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RETENTION EFFICIENCIES OF HALOGENATED AND NON-HALOGENATED HYDROCARBONS IN SELECTED WETLAND ECOSYSTEM IN LAKE VICTORIA BASIN

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Abstract

The determination of retention efficiencies of halogenated and non-halogenated hydrocarbon in selected wetland ecosystems in Lake Victoria basin was carried out. Qualitative and quantitative determination of the presence of residual hydrocarbons in Kigwal/Kimondi, Nyando and Nzoia wetland ecosystems using Gas Chromatography - Mass Spectrometer (GC-MS) instrument indicated the presence of residual organochlorines, organophosphorus, carbamates and synthetic pyrethroid hydrocarbons in water, sediment and plant materials. In order to compare the retention efficiencies of the wetlands, the wetland ecosystems were divided into three different sections, namely: inlet, mid and outlet. Calculations of mass balances of residual halogenated and non-halogenated hydrocarbons at the respective sections was done taking into account the partition of the studied compounds in samples of water, sediments and papyrus reed plant materials and analyzed using validated Gas Chromatography - Mass Spectrometer (GC-MS) method. From the analysis, several residual hydrocarbons namely: bendiocarb, benzene hexachloride (BHC), carbaryl, cypermethrin, decis, deltamethrin, diazinon, dieldrin, DDT, DDD, DDE, malathion, propoxur, sumithion, 5-phenylrhodanine, 1,3,5-trichlorobenzene, 1-(2-phenoxybenzyl)hydrazine were detected and quantified. The levels of the selected residual hydrocarbons in water samples were used to calculate the retention efficiencies of a specific hydrocarbon and the values recorded. Generally, River Nyando wetland recorded mean percentage retention efficiencies of 76 and 94% for dry and rainy seasons respectively; Kigwal/Kimondi wetland had seasonal mean percentage retention efficiencies of 63 to 78%. River Nzoia also had calculated seasonal mean percentage retention efficiencies of between 56 to 88%. Dry season had lower mean percentages retention efficiencies as compared to rainy season in the three wetlands of interest during the period of study. The study observed that retention efficiencies of tropical wetland ecosystems is greatly affected by its concentration within the wetland tank systems, anthropogenic activities, physical properties of the hydrocarbon, and environmental conditions among others. There are several anthropogenic activities which contributed to the presence of hydrocarbons in the wetlands and they included: agricultural, municipal, industrial and public health activities.

Keywords: model; wetland; ecosystems; retention; hydrocarbons

Introduction

Wetlands have been shown to remove pollutant materials from water that flows across them. In fact, artificial wetlands are being designed and constructed specifically for this purpose. Substances such as agricultural pesticides, fertilizers and human or animal wastes can settle out or be absorbed into wetland soils and plant biomass (ATSDR, 2010). Wetlands can aid in pollutant removal through reduction of flow velocity as water enters a wetland, causing sediments and chemicals sorbed to sediments to drop out of the water column, enabling denitrification, chemical precipitation, and other chemical reactions that remove certain chemicals from water through the action of various aerobic and anaerobic processes (Lawskowski, 2002). High rates of mineral and chemical uptake by vegetation and subsequent burial in sediments are some of the processes which contribute to retention ability of wetland ecosystems alongside a diversity of decomposers which aid decomposition processes in wetland sediments. A high accumulation of organic matter in wetland ecosystems can cause permanent burial of chemicals, and a high degree of contact of water flowing into the wetland with sediments can also lead to significant sediment-water exchange and contribute to retention of hydrocarbons in wetland systems (Jesús et al., 2008).

Natural vegetative wetlands have been cited as control of both point- and nonpoint-source pollution in surface waters. Several research data reported on the retention efficiency of constructed wetlands for several hydrocarbons (bendiocarb, carbaryl, 5-phenylrhodanine and sumithion) found varied values of retention efficiencies for each hydrocarbon with bendiocarb recording 84 to 95%, carbaryl 77 – 89%, 5-phenylrhodanine 86 – 99% as recorded by Kohler and Knight, (1996). In studies carried out in Playa, USA, the retention efficiencies of wetlands for organochlorine pesticides (dieldrin, DDT, BHC) was found to range from 65 to 79% with some recording lower values of 20% (Michael, 2010). Blackenberg et al (2007) performed an experiment in determining pesticide retention in an experimental wetland treating non-point source pollution from agricultural run-off. They found that benzene hexachloride was retained at a rate of 11-58%, dieldrin 75-80%, deltamethrin 89-97%, and diazinon at a rate of 55-62%. Another study in Australia, found the availability of pesticides in wetland ecosystems is affected by their individual chemical properties and such can reduce the retention efficiency of such compounds to between 22-75% of their concentrations in the watershed (Mackay et al, 2006). Other studies on determination of the retention efficiencies of constructed wetlands for pesticides were also recorded in Britain and their values ranged from 73-98% for organophosphates and above 75% for organochlorine pesticides (Hedman et al, 1996).

