UNIVERSITI PUTRA MALAYSIA

GROUNDWATER QUALITY AND QUANTITY, AND IRRIGATION REQUIREMENT FOR OIL PALM PLANTATIONS IN PEAT SWAMP, SOUTH OF SELANGOR, MALAYSIA

ADESIJI ADEOLU RICHARD

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By

ADESIJI ADEOLU RICHARD

Thesis submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

April 2016

DEDICATION

To the glory of Amighty God, the giver of life and knowledge, this study is dedicated to:

My wife, **Modupeola**
My children, **Inioluwa, Kolade, and Ajibola**
And to the loving memory of late Dad, **Pa Isaac Adigun Adesiji**

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirements for the degree of Doctor of Philosophy.

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Chairman : Professor Thamer Ahmad Mohammad, PhD
Faculty : Engineering

As a result of boom recorded globally in oil palm industries, many countries, especially in the Southeastern Asia region such as Malaysia and Indonesia have converted sizeable parts of their peat swamp forests to oil palm plantation. Prior to this conversion, these peat swamp forests had been the most important terrestrial ecosystem for carbon storage, regulating greenhouse gas emission and climate, and a source of water supply and flood control, particularly for the neighboring communities. Therefore, the conversion of the peat swamp forests for the purpose of agricultural practices which is oil palm plantations has done more damages than good.

Cultivation of oil palms on peat soil has greatly affected the environment and soil carbon in recent time, especially when such practice has been on for several years. Large concentrations of carbon stored in the peats over the years is being exposed to the atmosphere as a result of this indiscriminate land conversion for agricultural purposes and this has further aggravated the issue of global warming by increasing the amount of greenhouse gases in the atmosphere.

The water quality degradation is another negative effect of this practice. Due to the anthropogenic activities being practiced on the peatlands, soil carbon are escaping into the groundwater in dissolved form as dissolved organic carbon which seeps and pollutes the peatland streams which feed the adjoining rivers thereby becoming a source of pollution to the rivers used for municipal water supply.

This study therefore considers four main objectives including the best management practices or policies needed for greater outputs from the peatlands. The first objective considered the effects of oil palm plantation on soil chemistry with respect to different age of plantations. Soil analyses were carried out and the parameters

considered in soil analyses are; pH, moisture content, carbon, nitrogen, sulphur, and some heavy metals like, manganese, zinc, iron, copper, and phosphorus. Heavy metals present in the soil were determined using the double acid method while carbon, nitrogen, and sulphur were determined using flash combustion method.

The results of the soil analysis indicated both strong and weak correlations among carbon, nitrogen, sulphur, depth and pH during both dry and wet periods. During the dry period, carbon values ranged from the highest (49.07%) in the oil palm cultivated in the year 2000 to the lowest (11.66%) in 2010-cultivated oil palm. During the wet season, soil carbon ranged from highest 51.22 % at 0.5 m depth in 2000 study plot to the lowest as 37.04 % at 1.5 m depth in 2002 study plot. This suggests that soil carbon content of peat soil shows some levels of correlation with depth during the dry season as against the wet season. In other words, there is weak correlation of soil carbon with age of plantation and soil depth in dry season and none during the wet season. However, peat soil during the wet season recorded higher soil carbon content.

The second study focused on the hydrological influence on concentration of dissolved organic carbon (DOC) in both peatland groundwater and surface water with emphasis on rainfall distribution pattern and fluctuation in groundwater table. The result showed that the highest flux of DOC was observed during the high storm events and high water table while the lowest flux was observed when the groundwater table was at the lowest level. This shows that the hydrological factor is a significant factor for determining the peatland DOC flux.

Having established the link between the groundwater table and DOC flux, the third objective focused on the drivers of groundwater table fluctuation. The two drivers noted were soil moisture and soil temperature. With soil moisture probe and soil temperature sensors buried into the soil at two different depths of 5 cm and 70 cm, and pressure transducers inserted through a tube well into the groundwater in 10 different locations, the daily soil moisture and temperature at both depths and daily water table depths were determined over the period of 6 months. The results were collected from loggers with the aid of computer laptop and were analyzed using multiple linear regression of SPSS. The results showed significant relationship between precipitation, soil temperature and soil moisture at both 5 cm and 70 cm soil depths (70 cm in particular). The result also showed significant relationship between soil moisture at both depths and groundwater table fluctuations. However, there is no significant relationship between soil temperatures at both depths with groundwater table fluctuations.

