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Full Length Research Paper

Impacts of human activities on macroinvertebrate community structure along Chepkoilel River swamp, Kenya

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This study was set out to investigate the impacts of human activities along Chepkoilel River swamp on Macroinvertebrate community structure. Macroinvertebrates were sampled at six stations along Chepkoilel river swamp. Stations were chosen to correspond to different human activities and intensity of human presence and sampling done at each station for 6 months. Selected water quality parameters were measured at each sampling site. Sampled macroinvertebrates were identified, and taxon diversity, abundance, and evenness determined for each station. Composition and distribution results were used for bioassessment of ecological integrity of the swamp. Results showed significant ($p < 0.05$) spatial variation in macroinvertebrates community attributes and water quality parameters. Macroinvertebrates attributes further showed significant relationships with water quality parameters. Stations with high human disturbance recorded low abundance and diversity compared to those with low human disturbance. It was therefore concluded that human disturbance influenced macroinvertebrate community structure along Chepkoilel River swamp, consequently influencing the ecological integrity of the swamp.

Key words: Macroinvertebrates, swamp, community structure, human activities.

INTRODUCTION

Wetlands provide habitats for a wide range of flora and fauna and are important sources of water for human consumption. Wetlands further provide other functions like good soils, livestock grazing, and hydrological function of recharge and discharge of water, water purification, flood control, and stratum of carbon dioxide (MEMR, 2010). In Kenya, wetlands face rapid degradation as a result of both anthropogenic disturbance and natural causes which include urbanization, climate change, overexploitation, poverty, inadequate awareness and unsustainable management together with inadequate legislative framework.

Chepkoilel River originates from Kaptagat forest and there are various human activities along it. Some of these

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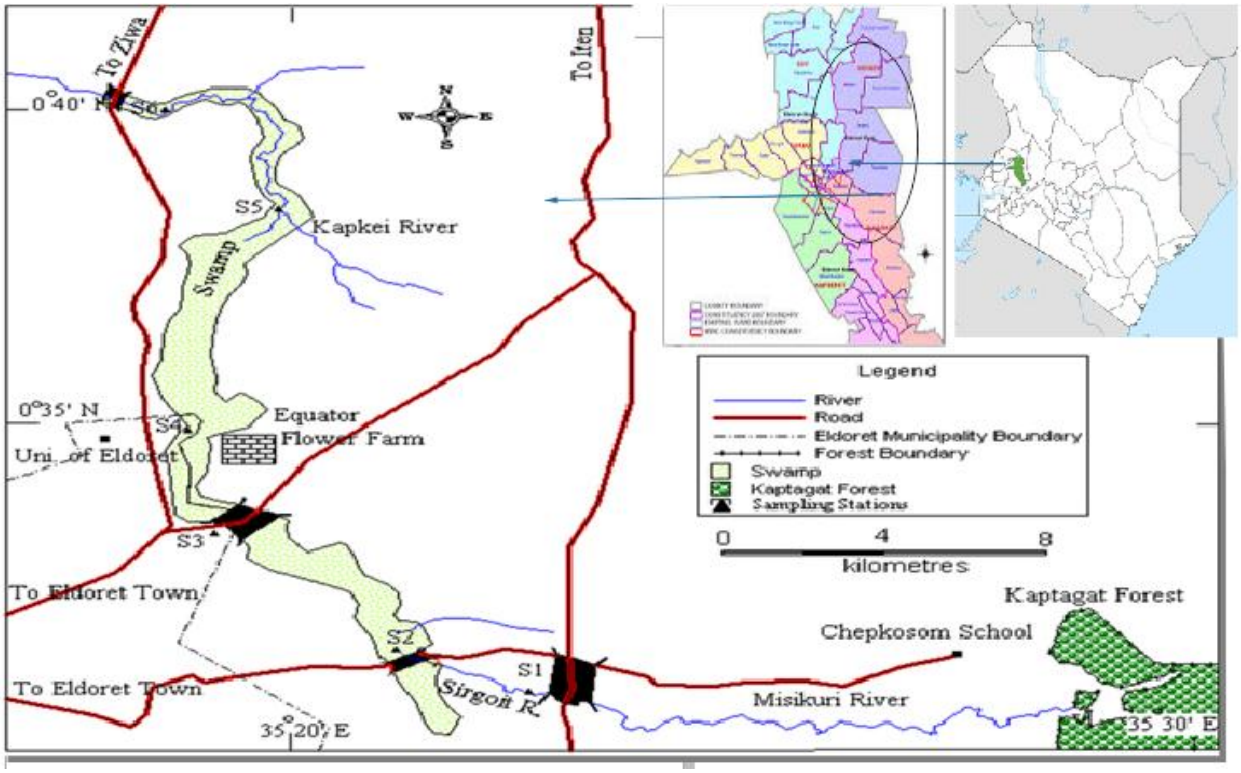

Figure 1. Map of Chepkoilel River swamp indicating the sampling stations.

activities include crop cultivation and animal grazing which is regulated by water depth, plantation of trees, emergence of smaller markets and brick making activities that leads to wetland degradation (Ambasa, 2005). The swamp supports a big flower farm, a university fish farm, and the university sewage treatment ponds also drain into it hence need for regular monitoring. Despite the presence of these activities, little effort has been done to characterize this swamp in terms of its ecological integrity making monitoring hardly possible.

Several methods of monitoring exist including use of physico-chemical parameters and biological indicators (Masese et al., 2009). The weakness of using physico-chemical parameters is that results obtained only reflect the water quality status at the time of sampling and impacts from non-point sources and habitat degradation may not be fully represented (Wang, 2001). The method is further expensive and also lack integrative capacity (Njiru et al., 2008). Aquatic biota such as zooplankton and fish are equally reliable but is relatively time consuming and expensive to sample and process. This study therefore seeks to develop a biomonotoring tool based on macroivertebrates to aid in regular biomonitoring. Macroinvertebrates are easy to sample and identify (Raburu, 2003). They also occupy a strategic position in the food web and are relatively sedentary thus, able to accumulate effects of stressors over some time (Barbour et al., 1999).

MATERIALS AND METHODS

Study area

Chepkoilel River swamp (Figure 1) lies between latitude 0 40' N and 0 35' S and longitude 0 37' E and 0 50' E at an altitude of 2180 m a.s.l. The swamp occurs on fertile volcanic soils in a gentle sloping terrain bordered by undulating plains. The soils are rich in montmorillonites and clays thereby encouraging extensive cracking during dry periods and water logging during wet seasons. The swamp covers approximately 5.6 km^2. Wetland vegetation is dominated by a central band of dense *Cyperus papyrus* flanked by shorter emergent vegetation dominated by other *Cyperus* spp. (*Cyperus rotundus*, *Cyperus triandra* and *Cyperus laevigatus*).

The wetland has a catchment of 210 km^2 and water supply is mainly by Chepkoilel River originating from Kaptagat forest where it is referred to as Misikuri River. The rainfall distribution is bimodal with an annual mean of 986 mm in two distinct seasons. The daily mean maximum and minimum temperature recorded in the area is 17.6 and 10°C, respectively (Jaetzold and Schmidt, 1983).

Study site

The study area was stratified into six stations on the basis of the types and intensity of human activities as shown in Table 1.

Sampling

Physico-chemical parameters and nutrients

Physico-chemical parameters: Physical and chemical parameters

Table 1. Description of sampling stations along Chepkoilel River swamp.

Station	Accronym	Site description/characteristics
Station 1	S1	The station was located at Koilel Bridge where the swamp begins and lacks the dominance of *Cyperus papyrus*. The catchment of this area is dominated by large wheat farms with a clear buffer zone. The main activities within the swamp at this point were bathing, swimming, fuelwood collection and limited animal grazing.
Station 2	S2	It is the point where *C. papyrus* macrophyte begins to appear. At this station there is human settlement, crop cultivation (maize and kales), animal grazing and tree plantations of eucalyptus trees.
Station 3	S3	This station was located at Marura Bridge along Eldoret - Iten road. The major human activities are car washing and animal grazing. Other activities included tree nursery, macrophyte harvesting and crop cultivation. There is a shopping centre at this station resulting to high human presence. Various substances originating from the shopping centre such as wastewaters, and parking papers are deposited into the swamp.
Station 4	S4	Station S4 was at the University of Eldoret fish farm. The wetland was protected or buffered from external disturbance due to restriction of access. Major human activities at this site included papyrus harvesting, animal grazing (sheep), and recreation activities by University students.
Station 5	S5	The station was located around Limnyomoi School about 600 m after the discharge point of the University of Eldoret's sewage treatment ponds. Human activities at this station included animal grazing, and relatively large maize farms and irrigated vegetable farms.
Station 6	S6	This station was near Kaprobu Bridge along Eldoret - Ziwa road. Beyond this point the swamp disappears and the river is again large as it was in station S1. There are large farms of wheat and maize at the catchment. Other activities around this place included animal grazing and watering of animals.

were measured in triplicates at each station. Conductivity was measured *in situ* using conductivity meter (OAKTON^R, Model WD-35607-10, Singapore), whereas the temperature and pH were measured *in situ* by a combined pH-and-temperature-meter, (OAKTON^R, Model pH/Mv/ºC METER, Singapore).

The Winkler titration (APHA, 1998) was used to determine dissolved oxygen (DO) and biological oxygen demand (BOD).

Nutrients: Water samples for total phosphorus and total nitrogen were collected in triplicates during each sampling occasion using 250 ml bottles, fixed at the site of collection using 1 ml concentrated sulphuric acid and then transported to the laboratory where they were analyzed according to standard methods (APHA, 1998). Total nitrogen and total phosphorus were determined using the persulfate digestion method (APHA, 1998).

Macroinvertebrates

Sampling of macroinvertebrates was done monthly for 6 months before mid-day in all the sampling stations. In each sampling station, three replicate macroinvertebrate samples were collected using a scoop net (0.5 m^2, 500 µm mesh size). The macroinvertebrates were washed through a 300 µm mesh size sieve, sorted live and preserved in 70% alcohol in labeled vials. In the laboratory, the macroinvertebrates were identified to genus level according to Merritt and Cummins (1996) and Quigley (1977), and then counted. They were further classified into tolerance status using existing literature.

Data analysis

Macroinvertebrate community were analyzed for taxon diversity, richness, evenness, and relative abundance were done to determine composition in all stations along the swamp.

One-way analysis of variance (ANOVA) (Zar, 2001) was used to test for differences between stations for macroinvertebrate abundance and water quality parameters at 95% confidence levels. The data on abundance was transformed, $\log_{10}$ (X+1), prior to ANOVA test to meet the statistical criteria for normality (Michael and Douglas, 2004). Multiple comparisons of means were done using Duncan's multiple range test (DMRT) to distinguish the specific stations that differed significantly from one another.

RESULTS AND DISCUSSION

Physico-chemical parameters and Nutrients

Physico-chemical parameters

Results on physico-chemical parameters are shown in Table 2. Temperature did not vary significantly between the stations along the swamp ($p > 0.05$) and it ranged between 18.7 and 22.7°C with the highest value at S3 and lowest at S5. DO was highest at station S1 and lowest at station S3 and the variation along the swamp

Table 2. Physic-chemical parameter values (Mean ± SEM) for each sampling station along Chepkoilel River swamp during the study period.

Parameter	Sampling stations along Chepkoilel River swamp						Test statistics	
	S1	S2	S3	S4	S5	S6	P	F
Temperature (°C)	21.06 ± 1.54^{b}	20.01 ± 1.62^{b}	22.7 ± 2.2^{b}	19.3 ± 1.49^{b}	18.7 ± 1.71^{a}	20.6 ± 1.66^{b}	0.081	14.37
DO (mg/L)	3.98 ± 0.31^{d}	1.67 ± 0.35^{b}	0.42 ± 0.18^{a}	2.87 ± 0.15^{c}	0.51 ± 0.21^{a}	3.85 ± 0.41^{d}	0.003	3.41
BOD (mg/L)	2.65 ± 0.58^{c}	1.19 ± 0.71^{b}	0.39 ± 0.09^{a}	2.77 ± 0.41^{c}	0.48 ± 0.19^{a}	3.26 ± 0.67^{d}	0.027	2.97
TSS (mg/L)	1.27 ± 0.06^{a}	1.93 ± 0.11^{b}	2.29 ± 0.17^{c}	1.97 ± 0.14^{b}	2.21 ± 0.09^{c}	1.44 ± 0.03^{a}	0.001	2.62
Conductivity (µS/cm)	123 ± 7.97^{a}	206 ± 9.43^{b}	279 ± 11.82^{c}	211 ± 8.91^{b}	255 ± 11.51^{bc}	126 ± 6.29^{a}	0.003	78.43
pH	7.21 ± 0.67^{d}	6.2 ± 0.53^{b}	5.89 ± 0.83^{a}	6.88 ± 0.54^{c}	5.99 ± 0.72^{a}	7.32 ± 0.55^{d}	0.012	2.57

Means with different superscripts across rows indicate significant differences at $p \leq 0.05$.

was significant. Biochemnical oxygen demand (BOD) was highest at station S6 and lowest at station S3. Conductivity and total suspended solids (TSS) were both highest at S3 and lowest at S1 and the variation was significant. The pH showed significant spatial variation along the swamp with lowest and highest values recorded in stations S3 and S6, respectively.

