

Aggregate flows and their implications on the environment: a preliminary assessment

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Abstract: Economic growth has propelled infrastructure development in Selangor and increased the demand for construction aggregates. Uncontrolled extraction of natural aggregates is depleting existing reserves, which is not sustainable for future development. Aggregate resource management is not holistic and systematic, as the resource is believed to be easily available and abundant. An assessment of the flow of aggregates, with respect to its utilization from extraction to disposal and taking into account dissipative losses to the physical environment, will be useful for formulating strategic interventions and managing this non-renewable resource in an effective manner. Preliminary results obtained using Selangor as a case study are encouraging, but there is much work to be done to address information gaps and develop a complete picture of the aggregate flow.

Abstrak: Pertumbuhan ekonomi telah menyumbang kepada pembangunan infrastruktur di Selangor dan meningkatkan permintaan untuk bahan binaan agregat. Pengeluaran sumber agregat secara tidak terkawal menyumbang kepada pengurangan sumber asli tersebut dan ini dijangka menjejaskan pembangunan secara lestari. Pengurusan sumber agregat tidak dilakukan secara holistik dan sistematik kerana agregat mudah diperolehi. Penilaian kitaran agregat berdasarkan aspek penggunaannya iaitu daripada pengeluaran kepada pembuangan dengan mengambilkira kesan terhadap alam sekitar fizikal, akan membantu pengurusan sumber ini secara lebih berkesan. Hasil awalan yang diperolehi daripada kajian kes di Selangor amat menggalakkan. Namun demikian lebih banyak maklumat diperlukan untuk memperolehi gambaran kitaran agregat yang lebih sempurna.

INTRODUCTION

Aggregates in general are defined as particles of rock which, when brought together in a bound or unbound condition, form part or the whole of an engineering or building structure (Smith and Collis, 2001). Aggregates in the construction industry are either crushed and combined with a binding agent to form bituminous or cement concrete, or treated alone to form products such as railroad ballast, filter beds or fluxed material (Langer, 1988). Portland cement and asphalt are the main form of binding agents for concrete. Concrete may be defined as a mixture of water, cement or binder, and aggregate, where water and cement or binder forms the paste and aggregate forms the inert filler (Smith and Collis, 2001). Aggregate is the major constituent of concrete, totalling up to 60-80% of its absolute volume.

Quarrying activities in Malaysia have produced various sizes and types of aggregates from crushed rock materials, with granite and limestone being the most common (JMG, 2002). The aggregates are used mainly in the construction industry. At the moment, aggregate resources are not managed in a systematic manner. They are extracted on demand, as the resource is believed to be easily available and abundant. There has been no comprehensive investigation regarding the impact of ongoing and proposed urban expansion on the long-term availability of aggregate resources. An assessment of the flow of aggregates, with respect to its utilization from extraction to disposal will be useful for formulating strategic interventions and managing

this non-renewable resource in an effective manner. This paper provides a brief overview of aggregates and the construction industry including aspects of aggregate waste management. A framework for analysing aggregate flows and preliminary assessment of environmental issues associated with this flow is then presented, using Selangor as a case study.

AGGREGATES AND THE CONSTRUCTION INDUSTRY

Aggregate Flows

Growth in economic and industrial development increases the demand for construction aggregates. This demand leads to increased extraction of aggregates for construction activities and contributes to increased environmental degradation as well as depletion of natural aggregate resources. In order to develop in a sustainable manner, existing aggregate reserves have to be accounted for with respect to its ability to meet future demand. In this context, there is need to map the material flow of construction aggregates.

Figure 1 shows the general flow of construction aggregates in the United States. In the United States, the supply of aggregates are derived from two sources, natural aggregates comprising crushed rocks from mining activities and recycled aggregates. The need for recycled aggregates to supplement natural aggregates (especially in road

construction) has increased because the available supply is much less than the total demand for aggregates. Aggregate recycling rates are greatest in urban areas where replacement of infrastructure occurs, natural aggregate resources are limited, disposal costs are high, or strict environmental regulations prevent disposal. The use of recycled aggregates, especially from demolition wastes, economically meets the needs of the market (Wilburn and Goonan, 1998).

