerals including bauxite ore deposits of India. According to grade wise distribution, about 77% resources are of metallurgical grade and about 4% resources are of refractory and chemical grades. Apart from this, if we consider states wise distribution, Odisha alone accounts for 51% of country's resources of bauxite followed by Maharashtra (5%), Jharkhand (6%), Gujarat (9%), Madhya Pradesh and Chhattisgarh (4% each) and Andhra Pradesh (16%). In the East Coast bauxite deposits, major bauxite resources are concentrated in two states i.e. Odisha and Andhra Pradesh. The state-wise bauxite ore reserves of India as on 01.04.2015 are presented in Table 2.

4.2 Bauxite Ore Production in India

As per the FITCH Report, the production of bauxite has been estimated to grow from 30.9 Mt in 2018 to 50.7 Mt by 2027 due to high demand in domestic

Table 1: The country-wise production of bauxite ore

In thousand tonne	2010	2011	2012	2013	2014	2015	2016	2017
World total	219000	248000	256330	298174	259585	292900	281300	303800
Australia	68535	69977	76281	81119	78632	80910	83517	89421
Brazil	32028	33695	34988	33849	35410	37064	37700	38123
China	30000	37000	44052	50339	65000	60788	66158	65000
Greece	1902	2324	1816	1844	1876	1831	1880	1927
Guinea	16427	17593	17326	18331	18743	16300	31500	46160
Guyana	1083	1818	2214	1713	1564	1526	1479	1459
India*	12064	12992	16612	21666	20201	28124	24745	22313
Indonesia	-	41000	31443	51024	2556	611	1485	3700
Jamaica	8540	10189	9339	9435	9677	9629	8540	8245
Kazakhstan	5310	5495	5170	5193	4516	4683	4801	4843
Russia	5000	5380	5166	5322	5589	5398	5432	5523
Saudi Arabia	-	-	760	1044	1965	2174	3843	3708
Suriname	3096	3236	2905	2671	2708	1865	-	-
Turkey	-	-	1521	796	800	1050	989	1001
Venezuela	3126	2455	2286	2341	2316	1123	1523	2672
Other countries	31889	4846	4450	5487	8033	6717	4477	6569

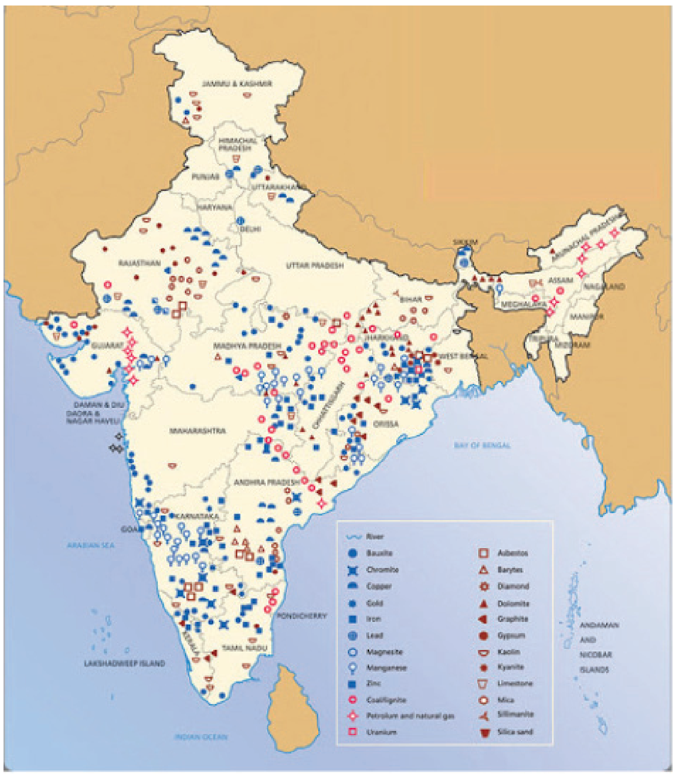

Figure 5: Shows the locations of major minerals including bauxite ore deposits of India

Table 2

	State	Total Resource
		(In '000 tonnes)
1	Odisha	1994574
2	Andhra Pradesh	615267
3	Gujarat	350581
4	Jharkhand	239061
5	Maharashtra	184574
6	Chhattisgarh	173755
7	Madhya Pradesh	173388
8	Goa	55168
9	Karnataka	45635
10	Tamil Nadu	24491
11	Uttar Pradesh	18908
12	Kerala	14096
13	Bihar	4114
14	Jammu & Kashmir	2725
15	Rajasthan	528
	Total	3896865