The mass balance of pesticides: propachlor, linuron and metamitron, and the fungicides propiconazole, fenpropimorph, metribuzin and metalaxyl in wetland ecosystems are found to be approximately 96% of applied pesticides on a constructed wetland (Haarstadand Braskerud, 2005). There was also a reported seasonal variation on mean percentage retention efficiency of constructed wetland ecosystem with dry season recording retention efficiency of between 12 to 67% and from 88 to 97% during rainy season. This is attributed to the increase in precipitation lag time in the wetland thus increasing sedimentation of soil particles in the wetland (Horner et al, 1994).

Models are a valuable and widely used tool in environmental planning. Effective environmental planning often demands qualitative and quantitative predictions of the effect of future managementactivities as arguments for policy makers and administration (Brezonik and Stadelmann, 2000). Models are applied to solve a widerange of wetland related problems under very different situations including an environmental agency who wants to quantify the effect of restored surface flow wetlands on water quality improvement at a catchment scale for the development of a wetland restoration program, a municipality plans aimed at restoring (reconstructing) a degenerated wetland and wants to know the effectof different wetland water levels on the water levels in the surrounding terrestrial area to avoidconflicts with neighboring landowners, and a wetland manager who anticipates to maintain the efficiency of nutrient removal processes in a wetlandand wants to know how different management strategies e.g. moving or sediment removal effect quantitatively the efficiency of removal processes to ensure a given water quality standard at theoutlet (Carleton et al, 2001).Each aspect can only be answered through the application of models; but each problem requires a different type and complexity of modeling approach. In this context, a model is simply defined asa tool to solve problems. The project therefore aimed at establishing the retention efficiencies for halogenated and non-halogenated hydrocarbons within Kigwal/Kimondi, Nyando and Nzoia wetland ecosystems.

Methodology

Lake Victoria

Lake Victoria basin covers an area of 184 200 km^2 of Kenya, Tanzania, Uganda, Rwanda and Burundi, and 21.5% of it lies in Kenya. The lake is a vital water reservoir with an average depth of 40 m and an expansive surface area of 68,870 km^2. Only a small portion (6% or 4,100 km^2) of the water surface occurs in Kenya, Uganda(45% or 31,000 km^2 or 12,000 sq mi) and Tanzania(49% or 33,700 km^2 or 13,000 sq mi). Lake Victoria, with a surface area of 68 000 km^2, is the world's second largest fresh water lake and is a main source of the River Nile. The eastern catchment is wholly in Kenya and comprises Mount Elgon, Cherangani, Mau Mountain ranges and other highlands in western and south western Kenya [23]. The average annual rainfall in the catchment ranges from 1300 mm in the Nzoia-Yala Basin in the north through 1415 mm in the Sondu Miriu Basin in the Kisii Highlands to 1040 mm in the Mara River Basin southern segment of Mau ranges. The eastern catchment is drained by six main rivers: L Nzoia (355 km in length and water discharge of 118 m^3/s), Yala (261 km and water discharge rate of 27.4 m^3/s), Nyando (320 km and water discharge of 33.5 m^3/s), Sondu Miriu, Gucha and Mara. River Nzoia and Yala have the largest subbasin of 15,143 km^2 followed by Mara River 13,915 km^2 and Gucha River 6612 km^2. The other two rivers, Nyando and Sondu Miriu, have relatively small subbasins of about 3600 km^2 (Arnotand Gobas, 2006).

The rivers draining the eastern catchment are short and tend to flow rapidly, transporting large loads of sediment and other pollutants from the catchment. They tend to have little aquatic vegetation, but they have linear blocks of woodland along their valleys. The flood plains are flooded during periods of high rainfall in the catchment. The affluent rivers enter the lake through extensive swampy deltas, dominated by herbaceous vegetation, especially papyrus (cyperus papyrus) and elephant grass (Vossia pyramidalis).

The northern basin is covered by the extensive Yala Swamp with numero open channels that drain the river and surface runoff slowly into the Lake. There are also extensive delta wetlands at the mouths of Nyando River and Sondu Miriu. The main freshwater issues inLake Victoria basin are exploitation of the fishery, water quality and supply, rampant water borne diseases and introduction of invasive species. The Lake and marginal wetlands receive factory effluent, oil, grease, and sewage and storm water from more than 18 towns in the basin and the catchment area (Luilo, 2008). Most of the eastern basin is agriculturally rich and hence the usage of pesticides is on the rise and residual pesticides are thought to be found in the wetlands.

Of the many wetland ecosystems found within the basin, three were selected for purposes of the study. They are; Kigwal/Kimondi wetland along River Yala; River Nzoia wetland at the found at the mouth of River Nzoia and River Nyando wetland at the mouth of River Nyando. The three tropical wetland ecosystems were selected due to their geographical location with respect to sources of hydrocarbons within the eastern side of Lake Victoria Basin.

