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Effects of December 2014 Great Flood on the Physico-Chemical Properties of the Soils in the Kelantan Plains, Malaysia

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Abstract

Heavy rain falling on land at the upper reaches of the Kelantan River, Malaysia, on December 2014, had resulted in severe soil erosion and untold damages to croplands. The lower reaches of the river were heavily silted with infertile materials considered unfit for crop production. A study was conducted to explain why the flood phenomenon occurred, to determine the physico-chemical properties of the sediments silted in the Kelantan Plains and to propose measures for soil mitigation. Results showed that the silted sediments were characterized by the presence of quarts, mica, feldspars, kaolinite, gibbsite and hematite believed to come from the top- and subsoil of the upland areas. The sediments' pH was very low and Al and/or Fe contents were very high, while nitrogen and carbon contents varied from area to area. Soils in the Kelantan Plains badly affected by this great flood needed to undergo proper ameliorative program. The most appropriate measure would be to apply ground magnesium limestone in combination with bio-fertilizer fortified with beneficial microbes that would increase their pH to a level above 5, which consequently eliminates Al^{3+} and/or Fe^{2+} that causes toxicity to the crops growing on them. The organic material so added would enhance the formation of soil structures. It is advised that the farming communities in the upper reaches of the Kelantan River would have to follow the advice advocated by the Department of Agriculture, Peninsular Malaysia, via MyGAP initiative, in order to sustain agricultural production on their land.

Keywords

Crop Production, Great Flood, Heavy Rainfall, Silted Sediments, Soil Properties

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1. Introduction

Immediately after the great flood of December 2014, the Malaysian government set up a national committee to study the immediate cause of the unprecedented phenomenon, estimated the economic loss to the country and suggested how to reduce its effects should a flood of that magnitude occurred again in the near future. The committee had since completed the study and submitted its findings to the government to take remedial actions. The following is the gist of the findings as appeared in the report published by the mainstream printed media. The study found that due to the flood, Malaysia suffered an economic loss of approximately USD 0.7 billion. About 300,000 people throughout the country were affected by it and the report concluded that the worst hit area was the district of Kuala Krai in Kelantan (**Figure 1**). The floodwater in the affected areas moved so fast with energy equivalent to that of tsunami, destroying and/or carrying away most of the houses and other properties located along its pathway.

On record, this flood was considered among the worst that hit the country in 200 years. It was assumed that flood of this nature could only occur once in a blue moon (possibly once in 1000 years). For the state of Kelantan, the phenomenon was unprecedented in the history of its existence. The occurrence of the flood was blamed squarely on the extraordinary rainfall occurring within a short duration and massive agricultural as well as logging activities [1] [2]. It was made worse by extensive soil erosion in the upland areas and the subsequent siltation of sediments on riverbed with muddy and sandy materials [3], containing some heavy metals [4] because of the uncontrolled land development in the upstream areas. It was believed by some in the country that soil erosion in the upper reaches of Kelantan River prior to the flood was already 100 times more than normal. During the height of the flood, trees were uprooted, abandoned logs were transported and the subsoil was eroded, which was subsequently silted in the lower reaches of the river (flood plains), causing untold damages to homes and agricultural lands alike (**Figure 1**).

What was the immediate cause of the flood and why soil erosion was so severe? It has been said by the experts that the flood was promoted by too much rain falling in the areas within a short span of time [1]. Hence, soils (top- and subsoil) were eroded and subsequently washed away, causing serious flood in the low-lying areas of Gua Musang and Kuala Krai districts (**Figure 1**). During the height of the flood, a large section of the downtown Gua Musang was painted reddish-yellow by the running floodwater, drowning vehicles and houses as they

Figure 1. A map showing Kelantan river system. Anonymous [5].

were for many days (**Figure 2**). The color of the floodwater itself was a clear indication of the presence of muddy materials presumably eroded from the subsoil of the areas under crop cultivation.

It is known, however, that the rate of soil erosion is dependent upon three factors: 1) The intensity of rainfall; 2) The slope of the land in the affected area; and 3) Plant cover. The more the rainfall, the higher is the soil erosion. This notion is well understood among the soil fraternity worldwide. Likewise, the rate of soil erosion is related to the slope of the land in the affected areas. Soil erosion occurs at the minimal rate if the land is flat or slightly undulating (0˚ - 5˚). It is for this reason that the Department of Agriculture, Peninsular Malaysia, prohibits agricultural activities on land with more than 25˚ slope; this is well explained in the newly introduced guidelines for good agricultural practices in Malaysia called MyGAP [5].

It is believed that if the hilly and/or undulating land in the districts of Kuala Krai or Gua Musang was mostly or fully covered by natural forest during the time of the flood, the damage suffered by human settlements and/or their properties would have been much less. Generally, we can say that land in upland areas of Kelantan should have about 70% plant cover in order to keep the soil stable. It goes without saying that under that situation soil erosion is minimal, only geological erosion occurs. It is known for years that the erosivity of rainfall in areas covered by undisturbed natural with >70% plant cover is acceptably low.

A study was conducted to: 1) to explain why the great flood phenomenon occurred; 2) to determine the physico-chemical properties of the sediments silted in the Kelantan Plains used for agriculture; and 3) to propose measures for soil mitigation. Part of the results of this study can be used by the authority to prepare a standard operation procedure (SOP) how to handle the aftermath should a flood of this magnitude occur again in future.

2. Experimental Section

2.1. Sampling of the Silted Sediments

The Faculty of Agriculture, Univesiti Putra Malaysia (UPM), set up a response team to check the aftermath of the 2014 great flood to determine the damage done to soils and crops in the lower reaches of the Kelantan River, which were the Kelantan Flood Plains. The Kelantan River drained its floodwater into the South China Sea (**Figure 1**). The state of Kelantan itself is located in the northeast coast of Peninsular Malaysia; the peninsula is bordered by Thailand in the north and Singapore in the south.

