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Checklist of tropical algae of Togo in the Guinean Gulf of West-Africa

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The phytoplankton is an important part of the biodiversity and one of the bases of food networks of freshwater, brackish and marine environments. This study is carried out to record the algae flora (microalgae and macroalgae) in Togo regarding the floristic diversities. The results show that 795 species of microalgae have been recorded in Togo belonging to 134 families, nineteen groups among which the most important in terms of number of species are the Bacillariophyceae (26%), Cyanophyceae (17%), Chlorophyceae (16%), Conjugatophyceae (12%) and Euglenophyceae (11%). The microalgae of Togo belong to 7 Divisions which are respectively Chromophyta (39%), Chlorophyta (32%), Cyanophyta (17%), Euglenophyta (11%), and Rodophyta (1%). More than 250 genera were recorded and the most represented genera are *Navicula*, *Nitzschia*, *Scenedesmus*, *Trachelomonas*, *Closterium*, *Cosmarium*, *Oscillatoria*, *Phacus*, *Pinnularia*, *Staurastrum*, *Strombomonas*, *Lyngbya* that cover 31% of microalga of Togo. For the macroalgae, 37 taxons were collected in total. Three Divisions of the macroalgae notably the Chlorophyta, Pheophyta and Rhodophyta are the most represented. The dominant species are from the Chlorophyta Division. These studies are still ongoing to improve the knowledge about the biodiversity of the aquatic environments algae in Togo.

Key words: Guinean Gulf, Togo, aquatic ecosystem, phytoplankton, microalgae, macroalgae.

INTRODUCTION

The phytoplankton constitutes the primary production in the watercourses and oceans (Field et al., 1998; Behrenfeld et al., 2001). It also constitutes an important part of the biodiversity and one of the bases of food networks of freshwater, brackish and marine environments (Tourte et

al., 2005).

In Togo, the researches conducted on plants covered a large portion of Angiosperms. But the researches on the phytoplankton and the algae in particular are relatively recent (Atanlé et al., 2013; Radji et al., 2013). Very

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recently, the Advanced Learning Support Project (PAES) in the West African Economic and Monetary Union - UEMOA - (Project: P-Z1-IAD-002N°2100155007376), enabled to extend the prospections on the phytoplankton nationwide.

This regain of interest in the phytoplankton organisms in Togo is motivated today by the fact that in the search for solution against the negative effects of climate change, these species as well as the macroflora contribute to the reduction of the greenhouse gases notably the carbon dioxide (Sayre, 2010). Moreover, they are also involved in the production of fertilizers, agro-food and cosmetic products, biofuel, antibiotics etc. (Cadoret and Bernard, 2008; Farid et al., 2009; Sydney et al., 2010; Priyadarshani and Rath, 2012). The phytoplankton study reveals to be very crucial because of its ecological, environmental, dietary, pharmacological and socio-economic importance. However, before getting to the implementations and valorizations of the phytoplankton flora in Togo, it is necessary to know their diversity. Thus, this study aims at analysing the algae flora (microalgae and macroalgae) in terms of floristic diversities, number of families, groups and main Divisions which compose the species in Togo. The targeted objective is to create a check-list and occurrences list of the phytoplankton species in Togo that will be the starting point for the drafting of the algae flora until now inexistent.

MATERIALS AND METHODS

The study zone

This study was conducted in Togo, located on the coast of the Gulf of Guinea in West Africa. The country covers an area of 56 600 km² and shares borders with the Atlantic Ocean in the South, Burkina Faso in the North, Benin in the East and Ghana in the West. Located in between the 6th and the 11th degree of latitude and between the 0th and 2nd degree of east longitude, the country stretches from North to South over 660 km. Its breadth varies between 50 and 150 km. Togo belongs to the muggy intertropical area marked by two main high speed currents. This intertropical climate varies markedly from the Southern regions to the Northern regions. Globally, the Southern regions have 4 seasons: a long dry season, from mid-November to March, a large rainy season, from March/April to July, a small dry season, from August to September and a small rainy season, from September to mid-November. The Central and Northern regions are characterized by two seasons: the rainy season (May to October) and the dry season (November to April). The rainfall varies from 882 to 1328 mm in the Southern regions and from 1000 to 1302 mm in the Northern regions. For the temperature, it varies from 26.4 to 27.4°C in the Southern regions and from 26.4 to 28.3 in the Northern regions. The relative average moisture is high in the Southern zones (73 to 78.5%) but low in the Northern regions (56 to 67%). The average evapotranspiration is of 1540 mm/year. From this ecological diversity, Togo offers a wide research field for the phytoplankton thanks to the multitude aquatic ecosystems (marine environment, streams, rivers, lakes, pools, etc.). The main aquatic ecosystems considered in this study can be grouped into:

(1) Lotic environment made up of (i) aquatic ecosystems of hydrologic regime influenced by the Sudanian Climate with one dry

season and one rainy season notably along the Oti River and its affluents (Koumougou, Kara and Mô), the Mono River and its affluents (Ogou, Anié, Amou and Khra) and (ii) aquatic ecosystems of hydrologic regime influenced by the sub-equatorial climate with two rainy seasons that alternate with two dry seasons. It takes into account the Haho stream, the Zio stream and its main tributary the Lili;

(2) Lentic environment: it's about lakes, lagoons and ponds in the South of Togo. Some of these watercourses are brackish and others are freshwaters. It includes also the Atlantic Ocean. Indeed, Togo is endowed with a coastline that stretches from West to East over a width 50 km, between the 6°01 and 6°05 latitudes Nord and the 0°70 and 1°40 longitudes East. The coastline is mainly sandy and has been subject for some years now to so severe marine erosion (Blivi, 1993). The offshore environment covers an area of 371 km. It is made up of a relatively flat and deep narrow continental table. It is 23 km wide and 100 m isobathic. The ocean bottoms are essentially sandy and sandy silt. Meanwhile there are many beach sandstone submarine levellings between 350 and 500 m from the coast. Togo has a special feature of beach-rock which is a geological formation made up of ancient corral reefs, today striped naked by the coastal erosion. This dead corral reef almost parallel at the shore is present on the sandy bottom in correspondance with 52 to 56 m isobathic over about 15 to 17 km along the coast. Beyond and up to the plateau fall, a large number of reef heads can be noticed. In the Gulf of Guinea, the sea surface temperature varies normally between 25 and 29°C but can fall down to 20°C during the upwelling of cold water (Segniagbeto and Van Waerebeek, 2010). The Guinean current is the main current in the Gulf of Guinea. It is supplied by the northern equatorial off Liberia and flows toward the East alongside the coast of Ghana, Togo, Bénin and Nigeria. The Gulf of Guinea concave topography deviate the Current of Guinea towards West that results into the South Equatorial Current. Upwellings of water rich of nutriments occur in the months of July and September as well as in January. The Gulf of Guinea tides originate from the South West. This concerns semi-diurnal tides with two irregularities. The tides height ranges from 1 to 3.5 m (during the storm). The macroalgae have been harvested in this environment. These aquatic ecosystems are distributed into the 3 main watershed catchment basins of Togo notably the Volta basin, the Mono basin and the Lac Togo basin.

Data collection

The data collection took into account all the seasons of the year 2013 and covered all the aquatic ecosystems of Togo. For each site of water sample collection, the geographic coordinates are taken with the Global Positioning System (GPS) and positioned on the watershed catchment basin map of Togo thanks to MapInfo Professional software (Figure 1). Two different data collection approaches were used. For the microalgae, the samplings are conducted at 20 cm of the water surface for the surface waters (less than 50 cm depth). For the deep areas (>50 cm), the samplings are conducted at three levels (surface, mid-depth and depth) using an integrated water sampler bottle (Druart and Rimet, 2008). In all 135 water samples were collected nationwide in pillbox of 250 ml. After sampling, the phytoplankton was immediately fixed by an 1% concentrated lugol's solution which gives a light brown colour to the sample (Thronsdén, 1978) and enables to better preserve the structure of the algae cells (Druart et al., 2005). The samples are kept in a cool place and in darkness up to the Palynology and Algology laboratory of the Faculty of Science of the University of Lomé. Each sample is left to rest for 24 h minimum to enable the sedimentation of the algae (Nielsen, 1933). Water was later on sampled on top of the algae residue through siphonage. The concentrated algae water residue was conserved in the pillbox. For the identification of the phytoplankton, a water drop is sampled

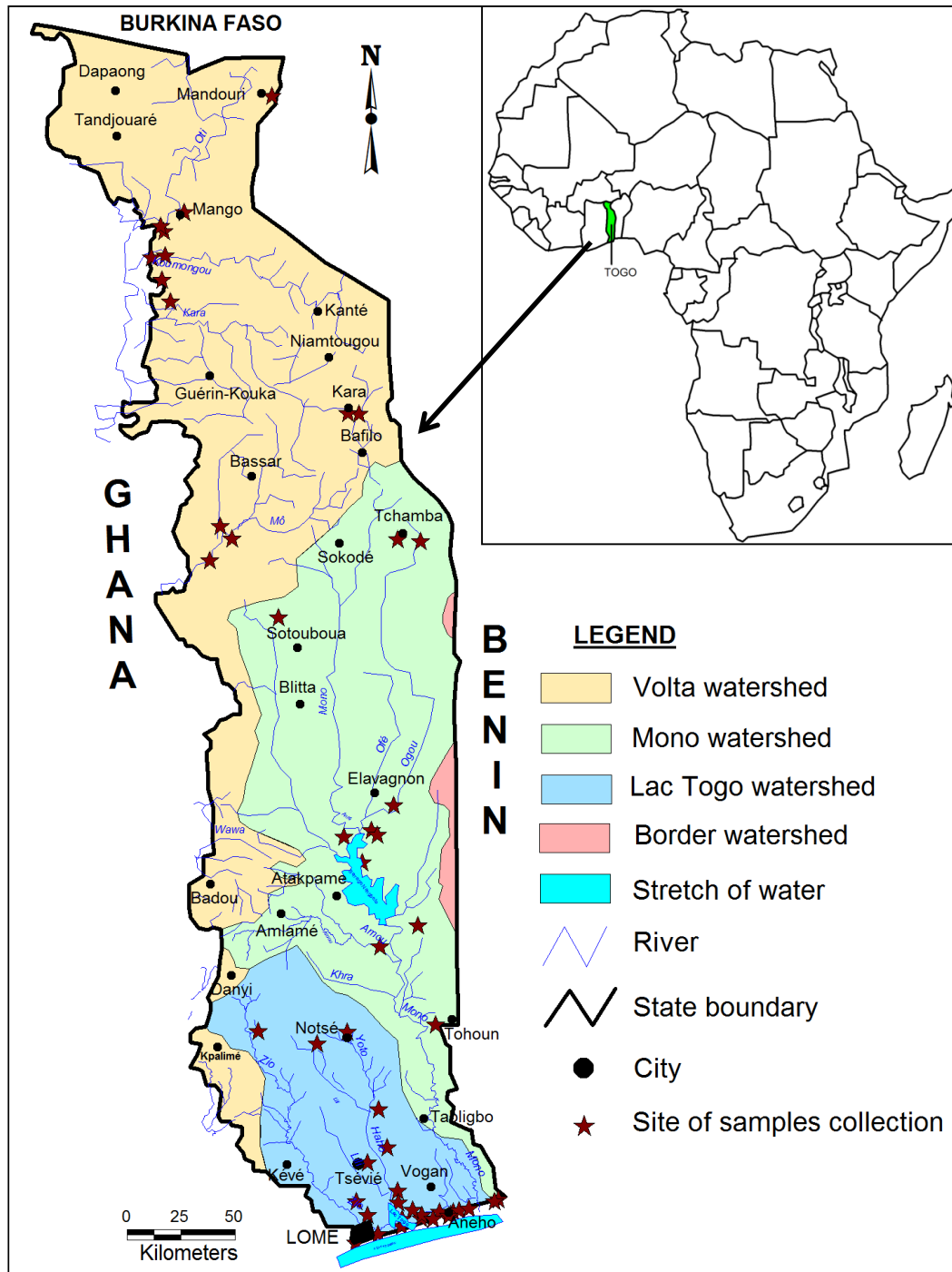


Figure 1. Siting of sampling.

thanks to a Pasteur pipette. This drop is deposited in between slides then observed with the photon microscope adapted to a light room and a camera connected to a computer. The observation is repeated 3 times for the same site in order to establish the algae composition of each site, that is, 405 observations. The observations are done according to vertical scannings. The pictures are taken with 10X and 40X objectives. As for Diatomeae, the identification level and taxonomy is hard, thus, oil immersion and

100X objectives were used. From the observations and the pictures, the identification of the species is done thanks to the works of Lauterborn (1915), Skuja (1956), Grönblad et al. (1958), Coute and Rousselin (1975), Komarèk and Anagnostidis (1995), Sournia (1968), Compere (1991), of Krammer and Lange-Bertalot (1986-2000), of Bourrelly (1968, 1970, 1972, 1990), and of Lavoie et al. (2008). For the macroalgae, the collections concern essentially the seaweeds. For this effect sampling are considered



Photo 1. Seaweeds cropping up on the beach-rock in low normal tides.

Table 1. Most represented genera of microalgae in Togo.

Group/Genera	Family	Representatives in the genera	
		Number of species	% compared to the total number of genera
I- Bacillariophyceae			
<i>Navicula</i>	Naviculaceae	31	4
<i>Nitzschia</i>	Nitzschiaceae	22	3
<i>Pinnularia</i>	Naviculaceae	16	2
II- Chlorophyceae			
<i>Scenedesmus</i>	Scenedesmaceae	29	4
<i>Closterium</i>	Desmidiaceae	24	3
<i>Cosmarium</i>	Desmidiaceae	24	3
<i>Staurastrum</i>	Desmidiaceae	14	2
III- Cyanophyceae			
<i>Oscillatoria</i>	Oscillatoriaceae	22	3
<i>Lyngbya</i>	Oscillatoriaceae	8	1
IV- Euglenophyceae			
<i>Trachelomonas</i>	Euglenaceae	27	3
<i>Phacus</i>	Euglenaceae	18	2
<i>Strombomonas</i>	Euglenaceae	9	1

over the coastline. The samples are taken during low tide on the hard substrata on foot in the encroachment zones and other hard substrata of the coastline by diving. The fishermen's nets once back from sea are scrutinized to find algae brought in. Moreover, more systematic harvest was conducted on the beach-rock, after obtaining from the captaincy of the Port Authority of Lomé pieces of information about the daily schedule of the low tides during which a larger part of the beach-rock shows on the surface (Photo 1). The algae are placed in vials filled with seawater to be identified in laboratory. The identification is carried out at the laboratory through direct the observation by means of microscope for the very little size specimen. After the identification, the specimens are kept at the Herbarium of the University of Lomé after a stay in the 4% formol. The classification of the algae per division, group, order and family being too complex and varied from one source to the other, the base list used in this article relied on AlgaeBase (Guiry and Guiry, 2014).

RESULTS

Microalgae's Richness in Togo

Presently, 795 species of microalgae have been recorded in Togo including 83% species totally identified and 17% identified only by the genera (Annexes). In total, 282 genera were recorded and the most represented genera are *Navicula*, *Nitzschia*, *Scenedesmus*, *Trachelomonas*, *Closterium*, *Cosmarium*, *Oscillatoria*, *Phacus*, *Pinnularia*, *Staurastrum*, *Strombomonas*, *Lyngbya* that cover 31% of microalgae of Togo (Table 1, Photo 2). The microalgae belong to 134 families of which the most represented (having more than 10 species) are the *Desmidiaceae*, *Euglenaceae*, *Scenedesmaceae*, *Naviculaceae*,



Oscillatoria platensis
Nordst
(Cyanophyceae)



Peridiniopsis sp.
(Dinophyceae)



Euglena oxyuris
Schmarda
(Euglenophyceae)



Phormidium tenue
Anagnostidis & Komárek
(Cyanophyceae)



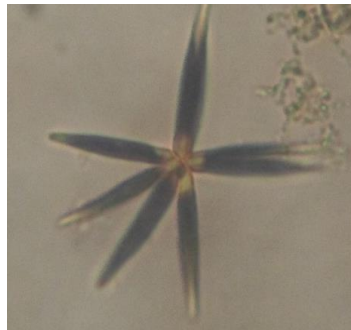
Closterium lineatum
Ehrenberg ex Ralfs
(Conjugatophyceae)



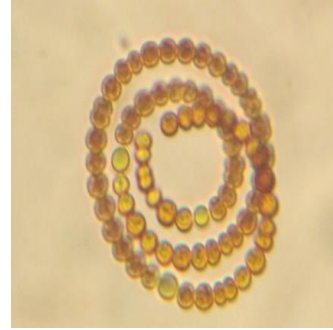
Hyaloraphidium contortium Pasch. y
Korch
(Chlorophyceae)



Pediastrum tetras
(Ehrenberg) Ralfs
(Chlorophyceae)



Actinastrum hantzschii
Lagerh
(Chlorophyceae)



Anabaena spiroides
Lemm.
(Cyanophyceae)

Photo 2. Some specimen of microalgae in Togo.