Materials and Methods

Chemicals and Reagents

Hydrocarbon standards (bendiocarb, benzene hexachloride (BHC), carbaryl, cypermethrin, decis, deltamethrin, diazinon, dieldrin, DDT, DDD, DDE, malathion, propoxur, sumithion, and 5-phenylrhodanine) were purchased from Chem Service Inc., USA. All standards were of 98.9 to 99.8% purity. Internal standard, tridecane was purchased from Aldrich (density = 0.756 g/cm^3; molecular mass = 184.37 g/mol; purity = 99%).
Solvents and chemicals: acetonitrile, ethyl acetate, hexane, methanol, pentane, acetone, diethyl ether, anhydrous sodium sulphate, florisil and phosphate buffer (pH 6.8) were obtained from E. Mersk, German.

Sampling and Field work

Water, sediment and plant material (papyrus reeds) samples were collected from three sampling points (inlet, midpoint and exit) at each wetland ecosystem as shown in Fig 1 below. The sampling period covered wet (August – September–October) which is the period in which there is heavy usage of pesticides for agricultural purposes within the basin alongside the high precipitation. The dry season sampling period was during the months of November to March every year of sampling period. Rainfall amounts from the year 2009 to December, 2013 were retrieved from Meteorological Department (Meteorological Department, 2014).

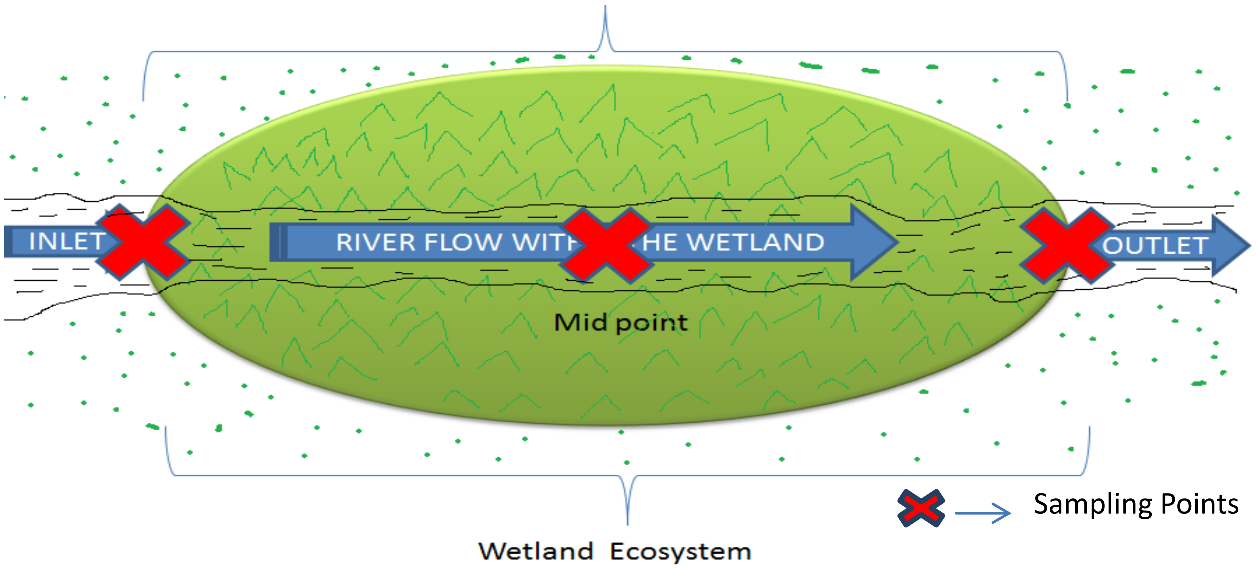

Fig 1: A Sketch Map of a Wetland Showing Sampling of the Respective Wetlands

Laboratory Preparation and Analysis

Extraction of Water Samples

Five (5) mL of water sample from the inlet of Kigwal/Kimondi wetland was mixed with phosphate buffer (pH 6.8) to stop any micro-organic process. The sample was passed through glass wool to remove sediments and coagulations, then mixed with 35mL of acetone and hexane mixture (3:2) and vortexed using vortex mixer for 10 minutes. The mixture was then centrifuged at a rate of 13,000 r/m for 5 minutes at a temperature of 25^{o}C. The supernatant was sucked from the sampling bottle and passed through anhydrous $Na_2SO_{4\,(s)}$ to remove any traces of moisture and concentrated by passing them through $N_{2(g)}$. One (1) µL of tridecane was added to 40µL of extracted water sample and 1µl of the mixture injected to GC-MS for residual hydrocarbon analysis. The extraction procedure was repeated for other collected water samples within Kigwal/Kimondi, Nyando and Nzoia wetlands.

