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Chemical and Biological Characterisation of Dredged Marine Soils from Northern Peninsular Malaysia

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Abstract

Dredging work involves a range of marine soils, varying from coarse to fine, clean to contaminated. The work includes excavation and disposal phase, may affect the marine environment through releasing of the possible contaminants. Dredged marine soils (DMS) are classified as contaminated waste that contain of organic matter and heavy metals. Contaminated DMS can harm aquatic organism, animals and human. It must be disposed safely to ensure the contaminants are not released. DMS was analyzed for identification of pathogenic bacteria. Due to the potential for transmission of diseases, this hazards becomes a major concern as the DMS has its own values for reuse or recycle purposes. Numbers of pathogen, including the indicator bacteria, *Escherichia coli* have been used to assess the level of contamination in marine environment.

Key-word: - dredged marine soils; contaminants; heavy metals; pathogenic bacteria

1. Introduction

The rapid population and industrial growth in marine areas are potential for adverse environmental impact. Besides, it could create a sensitive marine areas and affecting the ecosystem and ecological health (Brady *et al*, 2014). Relevant information on dredged marine soil characteristics is necessary in understanding the impact of these material have towards the environment and human. According to Manap & Voulvoulis (2015), characteristics of dredged marine soils also refer to the role of material as a contaminant source. An understanding of the marine soil characteristic was important in assessing the fate of pathogens and other contaminants in the soil (Zhao *et al*., 2014). Besides, the material’s characteristic can be used to determine suitable treatment and disposal methods (Martinez *et al*., 2009).

The dredged materials are characterized by a variation in composition. This variation could be related with the local environment such as micro-climates, human activity as well as sediment transportation and sedimentary process (Hossain *et al.*, 2012; Sany *et al.*, 2012). For example, deforestation has increased soil erosion leading to increased sedimentation of coastal environment (Khamarudin & Rashid, 2013). In addition, the amount of available water, precipitation during average and peak seasons, volume and velocity of discharge, basin geology and sediment load of waterways also lead to variation in sediment (Mouri *et al*., 2014). Sediment transportation and sedimentary process also found to affect the grain size variations. As a river flows from inland towards the sea, the flow path becomes broadened and the flow velocity gradually decreases, causing larger particles to settle to the bottom. The process is known as a sediment gradient.

Hence, the sediment gradient from inland area to the ocean ranges from coarse to fine. Therefore, in coastal areas, it is reasonable to assume that the marine soils have variation in colours, shapes and sizes (Das *et al*., 2013). According to Bortone and Palumbo (2007), the sediments that settle at the bottom of water body are loose particles of sand, clay, silt and other substances. In addition, IADC (2009) stated that rocks and gravels also considered types of dredged sediments. Dredged marine soils especially the fine-grained types have low shear strength, low permeability, high water contents and very compressibility which are susceptible to have large settlements. Hence, DMS are generally classified as waste materials (geo waste). This paper focused on the study of geo-properties of dredged material that was collected from two different locations.

2. Materials and Methods

DMS used in this study was collected from dredging site at Kuala Perlis, Malaysia in January 2016. Dredging site was located near the Kuala Perlis Jetty (Fig. 1). Selection of dredging site was made based on Malaysian Marine Department (Jabatan Laut Malaysia, JLM) dredging schedule. The soil was dredged at depth 4 to 6 m from sea level using backhoe dredger (Fig.2).

Figure 1. Location of dredging site at Kuala Perlis Jetty, Perlis, Malaysia

Figure 2. Backhoe dredger

The used of an appropriate container is necessary for minimizing the physical, chemical and biological reactions of sample during sampling until analysis time. Marine soils are collected in plastic sampling bag and stored in polystyrene box in order to protect the sample from being contaminated by external substances. The sample is keep in cool and dark during transportation time. Marine soil is stored in dark condition at temperature of 4℃ for microbial identification. The soils are best able to maintain its originality when stored in an air-dried condition at low humidity and just above the freezing temperature.

The analysis of DMS characterization were conducted according to the British Standard 1377:1990. The natural water content is about 240.74 % (3.4 *LL*), dried in an oven at 100 ºC (BS 1377-2:1990:3.2). The particle density value of dredged material is 2.36 Mg/m^3, measured using a small pyknometer method (BS 1377-2:1990:8.3). The liquid limit value is 71.70 % by using a cone penetrometer method (BS 1377-2:1990:4.3). The plastic limit and plastic index value for dredged material are 40.06 % and 31.64 %, respectively (BS 1377-2:1990:5). The dredged material was classified in high plasticity silt, *MH* for its soil type (Unified Soil Classification System).

