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Characteristics, Impacts and Management of Acid Sulphate Soils: A Review

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ABSTRACT: The opportunity has been taken to further highlight the salient features and ecological impacts as well as management options of acid sulphate soils. This is important in raising awareness for proper management of this soil so as to minimize its negative impacts for sustainable environmental management. Comprehensive review of relevant literature had been done to achieve this. The soil is extremely acid with pH values < 3.0. Extreme pH makes micronutrients and exchangeable bases to be available and unavailable, respectively. Consumption and bathing with very low pH water cause various skin diseases in humans. Short term impacts on aquatic life include fish kills, fish disease, mass mortalities of microscopic organisms, increased light penetration due to water clarity, loss of acid-sensitive crustaceans, destruction of fish eggs. Others include collapse of bridges and lands where filled with this soil due to soil's low load bearing capacity, weakening of concrete and steel structures and blockage of drainage pipes. The general approaches for management are avoidance and minimization of disturbance, neutralization, hydraulic separation, bioremediation, flooding and intermittent shallow drainage, water table management, deep soil mixing leaching, liming and growing of suitable crops and recognition. Policy makers are encouraged to take advantage of this information so as to ensure friendly environment for increased human and aquatic health as well as sustainable agriculture.

KEYWORDS: Acid Sulphate Soils, Characteristics, Impacts, Management.

I.INTRODUCTION

Acid sulphate soil is the common name given to soil containing iron sulphides (Dent, 1986; Sammut, 2004; Shaon and Suvo, 2015). Great group involved in acid sulphate soil are Sulphaquepts, Sulphaquents, Sulphihemists and Sulphohemists (Shaon and Suvo, 2015). They are also defined as pyritic sediments that can produce acid when exposed to oxidizing conditions. Though the pyrite in acid sulphate soils is microscopic (Figure 4), it has a very large surface area and therefore reacts rapidly when exposed to oxygen (Sammut, 2004). Thionic Fluvisols that developed under marine or brackish water are also called acid sulphate soils (Bhargava and Abrol, 1984). The soils are generally found in coastal areas where the land is inundated by salt water (Shaon and Suvo 2015). These soils are still being formed today in mangrove forests and salt marshes, estuaries and tidal lakes or low- lying coastal areas, back swamps and in esturine environments (Rebecca, 2004).

Major countries where acid sulphate soils are found include Australia (3000 ha), Vietnam (2140 ha), Venezuela (2000 ha), Brazil (1111 ha), Guyanas (1246 ha), Indonesia (4109 ha), Thailand (1500 ha), Malaysia (657 ha), Central America (650 ha), Madagascar (528 ha), India (390 ha) and Sweden 140 ha (Attanandana *et al.*, 1986; Angeloni *et al.*, 2004). In Nigeria, acid sulphate soil covers over 750,000 hectares of unclassified wetlands in the mangrove swamp of the Niger Delta (Dublin-Green and Ojanuga, 1988).

Activities such as cropping, grazing, urban and tourism development, highway construction, flood mitigation drains and floodgates, dredging, sand mining and aquaculture can all oxidize these soils causing major environmental harm. Water discharges are acidic and contain toxic concentrations of dissolved aluminium and iron that kill or make fish and oysters as well as humans more vulnerable to disease. Acidic soil water also stunts farm crops, creates scalds and enables acid tolerant weeds to spread. Economic losses caused by acid discharges are a major concern and threaten coastal industries. Acid discharges also causes millions of dollars-worth of damage to concrete and steel structures such as bridges, roads, and storm-water pipes.

Drainage of coastal wetlands for agricultural and urban development constantly releases enough sulphuric acid and aluminium which affect aquatic life. Acid water affects the health of fish and other aquatic life through damage to the skin and gills. Other impacts include mass mortalities of microscopic organisms, increased light penetration due to water clarity, loss of acid-sensitive crustaceans, destruction of fish eggs. Others include collapse of bridges and lands