Pollutant Mean Percentage Retention Efficiencies of Selected Wetlands

The concentration of pollutant in the wetland and hence its retention efficiency will continue increasing over time until saturation level is established. Past the saturation level, the wetland is unable to retain the pollutant and therefore the retention ability of such a system is reduced to negative value with the some concentrations of pollutant exiting the wetland tank. This level is depends on the physical and chemical properties of the wetland, the chemical properties of the pollutant in question and the nature of the wetland properties which were also measured and factored into the formula. Thus the retention efficiency of a wetland ecosystem for a certain hydrocarbon can be calculated using the formula:

$$\%\,\mathrm{Re}\,tention\ \ Efficiency = C(t)\times 100\%$$

with $C(t)=\dfrac{W_t}{(V)\left(\dfrac{U_{wo}A_{cwo}}{V}+k\right)}\left(1-e^{-(1+\frac{kV}{U_{wo}A_{cwo}})}\right)$

Calculated Mean Percentage Retention Efficiencies of Kigwal/Kimondi Wetland Ecosystem during Dry Season

The mean percentage retention efficiencies of different hydrocarbons in Kigwal/Kimondi wetland ecosystem during dry season are as recorded in figure 2 below.During dry season, the wetland indicated various values for the detected hydrocarbons with 5-phenylrhodanine, bendiocarb, carbaryl, DDT, diazinon and propoxur being highly retained in Kigwal/Kimondi wetland and cypermethrin and deltamethrin being less retained in the wetland matrixes. DDD, DDE, dieldrin and malathion indicated their ability to move in the aqueous layer (water) as their levels at the outlet was greater than their levels at the inlet. This may be due to theincrease of their concentrations from sediment perturbations, inputs from surface water flow from surrounding streams and re-suspension of sorbed hydrocarbons from sediments.

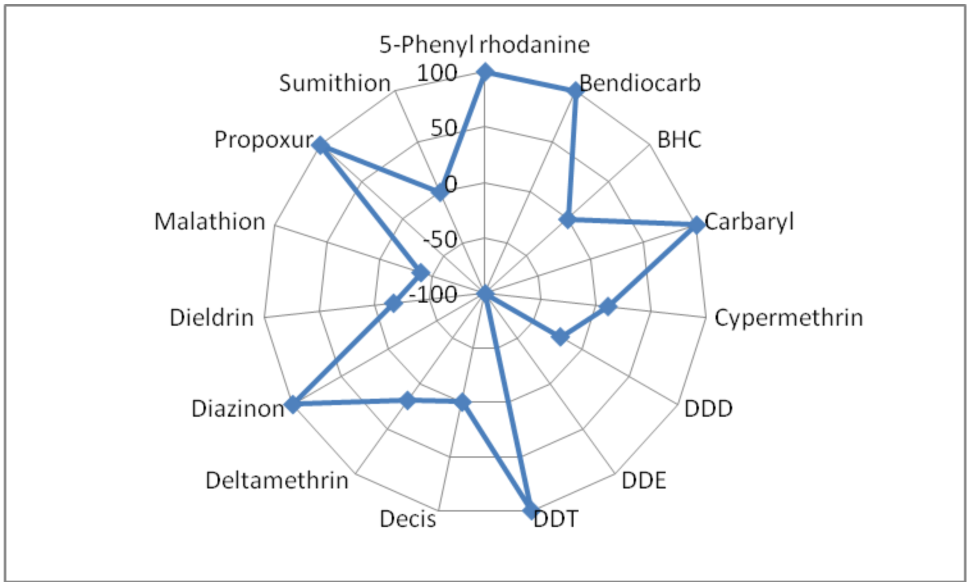

Figure 2: A graph of Mean Percentage Retention Efficiencies of Kigwal/Kimondi Wetland during the Dry Season

The positive retention efficiency (% RE > 0%) of such a wetland during dry season is attributed to partitioning of the respective hydrocarbon in different wetland matrixes (sediments, plant materials, organisms etc.), degraded and attenuated to other compounds. Some of the processes which played a major role in contributing to the positive retention ability of the wetland included the adsorption onto sediment particles, absorption to plant materials and aquatic organisms, volatilization of the hydrocarbons into the air (negligible) and degradation of the hydrocarbons. The recorded values of the soil/water partitioning coefficients (K_{oc}) of these hydrocarbons were between 2.12 to 160,000 (Shuklaet al., 2006) and octano/water partitioning coefficients ($\log K_{ow}$) ranging between 1.7 to 6.91 indicating that the hydrocarbons had greater potential of partitioning in sediments than in water.

Calculated Mean Percentage Retention Efficiencies of Kigwal/Kimondi Wetland Ecosystem during Rainy Season

Figure 3 shows the variation of retention efficiencies of detected hydrocarbons in Kigwal/Kimondi wetland during rainy season with positive efficiencies recorded for 5-phenylrhodanine, bendiocarb, BHC, diazinon, DDT and propoxur. The wetland was able to retain efficiently (100%) 5-phenylrhodanine, bendiocarb, sumithion, BHC and DDT hydrocarbons present in the ecosystem before the river exited. The retention efficiencies of carbaryl, DDD,DDE, malathion, dieldrin, cypermethrin, decis and cypermethrin were negative an indication that there was high concentration of such hydrocarbons at the outlet tank (output) of the wetland as compared to the inlet tank (inputs). There is a possibility that other chemical and physical processes could have contributed to such a situation. Such processes may be re-suspension ofsuch hydrocarbons from sediments due to high turbulence of water at the outlet section of the wetland and contribution of hydrocarbon inputs from surrounding agricultural farms through seepage of water to the ecosystem.

