Glass Production from River Silica of Bangladesh: Converting Waste to Economically Potential Natural Resource

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ABSTRACT

The Ganges-Brahmaputra river system at the Bengal Basin carries large amounts of sediments on the way to finally deposit at the Bay of Bengal. Those river-transported sediments form bar deposits during dry season in many areas of Bangladesh and accumulate economic mineral depositions at suitable geological environments. Dredging is a must for most of those rivers for proper navigation, as well as protecting bank erosion, which generates millions of tons of waste sand. The dredged materials from river beds are mostly composed of silicate minerals, especially quartz and feldspar along with several dark colored heavy minerals. Like the industrial processing of heavy minerals from bulk sands, various physical separation techniques can be utilized for the beneficiation of silica from those river-born silicate minerals in dredged sands. Those silica have been successfully upgraded to near-glass sand grade in the laboratory, however, they have yet to be utilized for any kind of commercial venture. The present study attempts characterization of several river sands through physical separation and laboratory analysis. The upgraded silica was successfully compared with several quality glass sands and laboratory production of glasses. This experimental production of glass from upgraded silica could potentially be economical considering its industrial application with positive environmental consequences through minimizing the dredging cost, increasing the navigability of the river and ecological balance along the flood plain.

1. INTRODUCTION

Bangladesh, the major part of the Bengal Basin, is comprised of hundreds of rivers, originating from the Himalayan mountain ranges in the north. The great Ganges-Brahmaputra-Meghna (GBM) river system carries billions of tons of sediment from Himalayan ranges into Bangladesh (Garzanti et al., 2004). Annual suspended sediment load of this river system is estimated to be 1.0-2.4 billion tons (Rahman et al., 2018). Due to flat geomorphology of the basinal area, currents deposit their bed load at the river bank areas during monsoons. In the dry season, those depositional areas become exposed in the form of numerous bars even at the middle of the river course. These bars can be as thick as 44 meters (Rahman et al., 2020) at places. Being a riverine country, Bangladesh still uses many of its river routes for communication purpose. Because of this, proper navigation of those rivers is very important for a smooth transportation system. For that purpose, dredging is a must in all major rivers which involves both cost and manpower. Every year, Bangladesh needs to spend substantial amount from its annual budget to keep the rivers running with sufficient water at its navigation routes. As a consequence, dredging is very much common in all major rivers. However, till now, the dredged materials are used for mostly earth filling and construction like conventional purposes. In many instances, dredged materials are kept in the vicinity of the river, from where they return to the same place in next monsoon.

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Which means, most parts of the dredging materials becoming wastes of large volume. Therefore, an alternate economic utilization of this waste or dredged materials would be significant findings for the country.

As stated earlier, Bangladesh has one of the largest river systems of the world. Some of the rivers are meandering, some are braided. Because of low gradients and high sediment loads, the riverbeds of most of the rivers in Bangladesh aggrades very quickly, which becomes a major environmental concern. Riverbed aggradation is so pronounced in Bangladesh that changes in riverbed level can be observed during one's lifetime. For example, the Old Brahmaputra was navigable for steamers only about 30 years ago, and is presently almost an abandoned channel. This situation is true for many other distributaries of the Ganges and Meghna, such as the Madhumati, the Bhairab, the Chitra, and the Ghorautra. The lesser water flow can also be caused by the low rainfall in the upstream area but it is reported that rainfall didn't decrease significantly during recent decades. Main causes of siltation or sedimentation in Bangladesh rivers are the control on natural water flow in the upstream area by artificial barriers, e.g., dams. The average sediment load of the Ganges-Brahmaputra river system has declined from 2.4 billion tons/year (67% delivered by the Ganges) to 1.6 billion tons/year (Milliman and Meade, 1983) since the diversion of the Ganges through the Farakka-Barrage damming project. From the border with India to the point where the Ganges meets the Brahmaputra, the riverbed has aggraded as much as 5-7 meters in recent years (Alexander, 1989). The aggradation causes several problems, such as flooding, unwanted erosion and deposition, destruction of navigation route, imbalance of ground water level, ecological hazards, decrease of fish and other resources, and saline water intrusion in coastal areas.