The differences in water quality between the stations can largely be attributed to land-use practices. DO for instance was lowest in S3 probably due to higher temperature. The high temperature resulted from reduced vegetation cover and high human activities like car washing, animal grazing, agriculture and even higher turbidity that comes with high human presence. High temperature reduces the solubility of oxygen, while turbidity reduces light penetration thus low primary productivity which in turn affects the availability of DO (Kalff, 2002). High water temperature facilitates the release of ions, consequently leading to high conductivity. During this study, it was recorded that TSS increased with an increase in temperature. Similar observation was made by Bailey et al. (1994).

Low pH values were recorded at Stations 3 and 5 and this was attributed to the higher temperatures at these stations due to reduced vegetation cover. High temperatures have been shown to increase evaporation thus inducing re-acidification of aquatic systems (Bowman et al., 2006) which in turn lowers the pH. The probable re-acidification due to temperature coupled with accidental spill at these stations of high human activity is the likely possible causes of low pH.

Station 1 which had dense vegetation cover recorded the lowest temperature values. Vegetation cover limits direct solar radiation reaching the water thus contributing to minimal fluctuations of temperature. High solar radiation as a result of low macrophyte cover and little water volume can explain high water temperature in the areas experiencing high macrophyte harvesting and grazing as in S3 and S6 (Bowman et al., 2006).

Nutrients

Total phosphorus concentrations were highest at the car wash station S3 (1.34 ± 0.23) and was lowest at S1 (0.59 ± 0.09), whereas total nitrogen levels were highest at station S5 (0.49 ± 0.11) and lowest at S1 (0.072 ± 0.009) (Figure 2). One-way ANOVA revealed significant differences between the sampling stations along the Chepkoilel River swamp during the study period in total phosphorus ($F = 5.29$, $p = 0.001$) and total nitrogen ($F = 1.66$, $p = 0.007$).

Total phosphorus did not vary significantly between Stations S1 and S6, further, S2, S4 and S5 also did not vary from each other, and S3 and S5 did not vary significantly. The total nitrogen also exhibited an almost similar trend with stations S1 and S6, and S2 and S4 showing insignificant variation. Stations S3 and S5 however, showed significant variation in total nitrogen levels with all the other stations (Figure 2).

The nutrient levels varied significantly among the stations. Station 3 recorded the highest concentrations of total phosphorus which could be due to the difference in the magnitude of animal grazing, and car washing. Total nitrogen was highest at Station 5, an area experiencing high crop cultivation. Animal grazing, crop cultivation and car washing have an effect on the concentration of nutrients as have been shown by other researchers. Robert and Rankin (1998) similarly obtained higher nutrient concentrations at a site that anthropogenic impact seemed to be more.

Macroinvertebrate diversity and abundance

A total 12 orders, 38 families and 42 genera were sampled during the study period (Table 3). Order Hemiptera had the highest number of genera (n = 9), followed by Coleoptera (n = 6). The order Decapoda on the other hand had only 1 genus, *Procambarus* sp.

In terms of number of taxa (Table 3), Station S6 had the highest number of genera (n = 31), followed by S1 and S2 (n = 29 and n = 22, respectively). The lowest number of genera was at Stations S3 and S5 (n = 16 and n = 20, respectively).

The diversity index was highest at S6 (2.51 ± 0.15) and was lowest at S3 (1.18 ± 0.09). The diversity decreased from S1 to S3 before increasing at S4 to S6 (Figure 3).

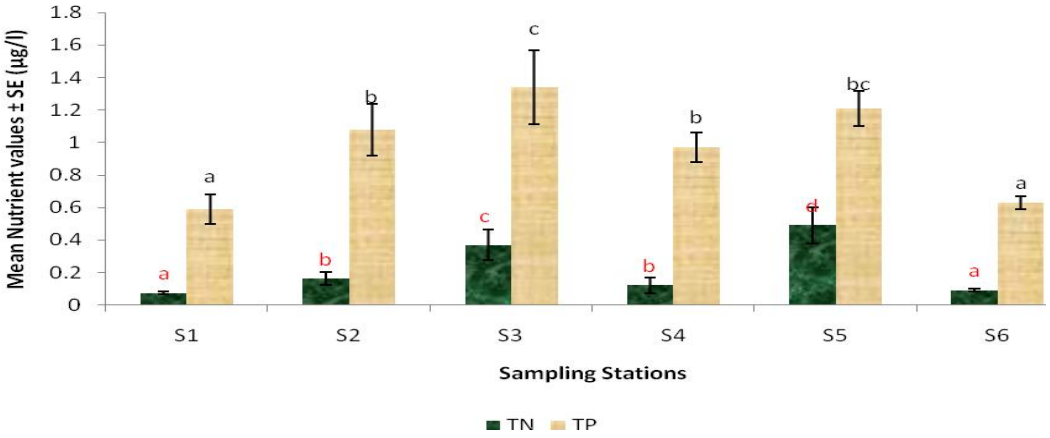

Figure 2. Nutrient (total nitrogen and total phosphorus) concentrations along Chepkoilel River swamp. Different letters show stations with significantly different means.

Evenness index also followed a similar trend reducing from S1 to S3 then began to increase from S4 until S6. The evenness index was highest at S1 followed by S6 and was lowest at S3.

A lower index is a sign of disturbance overtime, where a few tolerant genera dominate the community, while higher values are recorded from relatively undisturbed areas. Shannon-Wiener diversity index (H`) usually have values ranging between 1.5 and 3.5, rarely rising above 4.5 (Magguran, 1988). Only S3 (1.18 ± 0.09) fell out of this bracket which is an indication of very poor situation that needs urgent attention.

In terms of abundance, Station 1 had the highest with 1125 individuals that accounted for about 25.9% of the total followed by Station 6 with 21.4%. Station 3 recorded the lowest abundance of 201 individuals representing 4.6%. Stations 2, 4 and 5 had abundances of 774, 801 and 511 invertebrates, respectively.

The low abundance and composition of macroinvertebrates in S3 and S5 could be attributed mainly to high human activities taking place just above the sites. Station 3 which had the lowest diversity and abundance had cattle grazing, car washing, domestic washing, crop cultivation, human settlement and bridge construction. These activities have the potential to increase nutrient levels and sedimentation. At Station 5, there were similar activities as S3 though the intensity was lower. Nutrient input through urine and fecal deposition and trampling of sediments by humans and livestock which were the main occurrences in these two stations could have been responsible for the low diversity and abundance. Studies by Griffith et al. (2005) and Aura et al. (2010) have attributed reduced diversity of aquatic invertebrates to high nutrient levels and increased sedimentation.

Station 4 which was located 500 m below the equator flower farm recorded a higher diversity and abundance despite the presence of that point source pollution around. This could partly be due to the self-cleansing capacity of wetlands. From the flower farm to the S4 was a thick band of vegetation which was probably efficient in nutrient uptake trapping of sediments. Wetland vegetation is known to actively take up nutrients and trap sediments (Wang and Lyons, 2003).

Macroinvertebrate tolerance statuses

On tolerance levels (Figure 4), the swamp was dominated with semi-tolerant taxa (43%), while the tolerant were least in proportion at 26%. Station 3 on the other hand was dominated by the tolerant taxa (88.1%) and did not have any sensitive taxa. Station 4 also recorded higher percentage of tolerant taxa with few sensitive ones at 53.7 and 5.2%, respectively. The proportion of sensitive taxa reduced further in Station 5 (1.2%) and increased in Station 6 (24.7%).

There was a general decline in abundance of intolerant taxa as disturbance increases. The higher disturbance could be responsible for an increase in conductivity and nutrient levels and a decline in DO levels. High conductivity and nutrient levels coupled with low DO levels affects the occurrence and abundance of intolerant macroinvertebrate taxa (Hawkers, 1979). Kari and Rauno (1993) concluded that the distribution of aquatic macroinvertebrate occurrence is set by physical and chemical tolerance of the individual macro invertebrates to certain environmental factors. A similar conclusion can be drawn from this study where there was lower diversity and abundance was found at disturbed areas with poor water quality status.

Functional feeding guilds

The proportion of collector gatherers increased from

Table 3. List of taxa in Chepkoilel River swamp during the study period.

Orders	Family	Genera	Feeding guild	S1	S2	S3	S4	S5	S6
Ephemeroptera	Baetidae	*Baetis* sp	Grazers	x	x		x	x	x
	Ephemerelidae	*Ephemerella* sp	Grazers	x			x	x	x
		Hydrophlebia sp	Grazers	x	x		x		x
	Caenidae	*Caenis* sp	Gathering collector	x					x
Plecoptera	Nemouridae	*Nemoura* sp	Shredders	x					
	Chloroperlidae	*Chloroperla* sp	Predators	x					
Trichoptera	Psychomyiidae	*Tinodos* sp	Predators						x
	Hydropsychidae	*Hydropsyche* sp	Filter feeders	x				x	x
Hemiptera	Gerridae	*Gerris* sp	Predators	x	x	x	x		x
	Veliidae	*Vellia* sp	Predators	x	x	x	x	x	x
	Mesoveliidae	*Mesovellia* sp	Predators	x		x	x		x
	Corixidae	*Corixa* sp	Grazer	x	x	x	x	x	x
		Micronecta sp	Grazer		x		x	x	
	Notonectidae	*Notonecta* sp	Predators	x		x			x
	Belostomatidae	*Belostoma* sp	Predators	x	x	x			x
	Nepidae	*Nepa* sp	Predators			x	x		
	Hydrometridae	*Hydrometra* sp	Predators			x	x		
Coleoptera	Gyrinidae	*Gyrinus* sp	Predators	x	x	x	x	x	x
	Dysticidae	*Daetis* sp	Predators	x	x			x	x
		Ilybius sp	Predators	x					
	Elmidae	*Elmis* sp	Predators	x	x				x
		Limnius sp	Predators		x			x	x
	Hydrophilidae	*Enochrus* sp	Predators						x
Odonata	Gomphidae	*Gomphus* sp	Predators	x	x		x	x	x
	Libellulidae	*Trithemis* sp	Predators	x	x	x			
		Sympetrum sp	Predators				x	x	x
		Branchythemis spp	Predators	x					x
	Cordulegasteridae	*Cordulegaster* spp	Predators	x				x	x
	Platycnemedidae	*Platycnemis* sp	Predators	x	x			x	x
	Agriidae	*Agrion* sp	Predators	x	x			x	x
Diptera	Chironomidae	*Chironomus* sp	Filter feeders	x	x	x	x		x
	Tabanidae	*Tabanus* sp	Predators				x		
	Culicidae	*Culicida* sp	Filter feeders			x			
	Anthomyiidae	*Limnophora* sp	Filter feeders			x			
Oligochaeta	Lumbriculidae	*Lumbricus* sp	Gathering collector		x	x	x		x
	Tubificidae	*Tubifex* sp	Gathering collector		x	x	x	x	
	Erpobdellidae	*Erpobdella* sp	Gathering collector			x	x		
Pulmonata	Planobiidae	*Planorbis* sp	Grazers		x				x
	Sphaeriidae	*Sphaerium* sp	Grazers	x				x	
Prosobranchiata	Hydrobiidae	*Potamopyrgus* sp	Grazers						x
	Valvatidae	*Valvata* sp	Grazers	x			x	x	x
	Viviparidae	*Viviparus* sp	Grazers		x				x
Isopoda	Gammaridae	*Gammarus* sp	Gathering collector	x	x		x	x	x
	Assellidae	*Asellus* sp	Gathering collector	x			x	x	x
Decapoda	Cambaridae	*Procambarus* sp	Filter feeders	x	x	x	x	x	x
12	39	45		29	22	16	21	20	31

(x shows presence).