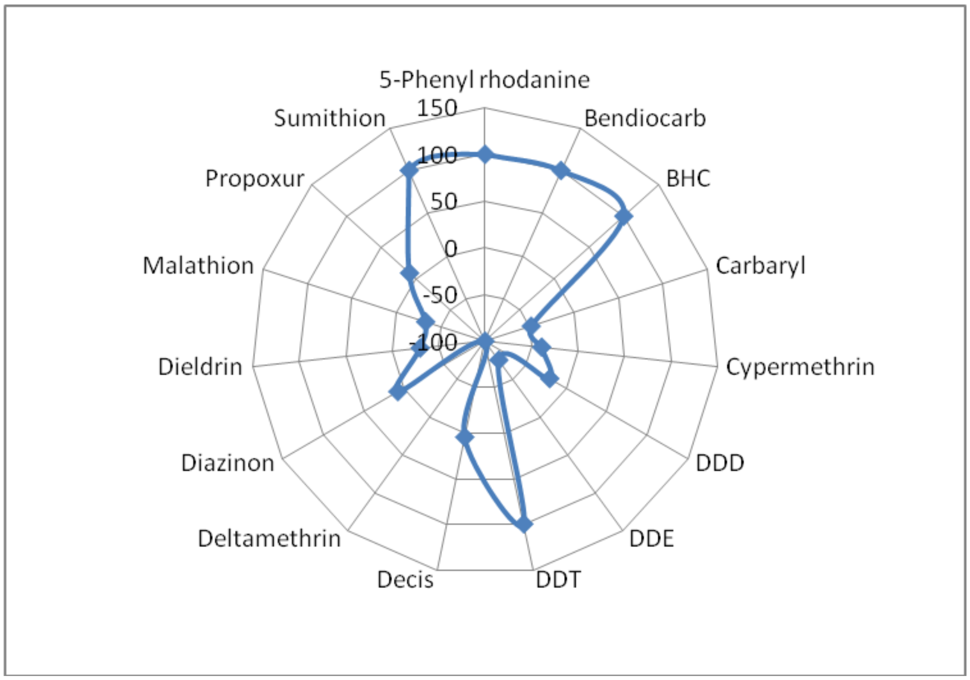

Figure 3: A graph of Retention Efficiencies of Kigwal/Kimondi Wetland during Rainy Season

The theoretical expectation is that, during rainy season, wetlands should retain pollutants to a greater extent due to the fact that there is more dilution, greater contact of pollutants with vegetation, high sedimentation due to low flow rate of the river water and increase is chemical processes like degradation of the hydrocarbons to other compounds, but due to the complex nature of the wetland, it was unable to retain several hydrocarbons in river water matrix.

Calculated Retention Efficiencies of River Nyando Wetland Ecosystem during Dry Season

The retention efficiencies of River Nyando wetland ecosystem during dry season were calculated and presented in figure 4 below. The figure shows a wide variation of such retention efficiencies with propoxur, carbaryl, bendiocarb, and diazinon, DDE, DDD and Malathion indicating values between 100% to 0.37%. The wetland is able to retain all the inputs of propoxur, diazinon and DDD as the river water traversed the wetland ecosystem and reduced bendiocarb, carbaryl, DDE, malathion, and sumithion to a certain degree. During the same period, 5-phenylrhodanine, BHC, cypermethrin, DDT, dieldrin, decis and deltamethrin had negative retention efficiencies and were not retained (reduced) from river water as their inputs from agricultural, industrial and municipal activities outweighed the removal of the same pollutants from water system.

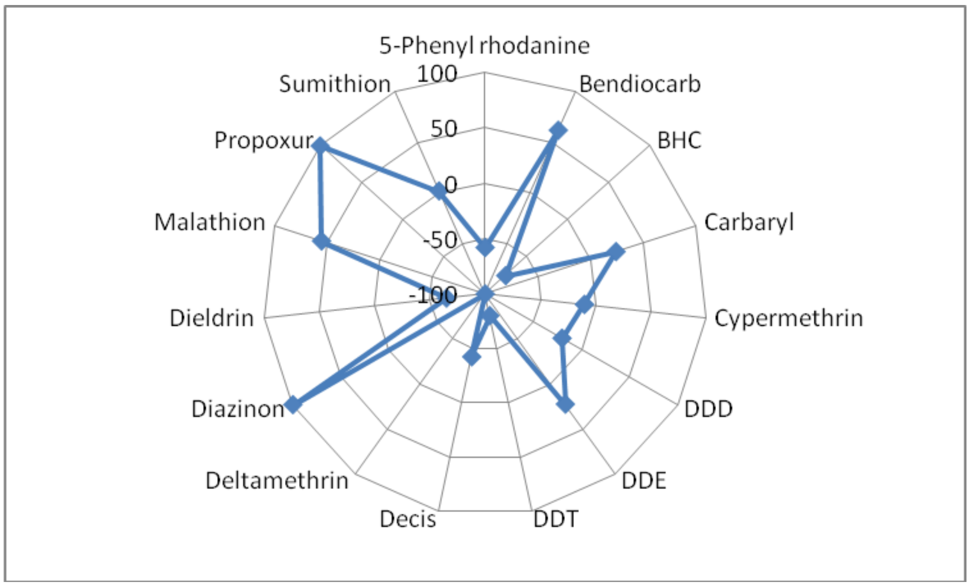

Figure 4: Mean Percentage Retention Efficiencies of River Nyando Wetland Ecosystem during Dry Season