The team had to suggest appropriate measures to mitigate the lands so that the farmers affected by the flood could go back to their normal business in due course. A special visit to the areas was made in mid-January 2015 to survey the affected lands in the vicinity of Kota Bharu and Tumpat districts as well as to meet selected farmers in these areas so as to understand their immediate need in order to get them back to their normal life. Sixteen soil samples from selected areas in Kota Bharu and Tumpat districts (**Figure 1**) were collected for preliminary analyses in the laboratories. The samples were taken using a shovel up to 15 cm depth (to be shown later).

Figure 2. Downtown Gua Musang during the height of the flood. Anonymous [6].

Special attention was paid to the paddy fields in these areas which were silted heavily during the height of the great flood.

2.2. X-Ray Diffraction Analysis

Samples for XRD analysis were not chemically treated as we wanted to identify the mineralogical composition of the silted sediments as they were. Small amounts of the air-dried silted sediments were taken from the bulk samples and immediately X-rayed using Philips PW 3440/60 X'Pert PRO available at the Department of Land Management, Faculty of Agriculture, Universiti Putra Malaysia, Serdang, Malaysia. The minerals present in the silted sediments were identified from diffractograms using d-spacing provided by the book of Shamshuddin [6].

2.3. Physico-Chemical Analysis of the Silted Sediments

The particle-size distribution of the silted sediments collected from the Kelantan Plains was determined by the method of Gee and Bauder [7]. The pH of the sediments was determined in water (1:2.5) using PHM210 Standard pH meter at 25˚C [8]. Total N was determined by Kjeldahl digestion method [9], while the available P was determined by the method of Bray and Kurtz [10] (1945). Exchangeable Ca, Mg and K were extracted using 1 M NH_4OAc [11] and the cations in the extracts were determined by atomic absorption spectrophotometer (AAS). Exchangeable Al was extracted by 1 M KCl and the Al in the extract was determined [12]. Total carbon was analyzed by LECO CR-412. The extractable Fe was determined by double acid method, with the Fe extracted by 0.05 M HCl in 0.0125 M H_2SO_4. In this method, five-gram soil sample was mixed with 25 mL of the extracting solution and shaken for 15 minutes. The solution was then filtered through Whatman filter paper number 42 before determining the Fe it contained by inductively coupled plasma—atomic emission spectrometry (ICP-AES).

3. Results

3.1. Minerals in the Silted Sediments

Results of the X-ray diffraction analysis (**Figure 3**) of sample 1 (**Table 1**) showed the presence of mica (10 and 5 Å) and feldspars (3.24 Å). Other important minerals included quartz (4.25 and 3.34 Å), kaolinite (7.2 and 3.57 Å) and gibbsite (4.84 Å), with hematite (2.5 Å) present in small amount. Goethite was believed to be present in the samples, but its XRD reflection of 4.18 Å was not clearly shown on the diffractogram (**Figure 3**). This was because the XRD analysis was carried out without first separating the samples into sand, silt and clay fractions by mechanical analysis. If the clay fraction was X-rayed instead of the fine earth (silted sediments), the weak goethite peak of 4.18 Å would have appeared on the XRD diffractogram shown in **Figure 3**.

3.2. Particle-Size Distribution

The particle-size distribution of the sediments silted in the Kelantan Plains is given in **Table 1**. Mostly, the clay contents of the sediments were in the range of 20% to 30%. Only one sample which was collected from a rice field contained about 48% clay. On the other hand, the silt contents were very high, consistent with the notion that these materials were from the subsoil (or even the saprolite) of the highly weathered profiles in the upper reaches of the Kelantan River; soils of this nature usually have high silt content below the solum. The texture of the sediments, as expected, ranged from sandy loam (at the river levee) to silty clay (in the rice field).

3.3. Chemical Properties of the Sediments

Table 2 shows the chemical properties of the sediments. The pH of the sediments ranged from 3.16 to 5.30. Crops grown in soil media with pH below 5 would be subjected to the stress H^+ and/or Al^{3+}. The EC was low, which was good for crop production. Crops in Malaysia would have problem growing in soil media with EC > 4 dS m^{-1}. It was observed that the exchangeable Ca ranged from 0.04 to 0.29 $cmol_c \cdot kg^{-1}$; these were considered as insufficient for crop growth, especially rice. The exchangeable Mg was also very low with values ranging from 0.11 to 0.54 $cmol_c \cdot kg^{-1}$. In contrast to exchangeable Ca and Mg, the exchangeable K were sufficient, with most of the values greater than 0.1 $cmol_c \cdot kg^{-1}$, the critical level for most crops in Malaysia. The available P varied from 4.00 to 44.73 $mg \cdot kg^{-1}$; the critical available level is 20 $mg \cdot kg^{-1}$.

