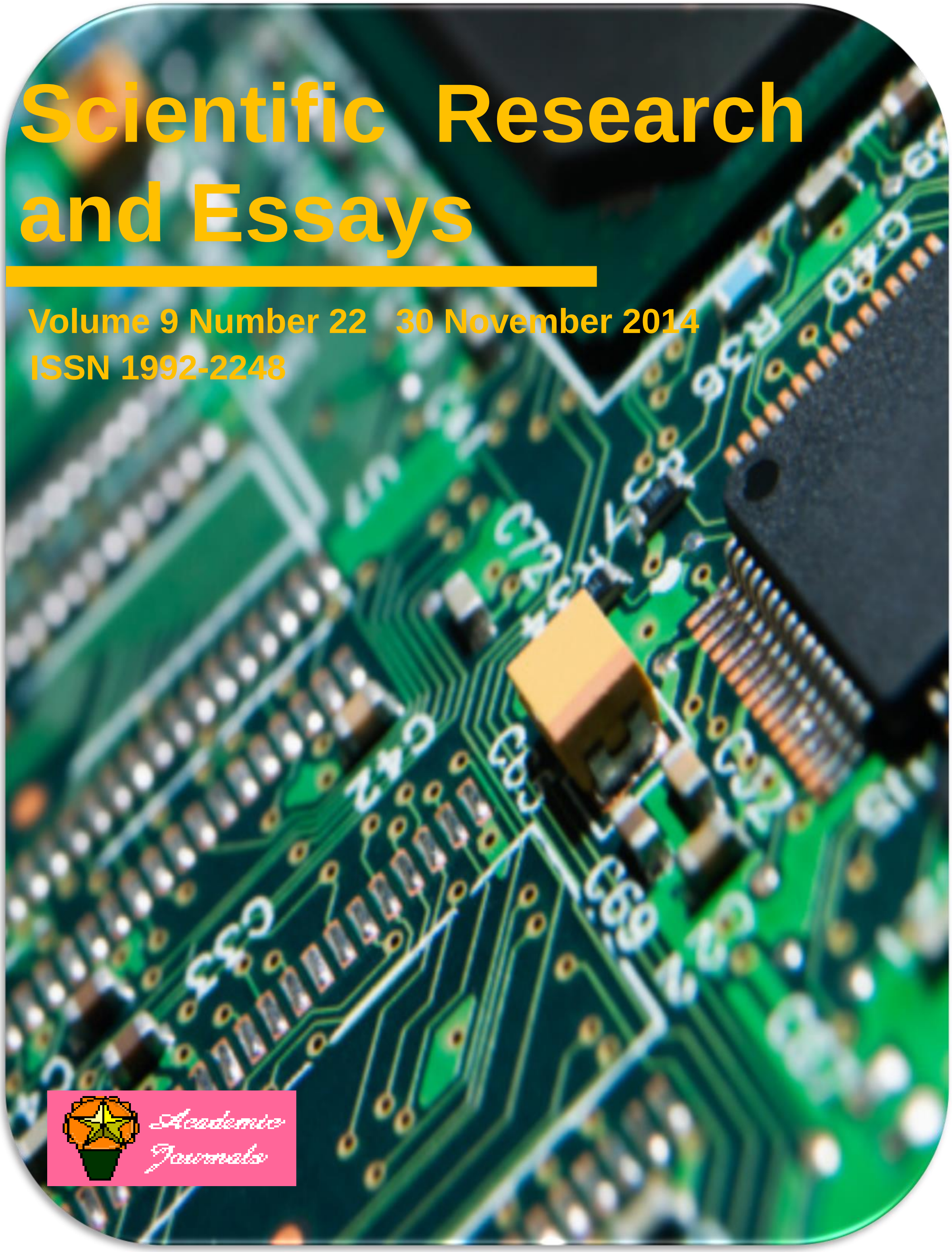
Scientific Research and Essays

Volume 9 Number 22 30 November 2014
ISSN 1992-2248



Academic Journals

ABOUT SRE

The **Scientific Research and Essays (SRE)** is published twice monthly (one volume per year) by Academic Journals.

Scientific Research and Essays (SRE) is an open access journal with the objective of publishing quality research articles in science, medicine, agriculture and engineering such as Nanotechnology, Climate Change and Global Warming, Air Pollution Management and Electronics etc. All papers published by SRE are blind peer reviewed.

Submission of Manuscript

Submit manuscripts as e-mail attachment to the Editorial Office at: sre@academicjournals.org. A manuscript number will be mailed to the corresponding author shortly after submission.

The Scientific Research and Essays will only accept manuscripts submitted as e-mail attachments.

Please read the **Instructions for Authors** before submitting your manuscript. The manuscript files should be given the last name of the first author.

Editors

Editorial Board

n detail.