Calculated Retention Efficiencies of River Nyando Wetland Ecosystem during Rainy Season

Figure 5 shows the retention efficiencies of the detected hydrocarbons in River Nyando wetland during rainy season. The hydrocarbons which were retained to a certain extent included: bendiocarb, carbaryl, DDD, DDE, diazinon, malathion, propoxur, and sumithion. These hydrocarbons were retained in the wetland ecosystem from water matrix and their concentration in the outlet tank was less or none. 5-phenylrhodanine, BHC, DDT, dieldrin, cypermethrin, decis and deltamethrin had higher levels in exit water which gave negative retention efficiencies. Most of these hydrocarbons emanated from upstream especially Nandi Hills and from agricultural activities (livestock and vegetable spraying). The wetland functional abilities are therefore compromised by human activities which enables pollutants to exit the wetland to Lake Victoria.

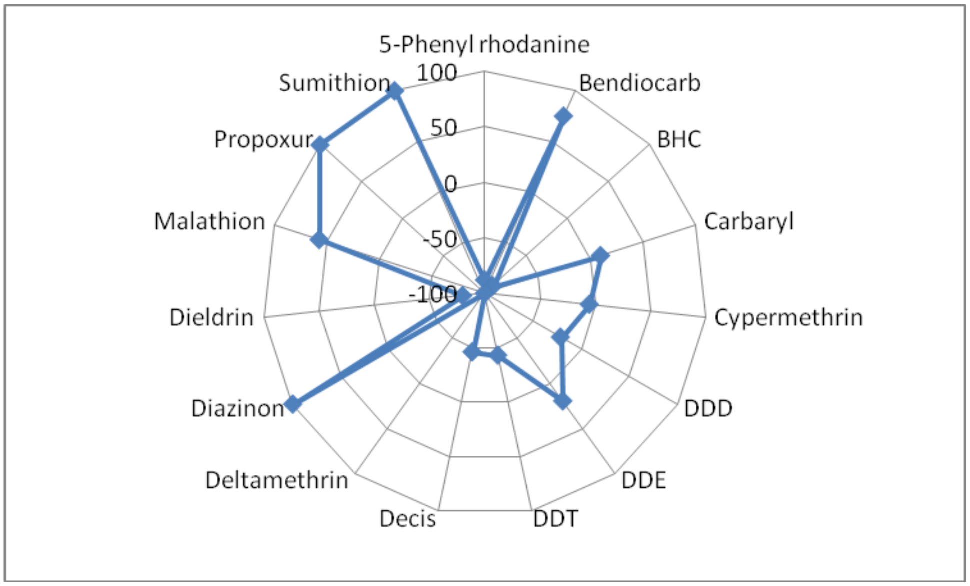

Figure 5: Mean Percentage Retention Efficiencies of River Nyando Wetland Ecosystem during Rainy Season

Calculated Mean Percentage Retention Efficiencies of River Nzoia Wetland Ecosystem during Dry Season

Figure 6 indicates the calculated retention efficiencies of selected hydrocarbons in River Nzoia wetland during dry season: cypermethrin, diazinon, DDT, DDD, DDE, dieldrin and malathion, were highly retained (100%) and other hydrocarbons which were less retained are: 5-phenylrhodanine, bendiocarb, carbaryl, deltamethrin, methomyl and propoxur which had negative retention efficiencies of up to -100%.