It was observed that the exchangeable Al in some sediments were very high, with the highest being 8.89

$cmol_c \cdot kg^{-1}$. At this level of exchangeable Al, the pH of the sediments would have been lowered considerably via a process called hydrolysis. For agricultural production in Malaysia, we are looking for soils with exchangeable Al of <1 $cmol_c \cdot kg^{-1}$. The contents of Al seen in this study was way above the level reported for the topsoil of Ultisols and Oxisols, which covers about 70% of Malaysia [13]. Like Al, extractable Fe was very high in some

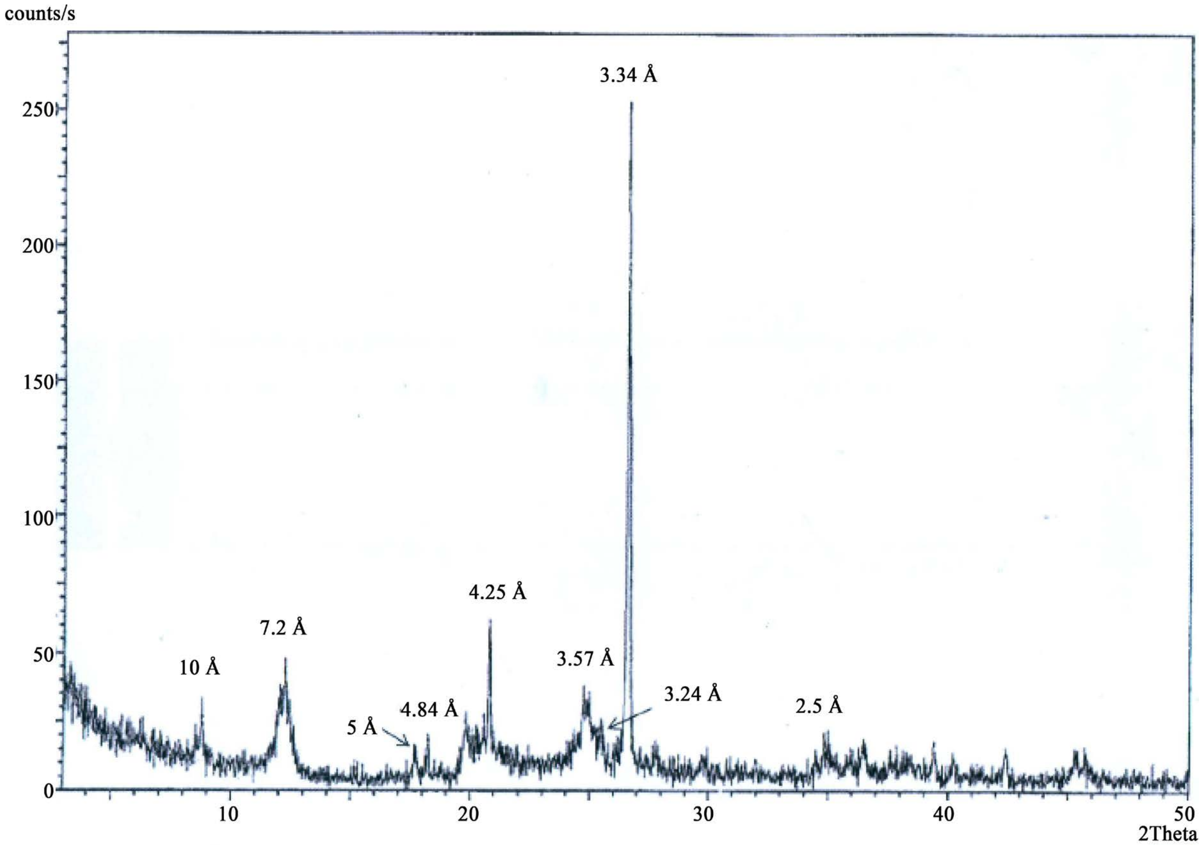

Figure 3. XRD of the silted sediments at Pasir Pekan Hilir, Kelantan (sample 1).

Table 1. Particle-size distribution of the silted sediments in Kelantan plains.

Sample	Clay	Silt	Sand	Total	Soil texture
	<2 µm	2 - 50 µm	50 - 2000 µm	(%)	USDA
		(%)			
1	21.81	68.89	9.29	100.00	Silt loam
2	7.29	20.21	67.06	94.56	Sandy loam
3	35.14	46.60	18.23	99.98	Silty clay laom
4	25.50	45.98	28.48	99.96	Loam
5	29.79	69.74	0.46	99.98	Silty clay loam
6	26.59	68.25	5.16	100.00	Silt loam
7	21.62	48.60	29.75	99.98	Loam
8	19.29	61.08	19.62	99.99	Silt loam
9	22.30	72.80	4.89	99.99	Silt loam
10	12.99	42.84	44.13	99.96	Loam
11	48.01	47.86	4.08	99.96	Silty clay
12	6.64	22.25	71.09	99.97	Sandy loam

Table 2. Chemical properties of the silted sediment in the Kelantan plains.

Sample	pH	EC	Exchangable cations ($cmol_c \cdot kg^{-1}$)				Ext. Fe	Avail. P	Total N	Total C	Total S
		dS/m	Ca	Mg	K	Al	($mg \cdot kg^{-1}$)	($mg \cdot kg^{-1}$)	(%)	(%)	(%)
1	3.57	0.45	0.17	0.25	0.19	5.09	167	21.84	0.10	0.84	0.08
2	4.56	1.87	0.13	0.14	0.11	1.74	72	12.60	0.18	0.93	0.01
3	5.30	0.94	0.13	0.35	0.06	1.08	77	5.73	0.27	2.32	0.02
4	3.71	0.37	0.09	0.33	0.15	6.52	123	4.00	0.223	1.88	0.02
5	3.66	2.89	0.27	0.12	0.18	5.29	152	5.89	0.24	2.04	0.02
6	3.53	1.8	0.10	0.52	0.25	1.86	72	6.98	0.26	2.10	0.02
7	3.58	2.88	0.07	0.17	0.08	2.96	180	44.73	0.23	1.98	0.02
8	3.55	3.27	0.08	0.34	0.09	8.96	131	44.21	0.15	0.96	0.01
9	5.16	0.61	0.09	0.24	0.13	1.05	37	7.70	0.12	1.09	0.08
10	3.89	0.34	0.09	0.54	0.20	2.51	75	5.59	0.16	1.94	0.10
11	3.85	0.42	0.04	0.14	0.10	2.62	94	11.41	0.09	1.07	0.09
12	3.30	1.5	0.32	0.27	0.16	5.54	104	16.59	0.06	0.41	0.07
13	3.16	3.76	0.06	0.11	0.57	2.94	106	10.92	0.12	1.01	0.07
14	3.31	3.65	0.29	0.18	0.18	4.30	102	11.62	0.11	0.86	0.08
15	3.78	0.63	0.16	0.27	0.09	6.32	198	18.90	0.05	0.23	0.03
16	3.36	0.69	0.18	0.26	0.26	2.07	174	8.26	0.04	1.10	0.16

samples, with values ranging from 37 to 198 mg/kg. Fe is more acidic than that of Al; hence, its presence results in lower pH.