Only way to solve the river bed aggradation problem is to remove the excessive sediment to increase the water carrying capacity of the rivers. This can be done by dredging and re-excavation of rivers. Continuous dredging of the rivers and channels and dispersion of the dredged sediments on the delta plain will not only increase the capacity of the rivers, but also increase the elevation of the land. Understanding the importance, the Government of Bangladesh has planned to take a 15-year action plan for proper river management and dredging, called Capital Dredging, to carry out dredging in all the major rivers of Bangladesh. The spoil management from the dredged rivers is also taken into consideration in the action plan. Hence, properly planned dredging of the river beds can be of huge positive impact to the national economy, by retrieving the rivers to their natural flows as well as using industrial minerals. The natural flow of rivers will largely reduce several major environmental problems of Bangladesh.

River sediments are rich in silicate minerals. In Bangladesh, most river sediments contain around 80-85% quartz and feldspar (Jasy et al., 2010). Fresh quartz (SiO_2) is the raw material for glass production, which contains 95.0 to 99.9% quartz depending on various good quality glasses. The percentage of SiO_2 varies in different qualities of glass with varying proportion of iron, aluminum, calcium and magnesium oxides (Norton, 1957). Upgradation of silica percentages in regular river bar sands of Bangladesh by physical separation were carried out and successfully compared with a few glass sand deposits (Rajib et al., 2009; Hossain et al., 2013). Laboratory scale glass production by such upgraded silica sand was possible as well (Rafi et al., 2018). Moreover, silicon chip production from placer silicon is also reported, provided that SiO_2 percentage can be upgraded in an appropriate quantity (Marshall, 2016). In view of those potentials, the objective of the present study was to upgrade river silica by widely used density, magnetic and electric separation techniques. In addition, characterization of those upgraded silica as an alternate of glass sand to produce glass was also attempted. Possible environmental consequences were discussed based on the potential commercial extraction of river sands.

2. METHODOLOGY

Bangladesh, a small country of 144,000 km^2. located at the tip of Bay of Bengal. The country is comprising of mostly deltaic sediments coming from the GBM river system. Padma (Ganga is the name at the upstream part in India) is one of the main rivers of the country entering from west to meet with Meghna at the middle part of the country. Gorai is the tributary of the River Padma, separating at the middle of its course in the country (Figure 1).

River dredging is a must for all major rivers of Bangladesh, especially for keeping the navigation route alive. As stated earlier, dredged materials are kept within the river banks (Figure 2), therefore, requires continuous dredging for success. Sand samples were collected from several major rivers of

Bangladesh (Figure 2(a), 2(b), and 2(c)) where bar deposition is quite frequent and dredging is being done continuously. Those bars are very much temporary deposition and inundates every year during rainy season. In next monsoon, they erode by flood water, and deposits again to become exposed during summer. Such phenomena can be found in both braided and meandering rivers which eventually narrow down the natural navigability.

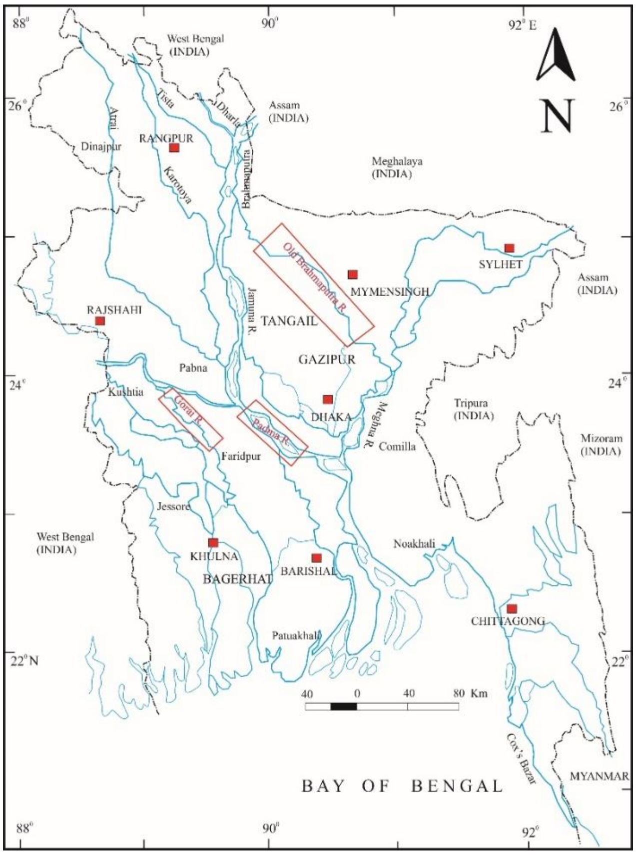

Figure 1. Location of sampling areas, as shown by red rectangles, in the context of major rivers of Bangladesh. Here, the Brahmaputra is designated as 'old' as the course is shifted during a major earthquake in 150 years ago. The current course of Brahmaputra is named as Jamuna.