Fees and Charges: Authors are required to pay a $550 handling fee. Publication of an article in the Scientific Research and Essays is not contingent upon the author's ability to pay the charges. Neither is acceptance to pay the handling fee a guarantee that the paper will be accepted for publication. Authors may still request (in advance) that the editorial office waive some of the handling fee under special circumstances.

Submission of a manuscript implies: that the work described has not been published before (except in the form of an abstract or as part of a published lecture, or thesis) that it is not under consideration for publication elsewhere; that if and when the manuscript is accepted for publication, the authors agree to automatic transfer of the copyright to the publisher.

Disclaimer of Warranties

In no event shall Academic Journals be liable for any special, incidental, indirect, or consequential damages of any kind arising out of or in connection with the use of the articles or other material derived from the SRE, whether or not advised of the possibility of damage, and on any theory of liability.

This publication is provided "as is" without warranty of any kind, either expressed or implied, including, but not limited to, the implied warranties of merchantability, fitness for a particular purpose, or non-infringement. Descriptions of, or references to, products or publications does not imply endorsement of that product or publication. While every effort is made by Academic Journals to see that no inaccurate or misleading data, opinion or statements appear in this publication, they wish to make it clear that the data and opinions appearing in the articles and advertisements herein are the responsibility of the contributor or advertiser concerned. Academic Journals makes no warranty of any kind, either express or implied, regarding the quality, accuracy, availability, or validity of the data or information in this publication or of any other publication to which it may be linked.

Scientific Research and Essays

Table of Contents: Volume 9 Number 22 30 November, 2014

ARTICLES

Research Articles

academicJournals

Vol. 9(22), pp. 932-958, 30 November, 2014
DOI: 10.5897/SRE2014.6113
Article Number: DBFDC3348776
ISSN 1992-2248 © 2014

http://www.academicjournals.org/SRE

Scientific Research and Essays

Full Length Research Paper

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

ISSIFOU Liassou[1], ATANLÉ Kossivi[1], RADJI Raoufou[1,2], LAWSON H. Latekoe[1], ADJONOU Kossi[1,2], EDORH M. Thérèse [1], KOKUTSE A. Dzifa[2], MENSAH A. Akossiwoa[3] and KOKOU Kouami[2]*

[1]Laboratory of Algology and Palynology, Faculty of Science, University of Lomé, P. O. Box 1515, Lomé, Togo.
[2]Laboratory of Botany and Plant Ecology, Faculty of Science, University of Lomé, P. O. Box 1515, Lomé, Togo.
[3]Laboratory of Plant Physiology and Biotechnology, Faculty of Science, University of Lomé, P. O. Box 1515, Lomé, Togo.

Received 9 September, 2014; Accepted 13 November, 2014

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%), Chorophyceae (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

*Corresponding author. E-mail: kokoukouami@hotmail.com, Tel: (+228) 90020411.

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 km^2 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 6^{th} and the 11^{th} degree of latitude and between the 0^{th} and 2^{nd} 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 (Koumongou, 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 coastine 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. Beyong 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 rn (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 (Throndsen, 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 mnimum 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

