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Construction pollution in Brunei

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Abstract. Despite its considerable contribution to the economy of a country, construction industry is held responsible for degrading sustainability in general, and environment in particular, in many ways. For example, it consumes about 40% of global resources and, generates almost half of all the pollution. However, their nature and degree may vary according to the type and scale of the projects, and often can be area or country specific. Especially, no research seems to have been conducted previously in Brunei Darussalam for identifying pollution from construction. Therefore, this study was undertaken to identify sources of construction related pollution and their mitigating strategies. However, this paper focuses only on sources of pollution and summarizes the outcomes from a questionnaire survey of 107 responses, comprising clients, contractors and consultants. Five groups of pollution were identified, with various sources within each group: air pollution that includes dust and GHG (greenhouse gas), water pollution, noise pollution, and solid waste. All the sources were observed to have different degrees of criticality, i.e. either critical or more critical, implying a general critically of the identified sources of pollution. However, the focus seems to be on developing an industry wide awareness towards pollution, with contractors to play key role to pollution and relevant activities, probably due to their engagement in executing construction at sites. The next step of the study is to further investigate for a holistic solution, while the outcomes are expected to help policymakers to develop and/or take appropriate measures to control pollution.

1. Introduction

Construction industry plays important role in a country's economy. In addition to build shelter for people and infrastructure, it contributes about 6% to 10% to the gross domestic product of a country [1] and engages about 10% of the young, healthy and stout workforce [2]. However, construction industry has also negative impact in a number of ways, including consumption of about 40% of the global resources [3], production of higher volume of wastes and debris [4] and generation of about half of all the air pollution, including one-third of all CO₂ emissions [5]. These are blamed to increase the ecological loading on the environment and/or Mother Nature and threaten human health. The nature of such pollution from construction varies from country to country, as the type and scale of construction projects may significantly vary. As such, researchers continue to more specifically identify pollution relating to construction of a specific country or area. However, to the knowledge of the authors, no such research was previously undertaken in Brunei Darussalam, as such, this study was undertaken to identify different kinds of pollution originating from construction activities and their



potential mitigating strategies. However, this paper very briefly reports the outcomes of a questionnaire survey on the sources of pollution only, due to space restrictions.

2. Literature review

Literature review suggested five broad groups of construction related pollution [6], namely:

- air pollution: dust, with 12 sources;
- air pollution: greenhouse gas (GHG), with six sources;
- water pollution, with 11 sources;
- noise pollution, with six sources; and
- solid waste, with 12 sources.

All these sources are shown in their entirety in table 1 to table 5. Air pollution contaminates the environment and changes the natural characteristics of the atmosphere by producing dust and generating GHG [7]. Soil related activities like site cleaning and levelling, and materials related activities like transportation and staking/unstacking, are more common sources of dust [8]. GHG emission is related to energy consumption by equipment and vehicles in construction, e.g. in manufacturing and transporting construction materials, transportation of construction equipment and workers, and disposal of waste [9-10]. Soil erosion is the main cause of water pollution, originating from various solvents, paints and spilled out oils on the soil surface of construction site, and washed away by rain water to water bodies [11].

High noise is common at construction sites, which is originated from powered and heavy mechanical equipment (e.g. bull dozer and excavator) operating on various construction activities like blasting, pile driving and pavement breaking [12-13]. Wastes are generated from retrofits, demolition as well as from new construction. As such they have relations with the way buildings/structures are designed, constructed and operated; materials are handled and the residuals are dealt with [14-15].

3. Research methodology

The objectives of this paper are to identify and prioritize the construction related sources of pollution. As mentioned before, five broad groups of construction related pollution and their various sources were extracted from literature. These were then consulted with two industry experts and adjusted on the basis of feedback received. A questionnaire was then designed using the adjusted items of sources, as shown in tables 1 to table 5. Section 1 of the questionnaire included an ‘introduction’ clarifying the aim and objectives of the questionnaire survey. Section 2 was designed to collect information of the respondents, to allow survey sample composition. Section 3 requested information on various items of sources under five broad groups of construction related pollution. Additional spaces were provided at the bottom of each group requesting respondents to add any additional factors, if they think suitable, and to assess the same. Moreover, blank space was also given at the end of the questionnaire, as section 4, to allow respondents to provide any comments on construction pollution in general. Respondents were requested to assess each of the sources, in terms of their frequency of occurrence and impact, both on a scale from 1 to 5: 1 being ‘the least frequent / important’ and 5 being ‘the most frequent / important’.