Approximately 200 kilograms of raw sand samples were collected from near surface deposition, approximately within a meter by hand auger, indicating the recent most sand deposition (Figure 2(f)). The total number of samples was 10. Six samples were from Gorai River covering 14 kilometers from upstream to downstream. The other four samples were from Brahmaputra and Padma Rivers. The sand augers are of 5 feet length with a designed bottom part to collect disturbed samples as it goes down. A column of 3-5 feet sands was collected from each point, which were mixed properly to get representative samples for laboratory separation.

Samples were first washed to remove the clay materials and later sieved through 400 and 63 µm mesh size to get rid of grains other than sands. This discarded fraction includes most of the larger grains of flaky micaceous minerals. Thereafter, shaking table, induced roll magnetic separator (IRMS) and electrostatic plate separator (ESPS) were used as gravity, magnetic and electric separators, respectively, for the enrichment of silica content. Figure 3 represent the standard method of separating heavy and light minerals from placer sands which has long been used in various countries like Australia, India, Brazil, etc. A pilot plant with a quality control laboratory is set up based on this separation procedure at Beach Sand Minerals Exploitation Centre of Bangladesh Atomic Energy Commission at Cox's Bazar, the major tourist place at the coastal district of Bangladesh. The variables of the separators were adjusted according to results obtained as checked by a standard binocular microscope for the quartz percentage in the sample. Such procedure was successfully applied to upgrade silica from river sand in a previous study (Rajib et al., 2009).

(a)

(b)

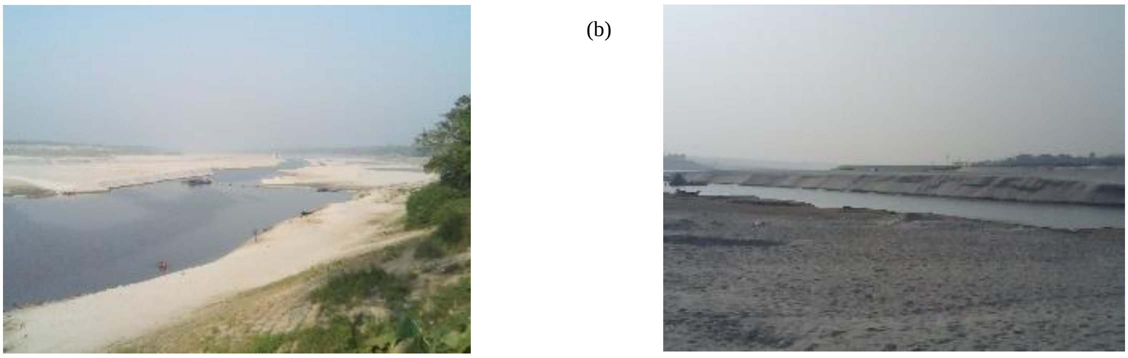

Figure 2. Bar sediments at the middle of major rivers of Bangladesh at (a, b, c) Gorai and (d) Padma rivers during summer. The pictures also represent the dredged sands are kept just beside river which returns to the dredging place in monsoon. Very bright colored sand at Gorai River (e) represents high amount of quartz or silica. Sampling with hand augers (f) is a standard method of collecting sand from shallow depth.