Oscillatoriaceae, *Bacillariaceae*, *Phacaceae*,
Nostocaceae, *Fragilariaceae*, *Pinnulariaceae*,
Hydrodictyceae, *Eunotiaceae*, *Gomphosphariaceae*,
Chlamydomonadaceae, *Oocystaceae*,
Merismopediaceae, *Diplopsliaceae*, *Selenastraceae*,

Stephanodiscaceae. These families cover 74% of algae plant community in Togo (Table 2). These most represented genera belong essentially to the most represented families in Togo. Nineteen groups make up the whole microalgae in Togo but the most important in

Table 2. Richness of microalgae families in Togo.

Group/Family	Representative in the family Number of species	% compared to the total number of families
1- Bacillariophyceae		
<i>Naviculaceae</i>	44	6
<i>Bacillariaceae</i>	34	4
<i>Pinnulariaceae</i>	17	2
<i>Eunotiaceae</i>	14	2
2- Chlorophyceae		
<i>Desmidiaceae</i>	81	10
<i>Scenedesmaceae</i>	53	7
<i>Hydrodictyceae</i>	15	2
<i>Chlamydomonadaceae</i>	12	2
<i>Oocystaceae</i>	12	2
<i>Selenastraceae</i>	10	1
3- Euglenophyceae		
<i>Euglenaceae</i>	54	7
<i>Phacaceae</i>	27	3
4-Cyanophyceae		
<i>Oscillatoriaceae</i>	36	5
<i>Nostocaceae</i>	21	3
<i>Gomphosphaeriaceae</i>	13	2
<i>Merismopediaceae</i>	11	1
5- Fragilariophyceae		
<i>Fragilariaceae</i>	19	2
6- Dinophyceae		
<i>Diplopsaliaceae</i>	10	1
7- Coscinodiscophyceae		
<i>Stephanodiscaceae</i>	10	1

terms of species richness are the Bacillariophyceae (26%), Cyanophyceae (17%), Chlorophyceae (16%), Conjugatophyceae (12%), Euglenophyceae (11%), Dinophyceae, Fragilariophyceae and Trebouxiophyceae (3%), Xanthophyceae (2%). Chrysophyceae, Cryptophyceae, Synurophyceae and Ulvophyceae contain respectively 1% of the algae flora. The Nephrophyceae, Rhodophyceae, Raphidophyceae and Stylonematophyceae are also a group that are present in Togo but in a low proportion (Table 3). The microalga of Togo belong to 7 Divisions which are respectively Chromophyta (39%), Chlorophyta (32%), Cyanophyta (17%), Euglenophyta (11%), Rodophyta (1%) (Figure 2).

Macroalgae richness in Togo

In total 37 taxa were collected and 27 from them were identified to the genera or to the species (Table 4, Photo 3). Three Divisions of macroalgae notably Chlorophyta, Phaeophyta and Rhodophyta are the most represented in term of number of species. The Chlorophyta (green

algae) dominates with 9 species.

DISCUSSION

This study is the most important to have carried out a relatively exhaustive analysis on the richness of the algae in Togo. On about 1,100 genera and 14,000 species spread in the world (Ilitis, 1980), 795 species of microalgae are grouped in 282 genera and 37 macroalgae in about 20 genera were identified, in other words, a contribution of about 2.3% of the world algae flora. This richness is very high compared to the precedent studies during which many authors tried to collect phytoplankton species in Togo. Indeed, during the research works in the freshwater ecosystems (lakes and lagoons) of Southern Togo, Edorh et al. (2008), Léné (2004), Bandje (2010), Gnofam (2010), Issifou (2012) and Radji et al. (2013) indexed a specific algae richness of about 200 taxa of microalgae. These authors showed that in these areas, the Chromophyta with the species such as *Cyclotella bodanica* Eulenstein ex Grunow, C.

Table 3. Most represented groups of microalgae in Togo in term of species.

Division/Group	Representatives in the group Number of species	% compared to the total number of Divisions
I- Chromophyta		
<i>Bacillariophyceae</i>	204	26
<i>Coscinodiscophyceae</i>	30	4
<i>Dinophyceae</i>	27	3
<i>Fragilariophyceae</i>	23	3
<i>Xanthophyceae</i>	15	2
<i>Chrysophyceae</i>	6	1
<i>Cryptophyceae</i>	5	1
<i>Synurophyceae</i>	5	1
II- Chlorophyta		
<i>Chorophyceae</i>	126	16
<i>Conjugatophyceae</i>	95	12
<i>Trebouxiophyceae</i>	21	3
<i>Ulvophyceae</i>	8	1
<i>Nephrophyceae</i>	1	-
<i>Raphidophyceae</i>	1	-
III- Cyanophyta		
<i>Cyanophyceae</i>	132	17
IV- Euglenophyta		
<i>Euglenophyceae</i>	91	11
V- Rhodophyta		
<i>Florideophyceae</i>	3	-
<i>Rhodophyceae</i>	1	-
<i>Stylonematophyceae</i>	1	-

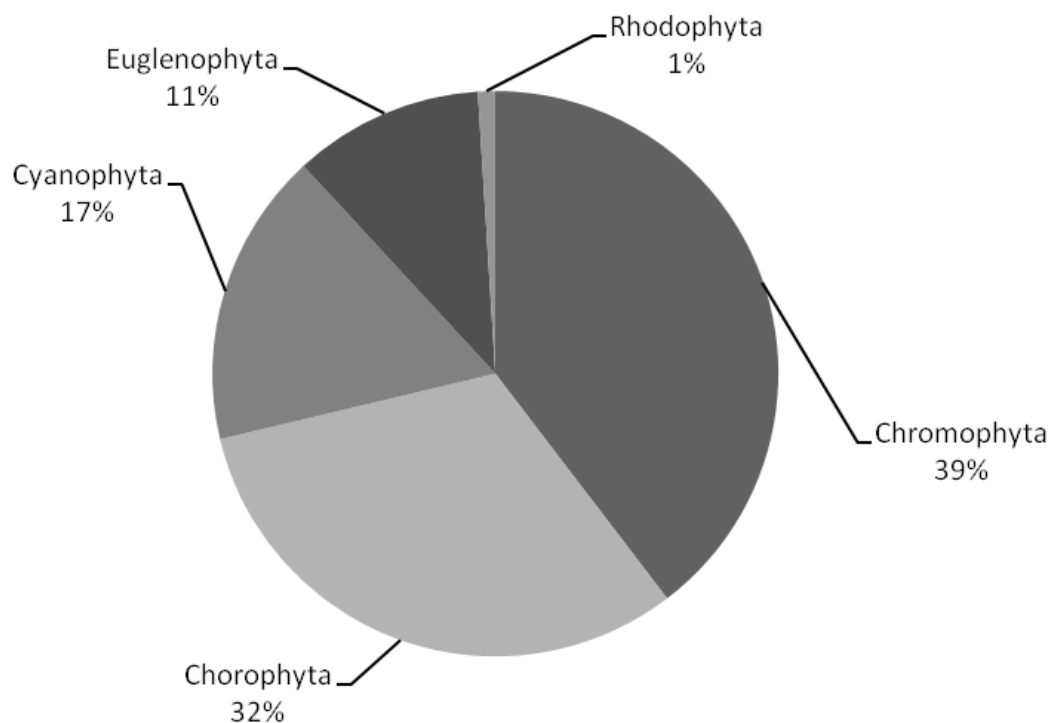
**Figure 2.** Distribution of the microalgae Division in Togo.

Table 4. Macroalgae collected in Togo.

Groups	Orders	Families	Species
Chlorophyta	Ulvales	Ulvaceae	<i>Ulva lactuca</i> L.
			<i>Ulva compressa</i> L.
			<i>Ulva rigida</i> C. Agardh
	Bryopsidales	Codiaceae	<i>Codium</i> sp.
		Caulerpaceae	<i>Caulerpa</i> sp.
		Bryopsidaceae	<i>Bryopsis plumosa</i> C. Agardh
Cladophorales	Cladophoraceae	<i>Chaetomorpha aerea</i> (Dillwiyn) Kützing	
		<i>Chaetomorpha implexa</i> Feldmann	
		<i>Cladophora laetevirens</i> (Dillwiyn) Kützing	
Phaeophyta	Laminariales	Laminariaceae	<i>Laminaria</i> sp.
	Fucales	Fucaceae	<i>Fucus ceranoides</i> L.
			<i>Fucus spiralis</i> L.
		Sargassaceae	<i>Sargassum muticum</i> (Yendo) Fensholt <i>Sargassum</i> sp.
	Dictyotales	Dictyotaceae	<i>Padina pavonica</i> (L.) Thivy <i>Dictyota dichotoma</i> (Hudson) J.V. Lamouroux
	Ectocarpales	Scytosiphonaceae	<i>Colpomenia peregrina</i> Sauvageau
Rhodophyta	Gigartinales	Cytocloniaceae	<i>Hypnea musciformis</i> (Wulfen) J.V. Lamouroux
		Petrocelidaceae	<i>Mastocarpus stellatus</i> (Estackhouse) Guiry
		Phylloporaceae	<i>Phyllophora</i> sp.
	Gracilariales	Gracilariaceae	<i>Gracilaria</i> sp.
	Bangiales	Bangiaceae	<i>Porphyra</i> sp.
	Rhodymeniales	Lomentariaceae	<i>Lomentaria clavellosa</i> (Lightfoot ex Turner) Gaillon
		Champiaceae	<i>Champia parvula</i> (C. Agardh) Harvey
	Palmariales	Palmariaceae	<i>Palmaria palmata</i> (L.) Weber & Mohr
Ceramiales	Rhodomelaceae	<i>Laurencia obtusa</i> (Hudson) J.V. Lamouroux	
Corallinales	Corallinaceae	<i>Lithophyllum byssoides</i> (Lamarck) Foslie	

compta Kütz., *Fragilaria ulna* Kitton, *Cymbella* spp. (mostly Diatomophyceae), the Chlorophyta such as *Hyaloraphidium contortium* Pasch. y Korch., *Crucigenia tetrapedia* Kirch., *Scenedesmus quadricauta* Bréb, *Closterium closterioides* (Ralfs) Louis et Peeters, *Cosmarium quadrum* Lundell, etc., and the Cyanophyta such as *Oscillatoria platensis* Nordst., *O. margaritifera* Kützing ex Gomont, *O. limosa* Gom., *Isocystis planctonica* Starmach, *Microcystis aeruginosa* (Kützing) Kützing, *Synechococcus aquatilis* Sauv., are the dominant groups. The current study shows that considering the whole territory, it is still the same groups of Chromophyta (39%), of Chlorophyta (32%) and of Cyanophyta (17%) that dominate, confirming therefore the observations of these authors. Only these three groups represent 88% of the algae in Togo. The same observations are made by Iltis (1980) that confirm that the tropical algae flora is made up of a high proportion of representatives from the three groups.

With regard to the Togolese marine macroalgae, the

only serious existing reference nowadays is Bandje (2004) that had identified 14 species of macroalgae of which 9 species fixed to the beach-rocks of the Togolese coast. This marine flora is far from reflecting the reality, making always unknown the marine flora of Togo. The current algae flora and the one indicated by Bandjé (2004) are far from the results of the first inventory of Colocoloff (1980). This author reported the presence of 170 species distributed in 37 families. The most represented genera are *Gracilaria* (12 species), *Ceramium* (8 species), *Gelidiopsis* (7 species), *Hypnea* (7 species), *Laurencia* (7 species), *Caulerpa* (4 species), *Chaetomorpha* (4 species), *Cladophora* (4 species), *Codium* (5 species), *Gracilariopsis* (4 species). These results from Colocoloff (1980) show that the Togolese marine environment is characterized by a diversified algae flora and that the studies are only at their beginning. The *Sargassum* genus is very abundant on the whole Togolese coast. Moreover, the analysis of the Togolese algae flora also shows that the Chromophyta occupy a great proportion



Ulva lactuca L.
(Chlorophyta)



Codium sp
(Chlorophyta)



Fucus spiralis L.
(Phaeophyta)



Sargassum muticum
(Yendo) Fensholt
(Phaeophyta)



Hypnea musciformis
(Wulfen) J.V. Lamouroux
(Rhodophyta)



Chaetomorpha aerea
(Dillwyn) Kützing
(Chlorophyta)



Cladophora laetevirens
(Dillwyn) Kützing
(Chlorophyta)



Porphyra sp
(Rhodophyta)



Padina pavonica (L.)
Thivy
(Phaeophyta)

Photo 3. Some specimen of macroalgae of Togo.

(39%) on the whole algae flora in Togo. This situation is not a particularity for Togo. Many other studies showed in different aquatic ecosystems that it is the Chromophyta (generally the Diatomeae) that dominate the algae flora (Cetto et al., 2004; Felisberto and Rodrigues, 2005; Fonseca et al., 2008). These authors explain this dominance by the fact that the Diatomophyceae occupy a great number of species and is also higher in density; which make them great competitors of nutrients in the aquatic habitats (Vermaat, 2005). Then the Diatomophyceae are equipped with morphological

structures that make them efficient in terms of space conquest in aquatic environment (Feng et al., 2011). From all the evidence, the algae flora of Togo is very rich and diversified but has been partially studied. Compared to Niger, the algae flora identified has 547 species dominated by the Cyanophyceae, the Diatomophyceae and the Eulichlorophyceae (Saadou, 1998). In Senegal, the inventory of the algae has started just as in Togo, indicating 133 genera and about 83 species (Compère, 1991). This author remarked that the freshwater and brackish algae are more numerous as well as the

microscopic algae must have had a special attention to complete the inventory. In many other countries in the sub-region, research works are conducted on the phytoplankton but the contrast remains the same; they are generally fragmented to have sufficient information among others on the biogeographical distribution over a continent. Globally it is demonstrated that the microalgae are cosmopolite with more than 60% met in diverse regions of the world while the species typically tropical represent about 40% (Iltis, 1980; Zongo et al., 2008).

It should also be mentioned that in the processing of the algae flora of Togo, some cases of potentially toxic algae were mentioned (Edorh et al., 2008; Bandje, 2010; Issifou, 2012). It is about *Anabaena* spp., *Merismopedia* spp., *Microcystis aeruginosa* (Kützing) Kützing, *Nitzschia bilobata* W.Smith, and *Oscillatoria rubescens* De Cand. These ones must be subject to a particular attention in the future works to analyse the level of nuisance for many of the rural populations depending on surface waters which are the privilege habitats of these algae.

Conclusion

It results from this study that in Togo, the knowledge about the biodiversity of the algae from the aquatic environments in Togo is advancing. In all 795 species of microalga belong to 82 genera, 134 families and 5 branches are the most dominant in Togo. Moreover, 37 taxa of macroalgae belonging to 3 Divisions notably the Chlorophyta, Pheophyta and Rhodophyta have been collected up to now. This first stage is necessary to further assume the studies on the distribution, the valorization of the phytoplankton biomass and the search for solution vis-à-vis the nuisance of the toxic species present in the surface waters used by the rural populations. The future research works must therefore be oriented towards this purpose.

Conflict of Interest

The authors have not declared any conflict of interest.

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ANNEXES

Checklist of Togolese Microalgae.