4. Discussion

4.1. Occurrence of the Flood in December 2014

The incidence of heavy rainfall in southern Kelantan (**Figure 1**) in December 2014 was related to a natural phenomenon called Madden-Julian Oscillation (MJO). At that time of the year, due to the high pressure in the Pacific Ocean, strong easterly wind from Indian Ocean carrying high amount of moisture blew into Peninsular Malaysia. When it met the strong westerly wind from Pacific Ocean coming from the opposite direction, extraordinary high rainfall occurred that resulted in the great flood. The rainfall recorded at Gunung Gagau, Gua Musang, Kelantan during December 15-24, 2014 period was 1986 mm. This was about two-third of the annual rainfall in that area of Kelantan. Can we imagine what would happen to the areas having that amount of rainfall in such a short period of time?

4.2. The Aftermath of the Flood

One of the worst affected sites visited during the field trip was Pasir Pekan Hilir, situated just across the Kelantan River, near Kota Bharu (**Figure 1**). The river levees were once fertile agriculture plots cropped to water melon, groundnut and scores of other cash crops. The flood had destroyed not only the crops, but also the land on the river bank (**Figure 4**). What was the immediate cause of this catastrophe? The farmers in the area seemed to believe that the damage could have been less if the land on the other side of the river was not disturbed by extensive development. As it were, Kota Bharu is now fast developing into a business center in the east coast state of Kelantan. The land along the river bank in Kota Bharu side was earmarked for constructing houses and shopping malls. As such, high walls were constructed that reduced/prevented the floodwater from flowing through its natural pathways. Hence, when the floodwater from the upstream reached Kota Bharu during the night of the fateful day (**Figure 5**), most of the water overflew the bank on the other side of the river into Pasir Pekan Hilir, causing untold damages to the agricultural lands and other properties alike.

The floodwater rose and moved so fast that it was very dangerous to evacuate the village folks in Pasir Pekan Hilir to the higher ground even though using power boats, let alone to save their belonging. That this actually

Figure 4. Complete destruction of agriculture plots on the river bank at Pasir Pekan Hilir.

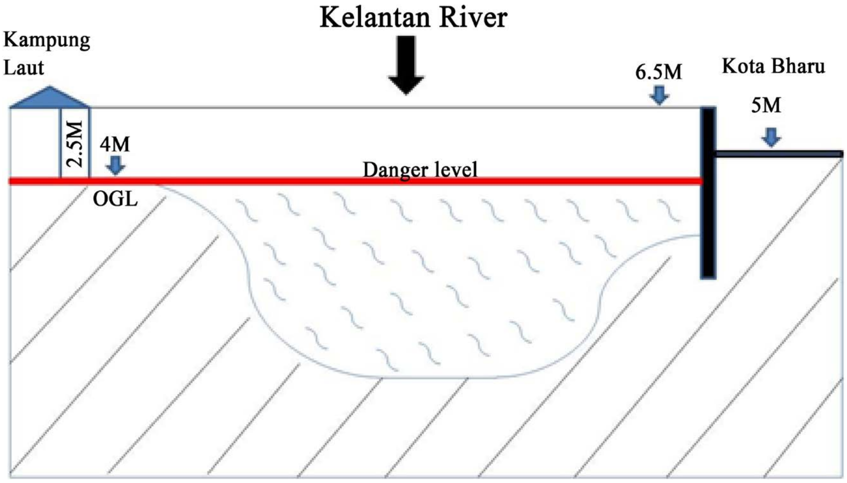

Figure 5. Kelantan River level at Kota Baharu during the height of the flood Modified from Azuhan [1].

happened was confirmed by Azuhan [1] of the Post Flood Recovery Unit, Prime Minister Department, Malaysia, who explained it eloquently in a paper presented on 2014 Kelantan Flood at the National Geoscience Conference held at Kota Bharu in July 2015. Note that Kampung Laut site marked in Figure 5 was about 0.5 km north (downstream) of Pasir Pekan Hilir shown in Figure 5.

A subsequent visit to a nearby area about 500 m away from the Kelantan River showed heavy siltation of muddy materials/sediments that had destroyed a corn farm just before it was about to be harvested (Figure 6). The silted sediments were as thick as 20 - 30 cm, having yellowish/reddish coloration (Figure 7), showing the presence of materials believed to come from the subsoil of the upper reaches of the Kelantan River (Figure 1). Agronomists would want to know the physico-chemical properties of these sediments before they could suggest suitable ameliorative program for the affected agricultural lands. Are the materials fertile enough for crop production in the present conditions? A good question to ask, but we need sufficient soil data before we can give satisfactory answer.