Table 1: Properties of dredged marine soils

Soil type	High plasticity silt, *MH*
Natural water content, w_{nat} (%)	240.74
Specific gravity, G_s (Mg/m^3)	2.36
Liquid limit, *LL* (%)	71.70
Plastic limit, *PL* (%)	40.06
Plastic index, *PI* (%)	31.64

3. Characterization of DMS

3.1. Physical characteristics

Sediment particles are classified into different sizes, namely fine particles size up to 2 µm (clay), particle size up to 16 µm (silt), particle size between 63 µm and 64 mm (sand and gravel), and particle size more than 64 mm (rock) (Manap & Voulvoulis, 2015; Zhao *et al*., 2014). However, most of the sediment was rich with silt and clay particles (Lee *et al.*, 2012). Evaluation of the physical characteristic of marine soils is necessary to determine its potential environmental impact. Fine sediments usually expected to adsorb pollutants more than the coarse fraction. A lowest contamination level was reported in the sediments with low portions of fine sediments (Martinez *et al*., 2009). A study by Zhao *et al*. (2014) also found high interaction of pathogenic bacteria with the fine particle sediments. The buried carbon in marine soils is one of the sources of organic matters. The composition of organic matters is affected by a process namely diagenesis process.

The process brings changes in the marine soils that take place prior to deposition and during early stages of burial under condition of low temperature and pressure. The organic matter in marine soils also depends on the bacterial process (Amirudin & Ali, 2013). The soils organic matter has ability to serve as the energy provider for bacteria growth and providing carbon for the formation of new cell material. The investigation by Zhao *et al*. (2014) found greater number of *E. coli* in soil with high organic matter than those with low organic matter. Dafini *et al*. (2013) discovered the relation between the textures of sediment with organic matter content. It was reported that higher organic matters was found associated with the finer fraction of sediment

3.2. Chemical characteristics

The presence of contaminants in soil and groundwater with heavy metals may impact the biological functions and structure of soils. The accumulation of heavy metals are associated with the type of soil, physicochemical properties and nature of the individual heavy metal. It is categorized as high stability in the environment and not biodegradable or leached.

The mobilization of heavy metals in soil occurs in aerobic conditions. Furthermore it could disrupt the normal biochemical processes, consequently has a negative effect on the biological activity (Mazurek *et al*., 2016). Physicochemical properties such as moisture content, pH and organic matter are important parameters in the accumulation and availability heavy metals (Fayiga & Saha, 2016; Fernandez *et al*., 2016). Soil pH is important factor affecting the availability of heavy metals because it relates closely with solubility and soil reactions (Fayiga & Saha, 2016). Yap and Pang (2011), were investigated the type of available heavy metals in Kuala Perlis sediments in the aquatic ecosystem. There are lead (Pb) and zinc (Zn) with concentration values of 25.77 and 55.73 µg/g (dry weight), respectively.

3.3. Biological characteristics

Covering around 70 % of the Earth, marine soils play a major role in ecosystem process and colonized by a vast, but unknown, diversity of microorganisms (Dorsaf *et al.*, 2014). The marine soils act as a reservoir for enteric microorganisms by provides favourable nutrient conditions and protection from the sunlight. For instant, fecal bacteria find sediments more favourable as a habitat than in overlying water (Alm *et al*., 2003). As such, biological properties are fundamental importance in controlling the diseases caused by pathogenic bacteria (Tchobanoglous *et al*., 2004).

Previous studies have also found that sediments can contain 100 to 1000 times as many fecal indicator bacteria than the overlying water. *Escherichia coli (E. coli)* and enterococci bacteria are associated with sediments where the properties and condition of the sediment could influence their survival and transportation.

Assessment of microorganism population in the dredged marine soils would give an idea about the degree of contamination occurred in that soil (Das *et al*., 2013). In the recent study, Estene *et al*. (2014) show the influence of microorganism community in measuring the soil quality.

4. Contaminations in DMS

4.1 Chemical contaminations

Pb is one of the toxic metals posing serious contamination risks to soils. Pollution by this heavy metal is harmful to the quality of the atmosphere, water bodies and food crops. It also endangers the health and well-being of animals and human beings by way of the food chain (Li *et al*., 2014). The impact of Pb on human health is a major concern especially for infants and children because it can damage their developing brain and nervous system (Fayiga & Saha, 2016). Pb is listed as the most hazardous elements and ranked among the top 20 contaminants by the USEPA. Besides affecting human health, this metal can have severe impact on biological processes, including microbial activities and production of plants (Rehman *et al*., 2017).

Pb is a neurotoxin which can affect almost every organ and system in the human body. This metal can reduce cognitive development and intellectual performance in children, damage kidneys and affect the reproductive system in a human body. Pb can also cause brittle bones and weaknesses in the wrist and fingers. Stored Pb in bones can re-enter the blood stream during periods of increased bone mineral recycling, and the mobilized Pb can be redeposited in the soft tissues of the body and cause musculoskeletal, renal, ocular and immunological complications. The exposure to Pb can be occur via unintentional soil ingestion, intake of Pb contaminated food-stuff and inhalation of soil particles containing Pb. As such, it is critical to evaluate the pollution of Pb in food-crops because vegetables are the essential sources of human nutrition (Qin & Chen, 2010; Goswami *et al*., 2012; Steenland & Boffetta, 2000; Rehman *et al*., 2017).