Division/Group	Family	Species
I-Chlorophyta		
1.1- Chlorophyceae	1.1.1- Chaetopeltidaceae	<i>Chaetopeltis orbicularis</i> Berthold <i>Leptosiropsis torulosa</i> C.-C.Jao <i>Stigeoclonium tenue</i> (C.Agardh) Kützing <i>Uronema elongatum</i> Hodgetts
	1.1.2- Characiaceae	<i>Actidesmium hookeri</i> Renisch <i>Korshikoviella schaefernai</i> (Fott) P.C.Silva
	1.1.3- Chlamydomonadaceae	<i>Carteria micronucleolata</i> Korshikov <i>Carteria multifilis</i> (Fresenius) O. Dill <i>Carteria simplex</i> Pascher. <i>Carteria</i> sp. <i>Chlamydomonas caudata</i> Wille. <i>Chlamydomonas coccifera</i> Gorosch. <i>Chlamydomonas globosa</i> J.W.Snow <i>Chlamydomonas muriella</i> Lund <i>Chlamydomonas pertusa</i> Chodat <i>Chlamydomonas</i> sp. <i>Sphaerella</i> sp. <i>Tussetia</i> sp.
	1.1.4- Chlorangiopsidaceae	<i>Gloeochloris minor</i> Korch.
	1.1.5- Chlorococcaceae	<i>Crucigeniella crucifera</i> Näg. <i>Nautococcus piriformis</i> Korshikov <i>Schroederia indica</i> Philipose. <i>Schroederia seligera</i> (Schroed.) Lemm. <i>Spongiochloris spongiosa</i> (Vischer) R.C.Starr
	1.1.6- Dictyosphaeriaceae	<i>Dictyosphaerium pulchellum</i> Wood <i>Quadriococcus ellipticus</i> Loc. Sauv. <i>Westella botryoides</i> (West) De Wildeman
	1.1.7- Dunaliellaceae	<i>Dunaliella</i> sp.
	1.1.8- Haematococcaceae	<i>Chlorogonium elongatum</i> (P.A.Dangeard) Francé <i>Chlorogonium fusiforme</i> Matvienko <i>Chlorogonium</i> sp.
	1.1.9- Hydrodictyceae	<i>Monoraphidium braunii</i> (Nägeli) Komárková-Legnerová <i>Monoraphidium contortum</i> (Thuret in Bréb.) Kom-Legnerová <i>Monoraphidium griffithii</i> (Brek.) Kom <i>Pediastrum aciculare</i> T. West <i>Pediastrum angilosum</i> Racib. <i>Pediastrum duplex</i> Meyen <i>Pediastrum</i> sp <i>Pediastrum tetras</i> (Ehrenberg) Ralfs <i>Tetraedron tumidulum</i> (Reinsch) Hansgirg <i>Tetraedron muticum</i> (A.Braun) Hansgirg <i>Tetraedron</i> sp. <i>Tetraedron triangulare</i> Korshikov <i>Tetraedron tumidulum</i> Hansg. <i>Tetraspora gelatinosa</i> (Vaucher) Desvaux
	1.1.10- Micractniaceae	<i>Micractinum pusillum</i> Fresenius <i>Phytelios viridis</i> Frenzel

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1.1.11- Neochloridaceae	<i>Golenkinia radiata</i> Choda
1.1.12- Oedogoniaceae	<i>Oedogonium globosum</i> Nordstedt ex Hirn
1.1.13- Palmellopsidaceae	<i>Asterococcus superbus</i> (Cienk.) Scherffel
1.1.14- Protosiphonaceae	<i>Protosiphon botryoides</i> (Kützing) Klebs
1.1.15- Radiococcaceae	<i>Coenochloris ovalis</i> Korshikov <i>Coenochloris</i> sp. <i>Thorakochloris planctonica</i> Fott.
1.1.16- Rhopalosolenaceae	<i>Kentrosphaera facciolae</i> Borzi <i>Pseudochlorothecium</i> sp.
1.1.17- Scenedesmaceae	<i>Actinastrum aciculare</i> Playf. <i>Actinastrum hantzschii</i> Lagerh. <i>Actinastrum</i> sp. <i>Ankistrodesmus bibraianus</i> (Reinsch) Koršikov <i>Ankistrodesmus fusiformis</i> Corda <i>Ankistrodesmus gracilis</i> (Reinsch) Korshikov <i>Ankistrodesmus</i> sp. <i>Ankistrodesmus spiralis</i> (W.B.Turner) <i>Ankistrodesmus viridis</i> (J.Snow) Bourrelly <i>Coelastrum cambricum</i> Arch. <i>Coelastrum pseudomicroporum</i> Korsch. <i>Coelastrum reticulatum</i> (P.A.Dangeard) Senn <i>Crucigenia crucifera</i> (Wolle) Collins <i>Crucigenia fenestrata</i> (Schmidle) Schmidle <i>Crucigenia quadrata</i> Morren <i>Crucigenia rectangularis</i> Näg. <i>Crucigenia</i> sp. <i>Crucigenia tetrapedia</i> Kirch. <i>Dimorphococcus lunatus</i> A.Braun <i>Golenkinia</i> sp. <i>Palmella</i> sp. <i>Scenedesmus abundans</i> (O.Kirchner) Chodat <i>Scenedesmus acuminatus</i> (Lagerheim) Chodat <i>Scenedesmus acutus</i> Meyen <i>Scenedesmus armatus</i> (R.Chodat) R.Chodat <i>Scenedesmus bicaudatus</i> Dedusenko <i>Scenedesmus carinatus</i> (Lemmermann) E.H.Hegewald. <i>Scenedesmus circumfusus</i> Hortobágyi <i>Scenedesmus crassus</i> Chodat <i>Scenedesmus denticulatus</i> Lagerheim <i>Scenedesmus dimorphus</i> Kütz. <i>Scenedesmus disciformis</i> Chod. <i>Scenedesmus dispar</i> Brébisson <i>Scenedesmus ecornis</i> Meyen f. <i>Scenedesmus flexuosus</i> (Lemmermann) Ahlstrom. <i>Scenedesmus grahneisii</i> (Heynig) Fott <i>Scenedesmus granulatus</i> West. <i>Scenedesmus gutwinski</i> Chodat (P. Bourrelly <i>Scenedesmus incrassatus</i> Bohlin. <i>Scenedesmus intermedius</i> Chodat <i>Scenedesmus nygaardii</i> Huber <i>Scenedesmus obliquus</i> Kütz. <i>Scenedesmus obtusus</i> Meyen

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	<i>Scenedesmus opoliensis</i> P.G. Richt.
	<i>Scenedesmus protuberans</i> F.E.Fritsch & M.F.Rich
	<i>Scenedesmus quadricauta</i> Bréb.
	<i>Scenedesmus smithii</i> Teiling. In: Guiry, M.D. & Guiry, G.M
	<i>Scenedesmus</i> sp.
	<i>Scenedesmus tenuispina</i> Chodat
	<i>Scenedesmus wisconsinensis</i> G.M.Smith
	<i>Tetrastrum heterocanthum</i> (Nordstedt) Chodat.
	<i>Tetrastrum staurogeniaeforme</i> Lemm.
	<i>Treubaria</i> sp
1.1.18- Schizomeridaceae	<i>Schizomeris leibleinii</i> Kützing
1.1.19- Selenastraceae	<i>Hyaloraphidium contortium</i> Pasch. y Korch.
	<i>Hyaloraphidium</i> sp.
	<i>Kirchneriella contorta</i> (Schmidle) Bohlin
	<i>Kirchneriella obesa</i> (West) West & G.S.West
	<i>Monoraphidium arcuatum</i> (Korshikov) Hindák
	<i>Monoraphidium convolutum</i> (Corda) Komárková-Legnerová
	<i>Monoraphidium griffithii</i> Legn.
	<i>Monoraphidium minutum</i> (Nägeli)Komárková-Legnerová
	<i>Monoraphidium</i> sp.
	<i>Selenastrum bibraianum</i> Reinsch
1.1.20- Sphaerocystidaceae	<i>Sphaerocystis schroeteri</i> Chodat
1.1.21- Treubariaceae	<i>Treubaria triappendiculata</i> C.Bernard
1.1.22- Volvocaceae	<i>Gonium</i> sp.
	<i>Volvox aureus</i> Ehrenberg
	<i>Volvox glabator</i> (Linné) Ehr.
	<i>Volvox</i> sp
1.2- Conjugatophyceae	1.2.1- Desmidiaceae
	<i>Actinotaenium cucurbita</i> (Bréb.) Teiling
	<i>Closterium aciculare</i> T.West
	<i>Closterium acutum</i> Bréb. ex Ralfs
	<i>Closterium closterioides</i> (Ralfs) Louis et Peeters
	<i>Closterium cynthia</i> De Notaris
	<i>Closterium diana</i> Ehrbg.
	<i>Closterium ehrenbergii</i> Menegh. ex Ralfs
	<i>Closterium gracile</i> Brebisson
	<i>Closterium intermedium</i> Ralfs
	<i>Closterium kuetzingii</i> Bréb.
	<i>Closterium lanceolatum</i> (Kützing.) in Ralfs
	<i>Closterium leibleinii</i> Kützing
	<i>Closterium lineatum</i> Ehrenberg ex Ralfs
	<i>Closterium longissimum</i> L.Viret.
	<i>Closterium lunula</i> (Müller) Nitzsch. ex Ralfs
	<i>Closterium macilentum</i> Bréb.
	<i>Closterium monileferum</i> (Bory) Ehrenberg ex Ralfs
	<i>Closterium navicula</i> (Bréb.) Lütkemüller
	<i>Closterium parvulum</i> Näg.
	<i>Closterium pseudolunula</i> Borge
	<i>Closterium</i> sp.
	<i>Closterium strigosum</i> Bréb.
	<i>Closterium subulatum</i> (Kützing) Brebisson
	<i>Closterium tumidulum</i> Johnson
	<i>Closterium venus</i> Kützing ex Ralfs

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Coelastrum microporum Näg.
Coelastrum proboscideum Bohlin in Wittrock, Nordstedt & Lagerheim
Coelastrum pulchrum Näg.
Coelastrum sp.
Cosmarium anomalum Delponte
Cosmarium binum Nordstedt
Cosmarium botrylis Menegh.
Cosmarium candianum Delponte
Cosmarium circulare Reinsch
Cosmarium contractum Kirchner
Cosmarium cornutum Corda
Cosmarium decoratum West et West
Cosmarium demersum Noda & Skvortzov
Cosmarium depressum (Nägeli) P.Lundell
Cosmarium dimaziforme (Grönbl.) Sc.+ Grönbl. v. concavum F.
Cosmarium laeve Rabenhorst
Cosmarium lundellii Delp.
Cosmarium pachidermum Luud. El Pardo
Cosmarium pseudoconnatum Nordstedt
Cosmarium quadratum Ralfs
Cosmarium quadrum Lundell
Cosmarium rectangulare var. *hexagonum* (Elfving) West & G.S.West.
Cosmarium redimitum Borge.
Cosmarium sp.
Cosmarium subauriculatum West & G.S.West
Cosmarium trilobulatum Reinsch
Cosmarium vexatum West.
Cosmarium zonatum Lundell
Desmidium swartzii Agardh
Docidium hexagonum (Börger.) Krieger.
Euastrum ansatum Ehrenberg ex Ralfs
Euastrum denticulatum (Kirchner) Gay
Euastrum sp.
Euastrum spinulosum Delponte
Micrasterias radians W.B.Turner
Micrasterias sp.
Micrasterias thomasiana Arch.
Micrasterias truncata Brébisson ex Ralfs
Pleurotaenium ehrenbergii (Ralfs) Delponte
Pleurotaenium eugeneum (W.B.Turner) West & G.S.West
Pleurotaenium sp
Pleurotaenium spinulosum Brunel
Staurastrum apiculatum Brébisson
Staurastrum dickei var. *rhomboideum* f. *depressa* T.J.C.Irénée-Marie
Staurastrum eckertii K.Förster.
Staurastrum orbiculare Meneghini ex Ralfs
Staurastrum sebaldi Reinsch
Staurastrum selenaeum R.L.Grönblad.

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		<i>Staurastrum sexangulare</i> (Bulnheim) P.Lundell
		<i>Staurastrum</i> sp.
		<i>Staurastrum subunguiferum</i> F.E.Fritsch & M.F.Rich.
		<i>Staurastrum teliferum</i> Ralfs
		<i>Staurastrum volans</i> West & G.S.West
		<i>Staurastrum wildemanii</i> Gutwinski
		<i>Staurodesmus dickiei</i> S. Lillieroth
		<i>Streptonema</i> sp.
	1.2.2- Gonatozygaceae	<i>Genicularia spirotaenium</i> Ramb.
		<i>Gonatozygon monotaenium</i> De Bary
	1.2.3- Mesotaeniaceae	<i>Mesotaenium macrococcum</i> (Kützing ex Kützing) J.Roy & Bisset
		<i>Netrium digitatus</i> (Ehr.) Itzigsohn & Rothe
		<i>Spirotaenia condensata</i> Brebisson in Ralfs
		<i>Spirotaenia minuta</i> Thuret in Brébisson
		<i>Spirotaenia</i> sp.
	1.2.4- Peniaceae	<i>Penium cylindrus</i> (Ehr.) Brébisson ex Ralfs
		<i>Penium magaritaceum</i> (Ehr.) Brébisson ex Ralfs
		<i>Penium</i> sp.
	1.2.5- Zygnematacea	<i>Mougeotia floridana</i> Transeau
		<i>Mougeotia scalaris</i> Hassall
		<i>Mougeotia</i> sp.
		<i>Spirogyra</i> sp.
1.3- Nephrophyceae	1.3.1- Nephroselmidaceae	<i>Myochloris</i> sp.
1.4- Trebouxiophyceae	1.4.1- Botryococcaceae	<i>Botryococcus braunii</i> Kützing
	1.4.2- Chlorellaceae	<i>Chlorella</i> sp.
		<i>Chloridella</i> sp.
		<i>Closteriopsis acicularis</i> (Chodat) J.H.Belcher & Swale
		<i>Closteriopsis longissimum</i> Smith
		<i>Muriella terrestris</i> J.B.Petersen
	1.4.3- Oocystaceae	<i>Chodatella echidna</i> (Bohlin) Chod.
		<i>Eremosphaera gigas</i> (W.Archer) Fott & Kalina
		<i>Gloxiidium rotatoriae</i> Korshikov.
		<i>Lagerheimia ciliata</i> (Lagerheim) Chodat
		<i>Netrium digitus</i> Itzigson et Rothe
		<i>Oocystaenium</i> sp.
		<i>Oocystis borgei</i> J.W.Snow
		<i>Oocystis elliptica</i> West
		<i>Oocystis lacustris</i> Chodat
		<i>Oocystis</i> sp.
		<i>Planctonema</i> sp.
		<i>Saturnella corticola</i> Skuja) Fott
	1.4.4- Prasiolaceae	<i>Stichococcus bacillaris</i> Nägeli
	1.4.5- Trebouxiaceae	<i>Dictyochloropsis</i> sp.
		<i>Raphidonema nivale</i> Lagerheim
1.5- Ulvophyceae	1.5.1- Cladophoraceae	<i>Cladophora crystallina</i> (Roth) Kützing
		<i>Cladophora</i> sp.
		<i>Cloniophora</i> sp.
	1.5.2- Gloeotilaceae	<i>Binuclearia eriensis</i> Tiffany.
		<i>Ulothrix</i> sp.
		<i>Ulothrix zonata</i> (Weber & Mohr) Kützing
	1.5.3- Ulvaceae	<i>Enteromorpha intatinalis</i> (Linnaeus) Nees

Annexes Contd.

II- Chromophyta**2.1- Bacillariophyceae****2.1.1- Achnantheaceae***Ulva* sp.*Achnanthes brevipes* Bréb.*Achnanthes childanos* Hohn & Hellerman*Achnanthes flexella* (Kützing) Brun*Achnanthes inflata* (Kützing) Grunow*Achnanthes lanceolata* (Brébisson ex Kützing) Grunow*Achnanthes* sp**2.1.2- Amphipleuraceae***Amphipleura lindheimeri* Grunow*Amphipleura pellucida* (Ehr.) Kütz.*Amphiprora alata* (Ehr.) Kütz.*Amphiprora paludosa* W.Smith*Frustulia rhomboides* (Ehrenberg) De Toni**2.1.3- Bacillariaceae***Bacillaria paxillifer* (O.F.Müller) T.Marsson*Cylindrotheca gracile* (Brébisson) Grunow*Denticula pelagica* Hustedt.*Denticula* sp.*Denticula thermalis* Kützing*Gomphonitzchia ungeri* Grunow*Hantzschia amphioxys* (Ehrenberg) Grunow in Cleve & Grunow*Hantzschia elongata* (Hantzsch) Grunow*Hantzschia* sp.*Nitzschia acicularis* Smith*Nitzschia acuminata* (W. Smith) Grunow*Nitzschia amphibia* Grunow*Nitzschia bilobata* W.Smith*Nitzschia dissipata* (Kützing) Grunow*Nitzschia dubia* W.Smith*Nitzschiaepithemiodes* Grunow in. Cleve*Nitzschia hungarica* Grunow*Nitzschia ignorata* Krasske*Nitzschia levidensis* (W. Sm.) Grunow*Nitzschia linearis* Hantzsch.*Nitzschia longissima* (Brébisson) Ralfs*Nitzschia navicularis* (Brébisson) Grunow*Nitzschia palea* Kütz.*Nitzschia recta* Hantzsch ex Rabenhorst*Nitzschia reversa* Smith*Nitzschia scalaris* Ehrbg.*Nitzschia sigma* Kütz.*Nitzschia sinuata* (W. Sm.) Grun.*Nitzschia* sp.*Nitzschia tryblionella* Hantzsch*Nitzschia vermicularis* (Kützing) Ralfs*Pleurosigma angulatum* (Queckett) W.Smith*Pseudo-nitzschia pungens* (Grunow ex Cleve) G.R.Hasle**2.1.4- Catenulaceae***Amphora commutata* Grunow*Amphora copulata* (Kützing) Schoeman & R.E.M.Archibald*Amphora lineolata* Ehrenberg*Amphora ovalis* (Kützing) Kützing*Amphora* sp.