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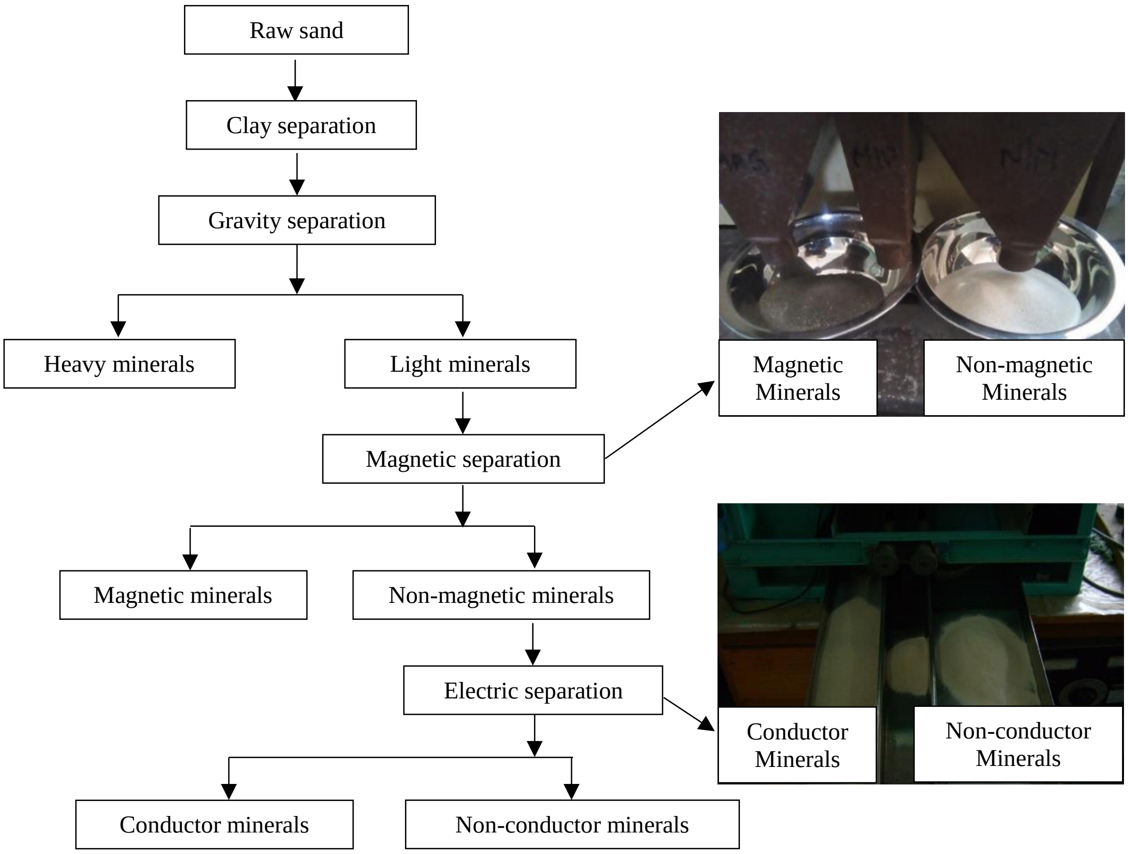


Figure 3. Generalized flow chart of the physical separation of river bar sand. The photographs show (top) white colored silica and feldspar rich part separated from dark colored magnetic minerals at magnetic separator and (bottom) white colored magnetic minerals were separated using electric separators to obtain silica-rich fractions at non-conductor part.

3. RESULTS

Silica content of river sand samples from several rivers, around 60-70%, could be enriched significantly by following a standard flow chart of physical separation procedure (Figure 3). The upgraded silica was analyzed for the grain size distribution and found to be mostly (97-98%) of more than 150 µm size (Table 1). Chemical composition (Table 2), determined by the commercial wet process revealed 86-88% SiO_2 with reasonably low percentages of oxides of K, Na, Fe, Ca, Mg, and Ti. However, alumina content was found to be significantly high (more than 7.5%). The recovery of upgraded silica from bulk sand was approximately determined as 65-70%.

Table 1. Grain size distribution of upgraded silica

Sample area	>350 mesh (%)	>150 mesh (%)	<150 mesh (%)	Total
Gorai sand	0	97.43	2.57	100.00
Padma sand	0	98.81	1.19	100.00

Table 2. Composition of upgraded silica sand by commercial wet process

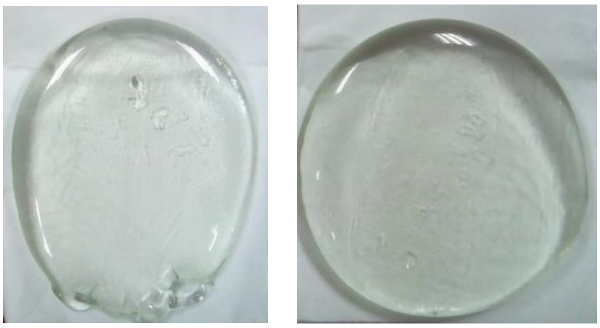
Testing parameters	Gorai sand	Padma sand
SiO_2	86.68	86.96
Al_2O_3	7.65	7.58
CaO	1.78	1.58
MgO	0.29	0.34
Fe_2O_3	0.14	0.12
Na_2O	1.14	1.13
K_2O	1.23	1.22
TiO_2	0.051	0.078
Cr_2O_3	0.00124	0.00135
LOI	1.03	0.97
Total	99.99	99.98

Values in %; LOI-loss on ignition

Glass making with this upgraded silica were successfully attempted with slight modification of standard composition. The newly made glass was found to be free from bubbles and any un-melted grains which are two of the most important criteria of quality glass production (Figure 4).