In Taiwan, Teng *et al.* (2001) have also mapped the material flow of construction aggregates with regard to the Taiwanese economy to evaluate the economic and technical feasibility of large scale recovery of waste resources (Fig. 2). The map came into consideration after Taiwan, a densely populated island nation, faced the double plight of aggregate shortage as well as increasing amounts of construction waste. The utilization of construction waste became more important following spikes in the supply of waste concrete from large-scale seismic events. For example, Taiwan's 1999 Chi-Chi earthquake generated over 10 million m³ of solid waste, which represents the bulk of demolition waste, and it was suggested that about 60% of this could be recycled or reused.

Aggregate Waste Management

The exploitation of aggregates should be sustainable, prudent and efficient in order to minimise impacts on the environment whilst maximising the beneficial use of natural resources. Sustainable construction demands that where it is practicable and technically possible, opportunities for producing aggregates from recycled and secondary sources should be maximised (Smith and Collis, 2001).

Recycling represents one way to convert a waste product into a resource. It has the potential to extend the life of natural resources by supplementing resource supply. It also reduces environmental disturbance around construction sites and enhances sustainable development of natural resources. Certain construction waste materials that are generated by construction projects may have on-site uses. In developed countries, reuse of aggregates in road pavements and sub-base is widely practised. Insufficient natural resources supply in urban areas has widely promoted recycling of demolition wastes.

In the United States, recycled aggregates supplement natural aggregates where extraction of natural aggregate resources (primarily crushed stone and sand and gravel)

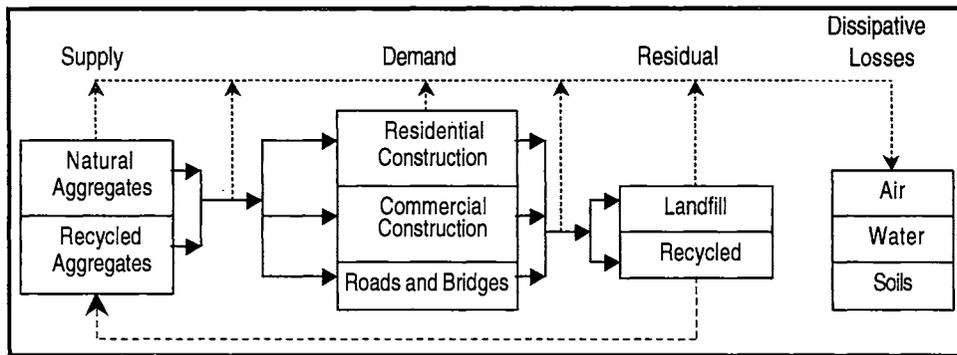


Figure 1. Construction aggregates flow system in the United States (after Wilburn & Goonan, 1998).