Annexes Contd.

2.1.5- Chaetoceraceae	<i>Wollea saccata</i> Wolle
2.1.6- Chroomonadaceae	<i>Chroomonas</i> sp <i>Chroomonas minuta</i> Skuja. <i>Chroomonas rubra</i> (Geitler)
2.1.7- Cocconeidaceae	<i>Cocconeis placentula</i> (Ehr.) Grun.
2.1.8- Cymbellaceae	<i>Cymbella caespitosa</i> (Kützing) Brun <i>Cymbella cystula</i> (Ehrenberg) O.Kirchner <i>Cymbella cuspidata</i> Kützing. <i>Cymbella lacustris</i> (C.Agardh) Cleve <i>Cymbella prostata</i> (Berkeley)Cleve <i>Cymbella</i> sp. <i>Cymbella turgidula</i> Grun. <i>Cymbella ventricosa</i> Cleve
2.1.9- Diploneidaceae	<i>Diploneis didyma</i> (Ehrenberg) Ehrenberg <i>Diploneis elliptica</i> Cleve <i>Diploneis interrupta</i> Kütz. <i>Diploneis marginestriata</i> Cleve <i>Diploneis mauleri</i> (Brun) Cleve <i>Diploneis oculata</i> (Brébisson) Cleve <i>Diploneis ovalis</i> Cleve <i>Diploneis smithii</i> (Brébisson) Cleve <i>Diploneis interrupta</i> (Kützing) Cleve
2.1.10- Eunotiaceae	<i>Eunotia faba</i> Ehrbg. <i>Eunotia guyanense</i> (Ehr.) de Toni. <i>Eunotia incisa</i> W.Smith ex W.Gregory <i>Eunotia monodon</i> Ehrenberg <i>Eunotia parallela</i> Ehrbg. <i>Eunotia pectinalis</i> (Kützing) Rabenhorst <i>Eunotia robusta</i> Ralfs <i>Eunotia serpentina</i> Ehrenberg <i>Eunotia</i> sp. <i>Schizothrix fuscescens</i> Kützing ex Gomont <i>Schizothrix lacustris</i> A.Braun ex Gomont <i>Actinella</i> sp. <i>Actinella brasiliensis</i> Grunow. <i>Actinella mirabilis</i> Grunow
2.1.11- Gomphonemataceae	<i>Gomphoneis herculaneum</i> Ehrbg. <i>Gomphoneis intricatum</i> Kützing <i>Gomphonema acuminatum</i> Ehrenberg <i>Gomphonema angur</i> Ehr. <i>Gomphonema angustatum</i> Grun. <i>Gomphonema constrictum</i> Ehrbg. <i>Gomphonema gracile</i> Ehrenberg <i>Gomphonema intricatum</i> Kützing <i>Gomphonema olivaceum</i> (Hornemann) Brébisso <i>Gomphonema olivatum</i> Kütz. <i>Gomphonema</i> sp.
2.1.12- Mastagloioaceae	<i>Mastagloia pumilla</i> (Cleve & Möller) Cleve. <i>Mastagloia grevillei</i> (Hassall) Elenkin. <i>Mastagloia</i> sp. <i>Mastagloia smithii</i> Grun.
2.1.13- Naviculaceae	<i>Anemoeoneis sphaerophora</i> (Kutz.) Pfitz.

Annexes Contd.

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- Aphanizomenon gracile* Lemm.
Caloneis amphisbaena (Bory de Saint Vincent) Cleve
Caloneis obtusa (W.Smith) Cleve
Caloneis permagma (Bailey) Cleve
Caloneis schumanniana (Grunow) Cleve
Caloneis sp.
Caloneis silicula (Ehrenberg) Cleve
Campylodiscus noricus Ehrbg
Navicula reinhardtii (Grunow) Grunow
Navicula americana Ehrbg.
Navicula amphibia f.
Navicula annulata Grun.
Navicula brevicostata (Cleve) Fricke
Navicula cocconeiformis Gregory ex Greville
Navicula confervacea (Kützing) Grunow
Navicula crucicula Lagerst
Navicula cryptocephala Kütz.
Navicula cuspidata Kütz.
Navicula dissipata Hustedt
Navicula elegans Smith
Navicula gallica (W. Smith) Van Heurck.
Navicula gastrum Ehrbg.
Navicula gibbula Cleve
Navicula integra Smith
Navicula lanceolata Ehrenberg
Navicula oblonga Kütz.
Navicula ovalis Smith
Navicula perigrina (Ehrenberg) Kützing
Navicula placenta Ehrbg.
Navicula placentula (Ehrenberg) Kützing
Navicula punctatae(Kützing) Donkin
Navicula pupula Kütz.
Navicula renhardtii Hérib.
Navicula rotunda Hustedt
Navicula seminulum Cleve
Navicula sp.
Navicula subtilissima Grunow
Navicula trivalis Lange-Bertalot. P. Benthic
Navicula tuscula (Ehrenberg) D.G.Mann & A.J.Stickle
Navicula viridula (Kützing) Ehrenberg
Raphidiopsis curvata Fristch.
Navicula cryptocephala Kütz.
Anemoeoneis serians Bréb.
2.1.14- Neidiaceae
Neidium affine Ehrbg.
Neidium productum (W.Smith) Cleve
Neidium sp.
2.1.15- Pinnulariaceae
Pinnularia acroesphaeria Raben.
Pinnularia borealis Ehrenberg
Pinnularia brebissonii (Kützing) Rabenhorst
Pinnularia breviscostata Cleve
Pinnularia cardinalis (Ehrenberg) W.Smith
Pinnularia divergentissima (Grunow) Cleve
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Annexes Contd.

	<i>Pinnularia gibba</i> Ehrenberg
	<i>Pinnularia lata</i> (Brébisson) W.Smith
	<i>Pinnularia legumen</i> Ehrenberg
	<i>Pinnularia major</i> Ehrbg.
	<i>Pinnularia mesolepta</i> (Ehrenberg) W.Smith
	<i>Pinnularia neomajor</i> K.Krammer
	<i>Pinnularia platycephala</i> (Ehrenberg) Cleve
	<i>Pinnularia</i> sp.
	<i>Pinnularia undulata</i> W.Gregory.
	<i>Pinnularia viridis</i> (Nita) Ehr.
	<i>Diatomella hustedtii</i> E. E. Maguin
2.1.16- Pleuromastigaceae	<i>Gyrosigma acuminatum</i> Kütz.
	<i>Gyrosigma angulatum</i> Quekett) Griffith & Henfrey
	<i>Gyrosigma attenuatum</i> (Kützing) Cleve
	<i>Gyrosigma diminutum</i> (W.Smith) Cleve.
	<i>Gyrosigma hippocampus</i> (Ehrenberg) Hassall
	<i>Gyrosigma</i> sp.
	<i>Pleuromastix bacillifera</i> A.Scherffel
	<i>Xanthodiscus lauterbachii</i> Schewk.
2.1.17- Rhizosoleniaceae	<i>Rhizosolenia calcar-avis</i> M.Schultze
	<i>Rhizosolenia obtusa</i> Hensen
	<i>Rhizosolenia</i> sp.
2.1.18- Rhoicospheniaceae	<i>Rhoicosphenia curvata</i> (Kützing) Grunow
2.1.19- Rhopalodiaceae	<i>Epithemia argus</i> (Ehrenberg) Kützing
	<i>Epithemia hyndmanni</i> W. Smith
	<i>Epithemia</i> sp.
	<i>Epithemia turgida</i> Ehrbg.
	<i>Rhopalodia gibberula</i> (Ehrenberg) Otto Müller
	<i>Rhopalodia gibba</i> (Ehrenberg) Otto Müller
2.1.20- Stauroneidaceae	<i>Stauroneis acuta</i> W.Smith
	<i>Stauroneis anceps</i> Ehrbg.
	<i>Stauroneis brasiliensis</i> (C.Zimmermann) P.Compère
	<i>Stauroneis crucicula</i> Grun.
	<i>Stauroneis phoenicenteron</i> (Nitzsch) Ehrenberg
	<i>Stauroneis</i> sp.
2.1.21- Stephanodiscaceae	<i>Cyclotella bodanica</i> Eulenstein ex Grunow
	<i>Cyclotella comta</i> Kütz.
	<i>Cyclotella distinguenda</i> Hustedt
	<i>Cyclotella ocellata</i> Pantocsek
	<i>Cyclotella</i> sp.
	<i>Cyclotella stelligera</i> Cleve & Grunow
	<i>Cyclotella styriaca</i> Kütz.
	<i>Stephanodiscus parvus</i> Stoermer & Håkansson
	<i>Stephanodiscus astrae</i> (Ehrenberg) Grunow
2.1.22- Surirellaceae	<i>Surirella angustata</i> Kützing
	<i>Surirella biseriata</i> Brébisson in Brébisson & Godey
	<i>Surirella capronii</i> Bréb.
	<i>Surirella verrucosa</i> Pantocsek
	<i>Surirella robusta</i> Ehr.
	<i>Cymatopleura solea</i> (Brébisson & Godey) W. Smith
	<i>Stenopterobia intermedia</i> F.W.Lewis
2.2- Chrysophyceae	<i>Dinobryon</i> sp.

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		<i>Eusphaerella turfosa</i> Skuja
	2.2.2- Chrysosaccaceae	<i>Chrysosaccus</i> sp.
	2.2.3- Chrysosphaeraceae	<i>Chrysosphaera</i> sp.
	2.2.4- Dinobryaceae	<i>Dinobryon</i> sp.
	2.2.5- Hydruraceae	<i>Hydrurus foetidus</i> (Villars) Trevisan
2.3- Coscinodiscophyceae	2.3.1- Attheyaceae	<i>Attheya zachariasii</i> J. Brun
	2.3.2- Aulacoseiraceae	<i>Aulacoseira granulata</i> (Ehrenberg) Simonsen <i>Aulacoseira</i> sp.
	2.3.3. Biddulphiaceae	<i>Hydrosera</i> sp. <i>Biddulphia laevis</i> Ehrbg.
	2.3.4- Chaetocerotaceae	<i>Chaetoceros borealis</i> J.W. Bailey <i>Chaetoceros constrictus</i> Gran <i>Chaetoceros socialis</i> H.S.Lauder <i>Chaetoceros</i> sp.
	2.3.5- Coscinodiscaceae	<i>Coscinodiscus argus</i> Ehrenberg <i>Coscinodiscus lacustris</i> Grun. <i>Coscinodiscus</i> sp. <i>Coscinodiscus wailesii</i> Gran & Angst <i>Merismopedia tenuissima</i> Lemm. <i>Nodularia harveyana</i> Thuret. <i>Terpesinoe musica</i> Ehrbg.
	2.3.6- Hemiaulaceae	<i>Eucampia zodiacus</i> Ehrenberg <i>Cerataulina pelagica</i> (Cleve) Hendey <i>Actinocyclus octonarius</i> Ehrenberg
	2.3.7- Melosiraceae	<i>Melosira arenaria</i> Moore ex Ralfs <i>Melosira granulata</i> (Ehrenberg) Ralfs <i>Melosira italica</i> (Ehrenberg) Kützing <i>Melosira roeseana</i> Rabenhorst <i>Melosira</i> sp. <i>Melosira varians</i> Lemm.
	2.3.8- Paraliaceae	<i>Paralia sulcata</i> (Ehrenberg) Cleve
	2.3.9- Rhizosoniaceae	<i>Proboscia alata</i> (Brightwell) Sundström <i>Rhizoselenia fallax</i> Sundström
	2.3.10- Stephanodiscaceae	<i>Stephanodiscus</i> sp.
	2.3.11- Thalassiosiraceae	<i>Thalassiosira</i> sp.
2.4- Cryptophyceae	2.4.1- Cryptomonadaceae	<i>Cryptomonas ovata</i> Ehrenberg <i>Cryptomonas</i> sp. <i>Cryptomonas tetrapyrenoidosa</i> Skuja
	2.4.2- Tetragonidiaceae	<i>Tetragonidium</i> sp.
2.5- Dinophyceae	2.5.1- Ceratiaceae	<i>Ceratium cornutum</i> (Ehrenberg) Claparède & J.Lachmann <i>Ceratium</i> sp
	2.5.1- Desmomastigaceae	<i>Desmomastix globosa</i> Pascher
	2.5.2- Dinophysaceae	<i>Dinophysis sacculus</i> Stein <i>Dinophysis acuta</i> Ehrenberg <i>Gymnodinium catenatum</i> H.W.Graham <i>Gymnodinium</i> sp. <i>Diplopsalis acuta</i> (Apstein) Entz <i>Thompsodinium</i> sp
	2.5.3- Glenodiniaceae	<i>Glenodiniopsis steinii</i> (Lemmermann) Woloszynska <i>Peridiniopsis borgei</i> Lemmermann <i>Peridiniopsis dinobryonis</i> (Woloszynska) Bourrelly

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		<i>Peridiniopsis elpatiewsky</i> (Ostenfeld) Bourrelly
		<i>Peridiniopsis</i> sp.
	2.5.4- Goniodomataceae	<i>Pyrodinium</i> sp.
	2.5.5- Gymnodiniaceae	<i>Gyrodinium</i> sp.
		<i>Amphidinium</i> sp.
	2.5.6- Peridinaceae	<i>Peridinium globulum</i> (Stein) Balech
		<i>Peridinium</i> sp.
		<i>Peridinium thompsonii</i> (Thompson) Bourrelly
	2.5.7- Phytodiniaceae	<i>Spondilosium</i> sp.
		<i>Phytodinium</i> sp.
		<i>Hypnodinium sphaericum</i> Klebs
	2.5.8- Prorocentraceae	<i>Prorocentrum</i> sp.
		<i>Exuviaella compressa</i> (Bailey) Ostenfeld
		<i>Prorocentrum micans</i> Ehrenberg
	2.5.9- Thaumatomastigaceae	<i>Hyaloselene compressa</i> Skuja
2.6- Fragilariophyceae	2.6.1- Fragilariaceae	<i>Asterionella formosa</i> Hassall
		<i>Asterionella japonica</i> Cleve
		<i>Asterionella</i> sp.
		<i>Ceratoneis arcus</i> (Ehrenberg) Kützing
		<i>Diatoma hiemale</i> (Lyngb.) Heib.
		<i>Diatoma</i> sp.
		<i>Diatoma vulgare</i> f. breve (Grunow) Bukhtiyarova
		<i>Fragilaria capucina</i> Desmazières
		<i>Fragilaria crotonensis</i> Kitton
		<i>Fragilaria crotonensis</i> Kitton
		<i>Fragilaria oceanica</i> Cleve
		<i>Fragilaria pinnata</i> Kitton
		<i>Fragilaria</i> sp.
		<i>Fragilaria ulna</i> Kitton
		<i>Fragilaria virescens</i> Ralfs
		<i>Synedra gaillonii</i> (Bory de Saint-Vincent) Ehrenberg
		<i>Synedra pulchella</i> (Ralfs ex Kützing) Kützing
		<i>Synedra</i> sp.
		<i>Thalassionema nitzschioides</i> (Grunow) Mereschkowsky
	2.6.2- Striatellaceae	<i>Striatella</i> sp.
	2.6.7- Tabellariaceae	<i>Tabellaria</i> sp.
		<i>Tabellaria fenestrata</i> (Lyngbye) Kützing
		<i>Tetracyclus rupestris</i> (Braun) Grunow
2.7- Raphidophyceae	2.7.1- Vacuolariaceae	<i>Vacuolaria virescens</i> Cienkow.
2.8- Synurophyceae	2.8.1- Cloramoebaceae	<i>Chlorokardion pleurochloron</i> Pascher
	2.8.2- Mallomonadaceae	<i>Mallomonas acaroides</i> Perty
		<i>Mallomonas reginae</i> Teil.
		<i>Mallomonas</i> sp.
		<i>Synura</i> sp.
2.9- Xanthophyceae	2.9.1- Centritactaceae	<i>Centritractus belanophorus</i> Lemm.
	2.9.2- Characidiopsidaceae	<i>Characidiopsis falx</i> Pascher et Ettl
		<i>Characidiopsis acuta</i> A. Pascher
		<i>Chlorokoryne</i> sp.
	2.9.3- Chloramoebaceae	<i>Thalassiosira fluviatilis</i> Cleve
		<i>Asterogloea</i> sp.
	2.9.4- Halosphaeraceae	<i>Halosphaeropsis viridi</i> Chadefaud
	2.9.5- Ophiocytaceae	<i>Ophiocytium majus</i> Nägeli