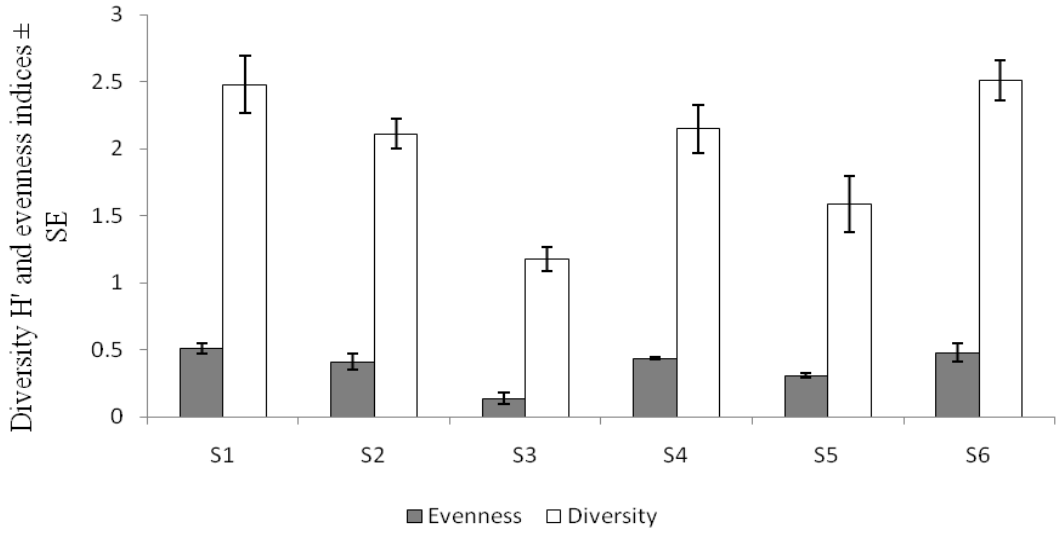

Figure 3. Diversity and evenness indices at different stations along Chepkoilel River swamp.

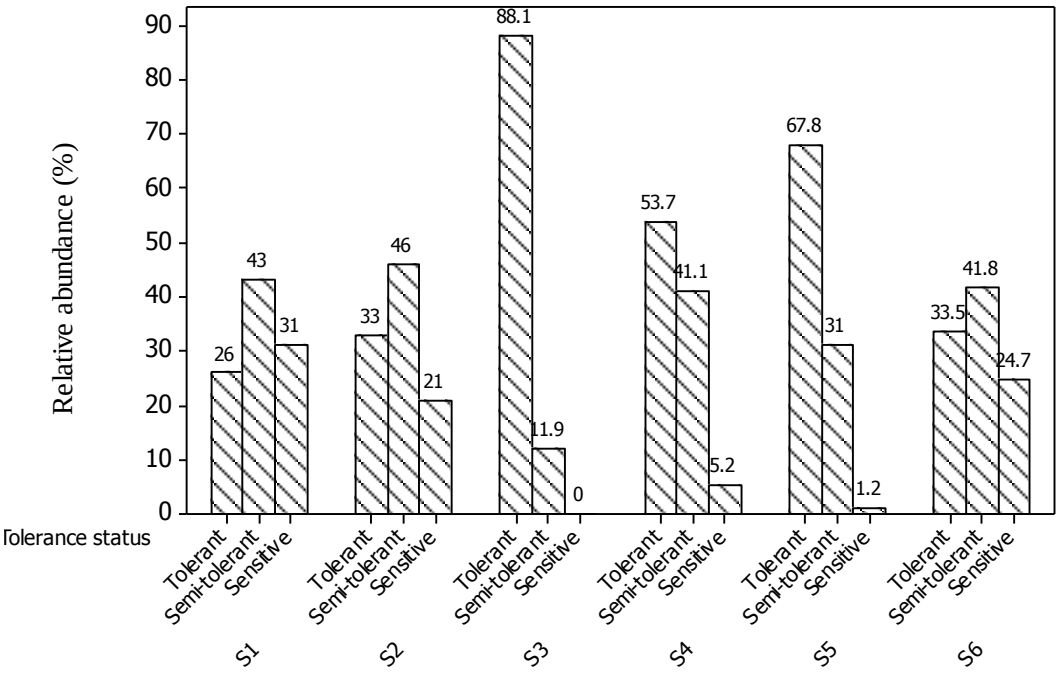

Figure 4. Relative abundance of the tolerance status at each station along the swamp.

Station 1 and got to its peak in Station 3 before dropping all the way to Station 6 (Figure 5a). Collector gatherers are macroinvertebrates that collect fine deposited organic matter for food. Their abundance at a station is usually expected to increase with disturbance mainly influx of organic matter from external sources (Raburu et al., 2009). The predators (Figure 5b) showed exact contrast of collector gatherers. The relative proportion was highest in Stations 1 and 6 with 55.2 and 54.8%, respectively, while was lowest at S3. Predation largely depends on visibility (Mason, 2002) which is more enhanced in clear waters (http://www.mnwhep.org). In turbid waters, predator vision is impaired making predators miss on their prey thus, reducing in numbers. High relative abundance of predators is therefore an indication of low turbidity and the reverse is true. Filter feeders filter and feed on fine organic matter in the water column. The availability of this food is enhanced by high total

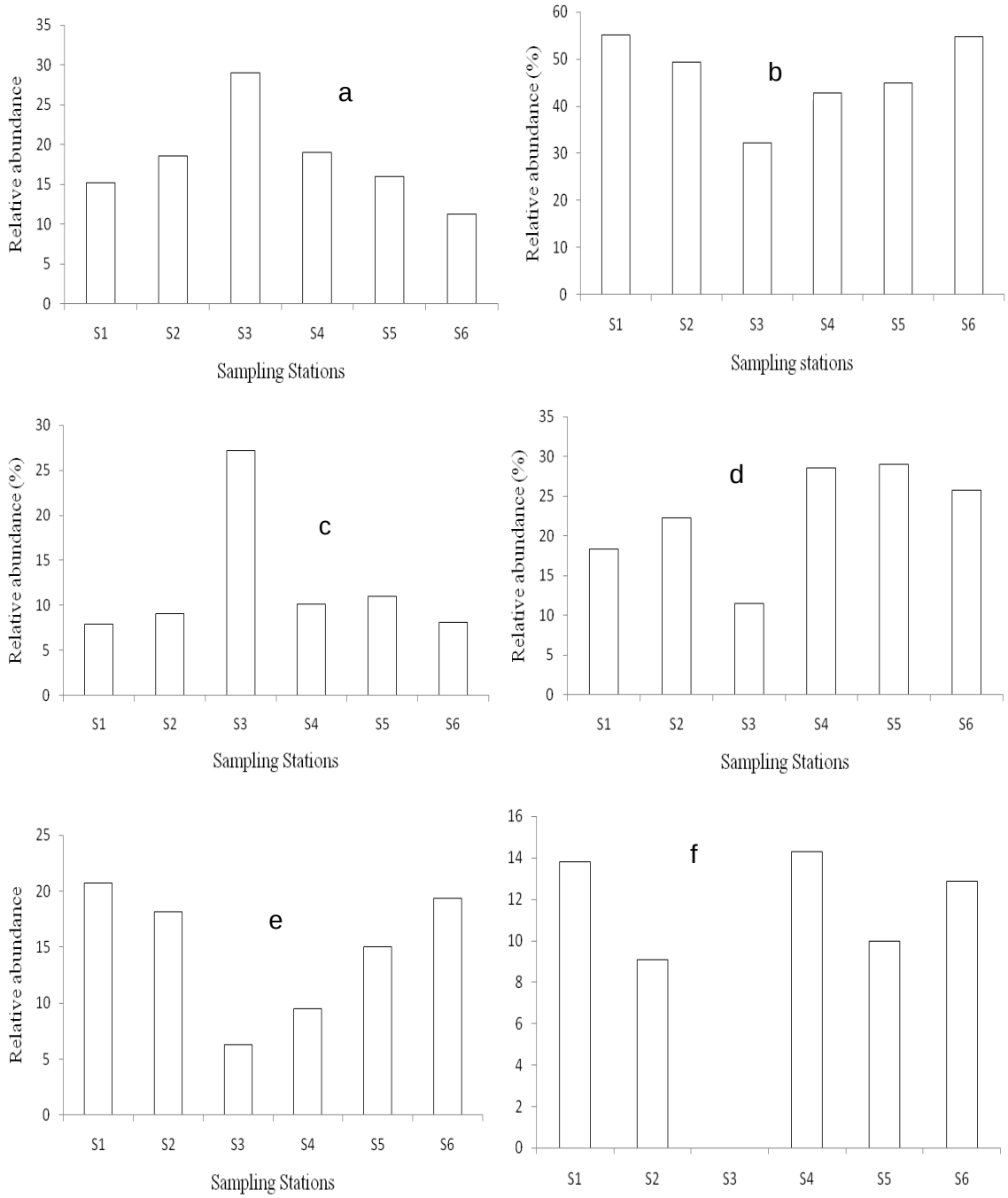

Figure 5. Relative abundance of selected macroinvertebrate attributes along the swamp (a - % Collector gatherers; b - % predators; c - % Filter feeders; d - % Grazers/Scrapers; e - % Odonata; f - % Ephemeroptera).

dissolved solids (TDS) which is a sign of allochthonous material influx hence, abundance increases with disturbance. In this study, filter feeders were more in Station 3 with a relative abundance of 27.2% as compared to all other stations that hardly went beyond 11% (Figure 5c). The proportion of grazers was highest in S4 and lowest in S3 (Figure 5d). Grazers feed on algae suspended in water or attached on rocks or debris. Being that the algae rely on nutrient levels they accumulate higher concentrations and transfers to the grazers leading to their depth (Cairns et al., 1993). The abundance of grazers is thus expected to decrease with increased disturbance.

The relative abundance of dragonfly and damselfly larvae found in samples tends to be higher in healthier wetlands. These insects pump water in and out of their

posterior end, which could expose them to pollutants. Some odonates lay their eggs on stems of aquatic plants, so if the plants are lost, they lose their egg-laying sites. In this study (Figure 5e), Odonata accounted for 20.7% of total abundance in Station 1 which was the highest followed by Station 6 (19.6%). The relative abundance was lowest at Stations S3 and S4 with 6.3 and 9.5%, respectively. Mayflies (Ephemeroptera) followed a relatively similar trend with no representation at S3 which is an area of high human presence (Figure 5f). Mayflies are sensitive to pollution. They are gill breathers, allowing them to take in pollutants directly from the water allowing direct intake of pollutants, but also making them more vulnerable to siltation in the water (Barbour et al., 1999).

The results of the composition and metric scores in this study show that disturbance and point source pollution alters negatively the water quality of a system therefore impacting on macroinvertebrate community structure.

Conflict of Interest

The author(s) have not declared any conflict of interest.

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Full Length Research Paper

Roof age effect on the quality of harvested rainwater and its health implication in a selected location, Southwest Nigeria

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Rainwater for potable uses has increased in developing countries due to population increase and the failure of conventional means of water supply. However, the quality of roof harvested rainwater and its health implication are issues that require urgent attention. The quality of rainwater harvested from galvanized roofing sheets (GRS) of different ages was investigated. Rainwater samples were collected on monthly basis from roofs of 5, 10 and 15 years between July and September and for three consecutive years. The samples were analysed using standard methods for physical, chemical and microbial parameters. A comparison of means was done using the Duncan Multiple Range Test ($p < 0.05$). The water quality results were compared with 3 established standards (NSDWQ, 2007; WHO, 2011 and USEPA, 2012) for drinking water. There was no significant difference in the quality of harvested rainwater from roof of different ages. The pH of the samples fall within the standard range of 6.5 to 8.5, while an average of 41.96 mg/L for total hardness is far below the minimum permissible value of 150 mg/L. The Lead concentration which ranges between 0.0033 and 0.0055 mg/L is also below the permissible range of 0.01to 0.015 mg/L. The feacal coliform *Escherichia coli* count of 0 cfu/ml does not show biological contamination and is in tandem with the standards. However, treatment may be required for total coliform count as indicated in NSDWQ (2007). It is concluded that rainwater harvested from GRS of different ages in Ogbomoso, Southwest Nigeria is of a quality which does not have or indicate serious health impact.

Key words: Rainwater harvesting, alternative water sources, water security, water quality, roofs age, public health, Nigeria, Africa.