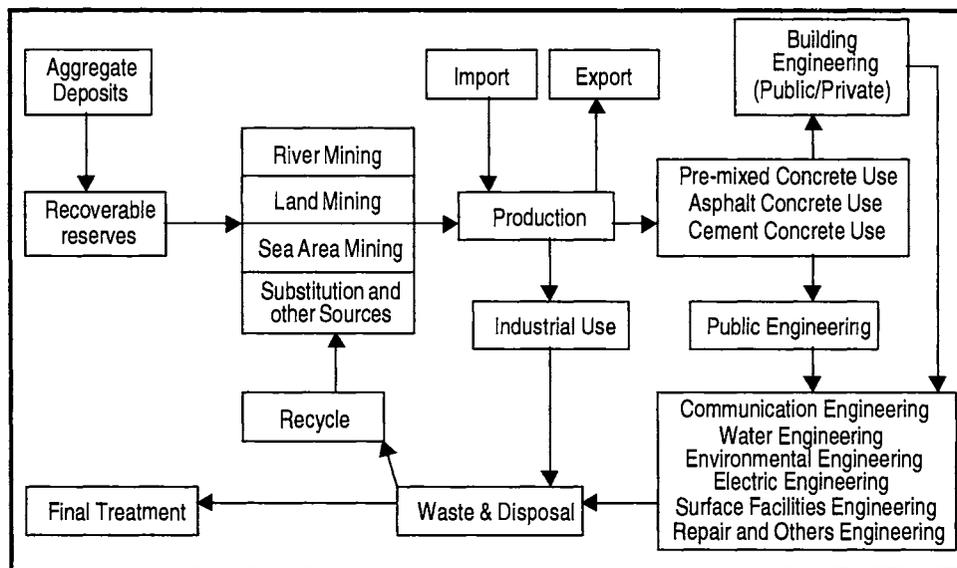


Figure 2. The framework of material flow analysis for construction aggregates in Taiwan (simplified after Teng *et al.*, 2001).

are increasingly being constrained by urbanization, zoning regulations, increased costs and environmental concerns (Wilburn and Goonan, 1998). Materials recovered either on-site or from process facilities are marketed externally to other construction projects. These different types of materials are graded to determine their recycling or reuse opportunities (Savage, 2002). Recycling facilities for construction and demolition wastes are well established, with almost 1200 facilities in the country. Concrete processing involves crushing and screening operations, to grade the different types of materials (Fig. 3).

In the United Kingdom, waste materials have been used as a substitute for primary aggregate materials in various applications. They have also been successfully applied to low specification applications in road construction and bulk fill. Examples of waste materials include power station ashes, blast furnace and steel slags, minestone, slate waste, china clay sand, municipal solid waste incinerator ashes and foundry sands.

In Hong Kong, recycled aggregates are widely used as a substitute to natural coarse aggregates in concrete or as a sub-base or a base layer in pavements. Innovative use of recycled aggregates from construction and demolition wastes has also been carried out to replace natural aggregates in moulded concrete bricks and paving blocks (Poon *et al.*, 2002).

AGGREGATES IN SELANGOR

Aggregate Production

Negeri Selangor Darul Ehsan is one of the most developed states in the country. The mining and quarrying sector in the state is relatively insignificant compared to the other economic sectors, contributing only 0.7% of the GDP and employing 0.2% of the total work-force in 2002 (GoS, 2003). Both metallic and non-metallic minerals are produced but the latter is more important consisting of aggregates, earth materials, sand and gravel, silica and

kaolin. In terms of tonnage, construction materials such as aggregates, earth materials and sand and gravel constitute more than 90% of the total minerals produced in Selangor (Pereira *et al.*, 2002).

Aggregate is a basic resource for physical development. In a rapid developing state such as Selangor, its production trend can be closely linked to the pace of economic expansion. The annual aggregate production rate in Selangor between 1980 and 1987 was between 10 to 14 Mt (Pereira *et al.*, 2002). The production dropped in the following years and regained only after 1990 with an increment of about 25% annually. The peak production was about 42 Mt in 1996 but in 1997, the production dropped tremendously by about 40% due to the economic slow down. Since then, production has increased at an annual rate of about 10% to 14 Mt in 2001 (JMG, 2002).

At one of its highest levels in 1995, aggregate production in Selangor was 14 tonne/capita, which is almost three times higher than the national aggregate production of 4.7 tonne/capita for that year. In one particular area i.e. the Langat Basin, consumption of aggregates was about 37 tonnes per capita, which is eight times higher than the national consumption (Pereira, 2000). This is on account of a few mega projects that were ongoing in the area during that period such as the Kuala Lumpur International Airport, the Shah Alam Highway and Putrajaya, among others. These development projects also served to spur an influx of commerce and industry into the state, further increasing the demand for aggregates.