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	2.9.6- Pleurochloridaceae	<i>Diachros pleiochloris</i> Pasch. <i>Goniochloris fallax</i> Fott <i>Goniochloris pseudogigas</i> (Bourrelly) Bourrelly <i>Pleurochloridella vacuolata</i> Pascher <i>Pleurogaster lunaris</i> Pascher
	2.9.7- Tribonemataceae	<i>Tribonema vulgare</i> Pascher
	2.9.8- Vaucheriaceae	<i>Vaucheria</i> sp.
III- Cyanophyta		
3.1- Cyanophyceae	3.1.1- Borziaceae	<i>Borzia trilocularis</i> Cohn ex Gomont <i>Sinaiella</i> sp.
	3.1.2- Chamaesiphonaceae	<i>Chamaesiphon curvatus</i> Nordst.
	3.1.3- Chroococcaceae	<i>Chroococcus dispersus</i> (Keissler) Lemmermann <i>Chroococcus limneticus</i> Lemmermann <i>Chroococcus minutus</i> (Kützing) Nägeli <i>Chroococcus</i> sp. <i>Chroococcus turgidus</i> (Kütz.) Nägeli
	3.1.4- Cyanobacteriaceae	<i>Aphanothece nidulans</i> Richter <i>Aphanothece saxicola</i> Nägeli
	3.1.5- Dermocarpellaceae	<i>Dermocarpa kernerii</i> (Hansgirg) Hansgirg
	3.1.6- Entophysalidaceae	<i>Chlorogloea</i> sp. <i>Chlorogloea fasciculata</i> (Ercegovic) Bourrelly. <i>Chlorogloea microcystoides</i> Geitler
	3.1.7- Gomontiellaceae	<i>Crinalium endophyticum</i> Crow
	3.1.8- Gomphosphaeriaceae	<i>Gomphosphaeria</i> sp. <i>Coelomoron pusillum</i> (Van Goor) Komárek
	3.1.9- Hapalosiphonaceae	<i>Loefgrenia anomala</i> Gomont
	3.1.10- Hydrococcaceae	<i>Hydrococcus rivularis</i> Kützing
	3.1.11- Mastigocladopsisaceae	<i>Mastigocladopsis jogensis</i> Iyengar et Desikachary
	3.1.12- Merismopediaceae	<i>Eucapsis alpina</i> Clements & Schantz <i>Lithococcus</i> sp. <i>Merismopedia convoluta</i> Brébisson ex Kützing <i>Merismopedia elegans</i> Braun. <i>Merismopedia glauca</i> (Ehrenberg) Kützing <i>Merismopedia punctata</i> Meyen f. <i>Merismopedia</i> sp. <i>Synechocystis aquatilis</i> Sauv. <i>Synechocystis crassa</i> var. <i>major</i> Geitler <i>Synechocystis diplococcus</i> (Pringsheim) Bourrelly <i>Synechocystis</i> sp.
	3.1.13- Microchaetaceae	<i>Anacystis</i> sp. <i>Microchaete</i> sp. <i>Microcoleus acutissimus</i> N.L.Gardner <i>Microcoleus lacustris</i> (Rabenhorst) Farlow ex Gomont <i>Microcoleus</i> sp. <i>Microcoleus vaginatus</i> Gomont ex Gomont <i>Microcystis aeruginosa</i> (Kützing) Kützing <i>Microcystis biformis</i> (A. Brown) Bourrelly <i>Microcystis elachista</i> (W. West & G. S. West) Compere <i>Microcystis incerta</i> (Lemmermann) Lemmermann <i>Microcystis robusta</i> (H.W.Clark) Nygaard <i>Microcystis viridis</i> (A.Braun) Lemmermann <i>Microcystis wesenbergii</i> West.

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3.1.14- Nostocaceae

Anabaena affinis Lemm.
Anabaena flos-aquae Lemm.
Anabaena oscillarioides Bory ex Bornet & Flahault
Anabaena sp.
Anabaena sphaerica Bornet & Flahault
Anabaena spiroides Lemm.
Anabaenopsis circularis (G.S.West) Woloszynska & V.Miller
 in V.Miller
Anabaenopsis sp.
Anabaenopsis tanganyikae (G.S.West) Woloszynska &
 V.V.Miller
Cylindrospermopsis raciborskii (Woloszynska) Seenayya &
 Subba Raju
Cylindrospermopsis sp.
Isocystis messianensis Borzi.
Isocystis planctonica Starmach
Isocystis sp.
Nodularia sp.
Nodularia spumigena Mertens ex Bornet & Flahault
Nostoc flosaquae (Linnaeus) Lyngbye
Nostoc parmelioides Kützing ex Bornet & Flahault
Nostoc piscinale Kützing ex Bornet & Flahault
Ophiocytium capitatum Wolle
Peroniopsis sp.

3.1.15- Nostochopsaceae**3.1.16- Nostochopsidaceae****3.1.17- Oscillatoriaceae**

Mastigocoleus sp.
Nostochopsis lobatus Wood
*Lyngbya birgei*G.M.Smith
Lyngbya bourrelyana Compère
Lyngbya cebennensis (Gomont) Compère
Lyngbya majuscula Harvey ex Gomont
Lyngbya muralis (Dillwyn) C.Agardh
Lyngbya putealis Montagne ex Gomont
Lyngbya rigidula Hansgirg.
Lyngbya sp.
Oscillatoria amphibia Agardh
Oscillatoria limosa Gom.
Oscillatoria tenuis Agardh ex Gomont.[J].Toxicon
*Oscillatoria acuminata*Gom.
Oscillatoria agardhii Gomont
Oscillatoria anguinis Gomont
Oscillatoria beggiatoiformis Gomont
Oscillatoria formosa Bory de Saint-Vincent ex Gomont
*Oscillatoria jenniferi*Gray
*Oscillatoria labyrinthiformis*Menegh
Oscillatoria lacustris Klebahn.
Oscillatoria margaritifera Kützing ex Gomont
Oscillatoria nigroviridis Thwaita ex Gomont
Oscillatoria okeni Agardh
Oscillatoria ornata (Kützing) Gomont
Oscillatoria platensis Nordst.
Oscillatoria princeps Vaucher.
Oscillatoria rubescens De Cand.

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		<i>Oscillatoria sancta</i> Kützing ex Gomont
		<i>Oscillatoria</i> sp.
		<i>Oscillatoria tenuis</i> Ag.
		<i>Oscillatoria terebriformis</i> C.Agardh ex Gomont
		<i>Plectonema malayense</i> Biswas
		<i>Plectonema purpueum</i> Gomont
		<i>Plectonema</i> sp.
		<i>Rhizosolenia eriensis</i> H.L.Smith
		<i>Rhizosolenia longiseta</i> O.Zacharias
		<i>Rhizosolenia setigera</i> Brightwell
		<i>Ammatoidea</i> sp.
		<i>Phormidium autumnale</i> Kützing ex Gomont
		<i>Phormidium luridum</i> (Kützing) Gomont
		<i>Phormidium chalybeum</i> (Mertens ex Gomont) Anagnostidis & Komárek
		<i>Phormidium formosum</i> (Bory de Saint-Vincent ex Gomont) Anagnostidis & Komárek
		<i>Phormidium hamelii</i> (Frémy) Anagnostidis & Komárek
		<i>Phormidium ornatum</i> (Kützing ex Gomont) Anagnostidis & Komárek
		<i>Phormidium</i> sp.
		<i>Phormidium tenue</i> Anagnostidis & Komárek
	3.1.18- Pseudanabaenaceae	<i>Planktolyngbya limnetica</i> (Lemm.) J.Komárk-Legnerová & G.Cronberg
		<i>Schizothrix</i> sp.
		<i>Pseudanabaena catenata</i> Lauterborn
		<i>Pseudanabaena</i> sp.
	3.1.19- Rivulariaceae	<i>Calothrix braunii</i> Bornet and Flahault
		<i>Calothrix gypsophila</i> (Kütz.) Thuret
		<i>Gloeotrichia echinulata</i> P.Richter
		<i>Gloeotrichia</i> sp.
		<i>Rivularia aquatica</i> De Wildeman
	3.1.20- Scytonemataceae	<i>Tolypothrix roberti-lamii</i> Bourrelly in Bourrelly & Manguin.
	3.1.21- Spirulinaceae	<i>Spirulina gigantea</i> Schmidle
		<i>Spirulina maxima</i> Setch.
	3.1.22- Symphyonemataceae	<i>Iyengariella tirupatiensis</i> Desikachary
	3.1.23- Synechococcaceae	<i>Synechococcus vantieghemi</i> Pringsheim
		<i>Synechococcus nidulans</i> Lagerh.
		<i>Synechococcus leopoliensis</i> (Raciborski) Komárek
		<i>Synechococcus linearis</i> (Schmidle & Lauterborn) Komárek
		<i>Synechococcus major</i> f. <i>crassior</i> Lagerheim
		<i>Synechococcus</i> sp.
		<i>Synechococcus aeruginosa</i> Nägeli
IV- Euglenophyta		
4.1- Euglenophyceae	4.1.1- Astasiaceae	<i>Distigma</i> sp
		<i>Gyropaigne lefevrei</i> Bourrelly & Georges
		<i>Rhabdomonas incurva</i> Fresenius
		<i>Rhabdomonas</i> sp.
		<i>Rhabdomonas tortuosum</i> (Stockes)
		<i>Sphenomonas</i> sp.
	4.1.2- Euglenaceae	<i>Cryptoglana pigra</i> Ehrenberg
		<i>Euglena acus</i> Ehrbg.

Annexes Contd.

Euglena allorgei Deflandre
Euglena deses Ehrenberg
Euglena granulata (G.A. Klebs) F. Schmitz
Euglena limnophila Lemm.
Euglena oxyuris Schmarda
Euglena pisciformis Klebs.
Euglena polymorpha P.A. Dangeard
Euglena proxima Dang.
Euglena sanguinea Ehrbg.
Euglena sp.
Euglena spirogyra Ehrenberg
Euglena texta (Dujardin) Hübner
Euglena tripteris (Dujardin) G.A. Klebs.
Euglena variabilis G.A. Klebs
Euglena viridis (O.F. Müller) Ehrenberg
Rhynchopus sp.
Strombomonas acuminata (Schmarda) Deflandre
Strombomonas conica V. Conforti & G.-J. Joo.
Strombomonas cylindrica V. Conforti & G.-J. Joo.
Strombomonas gibberosa (Playfair) Deflandre
Strombomonas lanceolata (Playfair) Deflandre
Strombomonas sp.
Strombomonas subcurvata (Proskina-Lavrenko) Deflandre
Strombomonas tambowika (Svirenko) Deflandre
Strombomonas verrucosa (Daday) Deflandre
Trachelomonas abrupta Svirenko
Trachelomonas armata (Ehrenberg) F. Stein
Trachelomonas bacillifera var. minima Playfair
Trachelomonas bernardimensis Vischer emend. Deflandre
Trachelomonas bulla F. Stein ex Deflandre
Trachelomonas caudata (Ehrenberg) Stein
Trachelomonas conica Playfair
Trachelomonas cylindrica Ehrbg.
Trachelomonas globularis (Awer.) Lemmermann
Trachelomonas hexangulata Svirenko
Trachelomonas hispida Lemm.
Trachelomonas kelloggi var. *coronata* Skvortzov
Trachelomonas klebsii Deflandre
Trachelomonas lefevrei Deflandre
Trachelomonas naviculiformis Deflandre
Trachelomonas oblonga Lemmermann
Trachelomonas obovata Stokes.
Trachelomonas rugulosa F. Stein ex Deflandre
Trachelomonas similis A. Stokes
Trachelomonas sinensis Skvortzov
Trachelomonas sp.
Trachelomonas stokesiana Palmer
Trachelomonas superba Svirenko
Trachelomonas verrucosa A. Stokes
Trachelomonas volvocina (Ehrenberg) Ehrenberg
Trachelomonas volvocinopsis Svirenko
Trachelomonas zebra (EHR.) KUTZ

Annexes Contd.

	4.1.3- Eutreptiaceae	<i>Eutreptia thiophila</i> Skuja
	4.1.4- Glenodiniopsidaceae	<i>Sphaerodinium polonicum</i> Wołoszynska
	4.1.5- Peranemataceae	<i>Peranema tortuosum</i> (Christen).
	4.1.6- Petalomonadaceae	<i>Dylakosoma pelophilum</i> Skuja
	4.1.7- Phacaceae	<i>Lepocinclis acuminatum</i> Deflandre
		<i>Lepocinclis caudata</i> A.M. Cunha
		<i>Lepocinclis colligera</i> Deflandre
		<i>Lepocinclis fusiformis</i> (H.J.Carter) Lemmermann
		<i>Lepocinclis marsonii</i> Lemm. Waikato R., Mercer (T).
		<i>Lepocinclis ovum</i> Lemm.
		<i>Lepocinclis</i> sp.
		<i>Lepocinclis stenii</i> Lemm.
		<i>Lepocinclis texta</i> (Dujardin) Lemmermann.
		<i>Phacus acuminatus</i> Stokes
		<i>Phacus agilis</i> Skja.
		<i>Phacus applanatus</i> Poch
		<i>Phacus caudatus</i> Hübner
		<i>Phacus ephipion</i> Ehrbg.
		<i>Phacus gamsii</i> Bourrelly
		<i>Phacus inflexus</i> Conard
		<i>Phacus longicauda</i> (Ehr.) Dujardin
		<i>Phacus mentaweiensis</i> Conrad
		<i>Phacus meson</i> Ehrbg.
		<i>Phacus minutus</i> (Playfair) Pochmann.
		<i>Phacus onyx</i> Pochmann
		<i>Phacus orbicularis</i> Hübn.
		<i>Phacus oscillans</i> Klebs
		<i>Phacus pulcher</i> Y.V.Roll
		<i>Phacus</i> sp.
		<i>Phacus tortuosum</i> (Lemmermann) Skvortzov
		<i>Phacus tortus</i> (Lemmermann) Skvortzov
V- Rhodophyta		
5.1- Florideophyceae	4.1.1- Wrangeliaceae	<i>Ptilothamnion richardsii</i> Skuja
	4.1.2- Rhodomelaceae	<i>Bostrychia scorpioides</i> (Hudson) Montagne
	4.1.3- Caulacanthaceae	<i>Sterrocladia amnica</i> (Montagne) F.Schmitz
5.2- Rhodophyceae	4.1.5- Acrochaetiaceae	<i>Andouinella violacea</i> (Kütz.)
5.3- Stylonematophyceae	4.1.6- Stylonemataceae	<i>Chroodactylon</i> sp.

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Full Length Research Paper

Design considerations for a sustainable power energy system in Khartoum

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Application of renewable energy in Sudan is a major issue in strategic planning for alternatives fossil fuels to provide part of local energy demand. Sudan is an important case study in the context of renewable energy because Sudan possesses relatively high profusion of solar radiation, moderate wind speeds. This paper discussed the efficient system of sustainable renewable energy for domestic used and its total cost. The method of this paper was collection of the basic data of solar radiation, wind speed, others required input data, and then hybrid optimization simulation model was developed using the electric renewable energy software Hybrid Optimization Model for Electric Renewable (HOMER). The simulation model has been used to find out the best technically viable renewable based energy efficient system for different numbers of household. It finds as the result some topologies of hybrid power. The simulation results have been presented the most efficient achievement and economic way for different numbers of household. The overall cost of energy would be low if the turbine cost decreases in Khartoum. The project lifetime has been considered for 25 years and the annual real interest rate has been taken as 4%.

Key words: HOMER, Khartoum- renewable energy, power system, domestic.

INTRODUCTION

A hybrid energy system generally consists of a primary energy sources working in parallel with standby secondary energy storage units. Hybrid Optimization Model for Electric Renewable (HOMER) has been used to optimize the best energy efficient system for Khartoum considering different load and wind-PV combination. Figure 1 reflects the propose scheme as implemented in HOMER simulation tool. HOMER software developed by

National Renewable Energy Laboratory (NREL), USA for micro-power optimization model, has been used to find out the best energy efficient renewable based hybrid system options for Khartoum. It contains a number of energy component models and evaluates suitable technology options based on cost and availability of resources (HOMER, 2005).