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where filled with this soil due to the soil's low load bearing capacity, weakening of concrete and steel structures and blockage of drainage pipes.
Management options include recognition, avoidance and minimization of disturbance, neutralization, hydraulic separation, bioremediation, flooding and intermittent shallow drainage, water table management, deep soil mixing, leaching, liming and growing of suitable crops.
The chemical reactions involved in the acidification starts with the oxidation of pyrite to ferrous iron, sulphate and acid. The ferrous iron is then oxidized to various end products. For each unit of pyrite oxidized, two units of sulphate and four units of free molecules of concentrated sulphuric acid are ultimately produced (Environmental News, 1998).
As a result of the extremely low pH (< 3.0) exhibited, very severe environmental hazards are caused by these soils including environmental degradation, destabilization of ecosystems, killing of aquatic life as well as reduction in the quality of human life wherever these soils exist. This is in addition to their agriculturally unproductive nature thereby reducing farm productivity in the face of global food insecurity as it relates to the ever increasing world population. Despite these serious challenges and the numerous researches conducted on them, hardly any comprehensive review exists on the subject matter to serve as base line, at a glance, for researchers and policy makers. Where it exists, the information is scanty and scattered.
There is, therefore, an urgent need to fully understand and document, in one piece, the characteristic features of these soils for better management so as to reduce their negative impacts on the environment for an overall sustainable environmental harmony and increased agricultural productivity. This paper is an attempt in this direction.

II. CHARACTERISTICS OF ACID SULPHATE SOILS

Acid sulphate soil contains a sulphuric horizon having pH < 3.5 along with sulphide (Dent, 1986) content (yellow colour). Sulphuric horizon is 15 cm or more thick and is composed of either organic or mineral soil material that has a pH equal or less 3.5 due to sulphuric acid and shows evidence that the low pH value is caused by sulphuric acid (Shaon and Suvo, 2015). It also contains sulphidic materials having oxidizable sulphur compounds. Compared with normal soil, the organic matter content of the acid sulphate soils is generally much higher. Great group involved in acid sulphate soil are Sulphaquepts, Sulphaquents, Sulphihemists and Sulphohemists. Hydrogen sulphide often formed in lowland rice and causes akiochi disease which retard rice plant roots to absorb nutrients. This is because low pH is unfavourable for organic matter decomposition and retard the ammonification, regardless of the high organic matter content.
The texture of acid sulphate soils is reported to range between clay to sand with mean values of 66 (Al), 23 (Fe), 29 (Si) 0.4 (Cr) and 29 (Mn) tonnes ha^{-1} for acid sulphate soils in Dulguigan (Bennet *et al.*, 2004). Calvert and Ford (1973) reported soluble Al and Fe up to 275 ppm and 100 ppm, respectively in acid sulphate soils. The pH values of acid sulphate soils have been reported to be < 3.0 (Shaon and Suvo, 2015). Organic carbon contents of soil samples were high. Due to high P fixation, these soils were deficient in available P. The potassium content was high and ranged from 142.1 mg·kg-1 to 326.4 mg·kg-1. Ca, Mg, Na and S content were also high (Fitzpatrick *et al.*, 1996). Iron, Mn and Al toxicity were reported to be prevalent in regions where these soils are found (Fitzpatrick *et al.*, 1996).
Actual acid sulphate soils (AASS) are those produced when the iron sulphides are exposed to air producing sulphuric acid while potential acid sulphate soils (PASS) are those where the iron sulphides are contained in a layer of waterlogged soil because it has the potential to oxidize to sulphuric acid (Sammut, 2004). Actual acid sulphate soils have a pH of less than 4. They vary in texture and often contain jarosite (Figure 2). Potential acid sulphate soils often have a pH close to neutral (6.5–7.5). They contain unoxidized iron sulphides and are usually soft, sticky and saturated with water and are also usually gel-like muds (Figures 3a and 3b) but can include wet sands and gravels (http://www.agric.nsw.gov.au/Arm/acidss/index.html).

Figures 3a and b show dark grey PASS being excavated from depth, in contrast with the brown well-drained surface soil.

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Figure 3a. Potential Acid Sulphate Soil.

Figure 3b. Potential Acid Sulphate Soil.

A typical soil pit shows both potential and actual acid sulphate soils together (Figure 1). The wet grey mud at the bottom of the pit is the iron sulphide layer. The mottled yellow layer (Figures 1a and 1b) above the wet mud is actual acid sulphate soil. The yellow colour is jarosite, a Sulphur mineral. Its presence shows that the iron sulphides are oxidizing and forming sulphuric acid (www.dnr.qld.gov.au.). The oxidation has occurred because the water-table has dropped and exposed the top section of the iron sulphide layer to air.

When drains are dug in the iron sulphide layer, excavated heaps of iron sulphide muds are often left beside the drain as shown in Figure 2. As this drain spoil oxidizes it produces acid. The acid makes it difficult for plants to grow on the spoil; when it rains the acid leaches into the drain water. The problems associated with drainage of acid sulphate soils mean that drainage works need to be undertaken with extreme caution and in consultation with relevant authorities.