INTRODUCTION

Water scarcity is one of several issues facing the world today. Water demand has increased over the last half-century and signs of water shortages have become common place (Miller, 1989; IPPC, 1990; Matondo et al., 2005; Kaldellis and Kondili, 2007). In many developing and underdeveloped economies, water supply to communities by conventional means shows a shortfall. In rural and semi-urban communities of Nigeria, apart from

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high poverty levels, rainwater harvesting as a means of solving water supply problems of inhabitants is widespread (Coker, 1999 and Lucas et al., 2005) and even to urban communities (Oni et al., 2008). Rainwater harvesting is a term used for the collection and storage of rainwater from rooftops catchments using simple techniques such as pots, tanks and cisterns as well as complex techniques such as underground check dams (Appan, 1999; Makoto, 1999; Prinz, 1999). Rainwater harvesting systems has the potential to mitigate water scarcity experienced by major cities and may bea solution to water scarcity depending on regional conditions (Hatibu et al., 2006; Hartung, 2007; Ghisi and Ferreira, 2007). The rainwater collection system relies on the provision of catchment area such as building roofs, then the collection and transport channels (gutters and pipelines), followed by storage facility and then discharges (Han et al., 2004). Some studies have highlighted the economic, social and environmental benefits of harvesting rainwater as an alternative water source (Hatibuet al., 2006; Hartung, 2007; Sturm et al., 2009). The issue of quality of harvested rainwater compared to surface or reservoir water has become a controversial one (Zhu et al., 2004). Deteriorations during harvesting, storage and household use have been reported (WHO, 2011). External pollution sources have the potential to influence rainwater quality (Simmons et al., 2001; Chang et al., 2004; Zhu et al., 2004; Sazakli et al., 2007). Several types of contaminants have been found in harvested rainwater which include heavy metals (Forter, 1999; Lee et al., 2010) and pathogenic bacteria (Ahmed et al., 2008). Cleanliness, age of catchment and atmospheric condition also contribute to harvested rainwater quality (Yaziz et al., 1989; Simmons et al., 2001; Chang et al., 2004; Zhu et al., 2004). Roof materials and age may be a source of environmental chemicals to rainwater over time. To the best of our knowledge, only a few studies have focused on the effects of roof type and age on the quality of harvested rainwater and their implication on health. This study examines the level of some elements in harvested rainwater samples from the popular galvanized iron sheet roof of different ages and the implication on the public health in Ogbomoso, an urbanized area in Southwestern Nigeria.

MATERIALS AND METHODS

The study was carried out in Ogbomoso (8°10`N, 4°10`E) Southwestern Nigeria. The mean annual rainfall is about 1200 mm and the mean maximum and minimum temperatures are33 and 28°C respectively. The relative humidity of the area is relatively high (approximately 74%) throughout the year except in January when the dry wind blows from the North (Olaniyi et al., 2010). Majority of the residents depend on groundwater (Adetunde et al., 2011) due to inadequate supply from the Ogbomoso zone of the Oyo State Water Corporation (Toyobo et al., 2011).

Rainwater samples were collected on monthly basis during rainy season (July – September) of 2009 to 2011 in 750 ml sample bottles in triplicates from roof of ages 5, 10 and 15 years. Three samples were also collected from an open place where the rainwater has no contact with any roof to serve as control. The surface of the roof was allowed to be washed by the first few millimeter of rain otherwise referred to as first flush (Yaziz et al., 1989). Samples for heavy metals were acidified with concentrated HNO_3 to keep the metals in solution and to minimize their adsorption to the walls of the sample bottles.

Physico-chemical parameters tested in the samples include pH, conductivity, total hardness (TH), total solids (TS), total dissolved solids (TDS), turbidity, specific gravity, Pb^{2+}, Cd^{2+} , Ca^{2+} , Mg^{2+}, Fe^{2+}, Al^{3+}, Cu^{2+}, NO_3^-, Cl^- and NH_4^+. Microbial parameters analysed include total aerobic count, total coliform count, faecal coliform count and *Escherichia coli* count. Each water sample was analyzed following procedures described by APHA (1998). Comparison of means was done using Duncan's multiple range test at $p<0.05$ level of significance using SPSS V.17 statistical software. The results were compared with three drinking water standards namely NSDWQ (2007), WHO (2011) and USEPA (2012).

RESULTS AND DISCUSSION

The results of the physico-chemical and microbial analysis of the rainwater samples are presented in Tables 1 to 3. The means of the parameters for rainwater harvested from three roofs show no significant difference in quality. However, the results from the control indicate a significant difference for TH and TDS. This difference could be attributed to dry deposits carried by rainwater from the roofs (Rodrigo et al., 2009). It is to be noted that roofs when eroded by water running over them release reddish-brown rust material into the water this being responsible for the difference in Fe^{2+} content of rainwater from roofs as compared to the control. The differences in total aerobic and total coliform counts for the control and rainwater harvested from the roofs could be traced to bird droppings and organic decomposition on the roof catchment which were absent in the sample directly from the sky (Rodrigo et al., 2009).

Physical parameters

The pH of the harvested rainwater from different roof ages was in the near-neutral range (pH 6.0 to 7.5). The mean pH was 6.78, 6.71 and 6.8 for samples from roofs of ages 5, 10 and 15 years respectively. The pH from the control sample was 6.94 (Table 1). There was no significant difference in the pH of rainwater from galvanized roofing sheets (GRS) of different ages and the control. Although pH usually has no direct impact on consumers (NSDWQ, 2007), it is one of the most important operational water quality parameters. The pHs of the samples which are in 6.5 to 8.5 range would contribute minimally to the corrosion of water mains and pipes in household water systems. There was no significant difference between the mean values of conductivity of water from the roofs of ages 5 and 15 years (15.27 and 14.67 µs/cm) and that of the control (10.46 µs/cm). A significant difference however existed

Table 1. Physical parameters of harvested rainwater in Ogbomosho compared to control and standards.

Roof ages (years)	pH	Conductivity (µs/ cm)	Total hardness (mg/L)	Total solids (mg/L)	Total dissolved solids (mg/L)	Turbidity (mg/L SiO_2)	Specific gravity (g/cm^3)
15	6.84 [a*]	14.67 [a]	40.89[a]	1199.78 [a]	72.78 [a]	0.33 [a]	0.99 [a]
10	6.71 [a]	8.54 [b]	43.04 [a]	1212.33 [a]	66.67 [a]	0.33 [a]	0.99 [a]
5	6.78 [a]	15.27 [a]	42.72 [a]	1215.00 [a]	67.22 [a]	0.33 [a]	0.99 [a]
Control	6.94 [a]	10.46[ab]	35.77 [b]	942.56 [b]	33.33 [b]	0 [a]	0.99 [a]
Standards							
NSDWQ 2007	6.5 – 8.5	1000	150	NA	500	5	NA
WHO 2011	6.5 – 8.5	NA	NA	NA	600	5	NA
USEPA 2012	6.5 – 8.5	NA	NA	NA	500	5	NA

*Means in columns of same parameter followed by same letters are not significantly different ($p<0.05$, Duncan's multiple range test), NA means Not Available.

between the values for and that of the roof of age 10 years (8.54 µs/cm) as shown in Table 1.The value for roof of age 10 years is not significantly different from the control as well. The values are however, below the maximum permissible value of1000 µs/cm by the NSDWQ. Thus, consumption of rainwater from the roofs poses no health risk in terms of conductivity. The mean total hardness (TH) of water from the roofs ranged from 40.89 mg/l to 43.04 mg/l while that of the control is 35.77 mg/L. There was no significant difference in the TH of water from the three roofs, although there is a significant difference in the value of the control. The difference in the TH value for the roofs and the control may be attributed to the presence of impurities on the surface of the roofs. The value of TH is however, lower than the minimum permissible value of 150 mg/L by the NSDWQ. Thus the TH has no health implication. There is no significant difference in the values of TS obtained from water from the three roofs (Table 1). However, the values are significantly higher than 942.56 mg/L of the control. The values of TDS obtained for water from the roofs are far below the limits set by the standards (Table 1). This indicated that rainwater from GRS of different ages is suitable for potable use in terms of TDS as the water could be considered soft. However, the level of TDS may affect the use of the water for other purposes such as laundry, and may also affect plumbing fittings. This difference may be attributed to the presence of dust particles on the surface of the roofs. The mean value of turbidity of water from the three roofs is 0.33 mg/L SiO_2. The value is not significantly different from the 0 mg/L SiO_2 of the control. This indicated that age of roof has not significantly impacted on the turbidity of rainwater.The value of 0.33 mg/L SiO_2 falls far below the permissible value of 5 mg/L SiO_2 stipulated by the three drinking water standards considered. Thus the consumption of rainwater from GRS of ages 5, 10 and 15 years pose no health risk to the consumer.

Chemical parameters

The mean value of Pb^{2+} in water from the three roofs ranged from 0.0033 to 0.0055 mg/L whiles the value for the control is 0 mg/L (Table 2). There is no significant difference in the concentration of lead in water from the three roofs and the control. Traces of Pb^{2+} in the rainwater samples can be attributed to the washings from particulates in the air resulting from automobile emissions and other industrial sources in the collection areas (Olobaniyi and Efe, 2007). However, concentrations were below the permissible levels proposed by WHO, USEPA and NSDWQ (Table 2), and as such, the use of rainwater from the roofs may not pose any health risk. Cd^{2+} was not detected in all the water samples (and the control). The water from the roof may be considered safe for potable uses as far as cadmium contamination is concerned. The values obtained for Fe^{2+} concentration are 0.100, 0.067 and 0.013 mg/L for 15, 10 and 5 years GRS respectively. These values are not significantly different (Table 2). The values are however significantly different from the control (0.013 mg/L) except for the value of 10 year GRS that is not significantly different. All the values are below the maximum limit allowable for Fe^{2+} concentration in the drinking water standard considered. Water from the roofs of different ages is safe for potable use in terms of iron concentration. No trace of Al^{3+} was detected in water from the roofs and the control. The water seems to be free of Al^{3+} contamination. The levels of Cu^{2+} in water from the GRS ranged between 0.050 – 0.051 mg/L (Table 2). There is no significant different in the level of copper from samples collected from roofs of different ages. However, the roofs have significantly added to the levels of copper in the water samples (Table 2) as indicated by 0 mg/L value of Cu^{2+} in the control. There may not be any danger of using water from the roofs for domestic purposes in terms of copper contamination as the values in water from all the roofs fall far below the

Table 2. Chemical parameters of harvested rainwater in Ogbomosho compared to control and standards (mg/L).

Roof ages (years)	Pb^{2+}	Cd^{2+}	Fe^{2+}	Al^{3+}	Cu^{2+}	NO_3^-	Cl^-	NH_4^+
15	0.0044 [a*]	0 [a]	0.100 [a]	0 [a]	0.050 [a]	0.26 [a]	0.27 [ab]	0 [a]
10	0.0055 [a]	0 [a]	0.067 [ab]	0 [a]	0.050 [a]	0.27 [a]	0.39 [a]	0 [a]
5	0.0033 [a]	0 [a]	0.100 [a]	0 [a]	0.051 [a]	0.18 [a]	0.23 [ab]	0 [a]
Control	0 [a]	0 [a]	0.013 [b]	0 [a]	0 [b]	1 [a]	0.013 [b]	0 [a]
Standards								
NSDWQ 2007	0.01	0.003	0.3	0.2	1	50	250	NA
WHO 2011	0.01	0.003	0.3	0.1	2	50	5	35
USEPA 2012	0.015	0.005	0.3	0.2	1	10	4	30

*Means in columns of same parameter followed by same letters are not significantly different ($p<0.05$, Duncan's multiple range test), NA means Not Available.

Table 3. Microbiological parameters of harvested rainwater in ogbomoso compared to control and standards (cfu/ml).