The fourth objective considered the groundwater recharge and soil moisture deficit estimation for the study area. The two parameters of soil moisture balance model were used to estimate the water requirement of the oil palms in all the study plots. The study plots were divided into four plots: 2000, 2002, 2006 and 2010, based on the years of peat swamp forest conversion to oil palm plantation. Two different hydrological models were used in this study. Hydrologic Modeling System, HEC-HMS was used along with recorded flow and rainfall data to establish a rainfall-runoff relationship for a nearby catchment which was calibrated and later validated before being used in the study area. HEC-HMS discharge values were adopted as observed flow and compared with soil moisture balance model. Soil moisture balance model was also calibrated and validated and used to check soil moisture status of oil palm in daily time step. Periods with water deficit for oil palms in all the study periods were observed and the irrigation water needs were estimated for each of the study plots. For 2000 study plot, the irrigation water need was estimated as 1.6 x 10^6 m^3, 0.689 x 10^6 m^3 for 2002 study plot, $0.607\ x10^6$ m^3 for 2006 study plot and $0.893\ x10^6$ m^3 for 2010 study plot. Irrigation water need of a plantation is therefore observed to be site specific which depends on the soil moisture deficit, readily available water in the oil palm root zone and oil palm rooting depth. River Labu, with basin of 260.72 km^2 was proposed as a source of irrigation water. The estimation of daily runoff discharge from Seventeen sub-basins of River Labu basin showed that the basin could provide the needed irrigation requirement for the four study plots. Estimation of a future oil palm water requirement using the soil moisture balance model would be recommended for further studies so as to aid in using the model as an advisory manual for the oil palm managers in order to enhance adequate water resources planning for oil palm productivity.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

KUALITI AIR BAWAH TANAH DAN KUANTITI, DAN KEPERLUAN PENGAIRAN UNTUK LADANG KELAPA SAWIT DI PAYA GAMBUT, SELATAN SELANGOR, MALAYSIA

Oleh

ADESIJI ADEOLU RICHARD

April 2016

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Akibat perkembangan industri kelapa sawit yang pesat di seluruh dunia, kebanyakkan negara, terutamanya di Asia Tenggara, seperti Malaysia dan Indonesia telah menukar hutan paya bakau kepada ladang kelapa sawit. Hutan paya bakau adalah ekosistem daratan yang paling penting sebagai takungan karbon, mengawal pengeluaran gas rumah hijau dan iklim, dan sebagai punca bekalan air dan kawalan banjir terutamanya bagi komuniti sekitarnya. Oleh itu, pengubahan hutan paya bakau bagi tujuan kegiatan pertanian iaitu penanaman kelapa sawit memberi lebih banyak keburukan daripada kebaikan.

Penanaman kelapa sawit di tanah gambut telah memberi kesan besar pada alam sekitar dan karbon tanih pada masa kini, terutama sekali di kawasan yang telah lama diterokai. Kepekatan tinggi karbon yang disimpan selama beberapa tahun di dalam tanah gambut telah terdedah ke atmosfera disebabkan pengubahan tanah sembarangan bagi tujuan pertanian dan ini menjadikan isu pemanasan global bertambah teruk dengan meningkatkan jumlah gas rumah hijau ke atmosfera.

Penurunan kualiti air juga merupakan salah satu kesan negatif implikasi kegiatan itu. Akibat daripada kegiatan antropogenik yang dijalankan di tanah gambut, karbon tanih telah terlepas ke dalam air bawah tanah dalam bentuk larutan iaitu karbon organik terlarut yang mana meresap dan mencemarkan aliran bersebelahan dengan sungai yang menjadi sumber air perbandaran bekalan air.

Kajian ini merangkumi empat objektif utama termasuk amalan pengurusan yang cekap ataupun polisi yang diperlukan untuk output terbaik dari tanah gambut. Objektif pertama mempertimbangkan kesan penanaman kelapa sawit terhadap kimia tanah berdasarkan umur ladang yang berbeza. Analisis tanah telah dijalankan dan parameter yang diuji adalah; pH, kandungan kelembapan, karbon, nitrogen, sulfur

dan logam berat seperti mangan, zink, besi, tembaga and fosforus. Kehadiran logam berat dalam tanah diuji dengan kaedah asid berganda sementara karbon, nitrogen and sulfur diukur dengan kaedah pembakaran kilat/marak.