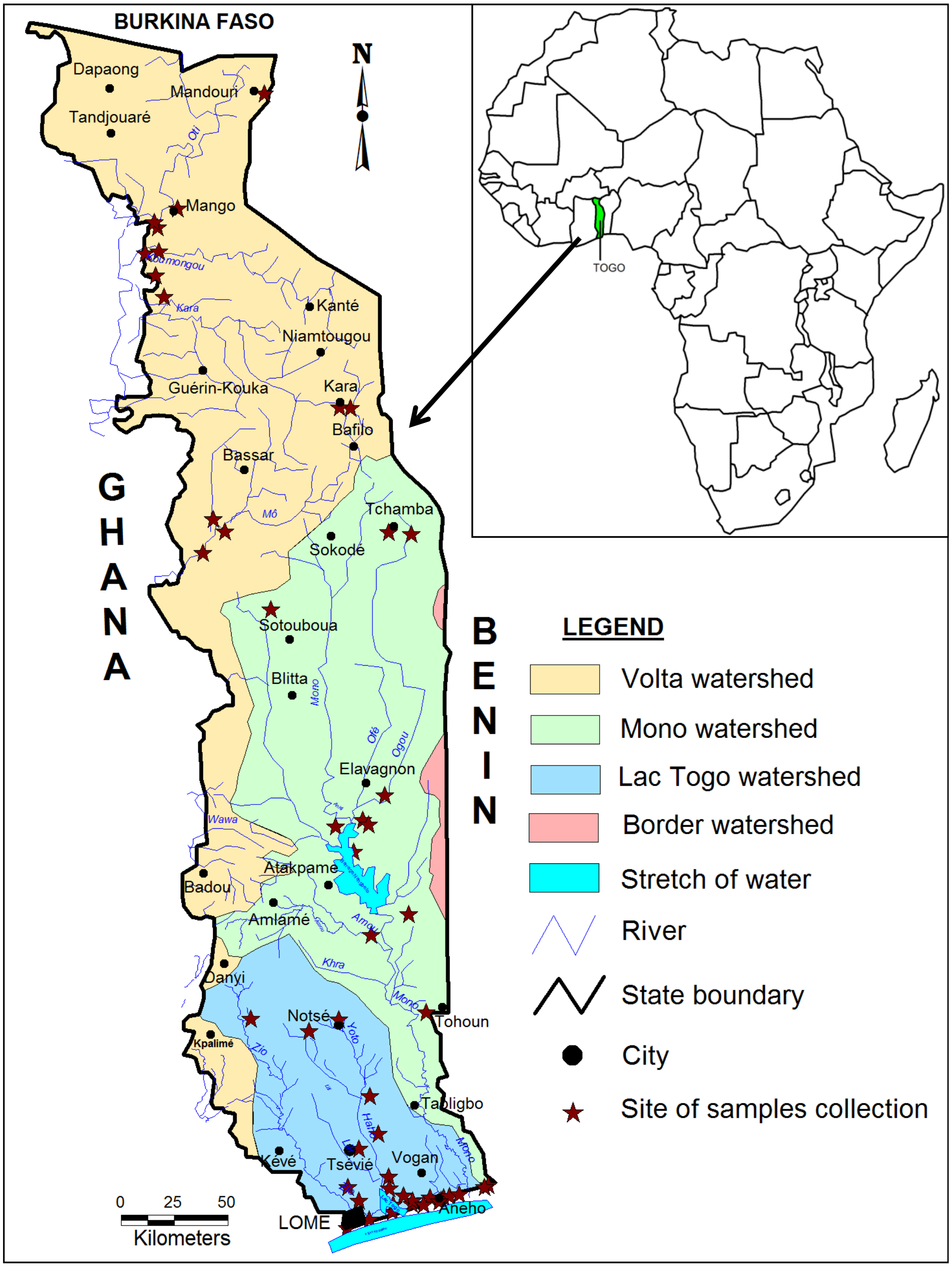


Figure 1. Siting of sampling.

thanks to a Pasteur pipette. This drop is deposited in between slides then observed with the photon microscope adaped 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

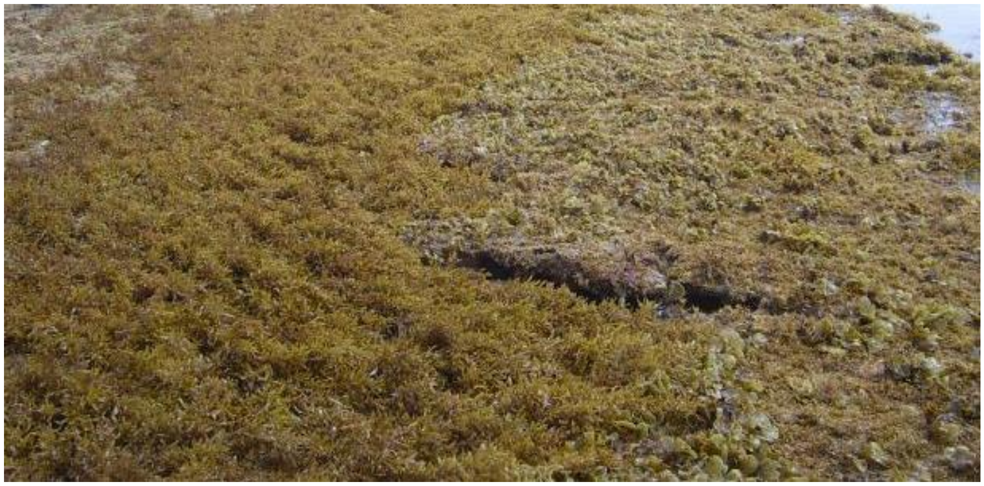


Photo 1. Seaweeds cropping up on the beach-rock in low normal tides.

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			
Navicula	Naviculaceae	31	4
Nitzschia	Nitzschiaceae	22	3
Pinnularia	Naviculaceae	16	2
II- Chlorophyceae			
Scenedesmus	Scenedesmaceae	29	4
Closterium	Desmidiaceae	24	3
Cosmarium	Desmidiaceae	24	3
Staurastrum	Desmidiaceae	14	2
III- Cyanophyceae			
Oscillatoria	Oscillatoriaceae	22	3
Lyngbya	Oscillatoriaceae	8	1
IV- Euglenophyceae			
Trachelomonas	Euglenaceae	27	3
Phacus	Euglenaceae	18	2
Strombomonas	Euglenaceae	9	1