Roof ages (years)	Total aerobic count	Total coliform count	Faecal coliform count	*E. coli* count
15	2767 [a*]	157 [a]	0 [a]	0 [a]
10	3467 [a]	150 [a]	0 [a]	0 [a]
5	3267 [a]	127 [a]	0 [a]	0 [a]
Control	120 [b]	0 [b]	0 [a]	0 [a]
Standards				
NSDWQ 2007	NA	10	0	0
WHO 2011	NA	NA	NA	NA
USEPA 2012	NA	NA	0	NA

*Means in columns of same parameter followed by same letters are not significantly different ($p<0.05$, Duncan's multiple range test), NA means Not Available.

maximum limit set by the standards. Table 2 shows that the average values of NO_3^- ranged from 0.18 – 0.27 mg/L in the samples from the GRS while the value for the control is 1 mg/L. There was no significant difference between the levels of NO_3^- in all the samples including the control. Thus the roofs have no significant effect on the level of NO_3^- in rainwater. All the values are below the recommended maximum values by the standards considered. Care must be taken, especially with infants, in the use of rainwater. When water with high concentration of NO_3^- (above 10 mg/L) is consumed by infants less than three months, it may lead to cyanosis and asphyxia (blue baby syndrome) (NSDWQ, 2007). Although the concentration of NO_3^- in the rainwater were within the acceptable standards (Table 2), it is only USEPA standard that has a maximum permissible value of 10 mg/L. The Cl^-values of 0.27, 0.39 and 0.23 mg/L in water from 15, 10 and 5 years GRS are not significantly different. These values are not significantly different from the control (0.013 mg/L) except the value from the 10 years GRS (Table 2). The values of chloride in the tested samples were far below the maximum limit provided by the three drinking water standards considered. High concentration of chlorine has no health implication (WHO, 2011); it may however affect the taste of the water. There were no traces of NH_4^+ in all the water samples.

Biological parameters

Total aerobic count (TAC) ranged between 2767 to 3467 cfu/ml (Table 3). There is no significant difference in the values of the TAC in the water from the roofs. There is however, a sharp difference in the value of TAC contamination in the control (120 cfu/ml) when compared with the water from the roofs. This indicated that runoff from roofs have been contaminated. There are no recommended values for TAC. The values of 157, 150 and 127 cfu/ml were recorded for the total coliform count (TCC) for water from 15, 10 and 5 years GRS respectively. There is no significant difference in the values. A significant difference however exists between the values of TCC of water from the roofs and the control. The control has a value of 0 cfu/ml. This implies that roof has introduced coliform contamination to the water. This may be due to the fact that roof harbours animals (rodents,

birds and bat) and dead leaves. These animals defecate on the roofs. Some of the animals may die and decay on the roof. While the dead animals and leaves are decaying, micro organism may be introduced. The values of TCC in water from all the roofs and the control are far above the limit of 10cfu/ml prescribed by the NSDWQ. This indicated that rainwater requires treatment for biological contaminations before it could be safe for potable use. One of the cheapest methods of achieving save rainwater is the application of first flush (Yaziz et al., 1989; Combees et al., 2000). Both the faecal coliform count and *E. coli* were 0 cfu/ml (Table 3). Thus the water is safe in terms of these contaminants.

Conclusion

There were no significant difference in the quality of water obtained from roof of different ages, though roofs impacted on the quality. The physical, chemical and microbiological parameters determined in the rainwater samples were found to be within the acceptable limits of the three standards for drinking water quality (NSDWQ, 2007; WHO, 2011; USEPA, 2012) except for the TCC that was found to be above the NSDWQ (2007) standard. However, the uses first flush and boiling will eliminate this problem. Thus waters collected from the roofs are suitable for drinking. However, care must be taken not to introduce impurities during storage and withdrawal.

Conflict of Interest

The authors have not declared any conflict of interest.

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Review

Efficacy of phytoremediation potential of aquatic macrophytes for its applicability in treatment wetlands: A review of developments and research

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Improving water quality through aquatic macrophytes has made them an essential component in constructed wetland systems (CWS). Experiments worldwide revealed that they do have a role to play in the treatment, but by and large it varied from region to region and species to species. CWS are proven to be an effective, low cost and sustainable alternative to the conventional methods of water treatment. This review included the study of 34 different varieties of macrophytes used for phytoremediation, different types of effluent treated, and experimental mesocosm/ microcosm studies. The ability of macrophytes in nutrient and heavy metal removal are evaluated. In spite of the well established reports indicating the positive role of macrophytes on environmental pollution control, there still exist differences in the performance of several species which are much harder to demonstrate. An effort has been undertaken to review the most researched aquatic macrophytes in the tropical areas, especially the Indian subcontinent so that it can be extended for its application in CWS.

Key words: Constructed wetlands, macrophytes, phytoremediation, water pollution.

INTRODUCTION

The aquatic macrophytes have multiple roles to play in constructed wetlands which have made them an essential component in constructed wetland systems (Brix, 1997; Tanner, 2001; Patel and Kanungo, 2013). Recent studies indicate that the comparison of treatment efficiency of vegetated and unplanted filters is not unanimous, in spite of the majority of the studies showing that systems with plants that achieve higher treatment efficiency (Vymazal, 2011; Odong et al, 2013). Aquatic plant species are very specific for the uptake of nutrients. Thus, the selection of the aquatic plant species is one of the skilled tasks prior to the design of the system (Srivastava, 2008). Presently, the confirmed practices and case studies aid in the selection of aquatic macrophytes rather than assessment of the efficiency of the locally adapted species which are still in the experimental stage in the developing countries (Gopal, 1999; Kivaisi, 2001). The studies in this paper were selected according to the following criteria: 1) studies carried out across India with aquatic macrophyte (floating/ emergent/ submerged) possessing phytoremediation potential. 2) Studies that had different experimental settings (microcosm to full-size constructed wetland systems (CWS) systems are chosen, with or without controls. 3) Our focus was on CWS,

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but we also included studies using other treatment systems as well that may contribute to removal. Here we review the published evidence to ascertain the efficacy of macrophyte species for pollution abatement studied in various parts of the region. We have especially selected the studies that reported the influent and effluent characteristics as they provide the most convincing evidence of removal efficiency of various species. Several studies focussed on different parameters ranging from nutrient removal, heavy metal removal, survivability under stress, dynamics of specific nutrients, etc. Successful phytoremediation requires an integrated approach for each specific site considering right from aquatic macrophyte selection, soil and water management, soil amendments, microflora activity, economics, biomass utilization, social acceptance, economic feasibility, complying with reuse standards and time available to achieve that (Rai, 2009). Besides, this technology is hugely dependant on other factors such as climatic conditions and the criteria for the selection of plant species, that is dictated by their availability, adaptability, pollutant removal capability, tolerance to water saturation, productivity, light demand, etc. It is clear from this review that phytoremediation of aquatic macrophytes can be utilised to remove a wide range of pollutants from wastewater at either a domestic or institutional or community or municipal level. Given the low operation, maintenance, and energy requirements, such systems could well be the systems for achieving sustainable wastewater management in the developing regions of the world.

METHODOLOGY

Thirty-four different varieties of macrophytes were reviewed in this paper which comprises of, 48% emergent, 32% floating and the remaining 20% as submerged species (Figure 1). The studies are selected considering the location as well so that it includes cases covering several states. We included 24 experimental studies that match our criteria, a majority of which were published in the last 5 years. In one case, we treated the two experiments as separate studies that were presented in the same paper (#3 and #4: Table 1 shows the study numbers). Also, we kept two studies as separate even though they have the same plant species, but performed at different times under different experimental conditions (#5 and #6).

The experimental period of the selected studies ranges from 10 days to 2 years. The number of species studied by an author ranges from 1 to 10 as shown in Table 1. Over half of the experiments were performed in microcosm units due to its low cost and ability to replicate and test a large number of macrophytes. However, results from such experiments must consider edge and container effects during interpretation/ scaling up (Tanner, 1994; Fraser and Keddy, 1997). Only two of the studies were carried out at mesocosm level and six were pilot/field scale. The types of wastewater treated ranges from several categories of domestic, industrial effluent and synthetic wastewater. The parameters studied includes several types of nutrients (BOD, COD, N, P, etc..) and heavy metals.

Aquatic macrophytes studied for pollutant removal

Aquatic macrophytes and bacteria in CWS uses the natural processes such as sedimentation, filtration, adsorption, biological degradation, volatilization, photolysis, biotic/abiotic degradation, nitrification/denitrification, microbial uptake, plant uptake, volatilization etc. to treat the wastewater in a controlled environment (Reed, 1995; Cooper et al., 1996; Constructed Wetlands Manual, 1998; Gray, 1999; Rai, 2009). Hammer and Bastian (1989) puts it as “man-made complexes of saturated substrate, emergent and submerged vegetation, animal life and water that simulate natural wetlands for human use and benefits”

In spite of the well established reports indicating the positive role of macrophytes on environmental pollution control, there still exist differences in the performance of several species which are much harder to demonstrate (Brisson and Chazarenc, 2009; Dhote and Dixit, 2009a,b). Plant species diversity enhances the performance of the wetlands (Zhanga et al., 2010).

Various types of wastewater treated using macrophytes

The use of constructed wetlands to treat various wastewaters at both small and large scale is now being recognized across the world due to its good treatment performances and low construction and operating costs (Kadlec et al., 2000; Sonavane, 2008). It has been accepted as a low cost eco-technology alternative to conventional treatment methods, especially beneficial to small communities that cannot afford expensive treatment systems (White, 1995; Green and Upton, 1995; Billore et al., 1999). Some of the earlier experiments were carried out in the early 1950s by Seidel (1961 and 1965) who experimented with macrophytes for treating different kinds of wastewater including phenol, livestock and dairy wastewater. Work done for the past few decades reveal that macrophytes have the potential for purifying different kinds of wastewater. Table 2 shows in detail the types of macrophytes used for the treatment of several types of wastewaters. The influent ranges from domestic wastewater (#5, #12, #13, #24), kitchen wastewater (#2), industrial effluent (heavy metal (#11, #17), battery producing unit (#1), dye wastewater (#21), dairy effluent (#8), coffee processing (#19), metal effluent solution

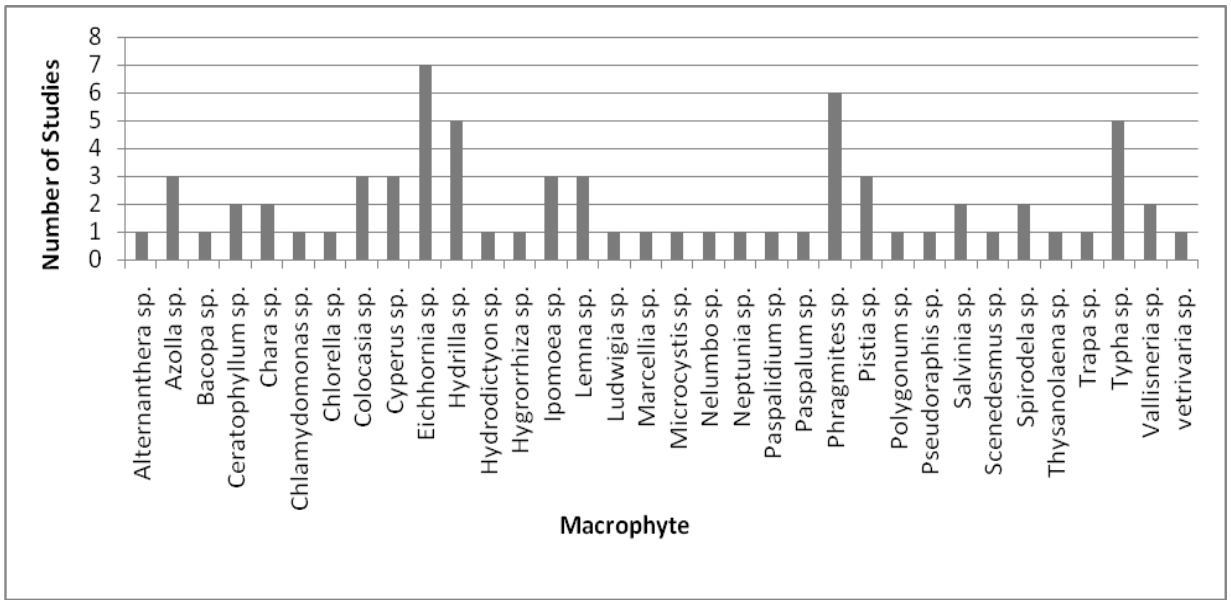

Figure 1. the aquatic macrophytes reviewed as part of this study.

enriched with iron and copper (#10), pulp and paper mill effluent (#14)), synthetic wastewater (soluble reactive phosphorus (#22), diammonium hydrogen phosphate (#20), heavy metal solution with lead and cadmium (#6)) and domestic/ industrial sewage (Table 2).