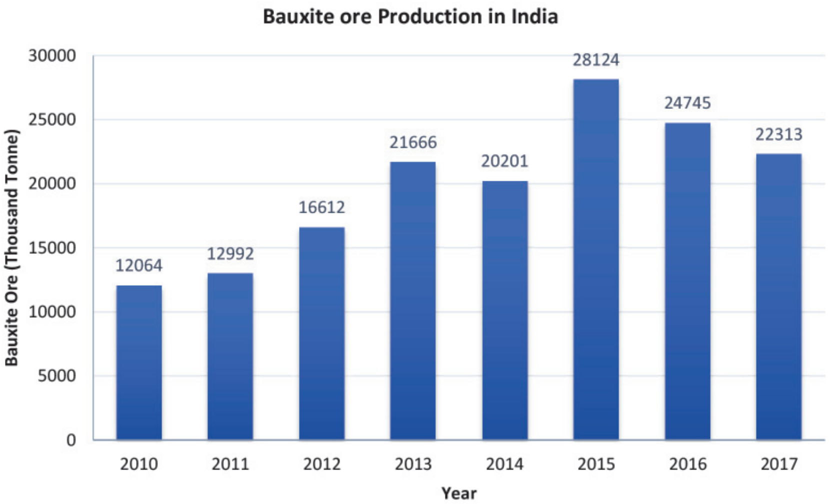

Figure 6: Bauxite ore production in India during 2010 to 2017 (Source: Indian Mineral Book 2018)

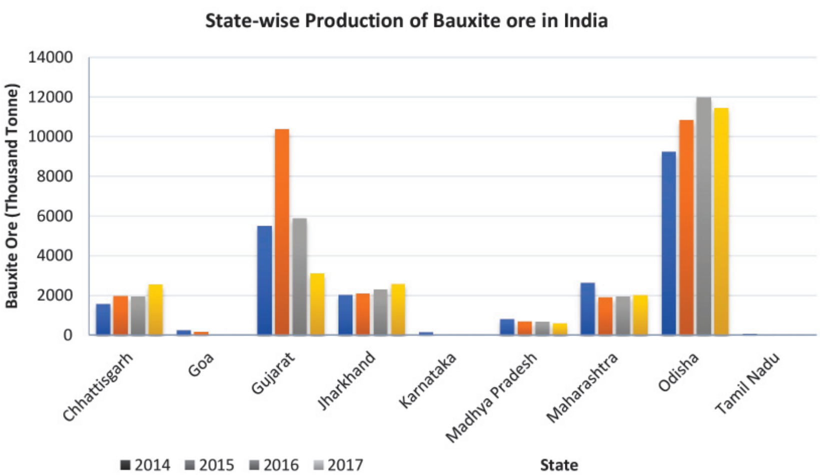

Figure 7: The state-wise bauxite ore production in India during 2014 to 2017 (Source: Indian Mineral Book 2018)

aluminium industry. With such a huge demand, the bauxite production in India has increased extremely from 2010 to 2017 as presented in Fig.6 (source: Indian Mineral Book, 2018). As per the graph, it is clear that India produces around 23.3 million tonnes of bauxite every year since 2013 and Odisha with 51% is the largest producer of bauxite in India followed by Gujarat (14%), Jharkhand (12%), Chhattisgarh (11%) and Maharashtra (9%). The state-wise bauxite ore production in India during 2014 to 2017 is shown in Fig.7.

5.0 Future Prospects of Bauxite Ore Resources with Sustainability

Aluminium is a low density, flexible, corrosion free, good heat and electricity conductor and easily operational metal. Most of these properties can be amended or improved by mixing with small amounts of other metals in aluminium. Because of above properties, aluminium has a very wide range of applications. Pure aluminium is used primarily by the electronics industry for capacitor foil, hard disc drives and conductor tracks on silicon chips. However, when alloyed mixed with small amounts of other metals such as copper, zinc, magnesium and silicon, aluminium becomes stronger and it can be made even more stronger than steel. For example, duralumin is an alloy of aluminium, copper, manganese and magnesium, aluminium constituting 90 to 94%.

Aluminium and its alloys are widely used in transportations like cars, trains, aeroplanes and ships where their low-density properties help in reducing fuel consumption and emissions of carbon substance. Apart from this, by making bicycles with this low-density aluminium can also benefit from reduced weight and increased strength.