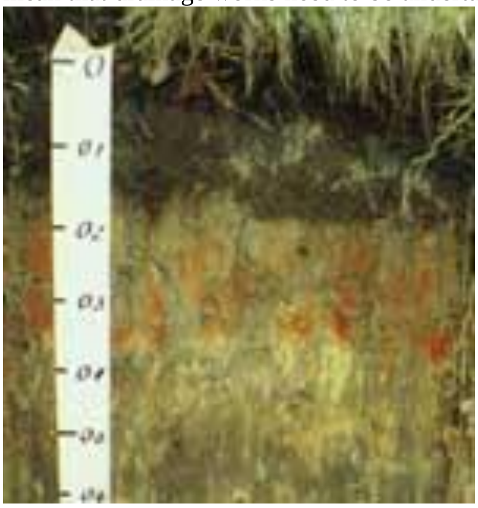

Figure1a. Actual and PASS

Figure 2. Drain in Acid Sulphate Soil showing yellow Jarosite.

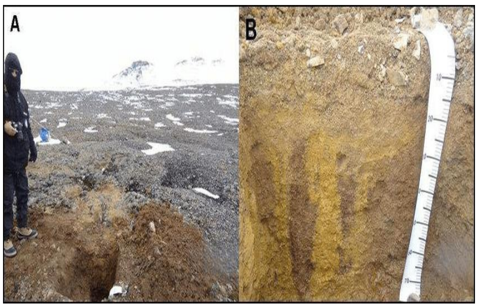

Figure1b. Actual and Potential Acid Sulphate Soils (PASS).

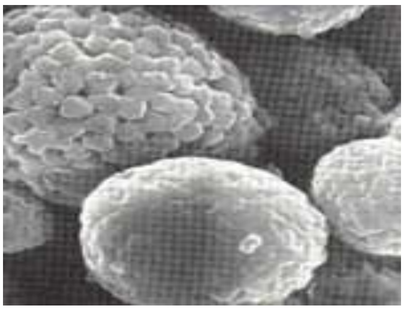

Figure 4. Pyrite (microscopic)

Source: Rebecca (2004); Sammut, (2004).

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Figure 1a shows a dark organic-rich surface soil from 0 to 0.15 m; an oxidised horizon with orange mottling from 0.15 to 0.35 m; and an AASS horizon from 0.35 to 0.90 m, characterised by the presence of yellow jarosite. The PASS horizon, which extends from 0.9 m downwards, consists of dark grey, wet, marine mud (www.dnr.qld.gov.au.).

III. IMPACTS OF ACID SULPHATE SOILS

The acid produced by oxidation of iron sulphides affects both soil and water, and can damage the environment severely. As sulphuric acid moves through the soil, it strips iron, aluminium and sometimes manganese from the soil. In some cases it also dissolves heavy metals such as cadmium. In the soil this mixture can make the soil so acid and toxic that few plants can survive (Rebecca, 2004). In some cases, where peat overlying the iron sulphide layer has burnt away, the iron sulphide layer is completely exposed to air. It produces so much sulphuric acid that nothing will grow, giving the soil surface a bare, scalded appearance (Figure 5). Acid sulphate soils reduce farm productivity.
The sulphuric acid lowers pH, which makes several soil nutrients less available to plants. The acid dissolves iron and aluminium from the soil so that they become available to plants in toxic quantities in soil water. The aluminium in acid water is toxic to most water organisms, because it damages their gills and at lethal levels can suffocate them. Cloudy green-blue water is an indicator of the presence of aluminium. Figure 6 shows green-blue acid slug moving into the brown waters of the Richmond River in Queensland. These conditions reduce plant growth, and only acid tolerant plants such as smartweed and spike rushes (Figures 7a and b) can survive. This effectively means loss of drought-refuge swamp pastures used in the past by farmers.
Animal productivity is affected by acid sulphate soils. The acid discourages good quality pasture. Grazing animals may take in too much aluminium and iron by feeding on acid-tolerant plant species and drinking acid water (Rebecca, 2004). When many of these waterlogged soils are drained their gel-like iron sulphide layer (Figures 3a 3b) dries out and the soil can actually shrink and subside. This may make farmland more prone to flooding and waterlogging (Rebecca, 2004).
Sulphuric acid produced by acid sulphate soils corrodes concrete, iron, steel and certain aluminium alloys. It has caused the weakening of concrete structures and corrosion of concrete slabs, steel fence posts, foundations of buildings and underground concrete (Figures 8a and 8b) water and sewerage pipes.