Due to the heavy siltation of muddy materials on the land, natural grasses in the vicinity of the corn farm were completely wiped out, leaving nothing for livestock to eat (Figure 8). Hence, a poor cow that survived the flood had no way of getting enough food to survive. The owner had to spend USD 5 per day feeding his precious animal to keep it alive. For sure, it will not be for long before he will run out of money to buy the feed. Before the flood, the cow was worth about USD 1000. At the time of the visit, it was seriously suffering from malnutrition that it became so thin; hence, nobody wanted to buy it even though the farmer reduced the price to as low as USD 250. It became a big challenge to help the poor farmer in Pasir Pekan Hilir get back to his own feet again.

Figure 6. A corn farm at Pasir Pekan Hilir destroyed by the flood.

Figure 7. The silted deposits at the corn farm.

Figure 8. A cow suffering from malnutrition from lack of grass.

How to make grasses grow quickly on lands heavily silted with sediments of unknown physico-chemical properties become the top priority if ameliorative program were to be carried to make them suitable for crop production again.

Many rice fields at both sides of the Kelantan River bank in Pasir Mas, Kota Bharu and Tumpat districts (**Figure 1**) were silted beyond imagination (**Figure 9**), destroying rice plants which were about 2-months old. New rice had since been re-transplanted, but its yield had yet to be evaluated, which could be used to determine the extent of damage done by the flood.

4.3. Physico-Chemical Properties of the Silted Materials

Most of the silted sediments were loamy in nature, while the rest contained high contents of clay (**Table 1**). Sediments found at the river levees (**Figure 4**) shown by sample 2 in **Table 1** contained high content of sand. The silt contents were exceptionally high, mostly with values >40%. This was indicative of the presence of freshly weathered materials coming from the subsoil, presumably eroded from the areas in the upper reaches of the Kelantan River. In terms soil structure development, the particle-size distribution shown in the study was considered acceptable or good. It was believed that addition of organic matter into the sediments would enhance the process of soil structure formation considerably.

For well the drained soils under Malaysian climatic conditions of high rainfall and temperature, weathering process is extreme [14] [15]. As such, primary minerals in the upland soils of Kelantan, such as mica and feldspars, shown by sample 1 (**Table 1**; **Figure 7**) can only be found in the subsoil. This goes to show that the materials in the floodwater were the infertile eroded subsoil materials coming from the upper reaches of the Kelantan River, which means Gua Musang and/or Kuala Krai areas (**Figure 1**; **Figure 2**). Other minerals found in the silted sediments included quartz, kaolinite, gibbsite as well as some hematite, which can be present in both the top- and subsoil [16]. These four minerals are generally considered as very stable, but with low fertility [14].

Hematite gives reddish coloration to any soil in the well-drained areas of Malaysia [17]. Hence, reddish-brownish coloration of the silted sediments at Pasir Pekan Hilir (**Figure 7**) was indicative of the presence of some hematite, which was confirmed by XRD analysis (**Figure 3**). Mica and feldspars take a long time to weather and consequently release some plant nutrients they contain into the soils. It means that the sediments deposited on the agricultural land during the flood at Pasir Pekan Hilir were infertile; hence, under their natural conditions were not expected to be good media for crop production.

The pH of the sediments varied considerably with most of them <4. At this level of pH, the activity of Al^{3+} in the sediments solution will certainly be above the critical level of 20 μM [18]. For rice, the critical water pH is 6 [18]; hence, rice will not grow normally unless the soils in the rice fields silted with these sediments were ameliorated with suitable amendments. However, rice has a special mechanism to protect itself against H^+ stress as well as Al^{3+} toxicity, meaning that it can even grow at pH 4 - 5 [19]. Ca and Mg contents in the sediments were

Figure 9. A heavily silted rice field in the Kelantan plains.

very low (**Table 2**). The critical level of these macronutrients for rice production are 2 and 1 $cmol_c$/kg, respectively [20]. The pH as well Ca and Mg contents can be increased by liming using limestone.

Total carbon in the sediments ranged from 0.23% to 2.32% (**Table 2**). That means in terms of organic matter contents, most of the sediments contained 2% - 3% (organic matter = total C × 1.724), which was considered sufficient for normal crop growth. In the case of total nitrogen, its value was 0.04% - 0.23%; a good soil contains >0.1% nitrogen. The N content of a soil is often positively related to the amount of organic matter as N is one of its most important constituents.

One of the most important findings of this survey was the low fertility of the sediments as shown by their high acidity, which was related with high concentration of Al and/or Fe (**Table 2**). For the silted sediments under investigation, the content of both metals was very high, with concentration way above the critical level for sustainable crop production. Where do the Al and Fe coming from? It could have been that during the process of mineral silicate weathering in the rocks forming the soils in the upper reaches of the Kelantan River, Al and Fe were released into the soft weathered materials (saprolite), which was located 1 - 2 m below the soil surface.

It was assumed that the yellowish/reddish coloration of the sediments in the studied areas was indicative of the presence of some hematite [17]. This was the color of the muddy water flowing into the Kelantan River during the height of the great flood [1] (**Figure 2**); hence, it was as dubbed as "Yellow Water Flood" by the locals. The high acidity as well as the high concentration of Al and/or Fe would significantly affect crop growth, especially rice and other acid non-tolerant plant species [21]. Al and Fe were toxic metals and if they were present in high amount in the soils silted with the sediments, they would curtail rice growth and its yield would significantly be decreased.

4.4. Relationship between pH and Exchangeable Aluminum

It was observed that the pH of the silted deposits was negatively correlated with the exchangeable Al and the relationship was given by the equation $Y = -0.1377x + 4.3532$ ($R^2 = 0.2450$). That means as the Al content increased, the pH of the silted deposits decreased (**Figure 10**). This Al could have come from the eroded subsoil of the upper reaches of the Kelantan River. The newly released Al had subsequently undergone hydrolysis in the presence of water, resulting in the release of protons that increased soil acidity [20]:

$$Al^{3+} \cdot 6H_2O + H_2O \rightarrow Al^{2+}OH \cdot 5H_2O + H_3O^+, \text{ pKa } 5.$$

Therefore, the more the Al in the sediments solution, the higher would be the acidity, which was indicated by the low pH (**Table 2**). The pH of the sediments would have to be increased by liming using ground magnesium (GML) at the appropriate rate to make sure that the soils affected by the flood suitable for crop production again. When sediments pH increases to a level above 5, Al starts to precipitate as inert Al-hydroxides [18] [21].