Nutrient removal by aquatic macrophytes

There have been several attempts by various authors to develop a CWS using aquatic macrophytes to remove nutrients and also comply with the most stringent effluent standards and many such studies clearly demonstrate that the stated objective can be fully met (Platzer, 1996; Laber et al., 1997; Weedon, 2003; Brix and Arias, 2005). Nutrient induced pollution is one of serious concerns in most urban areas of India where groundwater contamination by nutrients such as nitrates is at an unacceptable level in several regions (Gupta, 1981; Trivedy et al., 1988; Sonavane et al., 2008). Sewage contains a large amount of nitrogen and phosphorus apart from other harmful constituents. Increased levels of nutrients in water causes eutrophication thereby rendering them harmful for the aquatic organisms and also depletes the oxygen in water. Table 3 presents the list of macrophytes species studied for nutrient removal at various locations. Currently, systematic collection and remediation of nutrients/heavy metals from waste water are still rare and a large gap exists between the generation and treatment of wastewater (Vasudevan et al., 2011). The options which are available for cost-effective and environmentally compatible sewage treatment include land treatment, waste stabilization ponds, constructed wetlands, duck-weed pond, aerated lagoon, rotating biological contractors, up-flow anaerobic sludge blanket system and root zone treatment (CPCB, 2008). Among these, the constructed wetland systems are still mostly in research phase and its successful implementation is a not as common as seen in the developed world.

In Chennai, Tamil Nadu, Baskar et al. (2009) investigated *Phragmites australis* for the treatment of kitchen wastewater using a pilot-scale, integrated CW with Horizontal Sub-Surface Flow (HSSF) and Vertical Sub-Surface Flow (VSSF) technology for a period of 6 months. The system was designed with 18 m^2 capacity with Hydraulic Retention Time (HRT) of 7 days. On an average, the integrated CWS was found to reduce the concentrations of TSS, TDS, TN, TP, BOD, and COD by 41, 4, 76, 77, 75 and 36%, respectively. Artificial Floating Islands (AFI) vary considerably in their origin, development, species composition, community and physical structure and sustenance even though there are common vegetation elements (John, 2009). Billore et al. (2007) conducted two field-scale experiments using *Phragmites karka*, one through AFI in River Kshipra, Madhya Pradesh and the other through subsurface CW (SSCW) in Ujjain. The former has a size of 200 m^2 while the later 1050 m^2. 0.6 m peanut sized river gravel was used as filter media in the SSCW. On one hand the AFI system reduced the solids (TS and TSS) in the range of 35 to 62% BOD by 37 to 45% and Nitrogen by 16 to 45%. On the other hand, the SSCW system removed TSS with an average of 82% followed by TKN, COD, NH^{4+}-N and BOD ranging from 65-74%. NO^3-N concentration was slightly increased indicating nitrification. Also the DO level

Table 1. Details of the studies selected.

Study #	Authors	Location	No of species	Size and type of CW / other setup *, **	Study period	Control ***
1	Banerjee and Sarker, 1997	Kharagpur, West Bengal	1	Mesocosm, Lab-Scale OP	10 days	Yes
2	Baskar et al., 2009	Chennai, Tamil Nadu	1	Pilot-Scale, Integrated CW with HSSF and VSSF	6 month	No
3	Billore et al., 2007	River Kshipra, Madhya Pradesh	1	Field Scale, AFI	5 month	No
4	Billore et al., 2007	Ujjain, Madhya Pradesh	1	Field Scale, HSSF	12 month	No
5	Bindu et al., 2008	Kottayam, Kerala	1	Microcosm, SSF	20 days	Yes
6	Bindu et al., 2010	Kottayam, Kerala	1	Microcosm, Hydroponic system	20 days	Yes
7	Dhote and Dixit, 2009a,b	Bhopal, Madhya Pradesh	2	Microcosm, Lab-Scale	-	No
8	Dipu et al., 2010	Trivandrum, Kerala	4	Microcosm, Plastic Craits	15 days	Yes
9	Irfan and Shardendu, 2009	Patna, Bihar	1	Microcosm	2 months	No
10	Jain et al., 1989	New Delhi	2	Microcosm, Phytotoron House	14 days	No
11	Kumar et al., 2008	Vidyanagar, Gujarat	7	NA	NA	NA
12	Maheesan et al., 2011	Calicut, Kerala	1	Microcosm, Vertical Intermittent flow CW	90 days	No
13	Patel and Kanungo, 2010	Raipur, Chhattisgarh	1	Microcosm, Lab-Scale	1 year	Yes
14	Prabu and Udayasoorian, 2007	Coimbatore, Tamil Nadu	3	Microcosm, Bench-Scale	2 month	No
15	Prusty et al., 2007	Bharatpur, Rajasthan	7	NA	NA	NA
16	Rai et al., 1995	Lucknow	8	Microcosm, 4 liters(plastic troughs)	15 days	Yes
17	Rai, 2008	Singrauli, Uttar Pradesh	1	Microcosm, 40 liter aquarium	13 days	Yes
18	Rana et al., (2011)	Kalyani, West Bengal	1	Field Scale, Wetland Ponds (2 AP + 2 FP + 2 MP)	1 year	No
19	Selvamurugan et al., 2010	Coimbatore, Tamil Nadu	2	Microcosm	21 days	Yes
20	Sengupta et al., 2004	Bhubaneswar, Orissa	2	Microcosm	12 & 9 weeks	Yes
21	Sharma et al., 2005	Jaipur, Rajasthan	10	Microcosm & Field Scale, Vertical Upflow Wetland	2 years	Yes
22	Srivastava et al., 2009	Lucknow, Uttar Pradesh	7	Mesocosm, Plastic troughs	1 year	No
23	Tripathi and Shukla, 1991	Varanasi, Uttar Pradesh	5	Microcosm, 3 scale aquaculture	6 months	No
24	Vipat et al., 2007	Bhopal, Madhya Pradesh	1	Field Scale, HSSF	18 months	No

*Type of Treatment**.** AFI: Artificial Floating Island; AP: Anaerobic Pond; CW: Constructed Wetland; FP: Facultative Pond; HSSF: Horizontal Sub-Surface Flow; MP: Maturation Pond; OP: Oxidation Pond; SSF: Sub-Surface Flow; VSSF: Vertical Sub-Surface Flow, **Size of experimental units. Microcosm (columns, buckets): < 0.5 m^2; Mesocosm: 0.51m^2 to 5 m^2; Pilot/ Field Scale: > 5m^2 (Brisson and Chazarenc, 2009), ***Control. Yes: indicates presence of unplanted control.

was increased by 190% indicating an aerobic system.Bindu et al. (2008) conducted a laboratory scale studies using *Colocasia esculenta*. The study used control raceways and gravel (Rock chips of charnackite) based filter media for treating domestic wastewater. The quality of the treated water from plant based system was found to be better than those without plants. Also the species used was found to resist COD concentration as high as 1650 mg/L, indicating the scope for future. polyculture studies along with other native wetland plants Dhote and Dixit (2009a,b)

Table 2. The types of aquatic macrophytes used for the treatment of various wastewaters.

Type of wastewater	Type of macrophyte species*	Study # (Table 1)
Amended water(Containing Soluble Reactive Phosphorus)	E, F	22
Coffee processing wastewater	E	19
Dairy effluent	E, F	8
Domestic wastewater	E	5, 12, 24
Domestic wastewater	F	13
Dye wastewater	E, F, S	21
Heavy metal contaminated wetland	E, F, S	11
Industrial effluent (heavy metal)	F	17
Industrial effluent (battery producing unit)	F	1
Kitchen wastewater	E	2
Metal effluent solution enriched with iron and copper	F	10
Nutrient water (diammonium hydrogen phosphate dahp)	E	20
Pond water contaminated with industrial effluents	E, F, S	16
Pulp and paper mill effluent	E	14
Sewage (domestic wastewater)	E	3
Sewage mixed with industrial effluents	F	23
Sewage water	F	18
	F, S	7
Synthetic heavy metal solution (Pb and Cd)	E	6
Wetland water	E, S	15

* E : Emergent; F : Floating; S : Submergent

Studied the species *Eicchornia crassipes* and *Hydrilla verticillata* in their nutrient removal capabilities. *E. crassipes* is a free floating aquatic plant with abilities to remove nutrients and metals from wastewater (Boyed, 1970; Gupta, 1982; Reed et al., 1995). Growth rates of water hyacinths were found to be influenced by the nutrient composition of the water, plant density, solar radiation, and temperature (Reddy, 1984). *H. verticillata*, a species found to grow well in oxygenated water and has more area for the growth of denitrifying bacteria (Weisner, 1994). This study confirmed its efficiency in reducing COD, TSS, Nitrate, and Phosphate.

A comparative study among *Typha* sp., *Eichhornia* sp., *Salvinia* sp. and *Pistia* sp. was performed by Dipu et al (2010) to treat dairy effluents. The study concluded that emergent species were more efficient than the floating ones and that the *Typha* based system outperformed the systems based on the other three species. Irfan and Shardendu (2009) investigated the dynamics of nitrogen and its uptake and storage by *Pistia stratiotes* under six different experimental conditions with differing nitrogen concentrations. The nitrogen accumulation by *P. stratiotes* was found to be 5 to 15 times higher than the nitrogen content in the water and 2 to 3 times higher than the nitrogen content measured in the soil. Maximum accumulation of nitrogen in *P. stratiotes* was reported to be 15.25 mg g^{-1}. Maheesan et al. (2011) performed an experiment to investigate the treatment efficiency of *Vetrivaria sesmodia* in treating domestic wastewater. A vertical, intermittent flow constructed wetland was designed with gravel and sand as filter media as well as trickling filter. The result was reported to be positive with mean removal efficiency of 89.68% for BOD, 88.66% for COD, 75.56% for SS, 97.13% for NH4-N and 72.74% for Phosphate.

Prabu and Udayasoorian (2007), designed a microcosm scale integrated wetland to investigate the removal of colour, pollutant and phenol from pulp and paper mill effluents using *Phragmites australis, Typha latifolia,* and *Cyperus pangorei*. The pollutant and phenol removal was found to be greater in the system using *Phragmites* sp. Selvamurugan et al. (2010) designed a laboratory scale treatment system using *T. latifolia* and *Colacassia* sp to treat the effluents of coffee processing industry. The results concluded that the performance of *Typha* sp. was better than that of *Colacassia* sp. The percentage pollutant removal of *Typha* sp. was found to be 85.4% for BOD, 78.0% for COD and 57.0% for TS-whereas the percentage removal of *Colacassia* sp. was fair with BOD-81.2%, COD-73.7% and TS-54.8%. Sengupta et al. (2004) investigated the effects of nutrient supply and water depth on nutrient uptake by using two emergent species: *Phragmites karka, Thysanolaena maxima*. The results of the experiment concluded that the uptake of nitrogen and phosphorus increased with water depth and confirms that both the species tolerate flooding and were better suited for treatment of wastewater.

Sharma et al. (2005) conducted a lab and field- scale

Table 3. Macrophyte species studied for nutrient removal at various locations.

Macrophyte	Common name	Parameters studied	Study # (Table 1)
Azolla pinnata	Mosquito Fern, Duckweed Fern, Fairy Moss	pH, Tolerance to dye wastewater	21
Ceratophyllum demersum	Horn Wort, Coontail	pH, Tolerance to dye wastewater	21
Chara najas	Chara	P, NO_3, Ca, K	22
Colcasias sp, *Colocasia esculenta*	Taro, Elephant-Ear	pH, BOD, COD, NO_3^--N, PO_4^--P, EC, TS	5, 6, 19
Cyperus alopecuroides	Foxtail Flat sedge	pH, Tolerance to dye wastewater	21
Cyperus pangorei	Korai Grass	BOD, COD, TSS and Chlorinated Phenol	14
Eichhornia crassipes	Water Hyacinth	pH, Turbidity, EC, TDS, TSS, BOD, COD, TN, N, P, K, Sodium, NNO_3, TS, Tolerance to dye wastewater, SS, PO_4^--P, NO_3^--N, acidity, NH_4^--N, hardness and Coliform bacteria	7, 8, 21, 23
Hydrilla verticillata	Water Thyme, Indian Star-Vine	pH, Turbidity, EC, TDS, TSS, BOD, COD, TN, N, P, K, Na, NO_3, Ca, Tolerance to dye wastewater	7, 15, 21, 22
Ipomoea aquatica	Water-Spinach, White Morning-Glory	P, NO_3, Ca, K, Na	15, 22
Lemna aequinoctialis	lesser duckweed, three-nerved duckweed	pH, Tolerance to dye wastewater	21
Lemna minor L.	Duck weed	Temperature, pH, Turbidity, Salinity, EC, TDS, Alkalinity, Free CO_2, Total CO_2, Chloride, DO, Percentage O_2 Saturation, COD, Total hardness, Calcium hardness, Calcium, Magnesium, Nitrogen in Ammonical, Nitrite, and Nitrate form and Phosphate	13
Ludwigia repens	Creeping Primrose Willow	P, NO_3, Ca, K	22
Marcellia sp.	Goat Weed	P, NO_3, Ca, K	22
Phragmites australis	Common Reed	TSS, TDS, TN, TP, COD, BOD, Chlorinated Phenol	2, 14
Phragmites karka	Elephant Grass , Reed Grass	TDS, TSS, BOD, DO, COD, NH_4^+-N, NO_3^-N, Org-N, TKN, pH, Tolerance to dye wastewater, Coliform Bacteria, Turbidity, TS, Phosphate	3, 4, 20, 21, 24
Pistia stratiotes	Water Lettuce	pH, Turbidity, EC, TDS, TSS, BOD, COD, NNO_3, Na, TS, NO_3^--N, TN, P, NO_3, Ca, K	8, 9, 22
Polygonum barbatum	Joint weed, Smart Weed	pH, Tolerance to dye wastewater	21
Salvinia sp.	Water Fern	pH, Turbidity, EC, TDS, TSS, BOD, COD, NNO_3, Na, TS	8
Spirodela polyrrhiza	Giant Duckweed	pH, Tolerance to dye wastewater	21
Thysanolaena maxima	Broom Grass	Phosphate, N	20
Trapa natans	Water Chestnut	P, NO_3, Ca, K	22
Typha angustata	Cattail Narrow leaved	pH, Tolerance to dye wastewater	21
Typha latifolia	Bulrush, Broad leaf Cattail	pH, Turbidity, EC, TDS, TSS, BOD, COD, NNO_3, Na, TS, Chlorinated Phenol	8, 14, 19
vetrivaria sesmoida	Vetriver Grass	BOD_5, COD, SS, NH_4^-N, PO_4^-P and pH.	12