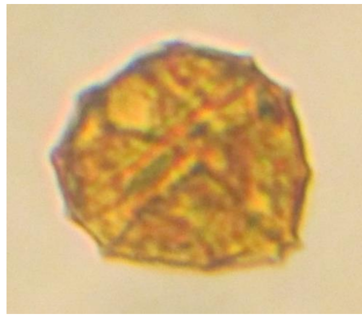
over the coastline. The samples are taken during low tide on the hard substrata on foot in the encroachment zones and other hard substrata of the coastline by diving. The fishermen's nets once back from sea are scrutinized to find algae brought in. Moreover, more systematic harvest was conducted on the 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 theidentification, 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 microalga 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)



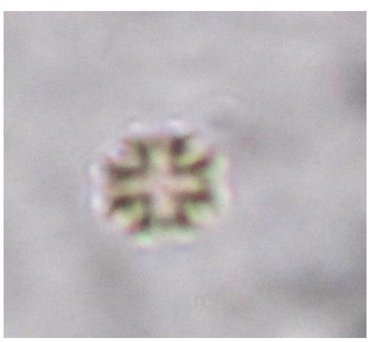
Peridiniopsis sp. (Dinophyceae)

Euglena oxyuris Schmarda (Euglenophyceae)

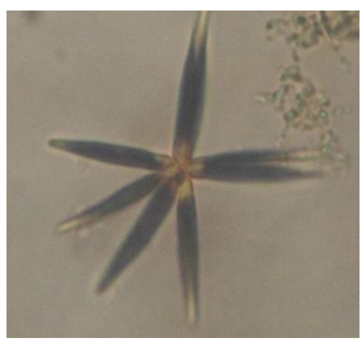
Phormidium tenue Anagnostidis & Komárek (Cyanophyceae)

Closterium lineatum Ehrenberg ex Ralfs (Conjugatophyceae)

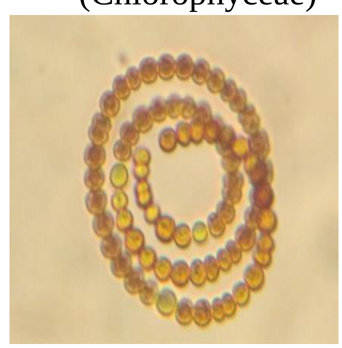
Hyaloraphidium contortium Pasch. y Korch (Chlorophyceae)



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, Hydrodictyaceae, 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		
Naviculaceae	44	6
Bacillariaceae	34	4
Pinnulariaceae	17	2
Eunotiaceae	14	2
2- Chlorophyceae		
Desmidiaceae	81	10
Scenedesmaceae	53	7
Hydrodictyaceae	15	2
Chlamydomonadaceae	12	2
Oocystaceae	12	2
Selenastraceae	10	1
3- Euglenophyceae		
Euglenaceae	54	7
Phacaceae	27	3
4-Cyanophyceae		
Oscillatoriaceae	36	5
Nostocaceae	21	3
Gomphosphaeriaceae	13	2
Merismopediaceae	11	1
5- Fragilariophyceae		
Fragilariaceae	19	2
6- Dinophyceae		
Diplopsaliaceae	10	1
7- Coscinodiscophyceae		
Stephanodiscaceae	10	1

terms of species richness are the Bacillariophyceae (26%), Cyanophyceae (17%), Chorophyceae (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, Raphydophyceae 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 (Iltis, 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		
Bacillariophyceae	204	26
Coscinodiscophyceae	30	4
Dinophyceae	27	3
Fragilariophyceae	23	3
Xanthophyceae	15	2
Chrysophyceae	6	1
Cryptophyceae	5	1
Synurophyceae	5	1
II- Chlorophyta		
Chorophyceae	126	16
Conjugatophyceae	95	12
Trebouxiophyceae	21	3
Ulvophyceae	8	1
Nephrophyceae	1	-
Raphydophyceae	1	-
III- Cyanophyta		
Cyanophyceae	132	17
IV- Euglenophyta		
Euglenophyceae	91	11
V- Rhodophyta		
Florideophyceae	3	-
Rhodophyceae	1	-
Stylonematophyceae	1	-