4.5. Relationship between pH and Extractable Iron

The pH of the silted deposits was also negatively correlated with the extractable Fe and the relationship was given by the equation $Y = -0.0072x + 4.6718$ ($R^2 = 0.2825$). Like Al, Fe had undergone hydrolysis in the presence of water [20]:

$$Fe^{3+} \cdot 6H_2O + H_2O \rightarrow Fe^{2+}OH \cdot 5H_2O + H_3O^+, \text{ pKa } 3.$$

That means as the Fe content increased, the pH of the deposits decreased (**Figure 11**). In reality, the hydrolysis of Fe produced more acidity than that of the Al, indicating that Fe was more acidic. This can be explained by the pKa value of Fe lower than that of the Al [20]. For rice, the form of iron toxic to it is Fe^{2+} [17]. The phenomenon of Fe^{2+} toxicity usually occurs within the first three weeks of the field after being flooded for rice cultivation. When water pH increases to the level above its pKa due reduction process Fe^{2+} will be precipitated as inert Fe-hydroxides; hence, no longer becoming a threat to rice growth.

4.6. Relationship between Total N and Total C

In contrast to the above-mentioned relationship, total nitrogen in the deposits was positively correlated with total carbon (**Figure 12**) and the relationship was given by the equation $Y = 0.0872x + 0.0275$ ($R^2 = 0.5904$). This clearly showed that we need to add organic matter into the silted deposits in order to increase nitrogen reserve

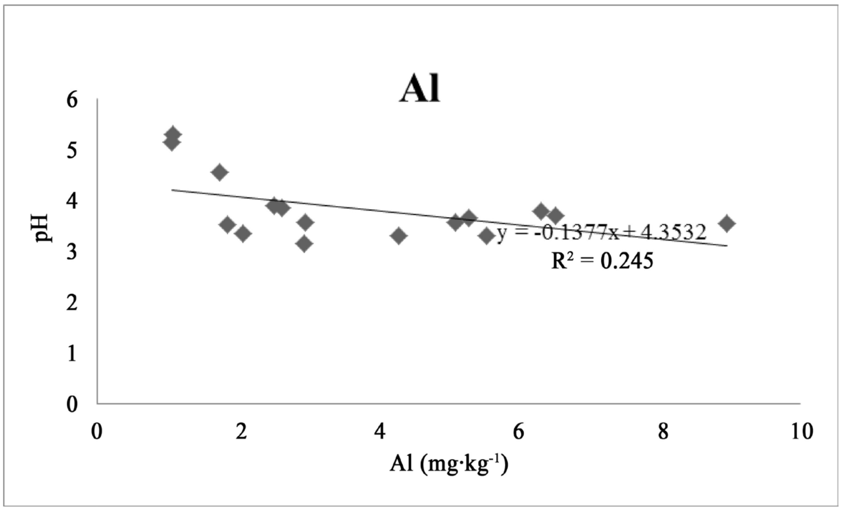

Figure 10. Relationship between pH of the sediments and exchangeable Al.

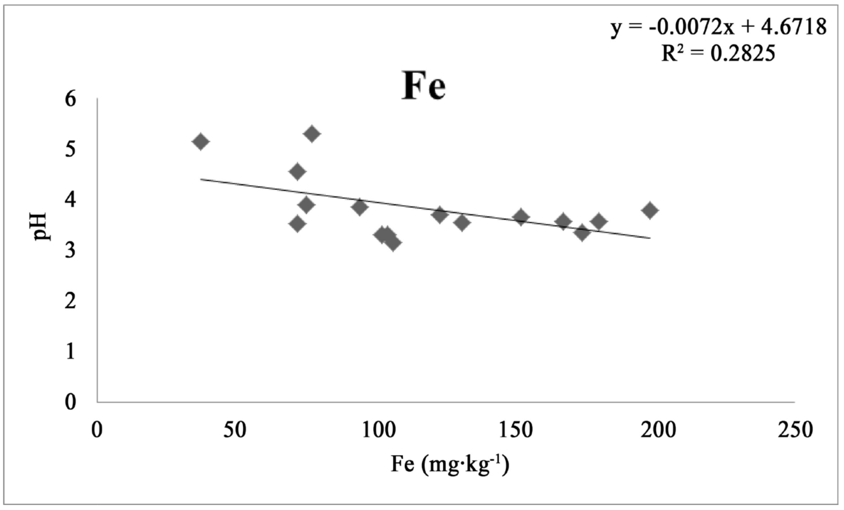

Figure 11. Relationship between pH of the sediments and extractable Fe.