The national production of aggregates in Malaysia is comparable to the annual production levels in some developed countries, such as the United States (4.8 tonne/capita; Tepordei, 1997), Canada (4.0 tonne/capita; Lyday, 1997), Australia (3.6 tonne/capita; Doan, 1997) and the United Kingdom (3.2 tonne/capita; Newman, 1997). However, these levels are far lower than the production levels in Selangor or the Langat Basin. While aggregate is a basic resource that is required to support physical development to ensure societal well being, aggregate production in Selangor, and in particular the Langat Basin during that period, was not sustainable for the long-term well-being of the environment. Such an extremely high rate of exploitation, unless controlled, would contribute to rapid depletion of natural aggregates. It would also increase the number of environmental problems, which are already a matter of concern, and threaten the sustainability of development.

Aggregate Flows and its Environmental Implications

At present, the urgency in conducting detailed evaluation of aggregate flows is absent. This is because natural resources are still believed to be abundantly available in Selangor and is considerably cheaper than recycling of construction and demolition wastes. In addition, demolition rates are relatively low at the moment. However, research

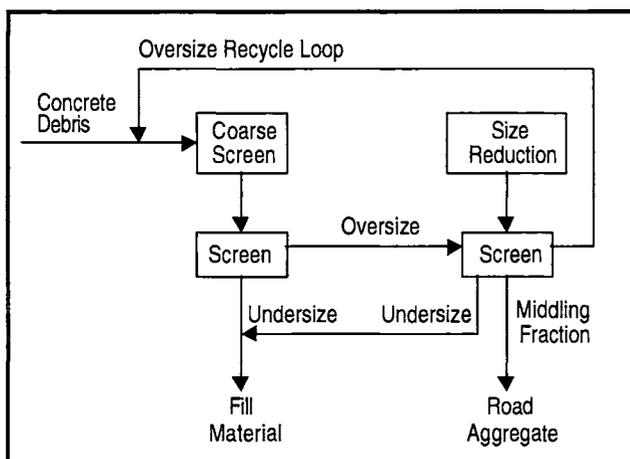


Figure 3. Concrete processing system (after Savage 2002).

has shown that aggregate resources in Selangor will become limited unless measures are taken to prevent sterilization of aggregate resources in the state due to urban expansion (GoS, 1999).

In view of this scenario, research has been initiated to assess the flow of aggregates, with emphasis on minimising its wastage in the construction industry and reducing environmental impacts associated with its exploitation. The preliminary flow analysis of construction aggregates is being conducted for Selangor to establish baseline information and evaluate opportunities for minimising waste and mitigating environmental impacts.

Natural aggregates in Selangor, derived from quarrying activities, are used in the construction of major building infrastructures, including roads and bridges (Fig. 4). The waste eventually ends up in open dumps. Illegal disposal of this waste is also prevalent. The process of extracting and processing aggregates into concrete for construction results in dissipations into the water, air and land surface, which then gives rise to environmental concerns. Similar dissipations occur during and after disposal of waste into dumpsites. In addition to this, the near absence of recycling results in an open loop in the aggregate flow and contributes to depletion of this resource.

Dissipations into water, air and land surface are of serious concern in the quarrying and construction stages of

the aggregate flow scheme. Quarrying causes many adverse environmental impacts among which include water, air and noise pollution, visual intrusion, loss of amenity and biodiversity and the generation of derelict land (DETR, 2000, cited in Hill *et al.*, 2001). Among the major impacts associated with the construction industry are soil erosion and sedimentation, flash floods, destruction of vegetation and dust pollution (Lee and Fong, 2002).

With respect to water quality, studies indicate that the main polluting substance from quarry and construction sites are suspended solids (Wan Nor Azami, 2001 and Suhana, 2002). Table 1 shows the standards in classification of water quality in Malaysia by the Department of Environment (DOE), Malaysia. Indicators to determine the water quality index (WQI) are pH, suspended solids (SS), ammoniacal nitrogen (NH₃-N), chemical oxygen demand (COD), biochemical oxygen demand (BOD₅) and dissolved oxygen (DO). On average, the WQI of streams draining a quarry is 51%, which falls in into Class IV and is considered very polluted. Similar conditions are reported in streams draining construction sites, with WQI levels of about 53% (Class III). Extremely high levels of suspended sediments are particularly prevalent during earthwork activities.