HOMER optimum configurations of appropriate power

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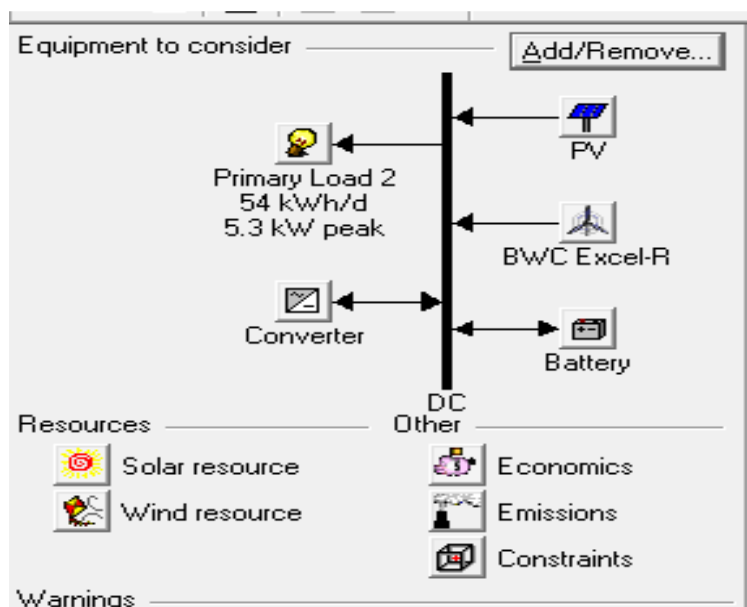


Figure 1. Schematic diagram of hybrid power system.

stations were suggested in the Plan depending on energy resources available in specific locations (Indradip and Chaudhuri, 2008). Analysis has been done for single home user as well as combination of 10 and 50 home users to get the most economic and technical viable options (James and James, 2005). HOMER models each individual system configuration by performing an hourly time-step simulation of its operation for a one year duration. The available renewable power is calculated and is compared to the required electrical load (Dalton et al., 2009).

Sudan lies between latitude 3° N 23°N and longitude 21°45/E and 39°E. This large area enjoys a variety of climates, from desert regions in the north to tropical in the south, and makes it a favourable environment for all activities of the integrated agricultural investment from production to processing industries. Sudan is a relatively sparsely populated country (UN.UONISCO, 2004) and Alnaser et al. (2007). Khartoum climate region in the summers are invariably hot (mean maximum, 41°C and mean minimum 25°C) with large variation; low relative humidity averages (25%). Winters can be quite cool. Sunshine is very prevalent. Climate is a typical desert and rain is infrequent and annual variation in temperature is large. The fluctuations are due the dry and rainy seasons. Two main air movements determine the general nature of the climate. First, a very dry air movement from the north that prevails throughout the year.

Khartoum is located at 15.38 latitude and 32.28 longitudes. Energy planners have long envisioned large utility-scale solar power plants covering large expanses of desert (Alnaser et al., 2004). While this vision has

many favorable attributes, the economics require careful investigation. Ground-mounted PV systems require the allocation of land, which must be acquired and prepared to accept the PV system. The cost of land and the cost of site work can be considerable (Anonymous, 1996). In Sudan and many others countries, the lack of available large open tracts of land has effectively precluded the grid connected PV option as afforded to develop in Sudan. As interest in solar electricity increases, there is a growing consensus that spread PV systems that provide electricity at or near the point of use will be the first to reach prevalent commercialization (IEA, 2002) and Sasitharanuwat and Rakwichian (2007). This study find that HOMER is Hybrid Optimization Model for Electric Renewable (HOMER) is design optimization model that determines the configuration, dispatch, and load management strategy that minimizes life-cycle costs (Steven,2005) and Sasitharanuwat et al. (2007).

This paper describes the designing and implementation process for hybrid system in Khartoum capital of republic of Sudan that took about 12 months, starting from January 2009 and HOMER. Simulation tool has been at length used in order to compare and optimize the electrical demand to the electrical energy that the system is bright to supply, on an hourly base.

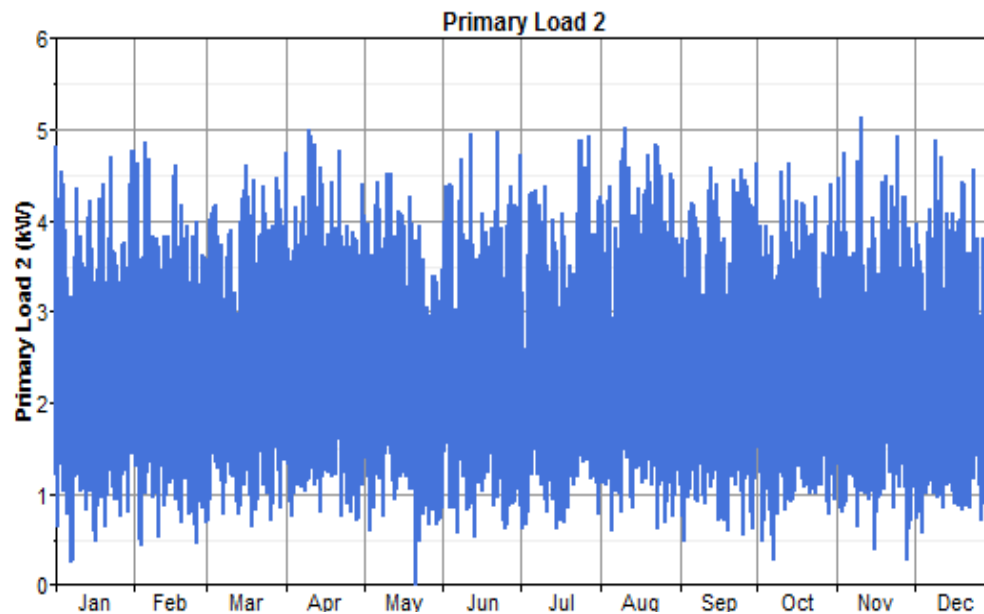
DESIGN PROCEDURE

Hybrid power system

HOMER simulates the operation of a system by making energy balance calculations for each of the 8,760 h in a year. For each

Table 1. Appliances for single home user.

Appliance	Quantity	Capacity (W)	Maximum use hour / day
Florescence light	4.2	10	4
B / W TV	1.5	15	4
Radio / cassette	1	5.5	5

**Figure 2.** Primary load 2.

hour, and compares the electric and thermal demand in the hour to the energy that the system can supply in that hour, and calculates the flows of energy to and from each component of the system. For systems that include batteries or fuel-powered generators. HOMER also decides for each hour how to control the generators and whether to charge or discharge the batteries. HOMER performs these energy balance calculations for each system configuration. It determines whether a configuration is feasible. The system cost calculations account for costs such as capital, replacement, operation and maintenance, fuel, and interest. System in HOMER Information about the load, resources, economic, constrains, controls and other component that have been used in HOMER are in Figure 1.

Electric load material

A typical load system, shown in the Table 1 for single home in the remote areas has been considered for the analysis. Monthly average hourly load demand (Sudanese perspective) has been given as an input of HOMER and then it generates daily and 2.3 kW/day monthly load profile for a year as get in Figure 2. It has been found that for this system each home user consumes energy around (338 W/day of Wh/day). The system also gives the opportunity for expanding its capacity in order to cope with the increasing demand in the future. This can be done by increasing either the rated power of diesel generator, renewable generator or both of them (Nayar et al., 1993; IEA, (2002).

RESULTS AND DISCUSSION

Renewable resources

As hourly data is not available therefore monthly averaged global radiation data has been taken from (NASA, 2008). HOMER introduces clearness index from the latitude information of the selected site and this index values are shown in Figure 3. HOMER creates the synthesized 8760 hourly values for a year using the Graham algorithm (Graham and Holland, 1990) which results in a data sequence that has realistic day-to-day and hour-to-hour variability and autocorrelation (HOMER, 2005). For wind monthly averaged (1999 - 2007) and Graham and Holland, (1990) measured data from (SEI) have been used along with the information of height = 30 m, elevation = 3 m ASL, surface roughness = 0.01 m (Benemann and Chehab, 2000; Benemann et al., 2001). HOMER create these monthly average data based on the other parameters such as Weibull factor "k" = 1.8, autocorrelation factor (randomness in wind speed) = 0.90, diurnal pattern strength (wind speed variation over a day) = 0.25, hour of peak wind speed = 22 m/s to generate hourly data for a year as shown in Figure 4

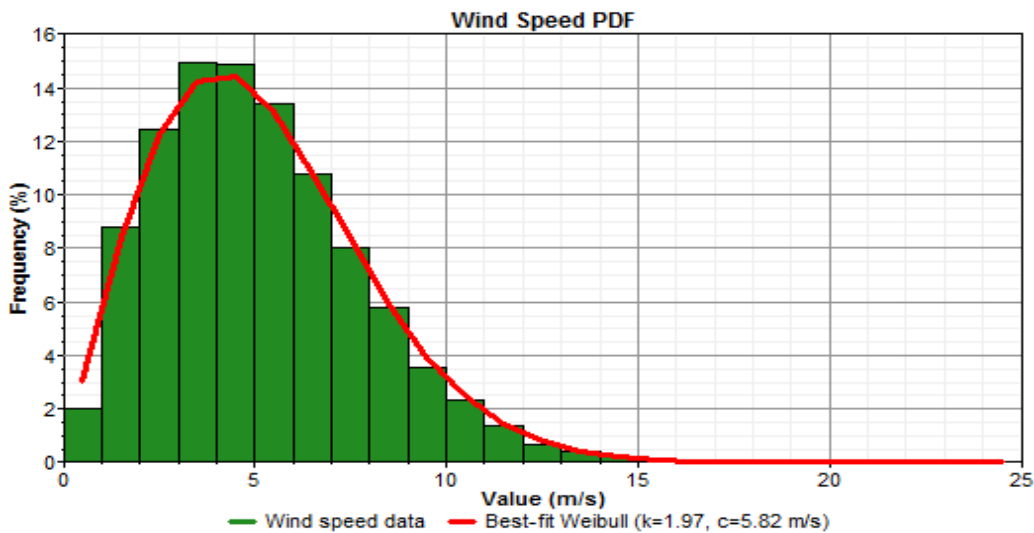


Figure 3. Solar analysis diagrams.

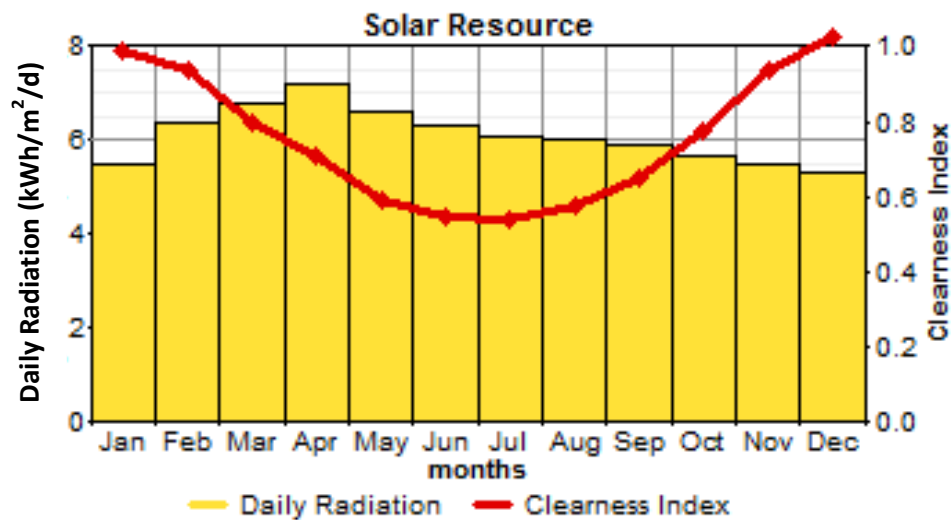


Figure 4. Daily wind speed.

(Ahmad and Nayar, 2004); certain of systematic result depend on different location to get the analysis Combining the renewable energy generation with conventional wind and PV power generation will enable the power generated from renewable energy sources to be more reliable and affordable (Rohinton, 2009).

Photovoltaic module

The cost of PV module including installation has been considered as 220 SP / W for Sudan (Anonymous, 1998). Life time of the modules has been taken as 25 years and these are tilted at 21° with no tracking mode

(ISE, 2008). As of this analysis we get the continuous of energy depend on the lifetime of a hybrid power system which has an ability to provide 24-hour grid quality electricity to the load. This system offers a better efficiency, flexibility of planning and environmental benefits compared to non renewable energy. Steven (2005) and Ahmed (2008) found that PV calculates the electric behavior of large and in homogeneously light up PV arrays that obtained the scale of photovoltaic module should become more gorgeous as costs of usual supplies increase (Dalton et al., 2009). Capacity shortage and fraction of excess electricity, cost of useful energy varies from 24 to 39 /kWh which is comparable to solar home system (Shafiuzzaman, 2005) that mean

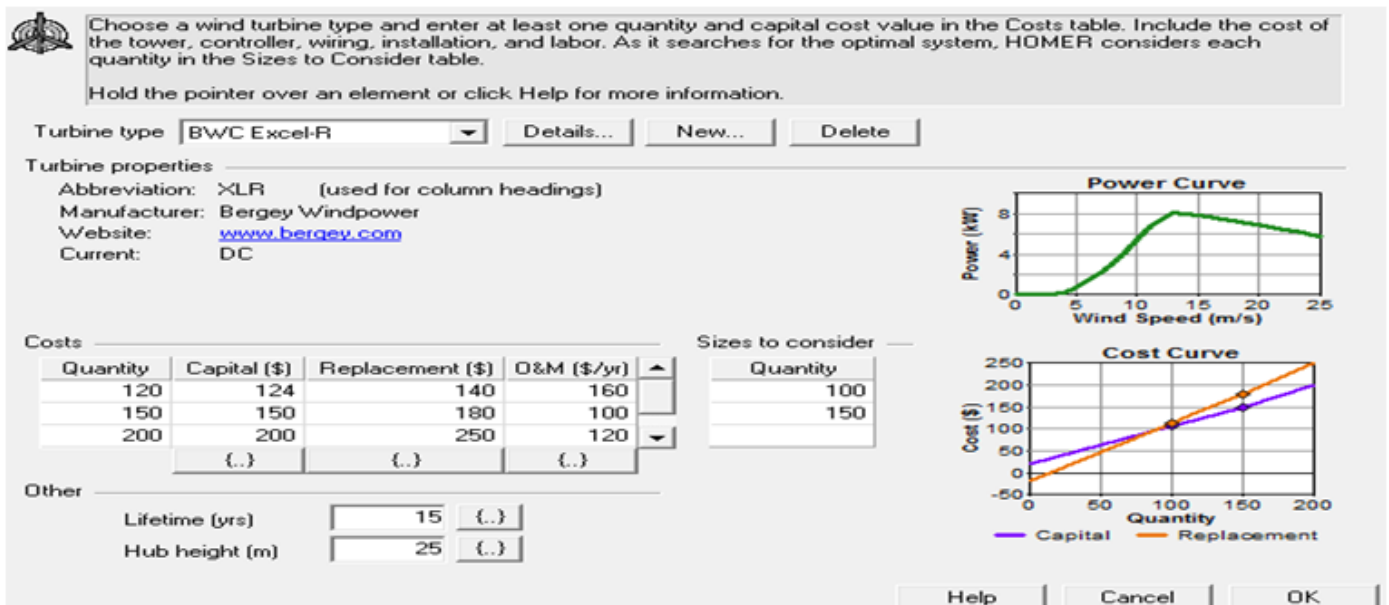


Figure 5. Wind turbine input.

the scale of solar system the one of the main factor of design the hybrid system.

Wind generator

The load demand is very low for a single home system and the price per kW turbine cost is very high for low capacity wind turbine compare to that of high capacity ones. Low capacity wind turbine is not much available (Awea, 1999); research and development are going on to improve the technology and designing low capacity turbine with low cut-in speed at around 2.5 m/s. Turbine with a capacity of 0.5 kW has been considered (Figure 5). The cost of the turbine with tower and installation has been considered as 96000 SP/turbine. For the load higher than 1 kW, turbine from Southwest Wind power, (model: W175, capacity, 3 KW) has been considered at the cost of 200000 SP/ turbine with tower and installation. Options analysis was done for only PV and wind that acquired after 2007-power demand including reverse system is supplied by using mini-grid connected hybrid power system with quite a few power options: PV/wind. HOMER Optimum configurations of appropriate power stations were suggested in the Plan depending on energy resources available in specific locations. Total 35 power stations have been proposed in the Plan. All of them are of hybrid types with Wind and battery bank (Indradip and Chaudhuri, 2008) for a 400 W capacity of Wind Home System (three home users) in coastal areas at a speed of 5 m/s the IRR, payback period and benefit-cost ratio are found to be around 16%, 8 years and 2 respectively. Results show

that considering energy consumption, environmental effects and remote accessibility most of the coastal regions are viable for wind home system (Shafiuzzaman, 2005) that obtained to the scale of project depending on the suitability for individual locations of the project of wind type of hybrid system.