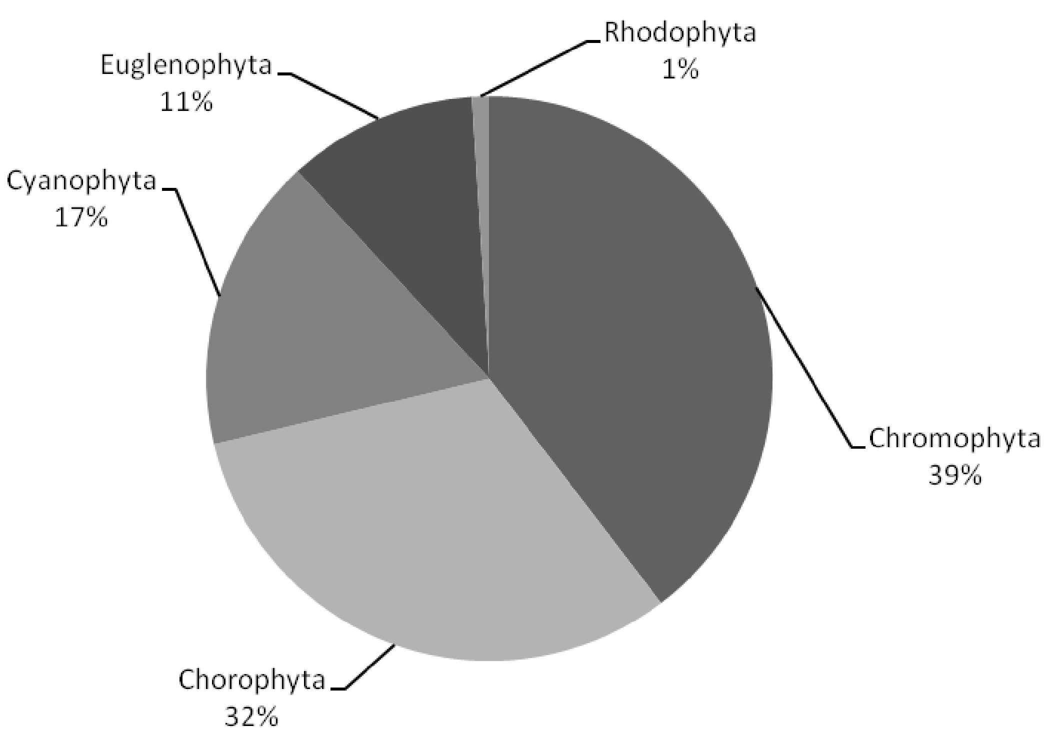


Figure 2. Distribution of the microalgae Division in Togo.

Table 4. Macroalgae collected in Togo.

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

comta Kűtz., *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, *Microcytis 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 nowaday 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

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 Euchlorophyceae (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 phytoplankter 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.

ACKNOWLEDGEMENTS

This work was conducted in the frame work of the Advanced Learning Support Project (PAES) in the member states of the West African Economic and Monetary Union – WAEMU P- Z1 – IAD – 002, Don : 2100155007376. The authors express their sincere gratitude to the West African Economic and Monetary Union.

REFERENCES

Atanlé K, Bawa LM, Kokou K, Djaneye-Boundjou G, Edorh MT (2013). Distribution saisonnière du phytoplancton en fonction des caractéristiques physico-chimiques du lac de Zowla (Lac Boko) dans le Sud-Est du Togo: Cas de la petite saison sèche et de la grande saison sèche. Journal of Applied Biosciences (JABs) 64:4847-4857. http://dx.doi.org/10.4314/jab.v64i1.88474

Bandje A (2004). Recensement des algues marines du Togo: caractérisation et distribution; Mém. Ing. Travaux; GEE-ESTBA/UL., 43 pp.

Bandje A (2010). Diversité et dynamique du phytoplancton dans les écosystèmes aquatiques du sud-ouest du Togo; Mém. DEA-FDS/UL, 46 pp.

Behrenfeld MJB, James T, Randerson JT, McClain RC, Feldman CG, Los OS, Tucker JC, Falkowski GP, Field B C, Field FR, Esaias EW, Kolber DD, Pollack NH (2001). Biospheric primary production during an ENSO transition. Science 291:2594-2597. http://dx.doi.org/10.1126/science.1055071

Blivi A. (1993). Géomorphologie et dynamique actuelle du littoral du Golfe du Bénin (Afrique de l'Ouest). Thèse de doctorat, Université de Bordeaux III., 458 pp.

Bourrelly P (1968). Les algues jaunes et brunes (Tome II). Ed. Boubée: Paris, pp. 438.

Bourrelly P (1970). Les algues bleues et rouges (Tome I). Ed. Boubée: Paris, p. 511. Bourrelly p. 1972. Les algues vertes (Tome III). Ed. Boubée: Paris, pp. 572.

Bourrelly P (1972). Les Algues d'eau douce. Initiation à la Systématique. Les Algues vertes Jaunes et les Brunes, et les Algues Bleues et Rouges. Paris, éd. N. Boubée.

Bourrelly P (1990). Les Algues d'Eau Douce. Initiation à la Systématique. Tome I: les Algues Vertes. Ed. Boubée: Paris, 511 pp.

Cadoret PP, Bernard O (2008). La production de biocarburant lipidique avec des micro-algues: Promesses et défis. J. de la Société de Biologie, 202(3):201-211. http://dx.doi.org/10.1051/jbio:2008022

Cetto JM, Leandrini JA, Felisberto SA, Rodrigues L (2004). Periphyton algae community in Irai reservoir, Parana State, Brazil, Acta Scientiarium: Biol. Sci. 26(1):1–7.