Another important use of the alloys is in packaging, generally in foil to protect food and in drinks cans. Domestic uses include cooker, plates, pots, saucepans and other cooking utensils, and in constructions or infrastructure sectors the alloys are used widely in doors, windows and casing. The sector-wise use of aluminium in India is shown in Fig.8.

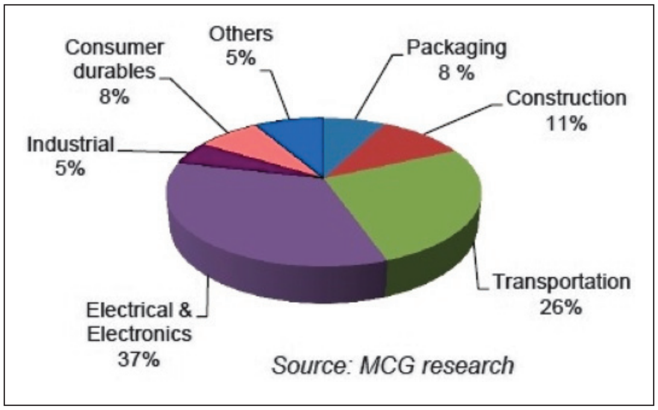

Figure 8: The sector-wise use of Aluminium in India (Source: MSG Research)

The world population growth and bauxite ore production from 2010 to 2017 shown in Fig.9 indicates a consistent increasing trend

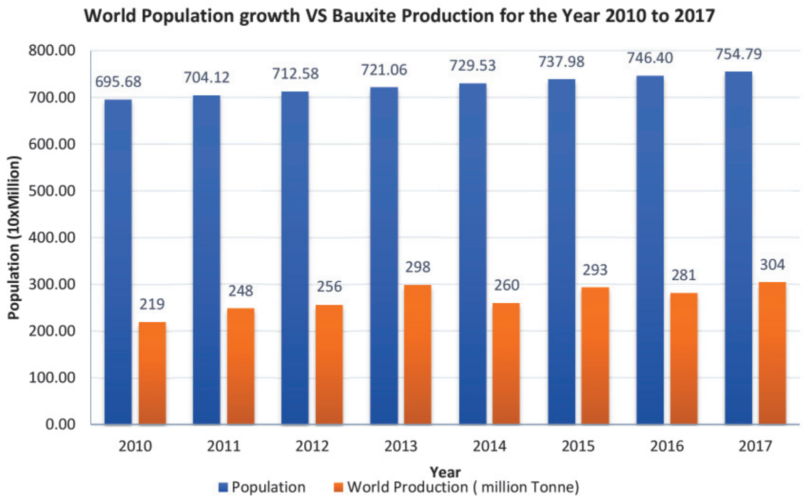

Figure 9: World population growth vis-à-vis bauxiteore production from 2010 to 2017 (Source: UN population division 2019 and Indian Mineral book 2018)

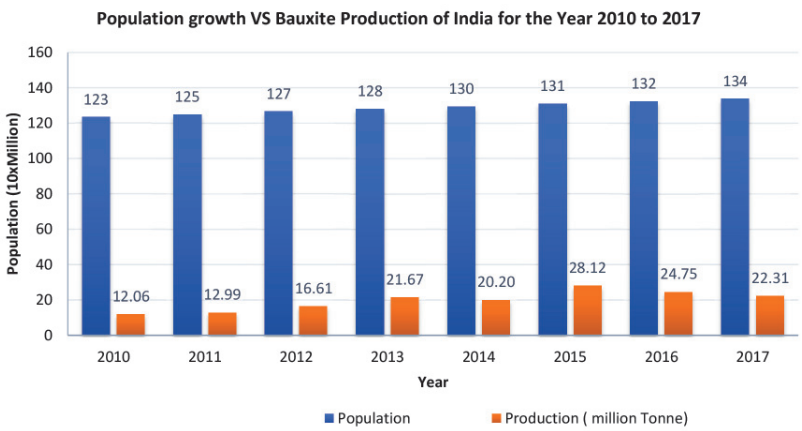

Figure 10: Population growth vis-à-vis bauxiteore production in India from 2010 to 2017 (source: UN population division 2019 and Indian Mineral book 2018)

(source: UN population division, 2018 and Indian Mineral Book, 2018). Globally, the demand for bauxite ore is increasing day by day, though the reserve is limited and exhausting. Hence, it is necessary to use advanced techniques and give more focus on the development of new exploration methods, scientific exploitation, advanced mine planning techniques, and mineral beneficiation processes to enhance the bauxite recovery from the ores.