Keputusan analisa tanah menunjukkan korelasi kedua-dua kuat dan lemah antara karbon, nitrogen, sulfur, kedalaman tanah dan pH semasa musim kering dan hujan. Semasa musim kering, rangkuman nilai karbon pada paras kedalaman tanah yang sama bermula dari yang tertinggi (49.07%), dijumpai di tanah yang mulai penamanan pada tahun 2000, hingga yang terendah (11.66%), di tanah 2010. Semasa musim hujan, karbon tanah adalah paling tinggi 51.22 % pada kedalaman 0.5 m pada tahun 2000 kajian plot hingga yang terendah 37.04 % pada kedalaman 1.5 m pada tahun 2002 kajian plot. Ini menunjukkan bahawa kandungan karbon tanah tanah gambut menunjukkan tahap korelasi dengan kedalaman semasa musim kering berbanding musim hujan. Dengan kata lain, terdapat korelasi yang lemah karbon tanah dengan usia perladangan dan kedalaman tanah pada musim kering dan tidak ada langsung pada musim hujan. Walau bagaimanapun, tanah gambut semasa musim hujan direkodkan kandungan karbon tanah tertinggi.

Objektif kedua kajian ini fokus kepada pengaruh hidrologikal terhadap fluks larutan karbon organik air bawah tanah dan air permukaan di tanah gambut dengan memberi tumpuan kepada corak taburan hujan dan turun naik aras air bawah tanah. Keputusan menunjukkan turun naik larutan organik karbon tertinggi diperhatikan semasa ribut kuat dan aras air bawah tanah tinggi manakala fluks yang paling rendah berlaku semasa aras air bawah tanah sangat rendah. Ini menunjukkan faktor hidrologikal adalah signifikan dalam menentukan fluks larutan karbon organik di tanah gambut.

Setelah menentukan hubungan di antara aras air bawah tanah dan fluks larutan karbon organik dalam kedua-dua air bawah tanah dan air permukaan, objektif ketiga memberi tumpuan kepada faktors yang menyebabkan turun naik aras air bawah tanah. Dua faktor tersebut adalah kelembapan tanah dan suhu tanah. Probe kelembapan tanah dan sensor suhu tanah ditanam pada dua kedalaman berbeza iaitu 5 cm dan 70 cm, serta transducer tekanan dimasukkan ke dalam air bawah tanah melalui perigi tiub yang terletak di 10 lokasi berlainan, kelembapan tanah dan suhu tanah harian di kedalaman yang berlainan serta kedalaman air bawah tanah diukur setiap hari selama enam bulan. Keputusan dikumpulkan dari loggers dengan bantuan komputer riba seterusnya dianalisis dengan menggunalan regresi linear pelbagai dalam perisian SPSS. Keputusan menunjukkan hubungan signifikan antara hujan, suhu tanah dan kelembapan tanah pada kedalaman 5 cm dan 70 cm (terutamanya 70 cm). Keputusan juga menunjukkan hubungan yang signifikan antara kelembapan tanah pada kedua-dua kedalaman dengan turun naik aras air bawah tanah. Walaubagaimanapun, tidak ada hubungan yang signifikan antara suhu tanah dan turun naik air bawah tanah pada kedua-dua kedalaman.

Objektif keempat mengambilkira aliran imbuh air bawah tanah dan anggaran defisit kelembapan tanah bagi kawasan kajian. Kedua-dua parameter kelembapan tanah model imbangan digunakan untuk menganggarkan keperluan air bagi kelapa sawit dalam semua plot kajian. Plot kajian telah dibahagikan kepada empat plot: 2000, 2002, 2006 dan 2010, berdasarkan tahun penukaran hutan paya gambut kepada ladang kelapa sawit. Dua model hidrologi yang berbeza telah digunakan dalam kajian ini. Sistem pemodelan hidrologi, HEC-HMS telah digunakan bersama-sama dengan data aliran dan hujan yang direkodkan untuk mewujudkan hubungan hujan-air larian bagi kawasan tadahan yang berhampiran yang telah ditentukur dan kemudian disahkan sebelum digunakan di kawasan kajian. Nilai pelepasan HEC-HMS telah diterima pakai sebagai aliran diperhatikan dan dibandingkan dengan model imbangan pelepasan kelembapan tanah. Model imbangan kelembapan tanah juga ditentukur dan disahkan dan digunakan untuk menyemak status kelembapan tanah kelapa sawit dalam kiraan hari. Tempoh dengan defisit air untuk kelapa sawit dalam semua tempoh kajian diperhatikan dan keperluan air pengairan dianggarkan bagi setiap plot kajian. Untuk plot kajian 2000, keperluan pengairan adalah $1.6\ x10^6$ m^3 untuk tahun 2002, $0.68\ x10^6$ m^3, bagi tahun 2006, $0.607\ x10^6$ m^3 dan bagi tahun 2010 ialah $0.893\ x10^6$ m^3. Keperluan pengairan air sebuah ladang adalah tapak spesifik di mana ia bergantung kepada kedua-dua ciri-ciri fizikal tanah gambut seperti tanah defisit kelembapan dan sifat-sifat tanaman seperti kedalaman perakaran tanaman. Sungai Labu, dengan lembangan 260.72 km^2 dicadangkan sebagai sumber air pengairan. Anggaran pelepasan air larian harian dari tujuh belas sub-lembangan dari lembangan Sungai Labu menunjukkan yang bahawa lembangan tersebut boleh menyediakan keperluan pengairan bagi empat plot kajian. Anggaran keperluan air tanaman pada masa depan dengan menggunakan model keseimbangan kelembapan tanah akan disyorkan untuk kajian lanjutan supaya dapat memberi bantuan dalam model sebagai manual nasihat bagi pengurus kelapa sawit bagi meningkatkan perancangan sumber air mencukupi untuk produktiviti kelapa sawit.