There are strong horizontal and vertical gradients of pollutant concentration in the soil. Heavy metals may also occur in the deeper parts of the soil profile as a result of vertical intra-soil water transport of pollutants (Mazurek *et al*., 2016; Rocco *et al*., 2016). This could result in the pollution of the underground aquifer layer hence, it will contaminating the water bodies and poisoning wells. Polluted water bodies has implications for public health and pose health risks, where the toxin could reach human's blood stream through drinking water. Furthermore, it could contaminate nearby surface water bodies, impacting the aquatic ecosystem which can affect their survival (Fayiga & Saha, 2016).

Different countries may have a different risk communications, ecological risk issues and acceptable risk level. These difference are caused by the different culture and purposes of protection among the communities. Most legislations are based on the total concentration of contaminants in soil and groundwater. Malaysia in year 2009 adopted the screening levels of the USEPA for determining subsurface contamination which may have potential significant risk to human health. It comprises of site screening of soil and groundwater criteria. In addition, the criteria for groundwater quality in Malaysia is determined based on the National Guidelines for Raw Drinking Water Quality from the Ministry of Health (revised in December 2000) as shown in Table 2. It indicates the benchmark levels for determining groundwater quality (Teh *et al*., 2016; DOE, 2010).

Table 2: Values for metals in National Guidelines for Raw Drinking Water Quality

Mn	**Cr**	**Zn**	**As**	**Fe**	**Cu**	**Pb**	**Cd**	**Hg**
				mg L^{-1}				
0.1	0.05	3	0.01	0.3	1.0	0.01	0.003	0.001

4.2 Biological contaminations

A growing number of human bacterial infections have been associated with recreational and commercial uses of marine resources. A human exposure includes swallowing or immersion of body as well as the consumption of contaminated seafood (WHO, 2001). Within 1999 and 2000, 59 diseases outbreaks were reported related with recreational water exposures and 61 % of these outbreaks were gastroenteritis (Alm *et al*., 2003).

A study by Janelle *et al*. (2006) had found a high number of pathogens been reported from the marine environment. Some pathogens such as Vibrio occur naturally in marine water while the others from fecal contamination sources. Feces in sediments which contain bacteria, viruses and protozoa can be ingested and also cause health problem such as intestinal diseases.

The survival of *E. coli* which is the indicators of fecal contamination in marine environment has been related to several factors of its surroundings. The results of past studies suggest the involvement of environmental factors such as solar exposures, temperature, salinity, nutrients, predation, and pH are influencing the ability of *E. coli* to survive. These factors will influence the survival by affecting their growth and death (Manjit, 2002).

Numerous studies have found higher concentrations of *E. coli* in marine soils than in water (Alam & Zafar 2013; Jamieson *et al*., 2005).The concentration of the indicator bacteria in DMS was found 18 times higher than in the marine water (Anuar *et al.*, 2014). The evidence provided by these studies suggests that marine soils are reservoir for *E. coli* as well as pathogenic bacteria.

Data obtained in the study conducted by Anuar and Chan (2015) indicated that Malaysian DMS is contaminated with various types of pathogen. The data suggests that pathogen could pose hazards and spread diseases towards human and environment by contact with contaminated marine soils. Several genus of bacteria were founded in the DMS samples namely *Serratia* spp., *Vibrio* sp. and *Enterobacter* sp. and *Vibrio* sp. According to the Malaysia Biosafety Clearing House 2010 (BCH), the variety of these bacteria fall into Risk Group 2. The bacteria in this group could cause human diseases, but effective treatments are available.

5. Conclusions

Treating the contaminated DMS are compulsory if it will be reused as the geomaterial in a civil engineering application. Besides ensuring the stiffness, the toxicity and mobility of the contaminants are also an essential in terms of environmental issue. Most pathogenic bacteria found in the DMS were grouped in the Risk Group 2.The presence of *E. coli* does not only indicate the occurrence of fecal contamination but also the potential presence of other pathogenic bacteria. High concentration of *E. coli* was detected in the DMS than in the marine water. This suggests that the soils can promote greater persistence of bacteria, especially when the soils provide a hospitable environment for pathogenic bacteria. Although the DMS has been recognized as a reservoir of pathogenic bacteria, but it is unlikely to pose serious hazards. The bacteria can cause disease to human but the risk of infection is limited under normal circumstances. Besides, effective treatments are usually available for effective curing of infected patients.

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