Likewise, the population growth vis-à-vis bauxite ore production in India during 2010 to 2017 (source: UN population division 2018 and Indian Mineral Book 2018) shown in Fig.10 depicts that the demand of bauxite ore increases with the population growth of the country. The demand for bauxite ore in India is increasing day by day with the increase in globalization and industrialization. Hence, there is a need for further exploration to augment the mineral resources and bridge the gap between resources and demand. This necessitates more attention on the prospects of bauxite ore resource and its sustainability.

In view of the above, the following points should be considered for sustainable utilization and conservation of bauxite ore resources of the country:

(i) Discovery of new bauxite ore deposits through regional exploration followed by detailed exploration.
(ii) Extraction of low-grade bauxite and preserve the same for future use.
(iii) Extent mechanization process to increase bauxite production to increase production.
(iv) Introduction of new technology and innovation in mining to reduce cost of production.
(v) Adoption of new prospects or well-designed exploration programmes and extract alumina from the low-grade bauxite ores using developed techniques based on economic and market demand.
(vi) Utilization of low-grade bauxite ore through blending and beneficiation as adopted in other countries like Brazil, Guinea and China.

6.0 Utilization of Low-Grade Bauxite Ores

In a recent notification issued by Indian Bureau of Mines, Nagpur vide C-284/3/CMG/2017, dated 24th May 2018, threshold value of bauxite is revised as below:

Items	Threshold limit
Alumina Content, Al_2O_3	30% min.
Total Silica, SiO_2	7% max.

In the current market scenario, it is generally considered uneconomic to treat bauxites containing more than 5% reactive silica due to excessive soda consumption in the Bayer's process. The various researches conducted till date are mainly done for reduction of iron and silica content present in the high-grade bauxite ore, the applicability of the same is required to be ascertained for pre-treatment of high silica containing low grade bauxite ore deposits.

Most mines abroad subject their run of mine ore (ROM) to the mineral dressing operation most suitable for their material. Crushing the ROM, usually in hammer mills, is an operation practiced worldwide. Depending on the bauxite, and the quality/grade required, the next stages are screening, scrubbing and washing, magnetic separation, and drying and calcining. Magnetic separation to remove iron, however, is normally practiced in a limited way to produce high value, special grade bauxites. At present, the production of bauxite in most operative mines in India is not sufficiently high as to warrant a capital-intensive beneficiation plant, which usually requires a large capacity to be really economical. Hence, ore dressing efforts have been mainly confined to removal of silica by manual and/or mechanized breaking, crushing, manual sorting and dry screening.

According to Prasad and Rao, 1996, gravity separation for beneficiation has been used to target valuable by-products from the reprocessing of Bayer residue. But it is unlikely that gravity separation could ever be used economically to reduce silica in lateritic bauxites because the principle of gravity separation process is mainly on density. Alumina and silica minerals in these bauxites are intimately mixed so that adequate liberation is not possible. Rao and Das 2014 conducted various pre-treatment process of samples collected from lateritic bauxite deposits collected from Kudag mines, Chhattisgarh, India. The sample on an average contains 39.1% Al_2O_3 and 12.3% SiO_2, and 20.08% of Fe_2O_3. Beneficiation techniques like size classification, sorting, scrubbing, hydrocyclone and magnetic separation were employed to reduce the silica content suitable for Bayer process. The studies indicated that, 50% by weight with 41% Al_2O_3 containing less than 5% SiO_2 could be achieved. The finer size fractions (less than 40 mm size samples) were subjected to scrubbing, hydrocyclone and magnetic separation and it was reported that silica content in the entire size fractions cannot be lowered to 5% and the total alumina content in most of the size fractions were less than 45%. Effect of flow ratio and feed pressure using hydro cyclones for pre-treatment of low-grade diasporic bauxite ore collected from Chenggang aluminium factory was studied by Shu-ling et al 2008. In a study conducted by Dwivedi et al 2005 on run off mine samples of Mainpat bauxite mine, single washing after crushing up to 75 mm was suggested to achieve better yield.

Flotation is particularly suited to diasporic ores in which there is sufficient liberation of alumina from silica minerals, and the silicate minerals are of a particle size suitable to flotation. This technology is not expected to be useful for lateritic bauxites where the silicate and alumina minerals cannot be sufficiently liberated to achieve good upgrading and recoveries. The depletion of high Al_2O_3 grade diasporic ore deposits has stimulated the improvement of bauxite concentration methods in China and Brazil. Flotation has been pointed to as a promising technique to be applied for pre-treatment of low-grade diasporic bauxite ores in order to suit the bauxite to the market specification (Massola et al. 2009, Marino 2012, Marino et al. 2013, Gibson et al 2017).