Battery with control

As the system considered the DC load only, battery and controller were also form as a main part of the performance evaluation of 10 kW PV power system (Sasitharanuwat and Rakwichian, 2007). Isolated battery from Trojan Company (Model: Trojan T- 105, nominal V: 6v, nominal capacity: 225 Ah) has been used at a cost of 10,000.00 SP/battery with charge controller. Optimized HOMER found for Algiers are composed of PV systems, wind generators and batteries (Malika, 2009). On the basis of local inspections and analysis with the HOMER model, the following design specifications were found to be optimal for a solar penetration of about 25%: PV capacity of 12 kWp, battery capacity of 108 kWh (50 batteries, 360 Ah, 6 V), and 12 kWp converter at Maldives (van Sark et al., 2004).

Constraints and economics

The project life time has been considered to be 25 years and the annual real interest rate has been taken as 4% (IEA, 2002). As the system has been designed for single

Table 2. HOMER details results.

Home	Load	PV module (KW)	Wind generator (quantity)	Battery (quantity)	Initial Cost SP	Total NPC	COE (SP/ Wh)
Single	338 Wh/day 115 KW Peak	0.15	0	2	61,890	98,470	49.5
20	6.8 KWh/day 2.3 KW peak	1.0	1	16	780,000	841,480	25.8
30	10.1 KWh/day 3.5 KW	2.0	1	24	978,890	1,463,300	23.8
40	13.5 KWh/day 4.6 KW	2.5	2	24	2,188,330	1,999,590	24.7
50	16.9 KWh/day 5.8 KW	3.5	2	8	1,567,220	1,940,985	20.1

and for multiple home users like 10 to 50, but the load consumed by the user is low so operation and maintenance cost has been taken 500 SP/year. There is no capacity shortage for the system and operating reserve is 10% of hourly load. Analysis shows that the cost of energy (KWH) is low for the system that is the combination of 50 homes (Roaf and Fuentes, 1999). Table 2 shows the load demand for each combination of homes with system architecture and financial summary.

Dalton et al. (2009) found that as the result of optimization a modeling for design a hybrid system using HOMER software demonstrated that, at 2004 prices, the NPC of the grid/RES hybrid configuration is comparable with the grid-only supply and resulted in a RF of 73%, a payback time of 14 years and a reduction in greenhouse gas emissions of 65%. Optimization modeling also showed that whilst a RES-only configuration can potentially supply 100% of power demand, at present electricity prices, which have nearly quadrupled since 2004, and predicts that a configuration of 3 Vests WECS (1.8 MW), an 800 kW converter and 3500 batteries provides the lowest NPC after 20 years at \$19.1 M and Shafiuzzaman (2005) found as result that payback period and benefit-cost ratio are found to be around 16%, 8 years and 2 respectively. Results show that considering energy consumption, environmental effects and remote accessibility most of the coastal regions are viable for wind home system.

van Sark et al. (2004) and van Roosmalen et al. (2004) found the system simulations showed that with a daily load of 207 kWh/day, the combination of a 12 KWp, PV system with a battery backup capacity of 108 kWh would be optimum, given the most suitable strategy for the use of two differently sized diesel generators now present. Reducing solar radiation and wind power also means less emission from the system as shown by the PV/wind system. In addition, the hybrid system reward able also

consider providing enough electricity for domestic using as needed by people in this particular remote area.

Conclusions

This paper could be summarized from the analysis that the project life time has been considered to be 25 years and the annual real interest rate has been taken as 4% as the system has been designed for single and also for multiple home users like 10 to 50, but the load consumed by the user is low operation and maintenance cost.

It will be better to use wind-PV combination system for 50 homes instead of single home system. The overall cost of energy would be low if the turbine cost decreases in Khartoum. The simulation results display that utilizing renewable generators such as PV and wind generator reduces the operating costs of using third class housing at Khartoum State.

Conflict of Interests

The authors have not declared any conflict of interests.

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Full Length Research Paper

Modification of the adaptive Nadaraya-Watson kernel regression estimator

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Nadaraya-Watson (NW) kernel regression estimator is a widely used and flexible nonparametric estimator of a regression function, which is often obtained by using a fixed bandwidth. Several studies showed that the adaptive kernel estimators with varying bandwidths have better performance results. In this paper, a new improvement of the NW kernel regression estimator is proposed and the bandwidth of this new improvement is obtained depending on the range of the observations. Simulated example is presented, including comparisons with three others NW estimators. The performance of the proposed new estimator is evaluated via the MSE criterion. The results of the simulation study were very promising; it shows that our modified NW estimator performs well in all cases.

Key words: Nonparametric estimation, smoothing parameter, local bandwidth factor, Nadaraya-Watson kernel regression estimator, modified Nadaraya-Watson (NW) estimator.

INTRODUCTION

In many statistical problems, nonparametric regression techniques are commonly used for describing the relationship between a response variable and some covariates. Let $\{(X_i, Y_i)\}_{i=1}^n \in \mathbb{R}$ be a random sample of bivariate data with size n . The nonparametric regression model is defined as:

$$Y_i = m(X_i) + \varepsilon_i, \quad (1)$$

where

$m(x_i)$: is unknown regression function, and

ε_i : are independent random errors with zero mean and

variance σ^2 ; $i = 1, 2, \dots, n$.

The nonparametric regression techniques are weighted

averages of the response variable, where the weights depend on the technique and the distance between the observations of the explanatory variable scaled by a smoothing parameter. One of the nonparametric regression estimation techniques is the Nadaraya-Watson (NW) kernel estimator. It is more flexible than the other nonparametric methods, and provides an accurate predictor of observations. The NW kernel estimator was first proposed by Nadaraya (1964) and Watson (1964). Nadaraya (1964) introduced the NW estimator as an approximation to the regression curve based on empirical data. He studied the properties of his suggested estimator when the sample size increases infinitely. Watson (1964) presented the NW estimator as a simple computer method for obtaining a "graph" from a large number of observations.

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The NW kernel estimator depends on one parameter which is called the bandwidth; it controls the amount of curve smoothing where large h produces a smooth density estimate (Wand and Jones, 1995). The bandwidth of the NW kernel estimator can be fixed or variable; the choice of the optimal bandwidth is a critical issue. The optimal bandwidth is the value that minimized the mean integrated squared error (MISE) which can be obtained by integrating the mean squares of errors (MSE). Several methods of selecting h can be used, Silverman (1986), Wand and Jones (1995) and Härdle et al. (2004) expanded in the bandwidth selections methods. One of these methods is the least square cross-validation or also called unbiased cross-validation; Scott and Terrell (1987) discussed it and presented a relationship between the biased and unbiased cross-validation. The variable bandwidth should be used rather than the fixed bandwidth in the case of long-tail or multi-modal distributions. Abramson (1982) suggested the inverse-square-root rule for the bandwidth h of a variable-kernel density, which reduces the bias more than the fixed-bandwidth estimator, even when a nonnegative kernel is used. Silverman (1986) discussed the kernel density estimation exhaustively. He gave details about the assumptions of the kernel weight and the properties of the estimator such as bias and variance. In addition, he proposed an adaptation for the kernel estimator by varying the bandwidth as nonparametric density estimation. Demir and Toktamış (2010) considered the adaptive Nadaraya-Watson (ANW) kernel regression estimators as a way to estimate the regression function. The results of their simulation study showed that the NW kernel estimator has a better performance when evaluating the local bandwidth factor based on the arithmetic mean instead of using the geometric mean. Also, their results did not oppose the previous studies in that the NW kernel estimator with the variable bandwidths is better than the fixed NW kernel estimator.

The purpose of this paper is to propose a new modification of the NW kernel regression estimator. The bandwidth of our modification is obtained by using the range of the probability density function of X_i . The idea behind our modification is that by increasing the local bandwidth factor and thus the bandwidth, better performance of the NW kernel estimator will be obtained. In more details, different selected types of the NW estimators, including our modified NW kernel estimator are presented in our study. Also, a brief description of the MSE criterion is given. Finally, a simulation study is conducted with useful concluding remarks given.

METHODS

An important factor that has a great impact on the smoothing results is the choice of the bandwidth or the smoothing parameter

h . Here, different Nadaraya-Watson kernel estimators are presented according to the selected type of the bandwidth.

Fixed Nadaraya-Watson kernel estimator

The bandwidth can be selected to be a constant over all the range of x ; this choice is suitable when the unknown regression function behaves the same over all the estimation range. The NW kernel estimator is often obtained with a fixed bandwidth which can be defined as:

$$\hat{m}_{NW}(X_i) = \int y f(y|x) dy = \frac{\int y \hat{f}(x,y) dy}{\hat{f}(x)}$$

$$= \frac{\sum_{i=1}^n Y_i K\left(\frac{x-X_i}{h}\right)}{\sum_{i=1}^n K\left(\frac{x-X_i}{h}\right)} \tag{2}$$

where

h : is the fixed bandwidth, $h > 0$, and

K : is the kernel function which satisfying the following conditions (Silverman, 1986):

- i) $\int_{-\infty}^{\infty} K(u)du = 1$
- ii) $\int_{-\infty}^{\infty} u K(u)du = 0$
- iii) $\int_{-\infty}^{\infty} u^2 K(u)du = \mu_2 \neq 0$
- iv) $V = \int_{-\infty}^{\infty} K(u)^2 du < \infty$

Several kernel functions are proposed in the literature. Gaussian kernel function is one of the most commonly used in practice (Härdle, 1990; Silverman, 1986); the Gaussian kernel function is defined as

$$K(u) = \frac{1}{\sqrt{2\pi}} e^{-u^2/2} \tag{3}$$

The fixed bandwidth can be selected depending on various methods such as; Silverman’s rule of thumb and cross-validation. In this paper, the least square cross-validation (LSCV) will be used according to its simple evaluation and its ability to be applied in any regression model. The LSCV minimizes the integrated squared error (ISE) rather than the MISE (Scott and Terrell, 1987), where MISE is the average of the ISE, and ISE is a distance measured between the fitted density $\hat{f}(x)$ and the true density $f(x)$ which is defined as

$$ISE = \int [\hat{f}(x) - f(x)]^2 dx \tag{4}$$

and

$$MISE = E(ISE)$$

The h_{LSCV} is the bandwidth that minimize the LSCV which is defined as

$$LSCV = \int \hat{f}^2(x) dx - \frac{2}{n} \hat{f}_{-i}(x_i) \tag{5}$$

where $\hat{f}_{-i}(x_i)$: is the *leave-one-out* kernel density estimator, which is obtained among the remaining $n - 1$ observations and can be defined by the following equation

$$\hat{f}_{-i}(x_i) = \frac{1}{(n-1)h} \sum_{i \neq j} K\left(\frac{x_i - x_j}{h}\right) \tag{6}$$

Variable Nadaraya-Watson kernel estimator

The fixed NW kernel estimator is not a good choice for the cases of multivariate, long-tailed, and the multi-modal distributions. The multivariate problem can be handled by increasing the sample size, but for the cases of the long-tail and the multi-modal distributions, varying the bandwidth is recommended. The estimator which is based on varying the bandwidth is called the variable NW kernel estimator, and has the following form:

$$\hat{m}_{NW}(x_i) = \frac{\sum_{i=1}^n \frac{y_i}{h(X_i)} K\left(\frac{x - X_i}{h(X_i)}\right)}{\sum_{i=1}^n \frac{1}{h(X_i)} K\left(\frac{x - X_i}{h(X_i)}\right)} \tag{7}$$

where $h(X_i)$: is the variable bandwidth.

Abramson (1982) gave the following formula to compute $h(X_i)$:

$$h(X_i) = \frac{h}{\sqrt{f(x_i)}}$$

where $f(X_i)$: is the probability density function of X_i which can be estimated by the kernel density estimator.

The variable bandwidth $h(X_i)$ can be obtained by the Silverman algorithm which is presented in Silverman (1986). He presented in his paper, an algorithm for the Abramson style estimator, and referred to it as an adaptive kernel estimator. In the first step, he obtained the prior kernel estimator with fixed bandwidth h which is denoted by $\tilde{f}(X_i)$. Then, he defined the local bandwidth factor λ_i , as:

$$\lambda_i = \left[\frac{\tilde{f}(x_i)}{g} \right]^{-\alpha} \tag{8}$$

where

g : is the geometric mean of $\tilde{f}(X_i)$, $g \neq 0$, and

α : is the sensitivity parameter, which satisfies $0 \leq \alpha \leq 1$.

At the last step, his suggested adaptive bandwidth is defined as:

$$h(X_i) = h \lambda_i \tag{9}$$

In (1982), Abramson gave the sensitivity parameter the value 0.5 since this value leads to good prediction results. Then, the variable NW kernel estimator can be written as follow:

$$\hat{m}_{NW}(x_i) = \frac{\sum_{i=1}^n \frac{y_i}{h \lambda_i} K\left(\frac{x - X_i}{h \lambda_i}\right)}{\sum_{i=1}^n \frac{1}{h \lambda_i} K\left(\frac{x - X_i}{h \lambda_i}\right)} \tag{10}$$

Adaptive Nadaraya-Watson kernel estimator

Demir and Toktamış (2010) modified the NW kernel estimator, their modification based on using the arithmetic mean instead of the geometric mean when computing the local bandwidth factor which is given as

$$\lambda_i^* = \left[\frac{\tilde{f}(x_i)}{\bar{X}} \right]^{-0.5} \tag{11}$$

where \bar{X} : is the arithmetic mean of $\tilde{f}(X_i)$.

Then, the ANW kernel estimator is defined by Equation 10 with replacing λ_i by λ_i^* . The authors used the arithmetic mean since its value is greater than or equal to the geometric mean (Lidstone, 1932), and that has made the value of the λ_i^* greater than λ_i . By

maximizing the value of the local bandwidth factor, the value of the bandwidth will increase too, and this will enhance the performance of the NW estimator. According to their simulation study and real data application, they showed that the performance of the ANW kernel estimator is better than the performance of the NW kernel estimator.

Modified Nadaraya-Watson kernel estimator

This part of the paper is dedicated to our modification which aims to enhance the predictive ability of the NW kernel estimator through increasing the value of the bandwidth. In our proposed NW kernel estimator we suggest to evaluate the local bandwidth factor based on the range of the observations instead of using the geometric or the arithmetic mean. Most of the times, the range will have a larger value, particularly if the phenomenon being studied has outliers. Thus, the local bandwidth factor and the value of the bandwidth h will be increased. The modified local bandwidth factor is given as:

$$\lambda_i' = \left[\frac{\tilde{f}(x)}{R} \right]^{-0.5} \tag{12}$$

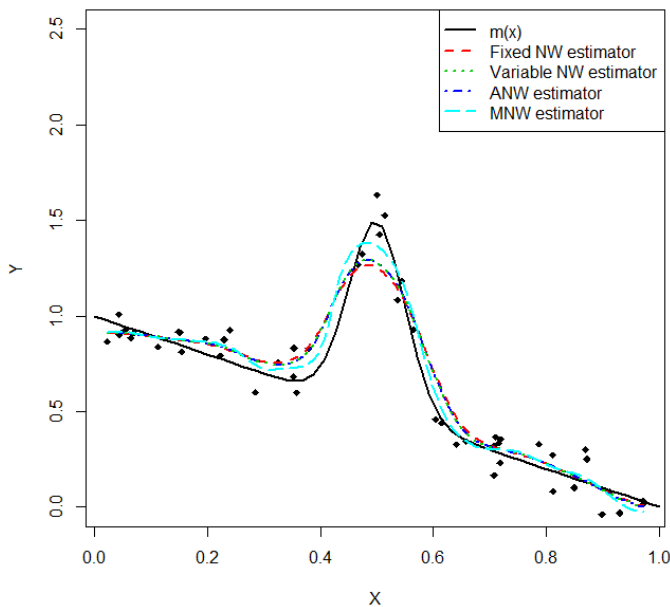


Figure 1. The real regression function and the NW kernel estimators of the regression function using sample size 50 and $h=0.16$.