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I certify that a Thesis Examination Committee has met on 07 April 2016 to conduct the final examination of Adesiji Adeolu Richard on his thesis entitled "Groundwater Quality and Quantity, and Irrigation Requirement for Oil Palm Plantations in Peat Swamp, South Selangor, Malaysia" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy.

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AE	Actual Evaporation
ASEAN	Association of Southeast Asian Nations
AWE	Available Water for Evaporation
BMPs	Best Management Practices
CPO	Crude Palm Oil
DID	Department of Irrigation and Drainage
DON	Dissolved organic Nitrogen
DO	Dissolved Oxygen
DOC	Dissolved organic Carbon
ENSO	El-Nino Southern Oscillation
ETo	Reference Evapotranspiration
FAO	Food and Agriculture Organization of United Nation
FC	Field Capacity
FIR	Field Irrigation Requirement
GEC	Global Environmental Centre
GHGs	Greenhouse Gases
HEC-HMS	Hydrologic Engineering Center-Hydrologic Modeling System
HS	Histo Soils
IPCC	Intergovernmental Programme on Climate Change
LUCLC	Land Use Change Land Cover
MCL	Maximum contaminant level
MMD	Malaysian Meteorological Department
MPOB	Malaysian Palm Oil Board
MNAP	Malaysian National Action Plan
NSE	Nash-Sutcliffe Efficiency
NSS	Near Surface Storage
PE	Potential Evaporation
POC	Particulate organic Carbon
PSF	Peat Swamp Forests

PWP	Permanent Wilting Point
RAW	Readily Available Water
RSPO	Roundtable on Sustainable Palm Oil
SOM	Soil Organic Matter
SMD	Soil Moisture Deficit
TAW	Total Available Water
TOC	Total organic Carbon
UNESCO	United Nations Educational, Scientific and Cultural Organization
USEPA	United State Environmental Protection Agency
VMC	Volumetric Moisture Content
WHCS	Water Holding Capacity of Soil
WRM	World Rainforest Movement
WWF	World Wildlife Fund
SCS-CN	Soil Conservation Service Curve Number
SPC	Surface Peat Cover

CHAPTER ONE

INTRODUCTION

1.1 Background of Study

Management of land use and its relationship with economic dependence of a nation has been a frequent research in the past years. In most of the developing nations, management of landuse is a key factor influencing the government policies' impacts on the teeming populace. In most of these developing countries, larger numbers of citizens rely mainly on land cultivation, most importantly where the larger percentage of population depends on farming. In Southeast Asian region, agricultural activities in oil palm industry, as a form of land use, have been mostly practiced on mineral soils before the sudden growth was recorded in the industry.

The rapid growth in palm oil industry has become so phenomenal and thus accounted for the largest percentage of oil and fats production in the world (Chin *et al.*, 2013). MPOB (2008) also reported that palm oil has been ranked as one of the worlds most traded commodities in Malaysia and accounted for about 74.1 % of total oil palm exported in 2011. Also in Malaysia in 2011, 24.1% about 17.6 million tonnes of the total global trade of oils and fats was accounted for by palm oil production. With all development in the industry and its economic contribution to the national income, the expansion of oil palm industry in terms of available lands for large scale and profitable cultivation is inevitable. As a result this expansion, there was a shift from mineral soils to organic soils in terms of oil palm plantations when the mineral soils (soils rich in nitrogen content) for farming activities could not meet up with growing oil palm production (Germer and Sauerborn, 2008).