experiment using 10 species that includes *Azolla pinnata, Ceratophyllum demersum, Cyperus alopecuroides, Eicchornia crassipes, H. verticillata, Lemna aequinoctialis, Phragmites karka, Polygonum barbatum, Spirodela polyrrhiza* and *Typha angustata*. All these species were screened for tolerance towards treating textile dye wastewater released during processing of printed cloth. The study revealed varied tolerance towards dye wastewater. Among the submerged, *Ceratophyllum* was found to be more sensitive and died within 24 h of exposure. The tolerance of free-floating species was found to be *Eicchornia* > *Spirodela* > *Azolla* = *Lemna*. It has been concluded that out of the 4 emergent species, *Phragmites* was the only plant species that survived and performed better than the rest in both the lab and field scale experiments.

Srivastava et al. (2009) studied the removal efficiency of soluble reactive phosphorus (SRP) from amended water by 7 different species of macrophytes (*Marcellia* sp., *P. stratiotes, Ipomoea aquatica, H. verticillata, Trapa natans, Chara najas, Ludwigia repens*). The SRP concentration accumulated by the plant tissue was found in the order *C. najas* > *P. stratiotes* > *H. verticillata* with a value 1.15, 1.05 and 1.04 mg g^{-1} dwt respectively. Though the performance indicates the potential of SRP accumulation by aquatic macrophytes, no single species was reported to have a potential for complete removal of nutrients from wastewater. Vipat et al. (2007) conducted a pilot scale project in Bhopal to study the efficacy of root zone treatment technology for the treatment of domestic waste water. A horizontal subsurface flow constructed wetland measuring 700 m^2 using *P. karka* was designed with no controls. The overall results were positive with percentage removal of Organic Nitrogen - 100%, Coliform Bacteria - 98.7%, Turbidity - 88.4%, TSS - 79.0%, Total Solids - 70.7%, TDS - 71.2%, COD - 77.8 %, TKN -8.9%, BOD - 65.7%, Nitrate Nitrogen - 62% and Ammonium Nitrogen - 53.3%. Lemna minor L., a tiny aquatic plant was studied by Patel and Kanungo (2010) for its potential in the removal of pollutants from domestic wastewater. The results indicate an increase in the value of pH, DO, Percentage O_2 saturation and decrease in value of Alkalinity, CO_2, Chloride, COD, Hardness, Nitrogen and Phosphorus thus indicating an improvement in the overall water quality. Tripathi and Shukla (1991) conducted a microcosm study in three stages that is, a water hyacinth culture followed by an algal culture, and finally a second water hyacinth culture. They experimented with sewage water mixed with industrial effluents by using aquatic macrophyte (*Eichhornia crassipes*) and algae species (*Microcystis aeruginosa, Scenedesmus falcatus, Chlorella vulgaris, Chlamydomonas mirabilis*). The percentage removal of various pollutants were reported as BOD (96.9%), SS (78"1%), total alkalinity (74.6%), PO4--P(89.2%), NO3--N (81.7%), acidity (73.3%), N H4--N (95.1%), COD (77.9%), hardness (68.6%) and coliform bacteria (99.2%). They concluded that the three-stage system of wastewater treatment described is probably the cheapest and most economic method which can be adopted throughout warmer and temperate climates.

Heavy metal phytoremediation using macrophytes

Heavy metal contamination poses many environmental and health problems (Ensley, 2000; Rai, 2009). These contaminants are not only prevalent in mine drainage but also found in storm water, landfill leachate and many other sources. The most commonly used methods of addressing heavy metal pollution are still the extremely costly process of removal. Some of the conventionaltechnologies include ion exchange, nanofiltration, reverse osmosis, chemical precipitation, coagulation etc. which are expensive and not ecofriendly. Economic consideration thus favours the need for an alternative cost-effective technology, as the cleanup of hazardous wastes by conventional technology is expensive (Rai, 2009). Aquatic macrophytes and weeds being hyper accumulators of metals are suitable for phytoremediation (Rai, 2009). The use of plants for remediation of metals offers an attractive alternative because it is solar-driven and can be carried out in situ, minimizing cost and human exposure (Salt et al., 1995, 1998).

Several alternate cost effective technologies are developed to clean up the heavy metals of which phytoremediation seems to be a promising one. Experiments have been done to assess the suitability of local wetland macrophytes for removal of heavy metals. Several macrophytes are screened for their metal accumulating properties for its application in CWs. Table 4 presents the various macrophytes species studied for heavy metal removal from natural and constructed wetlands. There are a number of physical, chemical and microbiological processes involved in the purification, like binding to soils, sedimentation, filtration, adsorption, microbial decomposition, precipitation as insoluble salts, chemical transformation and uptake by bacteria, algae, and plants (Boyd, 1970; Kadlec and Keoleian, 1986; Hiley, 1995; Kadlec and Knight, 1996; Mudgal et al., 2010). Adsorption plays an important role (Mukherjee and Kumar, 2005) in the removal of heavy metals as heavy metals are non-biodegradable and therefore removal of these metals is the only solution for water decontamination (Cheng et al., 2002; Ghosh and Singh, 2005; Bareen et al., 2008).

Several floating, submerged and emergent macrophytes (*Hydrodictyon reticulatum, Spirodela polyrrhiza, Chara corallina, Ceratophyllum demersum, Vallisneria spiralis, Bacopa monnieri, Alternanthera sessilis* and *Hygrorrhiza aristata*) were studied for their potential for heavy metal removal from pond water contaminated with heavy metals under laboratory conditions (Rai et al., 1995). The study focussed on the

Table 4. Macrophyte species studied for heavy metal removal at various locations.

Macrophyte	Common name	Metals studied	Study # (Table 1)
Alternanthera sessilis	Dwarf Copperleaf, alligator weed	Cu, Cr, Fe, Mn, Cd, Pb	16
Azolla pinnata	Mosquito Fern, Duckweed Fern	Fe, Cu, Hg, Cd	10, 17
Bacopa monnieri	Water hyssop, Brahmi	Cu, Cr, Fe, Mn, Cd, Pb	16
Ceratophyllum demersum	Horn Wort, Coontail	Cu, Cr, Fe, Mn, Cd, Pb	16
Chara corallina	Stone Wort, Green Algae	Cu, Cr, Fe, Mn, Cd, Pb	16
Colocasia esculenta	Taro, Elephant-Ear	Pb, Cd	5, 6
Cyperus alopecuroides	Foxtail Flatsedge	Na, K, Ca, Mg, Fe, Mn, Zn, Cu, Ni, Cr, Pb	15
Echinochloa colonum	Shama Millet, Billon Dollar Grass	Cd, Co, Cu, Ni, Pb, Zn	11
Eichhornia crassipes	Water Hyacinth	Cd, Co, Cu, Ni, Pb, Zn	11, 18
Hydrilla verticillata	Water Thyme, Indian Star-Vine	Cd, Co, Cu, Ni, Pb, Zn, Mg, Fe, Mn, Cr	11, 15
Hydrodictyon reticulatum	Water Net	Cu, Cr, Fe, Mn, Cd, Pb	16
Hygrorrhiza aristata	Wild Rice Relatives , Asian water grass	Cu, Cr, Fe, Mn, Cd, Pb	16
Ipomoea aquatica	Water-Spinach, White Morning-Glory	Cd, Co, Cu, Ni, Pb, Zn, Mg, Fe, Mn, Cr	11, 15
Lemna minor l.	Common/Lesser Duckweed	Fe, Cu	10
Nelumbo nucifera	Indian Lotus	Cd, Co, Cu, Ni, Pb, Zn	11
Neptunia oleracea	Water-Mimosa	Na, K, Ca, Mg, Fe, Mn, Zn, Cu, Ni, Cr, Pb	15
Paspalidium punctatum	Bristle Grass	Na, K, Ca, Mg, Fe, Mn, Zn, Cu, Ni, Cr, Pb	15
Paspalum distichum	Knot Grass, Eternity Grass	Na, K, Ca, Mg, Fe, Mn, Zn, Cu, Ni, Cr, Pb	15
Pseudoraphis spinescens	Mud Grass	Na, K, Ca, Mg, Fe, Mn, Zn, Cu, Ni, Cr, Pb	15
Salvinia rotundifolia	Butterfly/ floating/ water fern	Pb	1
Spirodela polyrrhiza	Giant Duckweed	Cu, Cr, Fe, Mn, Cd, Pb	16
Typha angustata	Cattail Narrow leaved	Cd, Co, Cu, Ni, Pb, Zn	11
Vallisneria spiralis	Tape Grass, Eel Grass	Cd, Co, Cu, Ni, Pb, Zn, Cr, Fe, Mn	11, 16

in Pariyej Community Reserve, Gujarat to ascertain the degree of heavy metal (cadmium, cobalt, copper, nickel, lead and zinc) contamination in water and sediments and the role of macrophytes in phytoremediation. *Typha, Eichornia* and *Ipomea* species performed better than the other four species. The results showed the significant differences in accumulation of metals like Zn, Cu and Pb in different plant organs, in roots than that of stems and leaves. Rai (2008) conducted a microcosm study that focused on the phytoremediation of Hg and Cd from industrial effluents from Singrauli Industrial Region using *A. pinnata*. After 13 days of the experiment the concentration of selected heavy metals in the tissues of *A. pinnata* was recorded between 310 and 740 mg Kg^{-1} dry mass, with the highest level found for Cd treatment at 3.0 mg/L^{-1} containing a metal solution. Rana et al. (2011) studied the performance of constructed wetlands in the reduction of cadmium in a sewage treatment cum fish farm at Kalyani, West Bengal.

The free floating, *E. crassipes* was planted in a series of wetland ponds comprising of 2 Anaerobic ponds, 2 Facultative ponds and 2 maturation ponds. The results of the study indicate the percentage reduction in cadmium

levels to be 30%. *Salvinia* species exhibit capacity for removing contaminants such as heavy metals, inorganic nutrients, explosives from wastewaters heavy metals such as Cu, Cr, Fe, Mn, Cd and Pb and evaluated eight different aquatic macrophyte species (Table 4: #16). The 15th day observation indicates that Cr level was brought from 4.866 µM to below maximum permissible limits by *C. demersum, H. reticulatum* and *S. polyrrhiza*. Similarly Fe and Mn levels were brought below maximum permissible limits within 15 and 7 days by *C. demersum* and *H. reticulatum* respectively. *B. monnieri* and *H. aristata* decreased Cd levels from 0.155 to 0.009 /µM whereas *S. polyrrhiza* and *H. reticulatum* reduced levels to 0.036 /µM after 15 days of treatment. Over 70% of Pb was removed by *C. demersum, H. aristata* and *H. reticulatum*. Out of the eight macrophytes studied *C. corallina, A. sessilis* and *V. spiralis* accumulated these metals to a lesser extent. *H. aristata*, the emergent *B. monnieri*, the free floating *S. polyrrhiza* and *H. reticulatum* and the rootless submerged plant C. *demersum* have shown promising potential for the removal of heavy metals from diluted wastewaters (Rai et al., 1995). *Azolla pinnata* and *Lemna minor* L. were investigated for iron and copper removal from a metal effluent solution in a microcosm study. Experimental solution contained in a 2 L plastic pots was kept in a phytotoron house and investigated for a period of 14 days. The results indicated that both the species are able to remove iron and copper effectively at low concentration of up to 6 to 8 days of treatment. The uptake potential and survival of *A. pinnata* was found to be higher than that of *L. minor* L. (Jain et al., 1989). Bindu et al. (2010) worked on Taro (*Colocasia esculenta*) a native amphibious plant of Kerala which was found to remove Lead and Cadmium from synthetic heavy metal solution at lower concentrations. In laboratory experiments *C. esculenta* was grown hydroponically in shallow raceways containing Hoagland medium amended with 20, 40, and 60 mg/L^{-1} of Pb and 2, 4, and 6 mg/L^{-1} of Cd. The quality of the treated water from the plant based system was found to be better than the one without plants. The species used was found to be a promising for the remediation of wastewater polluted with lower concentrations of Pb and Cd. The plants remained healthy and survived after 20 days with a concentration of 20 and 40 mg/L^{-1} of Pb and up to 4 mg/L^{-1} of Cd, indicating its suitability as a bio-agent (Bindu et al., 2010).