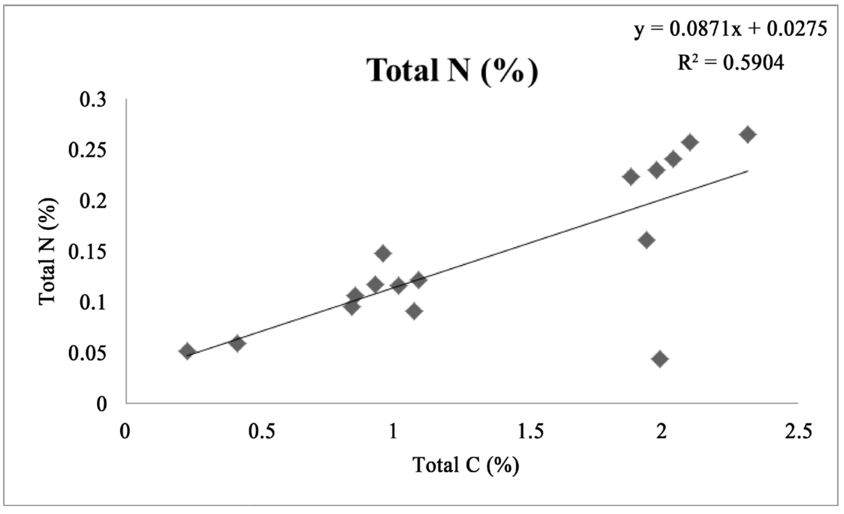

Figure 12. Relationship between total nitrogen in the sediments and total carbon.

for the healthy growth of rice and/or other crops planted on them. Nitrogen is an important component of organic matter. Based on carbon and nitrogen content, we can assume that most of the sediments silted by the floodwater in the Kelantan Plains were a mixture of the topsoil (high total C) and subsoil (low total C), with contents depending on the location where the samples were taken. Overall, the sediments under study contained insufficient amount of total carbon and/or total nitrogen; hence, agricultural production on soils silted with these materials would certainly be negatively affected.

4.7. To Enhance the Productivity of Soils in the Affected Areas

This study clearly showed that the sediments deposited on the agricultural lands in the Kelantan Plains during the great flood of 2014 were unsuitable for crop production, unless they were treated with appropriate amendments. Some of the silted sediments were too clayey, low in organic matter and nitrogen, but high in acidity, Al and/or Fe contents. The acidity in the sediments and the contents of the acid metals should be reduced to the acceptable level via appropriate means so that they no longer becoming a threat to the crops growing on the soils silted by the sediments.

Nor Sayzwani *et al*. [4] found that the sediments deposited at Dabong, Kuala Krai, which were located in the southern part of the state (**Figure 1**) contained low concentration of Pb and Cu, but Mn concentration was moderately high (1.8 - 17.3 mg·kg^{-1}). The concentration of Zn was high, with values ranging from 1.2 to 181.0 mg kg^{-1}. The addition of Zn into the soils during the flood was in a way enhanced their productivity as shown by the study of Panhwar *et al.* [22] who found that rice grown in the soils of the Kelantan Plains responded positively to Zn application. They found that due to Zn application, not only rice yield was increased, but also the quality of its grains was enhanced.

It was suggested in this study that the land affected by the flood in Kota Bharu and Tumpat districts should be adequately limed with ground magnesium limestone to reduce the acidity to the minimal level required for crop production, especially rice [14] [23]. However, the pH of the sediments at Dabong, Kuala Krai located a few hundred km south of Kota Bharu (**Figure 1**) was 5 - 6, which was moderately acidic [3]. For these sediments, no lime application was necessary [18]. To promote the formation of soil structures, organic matter in the form of bio-fertilizer fortified with beneficial microbes should be applied regularly at the rate depending on the amount already present in the silted sediments. In this way, crop production on the affected lands can be sustained at least till the next great flood comes again.

How to carry out proper mitigation of the lands/soils affected by the flood of this nature? A good question to ask, but it is difficult to a get a straight forward answer. An immediate comprehensive study is, therefore, necessary to be conducted. It is for this reason that the government of Malaysia had set aside some money for research to be conducted by universities in the country. The results of these studies would, to a certain extent, provide the baseline data required for long-term studies in future so as to reduce/prevent damages to lives and properties should flood of this magnitude occurs again. One will never know under the present state of global warming, flood of this magnitude is making a comeback sooner rather than later. Hence, we have to be prepared in case it happens again in the near future.

5. Conclusion

The lands/soils in the upper reaches of the Kelantan River were degraded because of the uncontrolled development in the areas for agriculture and/or logging activities. When heavy rain fell in these areas on December 2014, very serious flood occurred that resulted in severe soil erosion as well as untold damages to the agricultural lands and people properties. In the end, the areas in the lower reaches of the river were heavily silted with infertile materials considered unfit for crop production. The silted sediments were characterized by the presence of quarts, mica, feldspars, kaolinite, gibbsite and hematite, coming from the top- and subsoil of the upland areas. The pH of these sediments was mostly very low and Al and/or Fe contents were very high, while the nitrogen and carbon contents varied from area to area. Soils in the Kelantan Plains badly affected by this great flood needed to undergo proper ameliorative program. The most appropriate measure would be to apply ground magnesium limestone in combination with bio-fertilizer fortified with beneficial microbes that would increase their pH to a level above 5, which consequently eliminates Al^{3+} and/or Fe^{2+} that causes toxicity to the crops growing on them; the organic matter so added would enhance the formation of soil structures. The way forward for the farming communities in the upper reaches of the Kelantan River would be to follow the advice advocated by the

Department of Agriculture, Peninsular Malaysia, via MyGAP initiative, in order to sustain agricultural production on their land.

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Conflicts of Interest

The authors declare no conflict of interest.

References

[1] Azuhan, M. (2015) Kelantan Flood—Divine vs Anthropogenic Causes. *Proceedings of National Geoscience Conference*, Kota Bharu, 31 July-1 August 2015, Geological Society of Malaysia, 2-5.

[2] Sathiamurthy, E. and Kong, Y.H. (2015) Kelantan State Great Flood Event in December 2014—Hydrology Perspective. *Proceedings of National Geoscience Conference*, Kota Bharu, 31 July-1 August 2015, Geological Society of Malaysia, 41-42.