Organic soils, sometimes referred to as peat soils, are tropical soils which, by definition, are soils that contain more than 20 % organic matter (Couwenberg, 2009). Peat soils are formed by the accumulation of disintegrated plant remains which are inhibited from decaying as a result of incomplete aeration and high moisture content. Peat soils accumulate under suitable conditions such as high rainfall intensity and poorly drained ground. The productions of peat soils is also favoured by cool wet climate with water logged poorly drained environment which help preserve the plant remains and prevent them from rapid decomposition. These conditions highlighted above, though favour the formation of peat soils, make the peat soils unsuitable for agriculture. But the growth in oil palm industry and insufficiency of mineral soils to accommodate the oil palm growth encouraged the use of these peatlands for oil palm cultivation, but not without serious conditions which need to be met before sustainable oil palm cultivation on organic soils could be attained.

Due to landuse change and growth in oil palm industry, most of the peat swamp forests, PSFs had to be converted to oil palm plantations, especially in Malaysia and

Indonesia. This massive conversion of PSFs resulted in unwaranted effects as majority of peatlands lost their ecological and agricultural values.

Various works have been carried out on the dangers of these land use change practices on the environment and well being of the neighbouring communities. These include agricultural practices like land clearing of swamp forest in preparation for cultivation, fossil fuel burning and subsequent agricultural practices like fertilization and application of pesticides as pest control. As a result of these practices, most of the major nutrients needed by the plants and deposited in the peat swamp forest were lost to the streams draining the peatlands and some to the atmosphere (Hooijer *et al.* 2006; Tranvik *et al.* 2013; Song *et al.* 2015). Among the direct and indirect environmental impacts of urban development is the water resources and water quality degradation of the areas (USEPA, 2001; Whitehead *et al.* 2009; Brouns *et al*. 2015). As a result of changes brought to the soil in the degraded peats, the soils become loose and thus allow surface water in form of runoff to infiltrate into the soil thereby polluting the groundwater.

While landuse change becomes essential at times and important for social progress and economic development, there are limitations that are attached with landuse change. Johnson *et al.* (2009) reported that agricultural and urban landuse often increases stream inorganic Nitrogen (N) and Phosphorus (P) calculation, but not much is known about the impacts of human landuse on the cycling of organic carbon and Nitrogen within the peatland. Jain and Hussain, (2014) stated that normal levels of nitrates in water does not have a direct effect on aquatic insects or fish, but nitrates level in excess can create conditions which is difficult for aquatic insects or fish to survive.

One important factor that is associated with carbon content as one of the soil water quality parameters is the history of landuse which has lesser area of coverage in the past studies. Zhang *et al.* (2005), in their studies on soil salinization, pointed out that anthropological activities causing secondary salinization are mostly related to landuse change, such as overgrazing and unreasonable utilization of the land and water resources. According to John, (2005), almost a third of peatland areas in the coastal lowland of Sarawak were converted for oil palm plantation. And this have caused damages to biodiversity, loss of soil nutrients and serious danger to the water resources in the peat swamp forests area.

Cheng, (2011) reported that South Selangor Peatland Swamp in Peninsular Malaysia, with the area of 12,141 hectares was first gazetted as forest reserve in 1927. Many parts of the forest reserve have been lost to the development and some became oil palm plantations where farmers engage in illegal slashing and burning of forest which consequently exposed the carbon stored within the peat to the atmosphere. According to Cheng, (2011), the last degazettment in January, 2009 further reduced the peatland swamp to half its size. He also reported that commercial timber has been extracted from Langat South since the 1950s, which explains the general perception that the forest reserve in the region is a degraded one. Apart from the loss of most of the lands to agricultural practices, majority of the peatland swamp forest in Southern Selangor has also been lost to the development. According to Wu (2008), conversion of farmland and forests to urban development reduces the amount of lands available for food and timber production. Lubowski *et al*. (2006) reported that soil erosion, salinization, desertification, and other factor associated with intensive agriculture reduce the quality of land resources and future agricultural productivity.