4. DISCUSSION

Beneficiation of dredged materials from river sediments is not new, especially for the production of rare earth elements (REEs) containing minerals [e.g., Moscoso-Pinto and Kim (2021)]. Placer sands from the beach depositions are more common for this purpose (Kumari et al., 2015; Jordens et al., 2013). Although, utilization of light minerals, especially silica sands for any commercial purpose is not so common, except those from quartz sand or glass sand deposits (Pisutti et al., 2009).



Gorai glass   Padma glass

Figure 4. Laboratory production of glass from the upgraded river-born silica with various composition

The physical upgradation of silica from bar sediment was successful using various separators. After separating from bulk sands using gravity separators, light minerals are taken for further magnetic separations under electro-magnetic field suitable for dark colored minerals remaining from heavy minerals. For Bangladesh rivers, the non-magnetic part mostly composed of quartz and feldspar which needs to be further separated using electric separators under various electric field. The non-conductor part is supposed to be mostly quartz, although the conductor part also contains substantial amount of quartz grains due to their very close nature with feldspar, as shown in Figure 3 by similar color fractions at electric separation. The composition of the upgraded silica (from non-conductor minerals fraction) with the presence of very low Cr is comparable with a few quality glass producing sands of Bangladesh (Islam, 1985; Islam, 1986; Imam, 1996). Approximately 98% of the upgraded silica sand was also found to be more than 150 mesh (i.e., appx. 90 µm size) which is also within the range of a few glass producing sand grades (Rajib et al., 2009). The industrial grade glass sands generally use within the range of 100-600 µm grains, whereas, silica sands in one glass sand deposit of Bangladesh shows the size of 100-500 µm (Islam, 1985). The upgraded silica sand from Gorai River was found to be 100-300 µm in size which is even better sorted for industry operation for glass production.

As far as the chemical composition of industrial grade glass sand is concerned, the upgraded river silica is lacking in few parameters by quite a good margin. For example, the minimum quantity of SiO_2 needed for average quality glass production is around 95% (Norton, 1957). The glass sand deposits of Bangladesh from where local industries are collecting sands have more than 90% in-situ silica content. However, laboratory scale upgradation was possible from Gorai River sand previously (Rajib et al., 2009). Although glass production was not possible due to the small quantity of samples, the present attempt of utilizing larger quantity sands ended with less quantity SiO_2 content, but successful glass production. The reason for different chemical composition with less silica and high alumina content could be due to difference in measurement procedure. For example, previous work was entirely a laboratory scale analysis and therefore recycling of sample was possible due to small quantity sample. Sample recovery percentage was not considered significantly. The chemical composition was analyzed by X-ray fluorescence spectrometry. On the contrary, the present study was aimed to analyze the commercial aspects where glass production possibility with reasonable recovery percentage was considered. Therefore, samples were not recycled, which yielded less silica content. Moreover, these sands are deposited just from last year's flood, which may have changed composition from the previous study.

Although the obtained results are not suitable for the best quality of glasses, as sought by the most glass companies, however, they could be useful for producing intermediate quality glasses with high alumina content which may have economic use. For example, in typical float glass compositions, the oxides of silicon, sodium, calcium and magnesium account for around 98% of the glass [SiO_2: 72.6%, Na_2O: 13.6%, CaO: 8.6%, and MgO: 4.1%, as stated in Glass for Europe (2020)]. In that context, the studied upgraded silica is well behind in total composition, although, only silica content is well above the margin. However, a method for preparing aluminate glasses and glass-ceramic composites opens up new possibilities for generating mechanically strong structural components and high-hardness coatings (McMillan, 2004). Therefore, the present upgraded silica with high natural alumina content might have a good potentiality in glass making industry. Although, high silica content may decrease the density and phase transition temperature of the glass with minimum thermal expansion (Deshpande and Deshpande, 2009).