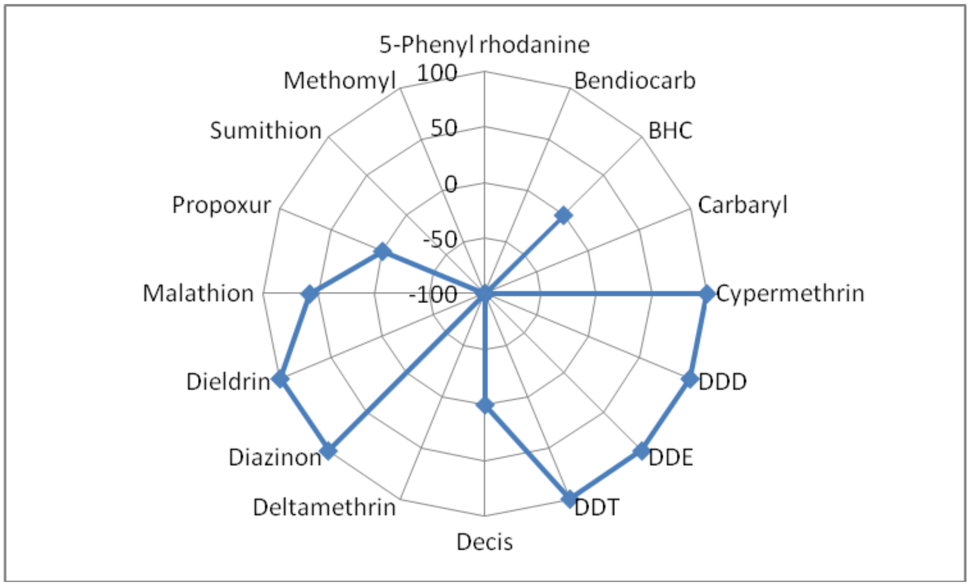

Figure 6: Mean Percentage Retention Efficiencies of River Nzoia Wetland Ecosystem during Dry Season

Calculated Mean Percentage Retention Efficiencies of River Nzoia Wetland Ecosystem during Rainy Season

River Nzoia wetland ecosystem retained almost all hydrocarbons (with variation in their retention efficiencies) with an exception of DDD and decis which had negative values of their retention efficiencies during rainy season (figure 7). The ability of the wetland to retain hydrocarbons during the rainy season was due to the effect of wide spread of water within the wetland which promoted greater interaction of water and vegetation and the low flow rate facilitated higher sedimentation and thus retention of hydrocarbons adsorbed into the soil particles. It was observed the presence of other hydrocarbons such as 1,3,5-trichlorobenzene, and methomyl which may be originating from industrial wastes in the basin.

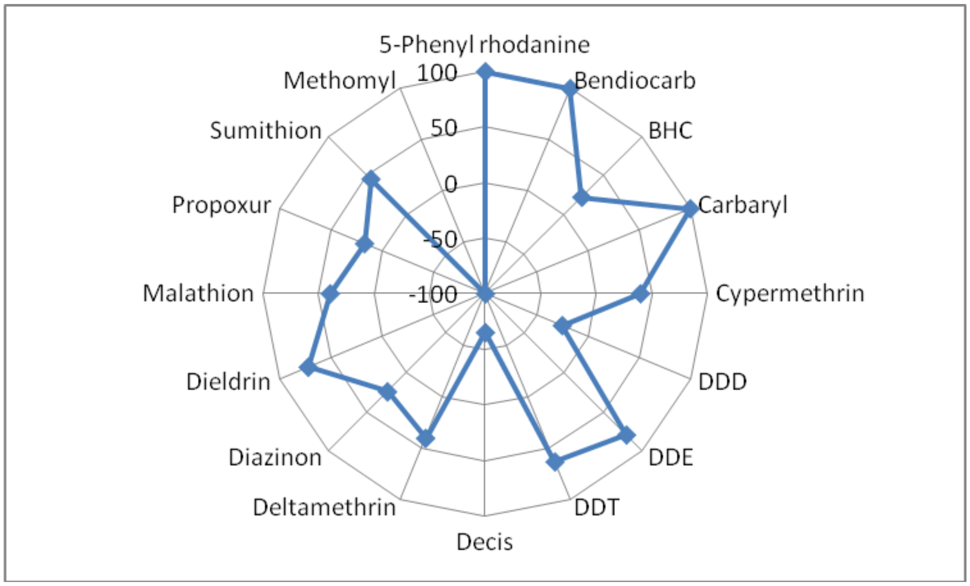

Figure 7: Retention Efficiencies of River Nzoia Wetland Ecosystem during Rainy Season

Seasonal Comparison of Retention Efficiencies of the Selected Wetland Ecosystems

Generally Kigwal/Kimondi wetland was able to retain hydrocarbons at a rate of 78% during the dry season unlike 3% during the rainy season. Since Kigwal/Kimondi wetland is situated in an area which is highly agricultural, the high influx of hydrocarbons to the wetland in river water and water seeping from the surrounding area of the wetland increased their levels in the wetland during the rainy season. This situation was compounded by the status of some physical parameters like increase in rainfall amount, high water flow rate, low pH values, and high turbidity made the wetland susceptible to high inflows of hydrocarbons from the non-point sources, and low sedimentation which made hydrocarbons to be less retained and thus exiting the wetland in water matrix. A highlynegative statistically significant correlation existed between rainfall amounts and average retention efficiency of Kimondi river ($r_{rainretention}$ = -0.9428; $p_{rainretention}$ = 0.05) with similar relationships between flow rate and turbidity noted ($r_{flowrateretention}$ = -0.7453, $p_{flowrateretrention}$ = 0.02; $r_{turbidityretention}$ = -0.8486, $p_{turbidityretention}$ = 0.04). A weak positive statistically insignificant correlation between pH values and retention efficiency was noted ($r_{pHretention}$ = 0.3711, $p_{pHretention}$ = 0.076) for observations made in Kigwal/Kimondi wetland ecosystem. The calculations of correlation between the physical parameters and retention efficiencies of Kigwal/Kimondi wetland ecosystem during dry season indicated a similar relationship.