In Malaysia, a Southeast Asian country, many studies on soil carbon dynamics as a result of land conversion through deforestation have been focused on Sabah and Sarawak with little studies on Peninsular Malaysia (Koh, *et al.* 2009). As a result of this, Peninsular Malaysia, with largest land mass among the three regions that make up Malaysia deserve consideration in terms of soil carbon loss to deforestation. Thus, the influence of land use management alteration will be investigated on South Selangor Peatland Swamp Forset Reserve area as how it has affected the soil and groundwater chemistry and quantity of carbon stored in the peatland and how it has encouraged the pollution of the nearby peatland streams which discharge to nearby Klang river. A lot of reasons have been cited by the Selangor State Agricultural Corporation for backing its proposal to turn Kuala Langat South Peat Swamp forest into oil palm plantation (Cheng, 2011). Among the reasons stated are that the peatland is not growing anything except a colonizing species called *mahang* (*Macaranga spp*) and that the peatland is a wasteland, which is not being utilized maximally. Cheng, (2011) further pointed out that the value of peat swamps is in its ecological uses. Topping the list is its role as a natural carbon sink. He also stressed that if the Langat South is drained for cultivation, the 27.7 million tonnes of carbon estimated by GEC (Global Environmental Centre) locked up in its soil will be unleashed, further fuelling global warming. World Rainforest Movement (WRM) (2002) revealed that the largest peat swamps are found in Pahang and Selangor. The above points by GEC stressed the fact that there is huge quantity of estimated carbon and other parameters locked up in the Southern Selangor peat swamps (WRM, 2002). The reports further revealed that not many research works have been carried out to check the impacts of these locked up compounds on the nearby streams, especially in Peninsular Malaysia. It also stated that drained peat swamps will lose their ecological functions of soaking and storing water to mitigate flood and as a water catchment; buffering coastal lands from the intrusion of salty marine water; filtering pollutants which will otherwise degrades lakes, rivers and groundwater. There has been high level of concerns that most rivers draining peatland and catchment are having their dissolved organic carbon, DOC and other water quality parameters rapidly rising as a result of release from nearby peatland (Freeman *et al.* 2001). Freeman *et al.* (2001) and Worrall *et al.* (2003) while studying on temperate peat soil suggested that 'the rising in concentration of the water quality parameters is due to increased decomposition in response to rising temperatures'.

Groundwater recharge estimation using hydrological and soil moisture balance models have been used with recorded success in modeling the crop water use in various soil types (De Silva and Rushton, 2007). Few studies, however, have been carried out on peatland groundwater estimation particularly the oil palm cultivated peat soil. Oil palm requires more moisture for its consumptive use than all forest trees combined together (Harahap and Darmosarkovo, 1999). Thus, high rainfall depth that would ensure soil moisture availability would be required for optimum oil palm productivity. Rainfall has been known as the source of water for the plants use. But not all the rainfall input in the catchment is available for plants use. In the water balance equation, [1.0], major components include; rainfall, runoff, evapotranspiration and change in storage

$$P = Q + E + \Delta S \qquad [1.0]$$

Where

P = precipitation
Q = runoff
E = evapotranspiration
ΔS = the change in storage (in soil)

The amount of water available to crops in the soil is a function of change in soil storage (ΔS). The amount is being replenished by groundwater recharge in the event of substantial amount of rainfall and low runoff. The part of rainfall the eventually gets used by the plants at the root zone is termed effective rainfall (Awulachew, 2009). In as much the effective rainfall is greater than crop consumptive water use, crops and in this case oil palms would enjoy soil moisture for major part of the water year. Crop water stress comes is resulted once the crop water consumptive use is greater than the effective rainfall. This leads to reduction in oil palm yield and can only be ameliorated with alternative to rainfall input which is irrigation. Deficit irrigation has been reported to be of great advantage as it is only required whenever there is deficit in crop water use. It eliminates wastages and it is very efficient (Gowing et al. 2009)

With all these points raised, this study is intended to investigate the impact of common land-use management typology alteration on the water quality in streams flowing through Southern Selangor Peat Swamps.

1.2 Statement of problems

As a result of the boom recorded in oil palm industry in Malaysia, most forested areas in the three Malaysian regions were converted to oil palm plantations thereby exposing the carbon and other major nutrients locked up in the soil, and therefore threatening the climate. Also, scarcity of suitable and available space for oil palm cultivation in some parts of the region caused the extension of the cultivation into available peat lands. This further caused gradual loss of soil carbon in dissolved form as dissolved organic carbon (DOC) and other nutrients stocked in the peat soil due to peat oxidation and greenhouse gasses emission to the atmosphere. Peat fires as a result of over drainage of the peat forest which cause haze and pollute the atmosphere has also been seen as the resultant effects of peat forest conversion for agricultural purposes. Further evidence with negative effects of peat forest conversion will be noticed in the nearby peatland streams as the change in colour of the nearby streams to brown indicates contamination with dissolved organic carbon (DOC) which is as a result of influx of nutrients from the peatland to the streams. This pollutes the streams which in turn pollutes the receiving river which serves as a major source of water for municipal water supply. There are many factors that determine the DOC concentration, among which are hydrological elements like precipitation, soil temperature and soil moisture. Various land use patterns such as deforestation, bush burning, overgrazing, urbanization, and farming activities like fossil fuel burning have also been encouraging the degradation of the peatland in terms of allowing the carbon dioxide, CO_2 and other soil nutrients like dissolved organic carbon, DOC and nitrous oxide, N_2O to escape into the nearby streams and directly or indirectly into the atmosphere. The availability of soil moisture for the use of oil palms is also of utmost importance. Oil palm is known for high consumption of water when compared to forest tress and annual crops. The estimation of water use by oil palm is between 1.83-4.13 mm palm^{-1} day^{-1} for its yield growth. Thus the amount of water available for consumptive use of oil palms for good yield becomes crucial. Since peatlands are known to be drained for the purpose of agriculture in order to lower the water table levels, there is need for the approximate estimation of how much water is recharging the water table for the use of oil palms. In other words, if oil palms are not receiving enough moisture from the surrounding soils than the soil is losing to peatland drainage and evapotranspiration, the oil palm yield will be extremely affected and the peatland affected.