Prusty et al. (2007) investigated the adsorption of alkali and transition metals in macrophytes of a wetland system comprising of seven different species of emergent and submerged aquatic macrophytes (*Paspalum distichum, Paspalidium punctatum, Cyperus alopecuroides, Pseudoraphis spinescens, Ipomoea aquatica, Neptunia oleracea* and *Hydrilla verticillata*). Plants were analyzed for alkali, alkaline-earth metals (Na, K, Ca and Mg), and transition metals (Fe, Mn, Zn, Cu, Ni, Cr and Pb). In this study Cu, Pb, Cr and Ni were not detectable (ND) in some of the plants. The highest concentration of Pb detected in the study was 0.02 µg/g in *Hydrilla* while it was undetectable in other plants except *Neptunia*. The highest level of Cu found in the macrophyte under the present study was 3.0 µg/g (in *Cyperus*). The Ni level was found at highest concentration in *Hydrilla* (0.2 µg/g). In all the macrophyte species, Mn was found to be in highest concentration followed by Fe and Zn. K followed Zn in all the plants except *Cyperus*. The overall study indicates that the alkali metals are restricted while the transitional elements are considerably accumulated. In the present investigation, all the metals were within the general concentration range. Nevertheless, there is the likelihood of elevated levels in the root parts.

Seven native aquatic macrophyte species (*Echinochloa colonum, Ipomoea aquatica, Eicchornia crassipes, Typha angustata, Hydrilla verticillata, Nelumbo nucifera* and *Vallisneria spiralis*) were investigated by Kumar et al. (2008) (Dhir, 2009). The role of *Salvinia rotundifolia* in remediating lead from Industrial (Battery producing unit) waste water was investigated by Banerjee and Sarker (1997). The results indicated over 95% removal of lead from the waste water by *Salvinia* sp.

While several aquatic macrophytes have shown the ability to hyper-accumulate metals from the wastewater, they are still vulnerable to the toxicants present in such environment which limit the plant growth and ability to hyper-accumulate. This can be overcome by adding endophytes (bacteria that favours growth) to the system which significantly improve the ability to phytoremediate and also favours the plant growth (Glick and Stearns, 2011). However, this process does not guarantee the complete remediation of the metals. This is because, on one hand, if plants are not harvested on time, they may die off and release the metals back to the water and on the other hand if they are harvested and not disposed off safely then it will only lead to a transfer of the problem to a different site. Through some species like *A. pinnata* can be used as a bio-fertilizer after some mild chemical treatment for metal removal, in general, they cannot be used as a bio-fertilizer or animal feed. Due to this, the safest option of disposal would be to produce biogas (Rai and Tripathi, 2007; Rai, 2007, 2009).

CONCLUSION AND RECOMMENDATION

This paper reviewed various studies in India and elaborated the experiences in using aquatic macrophytes for water treatment by delineating some of the key treatment efficiency parameters and performance issues. Experiences reveal that plants indeed play a vital role and improve the overall treatment efficiency. From this review, it is also clear that CWS systems utilizing the phytoremediation capabilities of aquatic macrophytes can be designed and operated to remove a wide range of pollutants from wastewater. Given the low operation,

maintenance, and energy requirements, constructed wetlands could well be the systems for achieving sustainable wastewater management at all levels.

It was found that the most frequently used plant among the studies reviewed is *Eichhornia* sp. (Water Hyacinth). Species of the genera *Phragmites, Hydrilla* and *Typha* sp. are the other frequently used ones followed by *Azolla, Colocasia, Cyperus, Ipomoea, Lemna* and *Pistia sp.* Based on the studies reviewed, kitchen wastewater seems not to be suited for phytoremediation due to relatively high pollutant load. *C. esculenta* is found to resist high COD concentration and thus can be used in situations containing high COD in the influent. In general, the emergent species outperformed the submergent species which might be accredited to their massive growth rates. *Typha* sp. was found to be better suited to treat dairy and coffee processing effluents whereas *Phragmites* sp. was found to be better suited to treat domestic, textile dye wastewater, pulp and paper mill effluents. Among the free-floating species, *Eicchornia* and *Ceratophyllum* was found to be better suited to treat textile dye wastewater. Treatment using multiple stages was found to be better than single stage treatment. Among the heavy metals remediation, *C. demersum* was found to be better suited to treat wastewater contaminated with heavy metals such as Cu, Cr, Fe, Mn and Pb. On the other hand, *H. aristata* and *C. esculenta* are found to be better suited to treat wastewaters contaminated with Pb and Cd. However, proper and timely harvesting of plants is very important so as not to release back the contaminants to the wetland through decay. The safest option of disposal in this case would be to produce biogas rather than using as fodder.

It was also found that CWS can be applied either at a domestic scale to treat domestic wastewater (Vipat, 2007; Bindu et al., 2008; Maheesan et al., 2011) or applied by small communities (Green and Upton, 1995; Laber et al., 1999) or serve as an economical alternative to secondary treatment of stabilization pond effluent, the most common treatment system in use in economically poor countries (Kivaisi, 2001; Fenxia and Ying, 2009). Though CWS has been widely used for wastewater treatment across the world, but to date, the technology has been largely ignored or adequate research is unavailable in developing countries where effective, low cost wastewater treatment strategies are needed the most (Kivaisi, 2001; Trivedy, 2007). In developing countries where at present only less than 30% of wastewater is treated due to the high costs incurred by the conventional wastewater treatment methods (Sonavane et al., 2008), there is a critical need for cost-effective, long-term, wastewater treatment technologies to deliver public health and environmental protection (Sundaravadivel and Vigneswaran, 2010). Most importantly, significant work is required on the various methods of handling the biomass generated by the macrophytes (Srivastav, 1993).

CWS being an attractive alternative to the conventional methods for the treatment of various types of wastewater, the potential for its application is enormous in the warm tropical and subtropical climates which aides in higher biological activity resulting in better performance. In spite of the encouraging results of the various studies reviewed, there are quite a few limitations noticed in several of the studies. Most of the systems are microcosm scale experiments; hence the operational/performance data obtained may not be of much use in the implementation of full-scale units. The studies are primarily focussed on monoculture experiments which even though useful, cannot rule out the efficacy of poly-culture experiments as the latter are found to be better in overall performance and seemed to provide the best and most consistent treatment for all wastewater parameters, while being least susceptible to seasonal variations (Karathanasis, 2003; Debing, 2009).

The study period should also be sufficiently long enough to get a more reliable and consistent data. Even though CW has a low operational and maintenance cost (Juwarkar et al., 1995), its practical application in the developing countries is not widespread. This is primarily due to lack of sufficient data, awareness and expertise. However, there are certain drawbacks of such systems, especially its adaptation in the developing countries which includes requirement of large land area, lack of published knowledge on native macrophyte species (Gopal, 1999), diverse characteristics of wastewater, lack of design principles and implementation methodology and cases of economic feasibility for large scale implementation (Batchelor and Loots, 1997; Kadlec and Knight, 1996). Moreover, the process dynamics of CWS are yet to be clearly understood combined with other practical limitations like mosquitoes/ pest problems, steep topography and a high water table which restricts the adoption of these systems (Sundaravadivel and Vigneswaran, 2010).

In the future, it is conceivable that an integrated, multidisciplinary and local research effort is required to achieve a greater success in the application of phytoremediation techniques for treating wastewater.

Conflict of Interest

The authors have not declared any conflict of interest.

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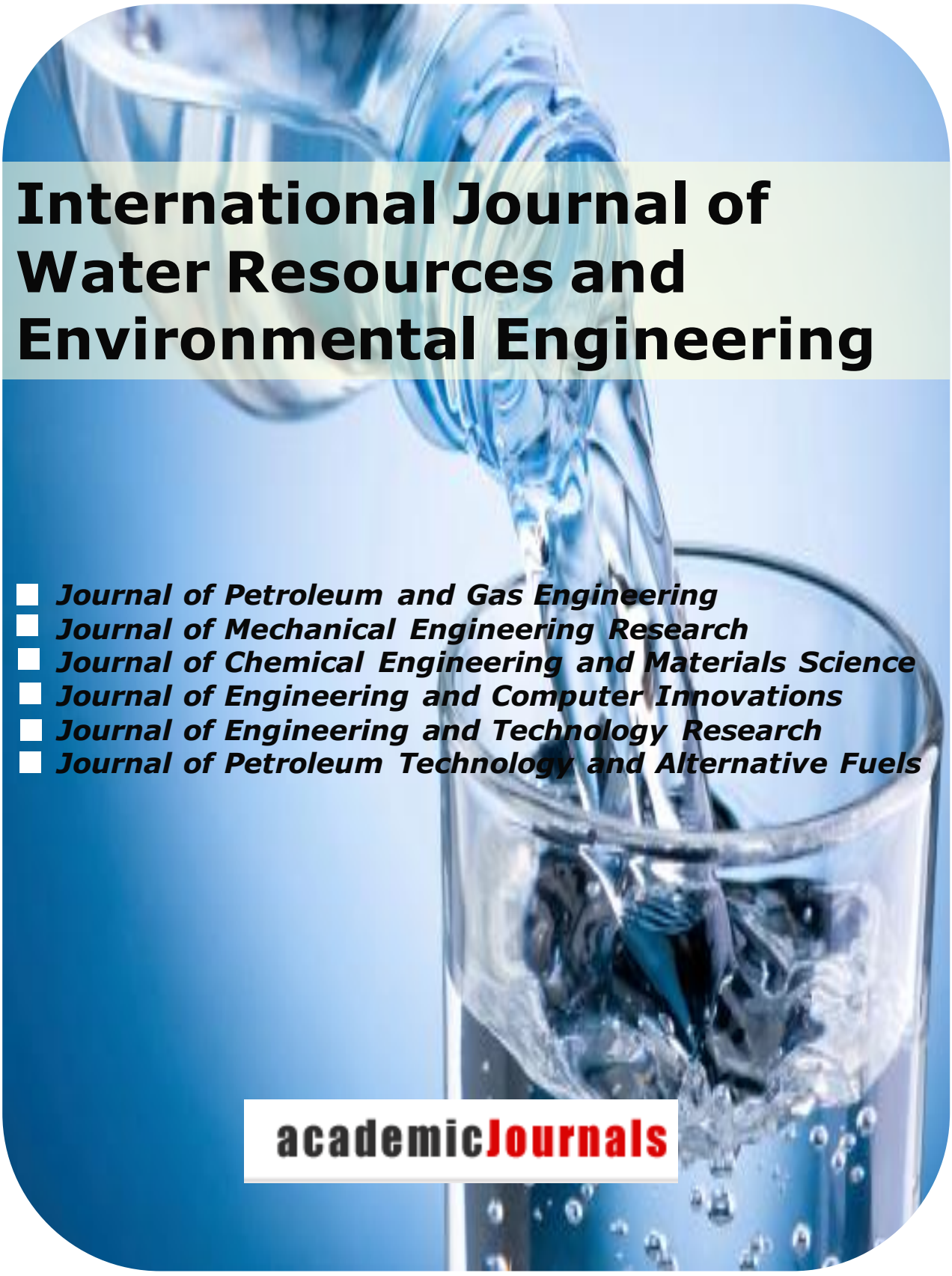

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