Figure 5: Bare, Scalded appearance of Soil Surface. Figure 6: Green-blue acid slug
Source: Rebecca (2004); Sammut, (2004).

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Figure 7a: Acid tolerant plants (smartweed) Figure7b: Acid Tolerant Plants (waterlilies and spike rushes).

Source: Rebecca (2004); Sammut, (2004).

Figure 8a: Corrosion of Concrete Pillars and Steel. Figure 8b: Corrosion of Sewage Pipes/Concrete

Source: Rebecca (2004); Sammut, (2004).

When acid sulphate soils are used as landfill they can affect plant growth and landscaping (Figure 9), and create erosion problems (Sammut, 2004). Developers of coastal subdivisions need to take particular care because disturbance and oxidation of iron sulphides during development may prevent establishment of gardens or lawns. Few plants will grow where acidity is as low as pH 2.7.

Acid water leached from oxidizing acid sulphate soils can cause rust-coloured stains and slimes. The dissolved iron in the acid water precipitates when it contacts less acid water, producing orange-red iron oxide scums. Perforated plastic pipe drainage systems can become blocked by iron oxides in and around the drains (Figure 10) (Sammut, 2004).

Figure 9: Collapse of Landfills Figure 10: Blocked Perforated Plastic Pipe

Source: Rebecca (2004); Sammut, (2004).

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A. Impact on Fish and Aquatic Life

Drainage of coastal wetlands for agricultural and urban development constantly releases enough sulphuric acid and aluminium to affect the aquatic food chain, fish populations, and the health of fish. Most aquatic life needs a minimum pH of 6 to survive. The pH of acid water can be as low as 2, and is often around 4 (Miller *et al.*, 1997). The lower the pH, the more acid the water. Fish and crustaceans try to avoid acid water, but if they cannot escape, they may die. Plants and sedentary gilled organisms, unable to escape the acidified water are often killed or their growth is stunted.
Massive fish kills (Figure 11) can occur when sulphuric acid is washed into waterways. This is a particular problem after droughts, when the water table has dropped and the iron sulphide layer has oxidized. Drought-breaking rains wash substantial quantities of sulphuric acid and aluminium into waterways, and massive fish kills can result (Figure 11).
However, fish kills are the most obvious effect of acid sulphate soils; the chronic, less visible effects such as reduced hatching and decline in growth rates are more common and widespread. Repeated flows of acid water prevent the fish population recovering. Not only are there fewer fish but there are more mosquitoes, because larvae-eating fish are unable to survive the acid water.
Acid water affects the health of fish and other aquatic life through damage to the skin and gills. Skin damage increases the susceptibility of fish to fungal infections which may lead to diseases such as epizootic ulcerative syndrome, also known as ‘red spot’ (Figure 12). Gill and skin damage (Figure 13) reduce the ability of fish to take in oxygen or regulate their intake of salts and water. ‘Red spot’ disease causes significant economic losses to commercial fishermen.

Figure 11: Massive Fish Kill Figure 12: Epizootic Ulcerative Syndrome (‘red spot’)

Source: Rebecca (2004); Sammut, (2004).

Figure 13: Skin Damage

Source: Rebecca (2004); Sammut, (2004).

Oysters are unable to escape acidified water as they are permanently attached to rock surfaces. Oysters exposed to either frequent or prolonged acidification stop feeding and experience breakdown of their shell and poor growth rates.