Colocoloff C (1980). Rapport de prospection sur les algues marines du Togo. Document Interne, Faculté des Sciences, Université de Lomé.

Compère P (1991). Contribution à l'étude des algues du Sénégal I: Algues du lac de Guiers et du Bas-Sénégal. Bull. Jardin Botanique Nat Belg., 61:171-267. http://dx.doi.org/10.2307/3668149

Coute A, Rousselin F (1975). Contribution à l'étude des algues d'eau douce du Moyen Niger (Mali). Bul. Mus. Nat. Hist. Nat. Paris Ser. 3, 277 Bot., 21:73-176.

Druart JC, Rimet F (2008). Protocoles d'analyse du phytoplancton de l'INRA: Prélèvement, dénombrement et biovolumes. INRA-Thonon, Rapport SHL 283 96 pp.

Druart JC, Robert M, Tadonleke R. (2005). The phytoplankton of Lake Geneva. Rap. Com. Int. pro. Eaux Léman contre pollution. pp. 89-100.

Edorh T, Blivi A, Bandje A, Abotsi K (2008). Présence d'algues toxiques dans les eaux marines et saumâtres du littoral togolais. Annales des Sciences Agronomiques du Bénin 10(2):165-177.

Farid Y, Etahiri S, Assobhei O (2009). Activité antimicrobienne des algues marines de la lagune d'Oualidia (Maroc): Criblage et optimisation de la période de la récolte. J. Appl. Biosci. 24:1543–-1552.

Felisberto SA, Rodrigues L (2005). Comunidades de algas perifiticas em reservatorios de diferentes latitudes. In: L. Rodrigues L, S.M. Thomaz SM, A.A. Agostinho AA, L.C. Gomes LC (Eds.), Biocenoses em Reservatorios: Padroes Espaciais e Temporais, Rima, Sao Carlos, pp. 97–114.

Feng J, Wang F, Xie S (2011). Structure and dynamics of the periphytic algae of Jinyang Lake in Shanxi Province, North China. Acta Ecologica Sinica 31:310-316. http://dx.doi.org/10.1016/j.chnaes.2011.07.003

Field CB, Behrenfeld MJ, Randerson JT, Falkowski P (1998). Primary production of the biosphere: Integrating terrestrial and oceanic components. Science 281:237-240. http://dx.doi.org/10.1126/science.281.5374.237

Fonseca IA, Siqueira NS, Rodrigues L (2008). Algas perifiticas a montante e a jusante do local de instalacao de tanques-rede em tributarios do reservatorio de Rosana, Estado do Parana, Brasil, Acta Scientarium: Biol.ogical Sciences. 31(2):135-141.

Gnofam N (2010). Variation saisonnière des paramètres physico-chimiques et du phytoplancton du lac de Zowla (lac Boko); Mém. Ing. Travaux; GEE-ESTBA/UL 47 pp.

Grönblad R, Prowse GA, Scott AM (1958). Sudanese Desmids. Acta Botanica Fennica 58:1-82.

Guiry MD, Guiry GM (2014). Algae Base.World-wide electronic publication, National University of Ireland, Galway. http://www.algaebase.org.

Iltis A (1980). Les Algues. In Durand J-R (ed.), Lévêque C. (ed.). Flore et faune aquatiques del'Afrique sahélo-soudanienne: tome 1. Paris : ORSTOM, 1980, pp. 9-61. (Initiations-Documentations Techniques; 44). http://www.documentation.ird.fr/hor/fdi:00552

Issifou L (2012). Contribution à l'étude de la diversité et de la dynamique du phytoplancton de la lagune de Lomé; Mém. Ing. Travaux; GEE-ESTBA/UL 44 pp.

Komarèk J, Anagnostidis K (1995). Cyanoprokaryota. Sübwasserflora von Milleleuropa pp. 49-96.

Krammer (de) K, Lange-Bertalot H (1986-2000). Bacillariophyceae. In: Susswasserflora von Mitteleuropa (Ettl H., Gerloff J., Heynig H., Mollenhauer D., eds). Spektrum Akademischer Verlag, Heidelberg, Berlin, pp. 1-5.

Lauterborn R (1915). Die sapropelische lebewelt. (Ein Beitrag zur biologie des Faulschlammes. Natürlicher Gewässer) Verh. Naturhist. Mediz. Ver. Heidelberg, N.F., 13:317-323.

Lavoie I, Hamilton PB, Campeau S, Grenier M, Dillon PJ (2008). Guide d'identification des Diatomées des Rivières de l'Est du Canada. Presses de l'Université de Québec, 341 pp.