Kigwal/Kimondi wetland was able to retain inflow hydrocarbons to a greater rate during dry season unlike during rainy season and thus the wetland performed its function well during this season. This is attributed to the low hydrocarbon levels in the wetland, low rainfall amounts, low turbidity values, low river water flow rate and relatively high pH values which facilitated partitioning, degradation of the pollutants and sedimentation thus lowering their levels in the river water.

River Nyando wetland was greatly affected by anthropogenic activities within the river basin and also within the wetland ecosystem. The activities like high usage of hydrocarbons within the basin, municipal and industrial activities contributed high levels of the selected hydrocarbons in the wetland and the fact that the wetland had been converted to agricultural farms and grazing field by the local community greatly affected its retention ability with values of 6% and 9% overall average retention efficiencies recorded for dry and rainy seasons respectively. It was evident that River Nyando traversed smoothly through the wetland with less resistance from vegetation and thus any levels of hydrocarbons in the incoming river water was less retained during dry season and the fact that high usage of hydrocarbons during rainy season, high flooding within the basin, high river water flow rate, low pH values, high turbidity worsened the situation. A negative statistically insignificant correlation existed between rainfall amounts, river water flow rate and turbidity values of the wetland ecosystem with the overall seasonal average retention efficiencies of the wetland ($r_{rainfallretention} = -0.4925$, $p_{rainfallretention} = 0.212$; $r_{flowrateretention} = -0.1165$, $p_{flowrateretention} = 0.089$; $r_{turbidityretention} = -0.7453$, $p_{turbidityretention} = 0.221$) were observed with a positive correlation between pH and retention efficiencies observed ($r = 0.1532$, $p = 0.185$).

Unlike Kigwal/Kimondi wetland ecosystem, which had high retention efficiencies during dry season, River Nzoia wetland recorded high retention efficiency during rainy season with a value of 88% calculated. This high retention could have been attributed to the low flow rate of river water during the rainy season as the topography of the wetland facilitated high water spread within the system. This facilitated high sedimentation (low turbidity), high rate of hydrocarbon partitioning from water matrix to sediments, aquatic organisms and plant materials and high rate of degradation during this season unlike during dry season where the river water traversed through the wetland with less resistance from vegetation which recorded as low as 16% overall average retention efficiency. A positive statistically significant correlation existed between the values of rainfall amounts, pH values, flow rate and water turbidity of River Nzoia wetland ecosystem with average retention efficiencies ($r_{rainfallretention} = 0.5392$, $p_{rainfallretention} = 0.02$; $r_{flowrateretention} = 0.4299$, $p_{flowrateretention} = 0.01$; $r_{turbidityretention} = 0.8444$, $p_{turbidityretention} =0.02$, $r_{pHretention} = 0.0435$, $p_{pHretention} = 0.111$). Similar correlations were observed between the physical parameters and the retention efficiencies of River Nzoia during dry season.

The positive results are in consistence with what was reported by various researchers as reported by Davis et al. (2001), Walker and Hurl (2002), Schulz and Peall (2001), Brezonik and Stadelmann (2002), Backstrom (2002), Verhoeven et al. (2006), Haarstad and Braskerud (2005), Haarstad and Braskerud (2003), Mallet and Perdriau (2006), Shabad and Il'nitskii (2000), Screenivasa R A (2006), Louise et al., (2008), and Blackenberg et al.,(2007) although negative retention efficiencies have an implication on the pollution status of such ecosystems.

Conclusion

From the study, mean percentage hydrocarbon retention efficiencies of tropical wetlands were calculated. The results derived from the application of the mathematical model were in consistent to what various researchers have reported. From the analysis, several residual hydrocarbons namely: bendiocarb, benzene hexachloride (BHC), carbaryl, cypermethrin, decis, deltamethrin, diazinon, dieldrin, DDT, DDD, DDE, malathion, propoxur, sumithion, 5-phenylrhodanine, 1,3,5-trichlorobenzene, 1-(2-phenoxybenzyl)hydrazine were detected and quantified. The levels of the selected residual hydrocarbons in water samples were used to calculate the retention efficiencies of the specific hydrocarbon and the values recorded. Generally, River Nyando wetland recorded overall average retention efficiencies of 76 and 94% for dry and rainy seasons respectively with River Nzoia having the highest overall average retention efficiency of 88% during rainy season and 56%. Kigwal/Kimondi wetland recorded the lowest of all overall retention efficiencies of 63% during rainy season and 78% for dry season. The study also observed several activities (agricultural, municipal, industrial and public health activities) that contributed to the presence and levels of hydrocarbons in the selected wetland ecosystems.

Recommendation

The study recommends the following as means of improving the wetlands functions:

i) The developed mathematical model should be subjected to long term experimental work to ensure its validation.

ii) To subject the model to other natural wetland ecosystems and constructed wetlands.

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