A total of 107 responsive responses were received from 32 clients, 47 contractors and 24 consultants (and 4 did not mention their affiliation) working in Brunei, with an average total work experience of 12.6 years, and average experience in construction of 11.3 years. This may indicate the quality of the data, as they are considered to reflect the experiential knowledge of the respondents. All such responses received were then converted in to ‘frequency index’ (FI) and ‘importance index’ (II), as suggested by Lim and Alum [16]:

Frequency (or Importance) Index (FI or II)

$$= (5n_5 + 4n_4 + 3n_3 + 2n_2 + n_1) / \{5(n_5 + n_4 + n_3 + n_2 + n_1)\} \quad (1)$$

where, n_1 the number of respondents who scored 1,
 n_2 the number of respondents who scored 2,
 n_3 the number of respondents who scored 3,
 n_4 the number of respondents who scored 4, and
 n_5 the number of respondents who scored 5.

The above two indices were then converted in to an overall index called “Criticality Index” (CInd), by multiplying FI and II. The CInd was then used to rank the overall implication of each source or factor within their respective groups of pollution.

$$\text{Criticality Index (CInd)} = \text{FI} \times \text{II} \quad (2)$$

As used in this paper, FI and II:

- ≥ 0.8 (or 80%) was considered ‘most frequent / important’,
- between 0.80-0.70 (i.e. 80%-70%) ‘more frequent/important’,
- between 0.7-0.6 (i.e. 70%-60%) ‘frequent / important’,
- between 0.6-0.4 (i.e. 60%-40%) ‘less frequent/important’, and
- ≤ 0.4 (i.e. 40%) ‘least frequent / important’ or negligible.

For Criticality index (i.e. CInd):

- ≥ 0.64 (i.e. 64%) most critical,
- between 0.64 - 0.49 (i.e. 64%-49%) more critical,
- between 0.49-0.36 (i.e. 49% - 36%) critical,
- between 0.36-0.16 (i.e. 36% - 16%) less critical, and
- ≤ 0.16 (i.e. 16%) less critical or negligible.

Space does not permit comparisons of rankings between different groups of respondents. Therefore, following sections summarise the results from the total sample only.

4. Sources of dust pollution

Table 1 summarizes the results of the sources of dust pollution. It shows that dust from spoils originating from ‘earthwork excavation’ is the most critical (rank 1) source of dust pollution with Criticality Index (CInd) of 46.53%. Although not shown here, this is composed of Frequency Index (FInd) of 65.83% (rank 1) and Importance Index (IInd) of 70.69% (rank 2). The latter led the factor ‘blasting/demolition activities’ to be the second most critical (rank 2) source of dust pollution, although it had FInd of only 60.00% (rank 7). The next critical sources of dust pollution are ‘transportation of soil’ (rank 3), ‘transportation of construction materials’ (rank 4), and ‘exposed stacks of construction materials’ (rank 5). The latter two had higher FInd (rank 2 and rank 3, respectively), but relatively low IInd (rank 9 and Rank 8, respectively). ‘On-site manufacture of materials’ is the last but one critical source of dust pollution (rank 11), with ‘on-site stacking of materials – during the stacking process’ at the bottom of the table. This last one is also the only source that is categorized as ‘less critical’ with the CInd of 35.06%. The other eleven sources of this group of dust pollution are seen to be within the range of 0.49-0.36 (i.e. 49% - 36%), therefore they all are critical; although some of the sources had FInd of ‘more frequent’ category. Further examination showed that the last source of dust pollution had frequency index of 57.28%, i.e. less frequent, although its impact was ‘important’ with the importance index of over 61%.

5. Sources of GHG emission

Table 2 summarizes the results of six identified sources of GHG pollution that are related to construction. ‘Disposal of construction waste’ and ‘use of construction equipment/vehicles’ are the two top-most sources of GHG emission. These two sources are also categorized ‘more critical’ since their criticality indices are within 49%-64%. The other four sources are within the category of

‘critical’, with transportation of construction equipment, and transportation of workers and materials rank 3 and rank 4 respectively. Embodied emission from materials is seen as the lowest critical in this group of sources of pollution, but as mentioned above, still is a ‘critical’ source of GHG emission. Although not shown here, further analysis showed that the top three critical sources had IInd of ‘more frequent’ category, and the other three sources had IInd of ‘frequent’ category. On the other hand, five sources had FInd of ‘frequent’ category, and only source had FInd of ‘less frequent’ category.

Table 1. Sources of dust pollution.