Gravity separation processes are suitable for the separation of the iron-rich components from the ROM bauxite. Depending on the grain size, which has to be processed, the Jig or the Spiral is an appropriate type of equipment. The products can be differentiated based on their colour. The darker, reddish fraction contains the iron-rich components removed in the high-gravity product (heavy fraction). The Al_2O_3 – rich lighter fraction is nearly white.

Magnetic Separation can be used to lower the iron content of the ROM bauxite. Depending on the grain size and the iron containing mineral, which has to be processed, the drum separator or the wet high intensity magnetic separator (WHIMS) is an appropriate type of equipment. There are an amount of studies that involve the removal of iron oxides by magnetizing the iron bearing compounds by reduction of Fe_2O_3 to Fe_3O_4, followed by magnetic separation. It was proved to be an effective way to decrease iron content of ores and tailings. In an experiment conducted by Yilmaz et al. 2015, the low grade diasporic bauxite ore of Yalvaç, Isparta, Turkey was roasted under reducing atmosphere and subjected to magnetic separation. The optimum parameters for removal of iron oxide and rutile from the non-magnetic ore were found to be 800°C for reduction temperature and 20000 Gauss of magnetic intensity. On the other hand, 600°C and 5000 Gauss were determined to be the optimum parameters for removal of silica from the non-magnetic ore. According to Bhagat et al. 2006, the magnetic separation method for the reduction of iron contents in bauxites for the production of refractory bauxites, however there does not appear to be any industrial application of this technology.

Chemical/thermal treatment of bauxite containing high silica was also experimented by Lin et al 1998, McCormick et al. 2002, Victor et al 2003 and Silva et al 2012. In Bio-leaching process, bacterial strains are mixed with bauxite and a growth medium (usually a glucose or related carbon source) from which certain elements of the minerals are extracted into solution. Groudeva and Groudev, 1983 also examined the specific use of “silicate” bacteria to remove silicates from bauxite but this process could not use commercially because huge time is required to complete this process in field.

Research is being done in most bauxite producing countries to develop cheap and innovative bauxite beneficiation processes. Research in India is also along international lines but confined to the laboratory. The Indian Bureau of Mines (IBM), Nagpur, the Jawaharlal Nehru Research Development and Design Center (JNARDDC), Nagpur and the Regional Research Laboratory (RRL), Bhubaneswar, all claim to have lab-scale processes that are ready to be upscaled to pilot plant levels. The IBM has done numerous beneficiation tests, using different methods, on various bauxite ore deposits found in India. The RRL claims to have developed a beneficiation process to produce non-metallurgical grade bauxite, whereas the JNARDDC says it has processes for both metallurgical and non-metallurgical grades. Of the three, only JNARDDC is still researching actively on bauxite beneficiation (Rayzman et al. 2003).

7.0 Concluding Remarks

The mineral deposits and their development play a vital role in the economic growth of any nation. Both bauxite and aluminium are considered as the backbone of the modern economy. The resources of metallurgical grade bauxite are adequate while those of the chemical and refractory grade bauxite are relatively limited considering the future requirements. As the demand for bauxite ore is consistently increasing globally, it is necessary to adopt innovative methods to extract alumina from both the low and medium-grade bauxite ores to meet the market demand. Moreover, it is necessary to shift the trend from regional to detailed exploration and adopt advanced techniques to exploit bauxite ore.

Further, the advanced computerized mine planning and design techniques and innovative mineral beneficiation processes like hydrocycloning, jigging etc. should be adopted for utilizing the low-to medium-grade bauxite ores. The grade of bauxite can be enhanced by extracting silica and other impurities from the bauxite ores for mineral conservation. This, in turn, will increase the efficiency of the existing alumina plant also to some extent. So, keeping in view the scarce bauxite ore resources, it is the need of the hour to take necessary steps in advance for proper exploration, exploitation, and utilization of bauxite ore for the sustainability of the future generations. The present government is creating a conducive environment for all manufacturing companies in India and abroad under Make in India Programme which will further boost the demand of aluminium requirement in coming future. A joint action plan is needed by industries, R&D institutions and academic institutes for more research in utilizing low grade bauxite ore for extraction of alumina for sustainable growth.

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