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They may also experience damage to their gills and other organs through the direct injurious effects of acid and aluminium, or the accumulation of iron. In many cases, oysters repeatedly exposed are killed or cannot be sold due to their poor condition. Oyster larvae may also be killed affecting wild populations and aquaculture.
Acid water affects the habitat of aquatic life. When acid water mixes with less acid stream water (above pH 4) the iron dissolved in the acid water precipitates and smothers plants and the streambed. These iron solids can move downstream and smother streambeds where there is no acid water.
High levels of aluminium in acid water can cause particles floating in the water to clump together and drop to the bottom, leaving the water crystal clear (Figure 14). This clarity looks attractive but indicates that the water is too acid for aquatic life. The clear water can be up to 5°C warmer than water with particles floating in it. The clear water allows acid-tolerant plants to saturate the water with oxygen which can kill fish through the 'bends' or gas bubble disease. Clear water also increases the risk of fish suffering sunburn and melanomas. In humans, bathing with this clear water can cause skin diseases (Rebecca, 2004).
Short term effects of acid water on fish and fish habitat include fish kills, fish disease, mass mortalities of microscopic organisms, increased light penetration due to water clarity, loss of acid-sensitive crustaceans, destruction of fish eggs and oyster mortalities. Long term effects of acid water on fish and fish habitat include loss of habitat, persistent iron coatings, alterations to water plant communities, invasion by acid-tolerant water plants, reduced spawning success due to stress, chemical migration barriers, reduced food resources, dominance of acid-tolerant plankton species, growth abnormalities, reduced growth rates, increased predation, changes in food chain and web, damaged and undeveloped eggs, reduced recruitment, higher water temperatures due to increased light penetration, increased availability of toxic elements, reduced availability of nutrients and poor growth in oysters and other bivalves.

Figure 14: Crystal Clear Water
Source: Rebecca (2004); Sammut, (2004).

The combination of fish kills, declining fish health and degraded habitat reduces fish populations in areas affected by acid water. Fish kills affect many ages of fish, and the loss of larvae and juveniles can be a regular occurrence. Some 70% of our commercial fish species spend part of their life cycles in estuaries, so the impacts of acid water raise major concerns for the future of commercial and recreational fishing industries, and the ecosystem. Researchers are currently looking at the long term impacts of acid water on fish populations.

IV. MANAGEMENT OF ACID SULPHATE SOIL

Our understanding of acid sulphate soil chemistry and its effects has increased rapidly over the past five years, but there is still much to be learnt about management and rehabilitation of these soils.

A. Avoidance

The best technique for managing acid sulphate soils is to avoid disturbing or draining the iron sulphide layer in the first place. Iron sulphides are harmless while covered by water. To avoid disturbing the iron sulphide layer, it is important to know where it is likely to be found, and some states produce maps for this purpose. It is necessary to take soil cores to find out the exact location and depth of the iron sulphide layer on a particular site.

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B. Recognition

It is useful to know what the iron sulphide layer looks like so that if it is uncovered accidentally it can be re-covered with water immediately. The photograph below shows excavated iron sulphide soil – dark grey and wet.
It is also important to be able to recognize indicators of actual acid sulphate soils to prevent further acidification of land and waterways. These indicators include the cloudy green-blue water, excessively clear water, iron stains, poor pasture, scalded soil, and yellow jarosite described earlier in this booklet.

C.Liming

Sulphuric acid can be neutralized with agricultural lime, but this is too costly for large areas of badly affected land. One technique that has had good results to date is liming of drains so that the
sulphuric acid produced in the drain walls is neutralized by the lime as it is washed out. Acid water can also be neutralized by lime.

D.Water cover

Re-flooding land with freshwater can halt further acidification. It may even reverse the acidification process if the site can be kept wet and there is sufficient organic matter. Water cover can enable acid tolerant grasses to recolonize severe acid scald areas preventing soil erosion.
However, freshwater reflooding may increase acid discharges if acid water can sit closer to the ground surface and more easily flow into waterways during moderate rainfall. The use of freshwater re-flooding requires caution and technical advice before it is applied. Seawater flushing may lead to increased acid neutralization but may cause other impacts that have not been fully investigated. For example, acid sulphate soils change chemically and physically once they are oxidised. The landscape may be at a much lower elevation due to soil shrinkage and may also transmit saltwater to areas previously unaffected. Research into both freshwater and seawater flooding of acidified lands is being investigated. Landowners are advised to seek expert technical advice for remediation of acid sulphate soil sites.
Forestry
Some commercially valuable tree species will grow on acid sulphate soils. Trials are underway to discover if trees can transpire large quantities of surface water to reduce acid export from backswamp areas. This experimental concept requires careful controls to prevent any further oxidation of potential acid sulphate material.

E.Sea water neutralization

A number of floodgates are now managed to open periodically to seawater to neutralize drain acid, control weeds and improve fish passage.
However, the use of seawater to neutralize acid produced by developments raises a number of ethical, moral and legal questions that need to be addressed. At present the biological impacts of seawater neutralization are unknown.

F.Shallow drainage

Wide, shallow drains like the one shown below allow surface water to drain quickly from the surface of low-lying land without exposing the iron sulphide layer beneath the soil. Deep, narrow drains are more likely to expose the iron sulphide layer and leak sulphuric acid into waterways.

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