Léné F (2004). Evaluation de l'état actuel de la lagune de Lomé; Mém. Ing. Travaux; GEE-ESTBA/Université de Lomé; 46 pp.

Nielsen ES (1933). Uber Quantitative Untersuchungenvon Marinem Plankton mit Utermohl'sumgekehrten Mikroskop. Journal du Conseil International pour l'Exploration de la Mer. 8:201-210. http://dx.doi.org/10.1093/icesjms/8.2.201

Priyadarshani I, Rath R (2012). Commercial and industrial applications of micro algae – A review. J. Algal Biomass Utln. 3(4):89-100.

Radji R, Bandje A, Issifou L, Edorh T, Kokou K (2013). Diversité et dynamique des assemblages phytoplanctoniques dans les écosystèmes aquatiques au Sud du Togo. Afrique Sci. 9(2). http://www.afriquescience.info/document.php?id=2781. ISSN 1813-548X .

Saadou M (1998). Evaluation de la biodiversité biologique au Niger: éléments constitutifs de la biodiversité végétale. Conseil National de l'Environnement pour un Développement Durable SE/CNEDD. Projet NER/97/G31/A/1G/99, "Stratégie Nationale et plan d'action - Diversité Biologique", 138 pp.

Sayre R (2010). Microalgae: The Potential for Carbon Capture. BioScience 60:722–727. ISSN 0006-3568, electronic ISSN 1525-3244.

Segniagbeto G, Van Waerebeek K (2010). A note on the occurrence and status of cetaceans in Togo. IWC Scientific Committee document SC/62SM11.

Skuja H (1956). Taxonomische und bioloische Studien Uber Das Phytoplankton Schwedischer Binnengewässer Nova acta regiae societatis scientiarum. Upsaliensis Ser. 4, 16, 3:1-404.

Sournia A (1968). Diatomées planctoniques du Canal de Mozambique et de l'Ile Maurice. Mem. O.R.S.T.O.M., 31. Paris, 120 pp.

Sydney EB, Sturm W, de Carvalho JC, Thomaz-Soccol V, Larroche C, Pandey A, Soccol, CR (2010). Potential carbon dioxide fixation by industrially important microalgae. Bioresour. Technol. 101:5892-5896. http://dx.doi.org/10.1016/j.biortech.2010.02.088

Throndsen J (1978). Preservation and storage. In Phytoplankton manual. Monographs on oceanographic methodology, Sournia A (ed). UNESCO, pp. 67-74.

Tourte Y, Bordonneau M, Henry M, Tourte C (2005). Le monde des végétaux: organisation, physiologie et génomique; Paris: Dunod, 384 pp.

Vermaat JE (2005). Periphyton dynamics and influencing factors. In: M.E. Azim, M.C.J. Verdegem, AA Van Dam, MCM Bederidge (Eds.), Periphyton Ecology, Exploitation and Management, CABI Publishing, Cambridge.

Zongo F, Zongo B, Boussim JI, Coute A (2008). Nouveaux taxa de micro-algues dulçaquicoles pour le Burkina Faso (Afrique de l'Ouest): I-Chlorophyta. Int. J. Biol. Chem. Sci. 2(4):508-528.

ANNEXES

Checklist of Togolese Microalgae.

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

Annexes Contd.

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

Annexes Contd.

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

Annexes Contd.

	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 lundelii Delp.
	Cosmarium pachidermum Luud. El Pardo
	Cosmarium pseudoconnatum Nordstedt
	Cosmarium quadratulum 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 (Börges.) 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.

Annexes Contd.

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

Annexes Contd.