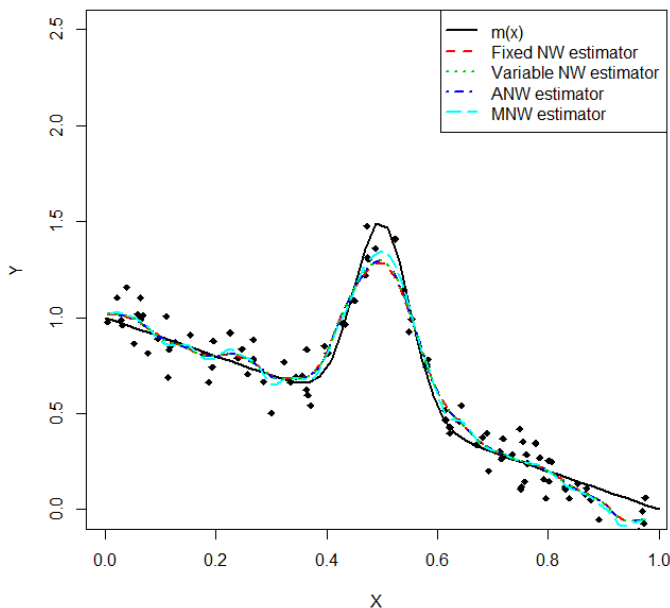


Figure 1. The real regression function and the NW kernel estimators of the regression function using sample size 100 and $h=0.08$.

where R : is the range of $\tilde{f}(X_i)$, which is the difference between the largest and smallest values.

Therefore, the modified Nadaraya-Watson (MNW) kernel estimator can be obtained by substituting λ'_i instead of λ_i in Equation (10).

Evaluation criteria

For the selection of the best performance NW kernel estimators, several criteria can be used. In general, the evaluation criteria are based on computing the distance between the observed values y_i and the predicted values \hat{y}_i which are obtained by using the estimated models. Here, the mean squared error (MSE) will be used. The best estimator is the one with the smallest MSE value. The MSE can be computed mathematically by using the following formula:

$$MSE = \frac{1}{n} \sum_{i=1}^n (y_i - \hat{y}_i)^2 \tag{13}$$

n : is the number of observations.

Simulation study

Here, the performance of the new proposed MNW kernel estimator is examined over three different selected NW kernel estimators; the fixed NW, the variable NW, and the ANW through a simulation study. The explanatory variables are generated from the uniform distribution based on the interval $[0,1]$ with six different sample sizes 25, 50, 100, 250, 300 and 600. The regression function is given by Hardle (1990) as:

$$Y_i = 1 - X_i + e^{[-200(x_i-0.5)^2]} + \varepsilon_i \tag{14}$$

Where the random errors ε_i have normal distribution with 0 mean and 0.1 variance. The fixed bandwidth h is obtained by using the unbiased cross-validation method. To evaluate the NW kernel estimators, the Gaussian kernel function is used. A 1000 simulation repetition for each sample size is used to compute the MSE criterion.

The graphs of the real regression function and the estimated regression functions which are computed based on the sample of sizes 50, 100, 250 are presented in Figures 1, 2, and 3. While the performance of the MNW kernel estimator comparable with the three selected NW kernel estimators is considered objectively, our comparable study is based on the MSE criterion. For each sample size, the MSE value of the fixed NW, variable NW, ANW and MNW kernel estimators which is based on Gaussian kernel function are computed. The results of the MSE criterion is presented in Table 1.

RESULTS

From the figures, it is clear that the performance of the MNW is superior to the fixed NW, the variable NW and the ANW kernel estimators. Also, the figures show that generally the performance of all the studied NW kernel estimators becomes better by increasing the sample size.

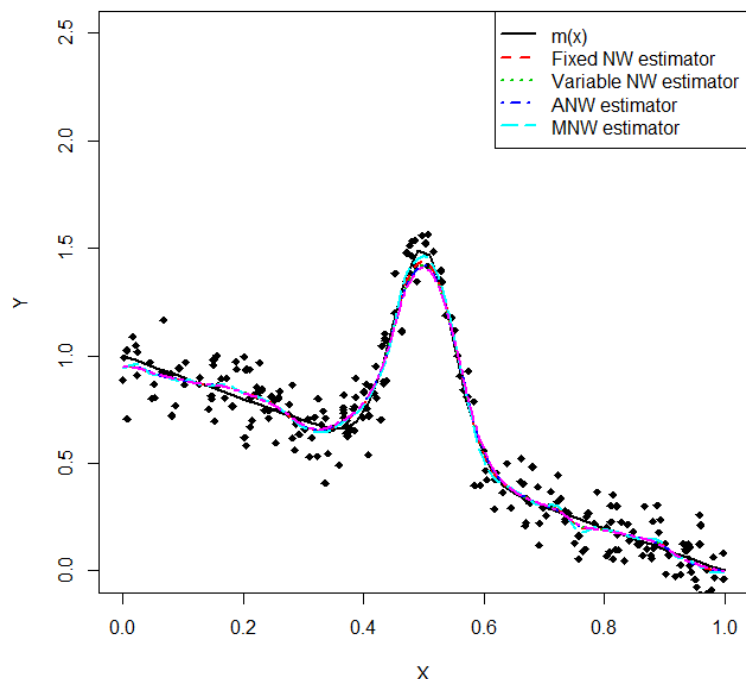


Figure 3. The real regression function and the NW kernel estimators of the regression function using sample size 250 and $h=0.06$.

Table 1. The MSE values of the NW kernel estimators.

Kernel functions	Sample size	Fixed NW kernel estimator	Variable NW kernel estimator	ANW kernel estimator	MNW kernel estimator
Gaussian	25	6.6588	4.1133	3.9618	3.8548
	50	3.5671	2.1655	2.0818	2.0120
	100	1.8340	1.1040	1.0570	1.0221
	250	0.7573	0.4685	0.4457	0.4265
	300	0.6325	0.3959	0.3764	0.3593
	600	0.3205	0.2120	0.2021	0.1920

And according to the simulation results in Table 1 we can conclude that:

- 1) The variable NW estimator gives noticeably better prediction results than the fixed NW estimator.
- 2) The ANW estimator has better performance than the variable NW estimator; same results were obtained by Demir and Toktamış in (2010).
- 3) Our suggested estimator gives better predictive capability in all cases.
- 4) All the estimators are enhanced by increasing the sample size.

Generally and according to our study and the study of Demir and Toktamış in (2010), we can conclude that any modification that aims to increase the local bandwidth factor will give an improved prediction results.

DISCUSSION

The Nadaraya-Watson (NW) kernel estimator is a non-parametric method that can be used for regression estimation, it is an easy and flexible method and has previously been shown to provide an accurate prediction results. In this paper we have proposed a new NW kernel regression estimator as a modification to the adaptive Nadaraya-Watson kernel estimator. Our suggestion based on enhancing the predictive ability of the ANW kernel estimator through increasing the value of the Local bandwidth factor by using the range instead of the arithmetic mean when calculating the bandwidths. By conducting a simulation study with different sample sizes, various NW kernel regression estimators have been compared with our new suggested kernel estimator. The

MNW kernel estimator seems to be superior to the other three NW kernel estimators in all cases. This estimator was more stable in comparison with the other kernel estimators; so according to our study when aiming to estimate the regression function the MNW kernel estimator is recommended.

Conflict of Interest

The authors have not declared any conflict of interest.

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Full Length Research Paper

Effect of transplanting age on seed yield and quality in Davana (*Artemisia pallens*)

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Davana (*Artemisia pallens* Wall ex. D.C.) is an important high valued annual medicinal and aromatic herb of India belonging to the family Asteraceae. An experiment was conducted at Department of Seed Science and Technology, Tamil Nadu Agricultural University, Coimbatore during 2011 to optimize the age of seedling for transplanting Davana to maximize the growth, herbage yield seed yield and seed quality attributes of Davana. The experiment was laid out with five different transplanting age of seedlings viz., 25-, 30-, 35-, 40- and 45-day-old seedlings in pot culture. The results revealed that 35-day-old seedlings exhibited better growth in terms of survival percentage (90%), plant height (45.1 cm), number of branches plant⁻¹ (18.5), number of flower heads plant⁻¹ (87.9), seed yield plant⁻¹ (531.8 mg), 1000 seed weight (110 mg), resultant seed germination (64%) and vigour index (168).

Key words: Age of seedling for transplanting, Davana, dry matter, germination, herbage yield, seed yield, vigour.

INTRODUCTION

Aromatic plants are the natural source of perfumes and fragrance widely exploited by essential oil industries across the world. Davana (*Artemisia pallens* Wall ex. D.C.) is an important high-valued annual aromatic herb of India belonging to the family Asteraceae and commercially cultivated in south India as a short duration crop from November to March. India has a monopoly in production and export trade of davana oil and India stands 3rd in essential oil production in the world. Davana is traditionally used in religious ceremonies and in making garlands, bouquets, floral decorations and floral chaplets, lends an element of freshness and a rich sumptuousness of fragrance to religious occasions (Narayana et al.,

1998). *A. pallens* possesses anti-inflammatory, antipyretic and analgesic properties and it is used in Indian folk medicine for the treatment of Diabetes mellitus (Al-Harbi et al., 1994). The productivity of any crop is the ultimate results of its growth and development and which is mainly depended on the transplanting age of seedlings. Exact age of transplant would therefore be helpful in understanding the relationship between the physiological state of the transplant, its survival in the field and its growth responses under various cultural systems and environments. Since Davana is sexually propagated and then transplanted, an attempt was made to optimize the age of seedling for transplanting Davana to maximize the

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Table 1. Effect of age of transplanting on seedling characters.

Treatment	Field emergence (%)	Seedling length (cm)	Dry matter production (g seedlings ⁻¹⁰)	Vigour index	Survival percentage (%)	Plant height (cm)
25 days seedlings	65 (53.73)	9.4	0.19	611	81 (64.15)	41.0
30 days seedlings	65 (53.73)	11.2	0.38	728	86 (68.02)	43.4
35 days seedlings	65 (53.73)	12.7	0.43	826	90 (71.56)	45.1
40 days seedlings	62 (51.84)	13.4	0.5	831	85 (67.21)	43.5
45 days seedlings	62 (51.84)	13.3	0.54	825	83 (65.65)	43.1
Mean	64	12	0.408	764	85 (67.21)	43.2
SEd	2.50	0.30	0.01	19.34	2.42	0.65
CD (P=0.05)	NS	0.64	0.03	41.23	5.16	1.40

Figures in parentheses indicate arc sine transformed values.

growth, herbage yield seed yield and quality.

MATERIALS AND METHODS

Pure seeds of *Davana* were obtained from the Horticultural College and Research Institute, Periyakulam. An experiment was conducted at Department of Seed Science and Technology, Tamil Nadu Agricultural University, Coimbatore during 2011. The experiment was laid out in a randomized complete block design with four replications. Five different transplanting age of seedlings viz., 25-, 30-, 35-, 40- and 45-day-old seedlings, with the spacing of 7.5 cm to accommodate 10 plants/plot. Based on recommendation 125:125:75 kg/ha. For single pot 6:6:3 mg/pot was calculated based on soil weight of the pot filled.

At the time of transplanting the seedling, seedling length (cm), dry matter production (g/10 seedlings) and vigour index observed. After transplanting, growth attributes such as plant height (cm), days to first flower, days to 50% flowering, number of branches/plant and yield attributes viz., number of flower heads/plant, seed yield/plant, seed yield/plot, 1000 seed mass and herbage yield/plot were recorded. Resultant seed quality such as germination (%) ISTA (1999), seedling length (cm) the distance between the tip of the primary leaf to the tip of the primary root, vigour index (Abdul-Baki and Anderson, 1873) (Table 2). Dry matter production (g seedlings⁻¹⁰) was achieved in an oven maintained at 85°C for 48 h and cooled in a dessicator for 30 min and then weighed in an electronic digital balance. The data obtained from experiments were analyzed by the 'F' test for significance following the method. Wherever necessary, the percent values were transformed to angular (Arcsine) values before analysis. The critical differences (CD) were calculated at 5% probability level.

RESULTS

No significant difference was observed for the field emergence (Table 1). Among the treatments evaluated, 25-day-old seedlings recorded the lowest seedling length, while the highest seedling length was recorded in 40-day-old seedlings, which was on par with that in the 45-day-old seedlings. Significant differences were recorded for dry matter production due to transplanting age of the seedlings. The higher dry matter production was recorded by 45-day-seedling followed by 40-day- seedling, and the lower dry matter production was recorded by 25-day-seedling. The maximum vigour index recorded by 40-day-

seedling which was on par with 45-day-seedling and 35-day-seedling. For survival percentage, the maximum value was recorded by 35-day-seedling and the minimum value recorded by 25-day-seedling. The plant height significantly differed due to age of seedling. The plant height was highest for 35-day-seedling and the lowest plant height recorded by 25-day-seedling.

Among the treatments evaluated, the first flowering came by 35-day-seedling and the late first flowering was recorded by 25-day-seedling. For 50% flowering 25-day-seedling has taken the maximum days and 35-day-seedling has taken the minimum days. For number of branches, the minimum number was recorded by 25-day-seedling and the maximum number recorded by 35-day-seedling. The maximum number of flower heads per plant was recorded by 35-day-seedling and the minimum number of flower heads per plant was recorded by 25-day-seedling. A significant variation in single plant yield was observed due to transplanting age of seedling. The maximum seed yield was recorded by 35-day-seedling and the minimum seed yield was recorded by 25-day-seedling. The higher 1000 seed weight recorded by 35-day-seedling and 25-day-seedling recorded lower 1000 seed weight.

Significant difference was observed in resultant seed quality characters due to transplanting age of seedling. The higher values recorded by the 35-day-seedling and the lower values recorded by the 25-day-seedlings for germination (%), seedling length, dry matter production and vigour Index (Table 3).

DISCUSSION

The age of seedlings at the time of transplanting is also an important contributor for better performance of seedlings. The effect of transplant age on yield is an issue often investigated by growers to maximize production potential. Amongst various factors affecting the yield, lack of high yielding cultivars, supply of inadequate amount of farm yard manure, the age of seedlings at the time of transplanting is an important

Table 2. Effect of age of transplanting on yield attributes.

Treatment	Days to first flowering	Days to 50% flowering	Number of branches plant ⁻¹	Number of flower heads plant ⁻¹	Seed yield plant ⁻¹ (g)	1000 seed weight (mg)
25 days seedlings	50	57	16.2	76.2	4.19	100
30 days seedlings	46	56	17.1	80.6	4.61	101
35 days seedlings	45	53	18.5	87.9	5.31	110
40 days seedlings	48	55	18.0	82.4	4.44	106
45 days seedlings	49	56	17.6	77.8	4.27	104
Mean	48	55	17.48	80.98	4.56	104
SEd	1.35	1.39	0.49	1.23	11.53	2.97
CD (P=0.05)	2.89	2.97	1.06	2.64	24.59	6.33

Table 3. Effect of age of transplanting on resultant seed quality.

Treatment	Germination (%)	Seedling length (cm)	Dry matter production (mg seedlings ⁻¹⁰)	Vigour index
25 days seedlings	58(49.60)	2.23	1.20	129
30 days seedlings	60(50.76)	2.31	1.22	139
35 days seedlings	64(53.13)	2.62	1.23	168
40 days seedlings	62(51.94)	2.45	1.21	152
45 days seedlings	61(51.35)	2.38	1.20	145
Mean	61(51.35)	2.40	1.21	146
SEd	0.66	0.01	0.00	2.25
CD (P=0.05)	1.45	0.04	0.01	4.90

factor (Safina et al., 2006). Hence, the experiment was conducted to optimize the age of transplanting for davana seedlings to maximize the seed yield.

Among the age of seedlings, seedlings transplanted at 35 days recorded the higher vigour index survival percentage. The survival percentage is decreased with increase in the age of seedlings. Plant height of the seedling significantly affected by various ages of transplants. At 35 days old seedlings recorded maximum height followed by 30 and 40 days seedlings. Hence, it could be hypothesized the temperature is quite suitable for younger seedling for better growth. Maximum number of branches (18.5) found in 35 days old seedlings where as the aged seedlings (45 days) transplants produced less number of branches. Overall younger seedlings produced higher numbers of branches than older seedlings, which might be due to less root damage and minimum transplanting shock, as younger seedlings can more easily establish themselves after transplanting in the main field (Naeem et al., 2011). These results agree with the findings of (Shin et al., 1999) in chilly plants and also (Safina et al., 2006). The reason might be the plants are enforced to stop their growth at particular level of temperature. Similar trend was also observed in seed yield and 1000 seed weight. 1000 seed weight is an important yield contributor that depends on genetic makeup and is the least affected by growing conditions (Ashraf et al., 1999). The seedlings transplanted at the age of 35 days recorded

highest seed yield and 1000 seed weight. This might be due to the transplanting of vigorous seedlings. The seed quality characters were significantly influence by transplanting age of seedling. The physiological potential of the seed in terms of germination (64%) and vigour index (168) were higher with the seedling transpalanted at the age of 35 days.

From this study, it can be concluded from all the parameters that 35 days old transplant exhibited best growth in terms of vigour index, survival percentage, plant height, number of branches plant⁻¹, number of flower heads plant⁻¹, seed yield plant⁻¹, 1000 seed weight, resultant and seed germination.

Conflict of Interests

The authors have not declared any conflict of interests.

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