The focus of this work is therefore to appraise these phenomena, looking into the effects of oil palm plantation and its related practices on the degradation of the peatlands and peatland water resources. Estimation of groundwater recharge in order to appraise the need for extra supply of water through the process of irrigation so as to improve the oil palm yield in the event the rainfall influence is not being felt on the groundwater availability. This will go a long way in water management planning of the tropical peatland, especially the cultivated ones. This will also require the use of some basic hydrological modelling like soil moisture balance model which will be suitable for routing groundwater recharge estimation.

South Selangor Peat Swamp Forest with total oil palm plantation area of 4,950 hectares was chosen as the study area. There are two major peat swamp forests in Selangor, a South-western state in Malaysia. There are; North Selangor Peat Swamp Forest (NSPSF) and South Selangor Peat swamp Forest (SSPSF). The two Peat swamp Forests are so unique due to the abundance of peat soil found in the regions. NSPSF has the total area of 73,592 hectares in the North-western part of Selangor State. Though, it is the largest remaining peat swamp forests on the west coast of peninsular Malaysia, it remains the less disturbed PSF. In other words, of the two PSFs in Selangor, South Selangor Peat swamp Forest remains the most disturbed PSF in the whole Selangor. Major part of the PSF have been converted for agricultural purposes in form of oil palm plantation and rubber plantation. South Selangor Peat swamp Forest had the initial area it occupied as 12,141 hectares when it was first gazetted as forest reserve in 1927. But due to subsequent anthropogenic activities in the PSF, many parts of the forest reserve have experienced various land-use changes and this had resulted to many parts of the reserve being lost to the development and some became oil palm plantations. The two International Airports (KLIA 1 & 2) in Malaysia are currently occupying sizeable parts of the peat swamp forest. The South Selangor Peat swamp Forest is also known as South Kuala Langat Peat Swamp Forests and was first converted to oil palm plantation in 1978 during the boom in the oil palm industry. As a result of this historical land-use changes and patterns, South Selangor Peat Swamp Forest (SSPSF) was therefore chosen as the study area considering the size of the oil palm plantation in the region and the nature of the peatlands.

1.3 Aim and objectives

This study investigates the impacts of land-use change peat swamp forest (PSF) to oil palm plantations which occurred between 1978 to 2010 on soil and water resources in South Selangor Peat Swamp. The specific objectives are:

1. to assess the impact of oil palm plantation age on peatland degradation
2. to evaluate the effects of hydrological factors on the variation of dissolved organic carbon concentration in the peatland.
3. To determine the impact of soil moisture and temperature fluctuation on water table level at tropical peatland
4. to estimate groundwater recharge and water requirement for oil palm plantation using hydrological and soil moisture balance models