With respect to air quality, public complaints about quarrying operations are far more common than those of

Table 1. Water quality classification from quarry operations and construction activities. Recalculated based on data obtained from Wan Nor Azami (2001) and Suhana (2002). ¹ Source: Department of Environment 1995

Parameter	Interim National Water Quality Standards in Malaysia ¹					Quarry Site	Construction Site
	I	II	III	IV	V		
WQI (%)	>92.7	76.5-92.7	51.9-76.6	31.0-51.9	<31.0	50.63	53.03
pH	6.5-8.5	6.5-9.0	5-9	5-9	-	7.03	6.10
NH ₃ -N (mg/L)	0.1	0.3	0.9	2.7	2.7	2.30	1.69
SS (mg/L)	25	50	150	300	300	83.00	217.0
BOD ₅ (mg/L)	1	3	6	12	12	1.51	17.2
COD (mg/L)	10	25	50	100	100	224.00	82.19
DO (mg/L)	7	5	3	1	1	0.17	4.14

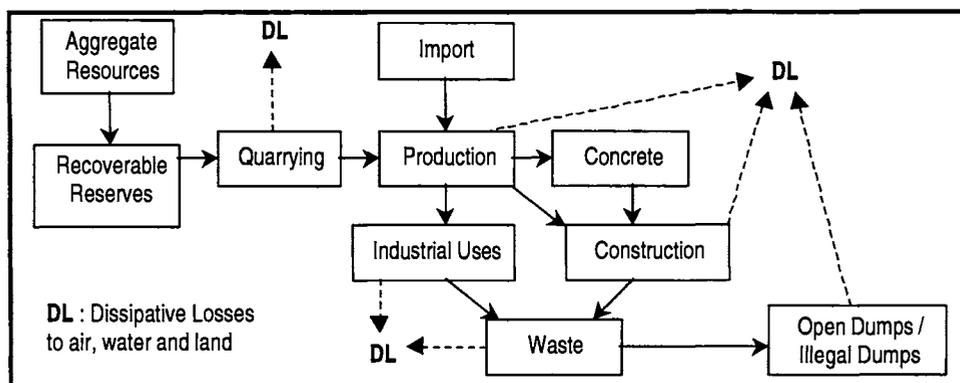


Figure 4. Construction aggregate flow in Selangor.

construction sites. This is probably because dust generation is more acute in quarrying compared to construction operations. The principal sources of dust from quarrying operations are related to comminution processes (crushing, drilling, blasting), screening, traffic movements, conveying and dumping of aggregate into the hopper and stockpiles. In the case of construction sites, traffic movement is the main source of dust. A 20-month dustfall monitoring program around seven quarries in granitic rocks showed that monthly dustfall rates range from 0.02 to 2.15 g/m²d, with dustfall levels decreasing away from the quarries (Ng, 2001). The mean dustfall level in areas located less than 1 km from the nearest quarry was 0.33 g/m²d, exceeding the DOE's recommended guideline of 0.133 g/m²d.

In Malaysia, recycling of construction aggregates is still not widely practised. This is due to many factors. Among these are lack of basic information regarding the types and amount of aggregate waste available, inadequate local market in buying recycled aggregates and absence of recycling facilities. In addition, research on the substitution of aggregates is at its infancy. For example, the production of quarry dust concrete is still being investigated.

In order to manage aggregate resources in a sustainable manner, a clear projection of its flows and dissipations is important. Clearly, quarrying and the construction activities have adversely affected the environment, in particular river and air water quality. However, these impacts can be minimised by designing and implementing effective environmental management plans. In addition, there is need for introducing recycling to arrest the depletion of aggregate resources in Selangor.

CONCLUSION

Adequate supply of aggregates for building and civil works is vital for social development and economic growth. Therefore, sustainable development in the construction industry should be in parallel with sustainable aggregate resource management. In this respect, the analysis of aggregate flows is useful for providing basic information to facilitate effective resource management. In the case of Selangor, there is much more work to be done to address information gaps and develop a complete picture of the aggregate flow.

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