SI. No.	Factors relating to dust pollution	CInd*	Rank
02	Earthwork excavation e.g. dusts from spoils	46.53	1
09	Blasting / demolition activities	44.48	2
01	Transportation of soil e.g. from overloading & subsequent fall /downslide	42.86	3
06	Transportation of construction materials	41.87	4
12	Exposed stacks of construction materials, e.g. sand, soil, gravel, etc.	40.66	5
03	Backfilling	40.36	6
05	On-site stacking of construction waste	40.23	7
10	Transportation of demolition waste	37.39	8
04	Land or site levelling	37.3	9
11	On-site stacking of demolition waste, as frequently kept uncovered	36.43	10
07	On-site manufacture of materials	36.08	11
08	On-site staking of materials, during the stacking process	35.06	12

* CInd: Criticality Index

Table 2. Sources of Greenhouse Gases (GHG) emission.

SI. No.	C3) Factors relating to Greenhouse Gases (GHG) emission	CInd *	Rank
05	Disposal of construction waste	50.08	1
02	Use of construction equipment / vehicles	49.35	2
03	Movement / transportation of construction equipment	46.11	3
04	Transportation of workers and materials	45.45	4
06	Miscellaneous on-site energy use: lighting, soldering, cooking, A/C, etc.	41.35	5
01	Embodied emission from materials (every material needs energy for its use in construction, and any kind of energy usage generates GHG / CO ₂)	38.65	6

* CInd: Criticality Index

6. Sources of water pollution

Table 3 shows the 11 factors or sources of construction related water pollution. Four sources are seen as ‘more critical’, since their CInd are between 49%-64%. The other seven sources are ‘critical’, as their CInd are between 36% - 49%. Soil erosion from construction/site clearing activities is seen to top the table, with a criticality index of 54.72%. This is followed by sedimentation from earth clearing activities. The indices of the next two sources are very close: ‘harmful’ chemicals from construction activities, and storm water runoff carrying wastes and contaminants. ‘Discharge of waste in to water bodies’ and ‘time-consuming construction methods’ rank 5 and 6 respectively. ‘General construction activities’ and ‘dumping of construction waste in waterbody’ appears to be the last two sources of construction related source of water pollution. On the whole: five sources are ‘frequent’, and other six sources are ‘less frequent’; compared to two ‘most important’ sources and nine ‘important’ sources of

construction related water pollution. It can therefore be said that the factors related to water pollution are of low frequency, but their impact is much higher if they occur.

Table 3. Sources of construction related water pollution.

SI. No.	Factors relating to WATER pollution	CInd *	Rank
01	Soil erosion from construction / site clearing activities	54.72	1
02	Sedimentation from earth clearing activities and resulting erosion	54.42	2
08	Oil, debris, paint and other harmful chemicals from construction activities	49.36	3
03	Storm water runoff carrying wastes and contaminants	49.09	4
04	Discharge of waste in to water bodies (non-solid)	45.51	5
11	Traditional/ time consuming construction methods (exposing to more rain, more run-off, more sediments, etc.)	45.3	6
10	Sewage effluent discharge during grouting	42.94	7
07	Waste water from washing 'dust suppression sprays' to equipment	42.03	8
05	Waterborne toxicity, originating from / relating to construction	41.35	9
09	General construction activities (spillage of stored liquid)	40.83	10
06	Dumping of (solid) construction waste in waterbody	39.42	11

* CInd: Criticality Index

7. Sources of noise pollution

Among the six sources of noise pollution relating to construction, as seen in table 4, two sources are 'more critical' with CInd in between 64% - 49% and four sources are 'critical' with CInd in between 49% - 36%. 'Fixed construction equipment/machine' like concrete mixtures and excavators tops the list with CInd of 53.12%. This is composed of FInd of 70.0% (rank 1) and IInd of 75.88% (rank 1). 'Earth moving/ site clearing equipment' like dumpers and bull dozers is the second in the list with CInd 50.94%, which is composed of FInd of 67.96% (rank 3) and IInd of 74.95% (rank 2). Criticality indices of the next three sources are close, with 'office cars/vehicles for staffs, workers and visitors' at the bottom of the table. On the whole, five sources are seen as 'frequent' and only one source as 'more frequent'. On the other hand, impact of three sources are 'more important', two sources are 'important' and only one source is 'less important'. Thus, the frequency and importance of the factors are of mixed category.