1.4 Scope and limitations of the study

This work focused on the impacts of land use alteration on peat soil and groundwater and surface water quality in tropical peatland in South Selangor Peat Swamps in Malaysia. The size of the site is 4,950 hectare and the study involves dividing the study area into sub-areas along the ages of plantations in the oil palm field. For the soil sampling, the samples have been collected twice; the first during the dry period (between April and June) and the second during the wet period (November-December). The parameters of interest were soil carbon, nitrogen, sulphur, soil carbon/nitrogen ratio, soil moisture content, soil pH, and some heavy metals such as zinc, copper, and iron. The study further involved installing observation wells in all the study plots within the study area to assess the groundwater and dissolved organic carbon DOC concentration into the groundwater body; two wells in each of the plots and one observation well each in all the field drains surrounding the plantation. The water quality parameters were measured every two months from May, 2013 to December, 2014. This helped in appraising the seasonal variation in the parameters' concentration in the groundwater body within the Peatland. The parameters under consideration along with DOC are temperature, pH, turbidity, conductivity, and dissolved oxygen (DO). The results of the laboratory tests on soil samples for both physical and chemical properties of the soil were estimated and analyzed using correlation analysis of IBM SPSS statistics 21. Statistical analyses on the soil paramters using one-way ANOVA were conducted on soil samples collected during both the raining and less raining sampling periods. Graphical analysis using Excel workbook was used in analyzing and comparing the results of the groundwater analysis of DOC, pH, groundwater fluctuation, daily rainfall depth, daily evaporation and surface temperature. Soil moisture balance model was used to estimate groundwater recharge in the peatland. Both peat soil properties and crops properties, in this case, oil palms were used as inputs in the model together with some meteorological data such as rainfall, maximum and minimum surface air temperature and reference evapotranspiration. Groundwater recharge and soil moisture deficit estimations were limited to only 2014 water year due to the inavailability of data for other water years. For the moisture contents at field capacity and permanent wilting point, volumetric moisture content (*VMC*) at 5 cm and 70 cm were observed, but *VMC* values at 70 cm were used in the model. For groundwater recharge and crop water requirement estimations, Hydrologic Engineering Center-Hydrologic Modeling System (HEC-HMS) and soil moisture balance models were used and were calibrated and validated with the recorded flow and rainfall data before being parametrized for the study areas. As there were no direct measurement of runoff for the study area, recorded flow and rainfall data from a nearby Semenyih catchment were used along with HEC-HMS software before being used for runoff estimation of the study area with soil moisture balance model.

1.5 Thesis structures

Thesis structure of this work is in chapters, ranging from Chapter One to Chapter Seven. Chapter one begins with general introduction of some salient points in the field of land use management alteration and its influence on soil chemistry and peatland groundwater due to anthropogenic and natural activities on tropical peatland particularly in Malaysia. It further includes the activities that are being practiced in the study areas which encourage nutrients' losses. Statement of problems was clearly defined in chapter one giving the basic needs for this study and explaining some reasons behind the actions employed so far in the study. Aim and objectives are clearly defined and stated in chapter one. This streamlines the research to specific focus in order to be precise in the findings at the end of the research. Scope of works also gives the limit of this study so as to be mindful of the area of coverage of the research. Chapter two gives the detailed reviews of past literatures covering the subject areas in order to bring home the needed knowledge in the subject area in question. Related literatures are well studied and the relevance to the subject area is well stated out in order to help in checking the areas of common interests in those past studies and this present one. The subsequent chapters are tailored to deal specifically with each of the specific objectives stated in chapter one.

Chapter three starts the chapter of research findings presentation as highlighted in the previous chapter. In chapter three, the topic 'Assessment of seasonal impact and oil palm plantation age on soil chemistry' is the research topic under consideration. The chapter gives the comprehensive introduction as regards the topic relative to the past studies in the subject area. The results presented agree with most of the past research findings in the subject areas. The results in this chapter has some relevance with the finding of the proceeding chapter four which, unlike chapter three, is based on the study of groundwater chemistry of the tropical peatland.

Chapter four focuses on the research titled, ‘seasonal and hydrological drivers and variation of dissolved organic carbon concentration in tropical peatland water resources’. The research gives the in-depth review of the past studies in the subject and the relevance of their findings to this present study. Past studies on the southeast tropical peatland are also emphasized and the relationship between the study and the study reported in chapter three explained. The findings are analyzed and conclusions drawn agreed with past studies on the same subject matter.

Chapter five focuses on the research titled, ‘Impact of soil moisture and soil temperature fluctuation on water table level at tropical peatland’. The emphasis here is on the influence of soil physical characteristics like soil moisture and temperature at two separate depths on the fluctuation of groundwater levels. The chapter explains the correlation between these two soil characteristics as it is influenced by surface temperature and as they influence the groundwater which also dictates the decomposition and deposition of organic matters both at soil surface and beneath the soil surface. The results are analyzed and appropriate conclusion given to support the hypotheses.

Chapter six gives the estimation of irrigation needs of oil palms in the study area when there is soil moisture deficit in the root zone. Hydrological Modeling System (HEC-HMS) and soil moisture balance models were used in the estimation and the output parameters in the models like groundwater recharge, surface runoff, soil mosture deficit and actual evapotranspiration were used in checking the oil palms water deficit on daily time step. The periods of soil water deficit per month were observed and oil palm irrigation need estimated which varied from one study plot to another.

Chapter seven gives the general conclusions and recommendations based on the available results from all the various studies in the previous chapters including the future studies that might help improve the oil palm industry and the environment in terms of reducing the emissions from the peatlands for the environmental sustainability.

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