[3] Nurul Akma, J., Khanan, Z., Haq, U.Y. and Bhat, I. (2015) Effects of Recent Flood on Soil Properties. *Proceedings of National Geoscience Conference*, Kota Bharu, 31 July-1 August 2015, Geological Society of Malaysia, 207.

[4] Nor Sayzwani, S., Siti Hajar, Y., Musfiroh, J., Farah, K.K., Noor Syuhadah, A. and Zulhazman, H. (2015) Determination of Heavy Metal Concentration in Soil at Dabong, Kelantan. *Proceedings of National Geoscience Conference*, Kota Bharu, 31 July-1 August 2015, Geological Society of Malaysia, 235.

[5] DOA (2013) Ministry of Agriculture and Agri-Based Industries. Putrajaya, Malaysia.

[6] Shamshudin, J. (2011) Methods in Soil Mineralogy. UPM Press, Serdang.

[7] Gee, G.W. and Bauder, J.W. (1986) Particle-Size Analysis. In: Klute, A., Ed., *Methods of Soil Analysis*, Part 1, 2nd Edition, Agron. Monogr. 9, ASA and SSSA, Madison, 383-411.

[8] Benton Jr., J. (2001) Laboratory Guide for Conducting Soil Tests and Plant Analysis. Laboratory Guide for Conducting Soil Tests and Plant Analysis. CRC Press LLC, New York. http://dx.doi.org/10.1201/9781420025293

[9] Bremner, J.M. and Mulvaney, C.S. (1982) Nitrogen-Total. In: *Methods of Soil Analysis*, *Agron*. No. 9, *Part* 2: *Chemical and Microbiological Properties*, 2nd Edition, Madison, 595-624.

[10] Bray, R. and Kurtz, L.T. (1945) Determination of Total, Organic, and Available Forms of Phosphorus in Soils. *Soil Science*, **59**, 39-46. http://dx.doi.org/10.1097/00010694-194501000-00006

[11] Bottini, N., Musumeci, L., Alonso, A., Rahmouni, S., Nika, K., Rostamkhani, M. and Mustelin, T. (2004) A Functional Variant of Lymphoid Tyrosine Phosphatase Is Associated with Type I Diabetes. *Nature Genetics*, **36**, 337-338. http://dx.doi.org/10.1038/ng1323

[12] Kotzé, W.A.G., Joubert, M., de Villiers, J.F., van der Westhuizen, M. and van der Bank, D. (1984) Measurement of Exchangeable Aluminium in Soils and Clay Minerals by Isotopic Exchange. *South African Journal of Plant and Soil*, **1**, 57-60. http://dx.doi.org/10.1080/02571862.1984.10634110

[13] Shamshuddin, J. and Fauziah, C.I. (2010) Weathered Tropical Soils: The Ultisols and Oxisols. UPM Press, Serdang.

[14] Shamshuddin, J., Wan Noordin, W., Roslan, I., Fauziah, C.I. and Panhwar, Q.A. (2015) Ultisols and Oxisols: Enhancing Their Productivity for Oil Palm, Rubber and Cocoa Cultivation. UPM Press, Serdang.

[15] Anonymous (2015) https://www.google.com/Search?q=isch&imgil=x44py87FNfsUeM%253A%253BJJ

[16] Anonymous (2015) https://www.google.com/webhp?sourceid=chrome-instant&rlz=1C1CHNQ_enMY654MY655&ion=1&espv=2&ie=UTF-8#q=flood%202014%20malaysia

[17] Anda, M., Shamshuddin, J., Fauziah, C.I. and Syed Omar, S.R. (2008) Pore Space and Specific Surface Area of Heavy Clay Oxisols as Affected by Their Mineralogy and Organic Matter. *Soil Science*, **173**, 560-574. http://dx.doi.org/10.1097/SS.0b013e318182b0a9

[18] Alia, F.J., Shamshuddin, J., Fauziah, C.I., Husni, M.H.A. and Panhwar, Q.A. (2015) Effects of Aluminum, Iron and/or

Low pH on Rice Seedlings Grown in Solution Culture. *International Journal of agriculture and Biology*, **17**, 702-710. http://dx.doi.org/10.17957/IJAB/14.0019

[19] Shamshuddin, J., Elisa Azura, A., Shazana, M.A.R.S., Fauziah, C.I., Panhwar, Q.A. and Naher, U.A. (2014) Properties and Management of Acid Sulfate Soils in Southeast Asia for Sustainable Cultivation. *Advances in Agronomy*, **124**, 91-142. http://dx.doi.org/10.1016/B978-0-12-800138-7.00003-6

[20] Dobermann, A. and Fairhurst, T. (2000) Rice: Nutrient Disorders & Nutrient Management. Handbook Series, Potash & Phosphate Institute (PPI), Potash & Phosphate Institute of Canada (PPIC) and International Rice Research Institute, Philippine, 191.

[21] De Coninck, F. (1978) Physico-Chemical Aspects of Pedogenesis. International Training for Post-Graduate Soil Scientists, Ghent University, Ghent.

[22] Panhwar, Q.A., Naher, U.A., Radziah, O., Shamshuddin, J., Mohd Razi, I., Dipti, S.S. and Karabalei Aghamolki, M.T. (2015) Quality and Antioxidant Activity of Rice Grown on Alluvial Soil Amended with Zn, Cu and Mo. *African Journal of Botany*, **98**, 77-83.

[23] Shamshuddin, J. and Ismail, H. (1995) Reactions of Ground Magnesium Limestone and Gypsum in Soils with Variable-Charge Minerals. *Soil Science Society of America Journal*, **59**, 106-112. http://dx.doi.org/10.2136/sssaj1995.03615995005900010017x