In addition to silica content, river sands of Bangladesh generally contain other valuable heavy minerals of significant quantity, approximately 4.5-17.0 wt% (Rahman et al., 2014, Rahman et al., 2016). During the process of industrial production of glass making silica sand, those heavy minerals could be important by-products. In Bangladesh, individual heavy mineral separation from such types of river sands has already been found successful (Rahman et al., 2015).

The deposition of bar sediments every year on both sides of the rivers makes significant morphological changes at the fluvial environment. This environment is very important for natural navigability of the river throughout the year. However, because of excessive sand deposition, most of the rivers are inaccessible for river transport, even in rainy season due to lack of water depth. As a result, each year, a huge amount of financial involvement is necessary simply for dredging to obtain minimum navigability. The Bangladesh Water Development Board has estimated that the capital dredging and river management works of the country would involve over 36 billion m^3 of dredging in 23 big rivers needing a budget of nearly BDT 1 million Crore. The government of Bangladesh is planning a 50-year mega plan of capital dredging to bring back navigability in rivers, including the Padma, the Meghna and the Jamuna, and reports that approximately BDT 31,000 would be needed which short, mid and long term phases. As stated earlier, Bangladesh's rivers carry approximately 2 billion tons of sediments in their waters every year, a significant portion of which can be utilized as mineral resource by proper planning and execution. The dredged materials are mostly composed of silicate minerals, especially quartz and feldspar along with various dark colored heavy minerals. Various physical separation techniques can be utilized for the beneficiation of both silica and heavy minerals from those river-born silicate minerals (Figure1). At the Bangladesh Atomic Energy Commission (BAEC) price of Tk. 10,000 per ton of magnetite or ilmenite to up to Tk. 60,000 per ton of zircon, those minerals in river sediments could be worth several thousand crores. For example, BAEC estimated the economic heavy minerals reserves at beach areas of Bangladesh of about 1.76 million tons which has a present market price of nearly 2,000 crore taka. Considering the volume of river dredged materials and amount of economic minerals in them, separation of minerals could be economically feasible. Besides, the ecological environment of the riverine area is also significantly changed due to the huge deposition of silts and sands.

Therefore, if such beneficiation of river silica could be commercially possible, it will facilitate the use of a huge quantity of river sands of the country. Mining of these silica sands from river beds and bars will also minimize the dredging cost which is a must in almost every major river of the country. Automatic dredging will enable the river navigation as well as maintaining the environmental balance of the flood plain. Increasing the navigability of the river would also reduce the flood risk and bank erosion which are major problems during monsoon season at several rivers. These would not only work as value addition, but also contribute to various aspects of SDGs and the Delta Plan-2100 of Bangladesh. Moreover, different other valuable heavy and light minerals, which have variety of industrial uses, can be produced as byproducts from the upgradation processes. Removal of those excess sands from river banks could have therefore significant importance for the overall socio-economic development of the country.

5. CONCLUSION

The study presents the beneficiation of a waste materials which could turn out to be a potential natural resource in the river depositions. The rivers in Bangladesh carry ample sediment for dredging and dispersion on the flood plains. These sediments are mostly sand sized and not only full of very economic mineral like quartz or silica but also include heavy minerals like ilmenite, magnetite, garnet, pyroxene, hornblende, and zircon, etc. All these minerals have familiar industrial uses. Hence, the river bars, formed by the excessive sedimentation, are full of natural resources which need to be properly studied. Upgraded silica from those river bar sediments was successfully utilized in producing glass with a small batch (less than 1,000 gm). Therefore, bench scale glass production (with approximately few tens of kg) is necessary before going for any pilot-plant scale experiment. Industrial use of such type of silica sand to produce different types of glasses will lead to the discovery of alternate glass sand deposits in Bangladesh. In addition, commercial utilization of a ‘rejected’ or waste material would boost the local industry as well as convert the enormous deposit of river sediment to a natural resource. Besides, proper solution of excessive sedimentation problem by dredging and re-excavation of rivers will benefit Bangladesh and similar countries in many other ways, e.g., reducing the severity of flood, retrieving navigation routes, natural resource recovery, reducing groundwater vulnerability risk, creating natural shield against sea level rise due to climate change, saline water intrusion, and overall ecological balance. Therefore, having an enormous source of river bar sediments in most of the major rivers in the country, Bangladesh could have potential resources of industrial grade, provided the proper management of the materials.

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CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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