8. Sources of solid waste

Table 5 summarizes the results of 12 sources of construction related solid waste. It shows that four sources are 'more critical' as their CInd in between 49% - 64% and the other eight sources are 'critical' for their CInd in between 36% - 49%. 'Contractors' lack of awareness towards the importance of waste' tops the table (rank 1) with CInd 53.83%, which is composed of FInd of 66.14% (rank 1) and IInd of 81.39% (rank 1). This is followed by their 'lack of environmental awareness' (rank 2, CInd = 52.75%), 'left over materials' (CInd = 49.4%, rank 3), and 'lack of waste management plans' (CInd = 49.02%, rank 4). All these seem to be the key to sustainable management of construction waste. 'Lack of appropriate site management / plan' (rank 5, with CInd = 47.55%), 'waste from construction operation' (rank 6, with CInd = 45.92%) and 'random dumping of materials' (rank 7, with CInd = 45.61%) are in the middle of the table. 'Waste from materials handling' (rank 11, with CInd = 39.57%) and 'non-standard design' (rank 12 with CInd = 37.23%) take the last two places in the table. According to FInd, six sources are 'frequent' and other six sources are 'less frequent'. On the other hand, two sources are 'most important' and the other ten sources are 'more important', as per the observed IInd. It can therefore be said that the impact of the factors are much higher than their rate

of occurrences. Also, overall result of this group of construction-related pollution is probably the most meaningful; as 44 % (i.e. 47 out of 107) respondents are contractors, and they are highlighting their own shortcomings and lapses. This may be considered to reflect the actual situation in the industry that contractors do not take initiatives of their own, but they are mostly driven by clients, at least in Brunei construction industry.

Table 4. Sources of construction related noise pollution.

Sl. No.	Factors relating to NOISE pollution	CInd*	Rank
01	(Fixed) Construction equipment/machines: concrete mixers, excavators, etc.	53.12	1
02	Earth-moving/site clearing equipment/vehicles e.g. dumpers, bull dozers, etc.	50.94	2
03	Moving vehicles, e.g. for carrying materials, wastes, etc.	48.18	3
04	Materials handling, e.g. loading, unloading, stacking, etc.	46.57	4
05	Miscellaneous works at site, e.g. soldering, rod cutting/bending, washing...	45.94	5
06	Office cars/vehicles of staffs, workers and visitors	38.03	6

* CInd: Criticality Index

Table 5. Sources of solid waste.

Sl. No.	Factors relating to solid waste	CInd *	Rank
08	Contractor's lack of awareness towards the importance of waste	53.83	1
12	Lack of environmental awareness by contractor	52.75	2
07	Left-over materials, e.g. after construction	49.4	3
10	Lack of waste management plans	49.02	4
11	Lack of appropriate site management / plan, e.g. location of stack yard	47.55	5
06	Waste from construction operation, e.g. site clearing and earth moving	45.92	6
01	Random dumping of materials (e.g. concrete & mortar) in the surroundings	45.61	7
02	Non-standard disposal, e.g. tires, bitumen barrels, residual asphalt/paints...	41.2	8
09	Improper inventory management, e.g. ordering more	41.02	9
04	Design errors or late changes, requiring demolish and/or changes in materials leading to waste	40.59	10
05	Waste from materials handling during staking, loading and unloading	39.57	11
03	Non-standard design, using non-standard size of materials	37.23	12

* CInd: Criticality Index

9. Concluding observations

This paper has very briefly presented the outcomes of a questionnaire survey from Brunei that targeted identifying and prioritizing the various sources of construction related pollution. From among 47 sources of construction related pollution, only one source has been found to be 'less critical': on-site staking of materials, during the stacking process, which is in the broad group of dust pollution. On the other hand, 12 sources have been identified as 'more critical' in terms of their criticality indices. The remaining 34 sources have been observed to be 'critical', in four groups of pollution. The group of dust pollution has no source in the category of 'more critical' or higher. On the whole, the identified sources are mainly seen in the category of 'critical' or 'more critical'. It is expected that the results will help the policymakers to devise suitable policies to mitigate construction-related pollution.

Space restriction did not permit comparison of ‘opinions’ by different groups of respondents, e.g. clients, contractors and consultants, as well as between the respondents of different ‘nature of job’ like managerial vs. engineering. This would certainly allow meaningful insights. Nevertheless, the results do imply the relevance of the identified sources. The paper, in the least, has also demonstrated a methodology of extracting sources of pollution from literature, and ratified them by industry experts. Results from this study may not be generalized to other industry/country, but the methods can be easily followed to identify country or region specific sources of pollution. The next step of the study is to further seek a holistic solution.

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