		Ulva sp.
II- Chromophyta		
2.1- Bacillariophyceae	**2.1.1- Achnanthaceae**	*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.) Kűtz.
		Amphiprora alata (Ehr.) Kűtz.
		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 Kűtz.
		Nitzschia recta Hantzsch ex Rabenhorst
		Nitzschia reversa Smith
		Nitzschia scalaris Ehrbg.
		Nitzschia sigma Kűtz.
		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	*Wollea saccata* Wolle
	2.1.6- Chroomonadaceae	*Chroomonas* sp
		Chroomonas minuta Skuja.
		Chroomonas rubra (Geitler)
	2.1.7- Cocconeidaceae	*Cocconeis placentula* (Ehr.) Grun.
	2.1.8- Cymbellaceae	*Cymbella caespitosa*(Kützing) Brun
		Cymbella cistula (Ehrenberg) O.Kirchner
		Cymbella cuspidala Kutzing.
		Cymbella lacustris (C.Agardh) Cleve
		Cymbella prostata (Berkeley)Cleve
		Cymbella sp.
		Cymbella turgidula Grun.
		Cymbella ventricosa Cleve
	2.1.9- Diploneidaceae	*Diploneis didyma* (Ehrenberg) Ehrenberg
		Diploneis elliptica Cleve
		Diploneis interrupta Kűtz.
		Diploneis marginestriata Cleve
		Diploneis mauleri(Brun) Cleve
		Diploneis oculata (Brébisson) Cleve
		Diploneis ovalis Cleve
		Diploneis smithii (Brébisson) Cleve
		Diploneis interrupta (Kützing) Cleve
	2.1.10- Eunotiaceae	*Eunotia faba* Ehrbg.
		Eunotia guyanense (Ehr.) de Toni.
		Eunotia incisa W.Smith ex W.Gregory
		Eunotia monodon Ehrenberg
		Eunotia parallela Ehrbg.
		Eunotia pectinalis (Kützing) Rabenhorst
		Eunotia robusta Ralfs
		Eunotia serpentina Ehrenberg
		Eunotia sp.
		Schizothrix fuscescens Kutzing ex Gomont
		Schizothrix lacustris A.Braun ex Gomont
		Actinella sp.
		Actinella brasiliensis Grunow.
		Actinella mirabilis Grunow
	2.1.11- Gomphonemataceae	*Gomphoneis herculaneum* Ehrbg.
		*Gomphoneis intricatum*Kutzing
		Gomphonema acuminatum Ehrenberg
		Gomphonema angur Ehr.
		Gomphonema angustatum Grun.
		Gomphonema constrictum Ehrbg.
		Gomphonema gracile Ehrenberg
		Gomphonema intricatum Kützing
		Gomphonema olivaceum (Hornemann) Brébisso
		Gomphonema olivatum Kűtz.
		Gomphonema sp.
	2.1.12- Mastagloiaceae	*Mastogloia pumilla* (Cleve & Möller) Cleve.
		Mastagloia grevillei (Hassall) Elenkin.
		Mastagloia sp.
		Mastagloia smithii Grun.
	2.1.13- Naviculaceae	*Anemoeoneis sphaerophora* (Kutz.) Pfitz.

Annexes Contd.

	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 Kűtz.
	Navicula cuspidata Kűtz.
	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 Kűtz.
	Navicula ovalis Smith
	Navicula perigrina (Ehrenberg) Kützing
	Navicula placenta Ehrbg.
	Navicula placentula (Ehrenberg) Kützing
	Navicula punctatae(Kützing) Donkin
	Navicula pupula Kűtz.
	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 Kűtz.
	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

Annexes Contd.

		Pinnularia gibba Ehrenberg
		Pinnularia lata (Brébisson) W.Smith
		Pinnularia legumen Ehrenberg
		Pinnularia maior Ehrbg.
		Pinnularia mesolepta (Ehrenberg) W.Smith
		Pinnularia neomajor K.Krammer
		Pinnularia platycephala (Ehrenberg) Cleve
		Pinnularia sp.
		Pinnularia undulata W.Gregory.
		Pinnularia viridis (Nita) Ehr.
		Diatomella hustedtii E. E. Maguin
	2.1.16- Pleuromastigaceae	*Gyrosigma acuminatum* Kűtz*.*
		Gyrosigma angulatum Quekett) Griffith & Henfrey
		Gyrosigma attenuatum (Kützing) Cleve
		Gyrosigma diminutum (W.Smith) Cleve.
		Gyrosigma hippocampus (Ehrenberg) Hassall
		Gyrosigma sp.
		Pleuromastix bacillifera A.Scherffel
		Xanthodiscus lauterbachi Schewk.
	2.1.17- Rhizosoleniaceae	*Rhizosolenia calcar-avis* M.Schultze
		Rhizosolenia obtusa Hensen
		Rhizosolenia sp.
	2.1.18- Rhoicospheniaceae	*Rhoicosphenia curvata* (Kützing) Grunow
	2.1.19- Rhopalodiaceae	*Epithemia argus* (Ehrenberg) Kützing
		Epithemia hyndmanni W. Smith
		Epithemia sp.
		Epithemia turgida Ehrbg.
		Rhopalodia gibberula (Ehrenberg) Otto Müller
		Rhopalodia gibba (Ehrenberg) Otto Müller
	2.1.20- Stauroneidaceae	*Stauroneis acuta* W.Smith
		Stauroneis anceps Ehrbg.
		Stauroneis brasiliensis (C.Zimmermann) P.Compère
		Stauroneis crucicula Grun.
		Stauroneis phoenicenteron (Nitzsch) Ehrenberg
		Stauroneis sp.
	2.1.21- Stephanodiscaceae	*Cyclotella bodanica* Eulenstein ex Grunow
		Cyclotella comta Kűtz.
		Cyclotella distinguenda Hustedt
		Cyclotella ocellata Pantocsek
		Cyclotella sp.
		Cyclotella stelligera Cleve & Grunow
		Cyclotella styariaca Kűtz.
		Stephanodiscus parvus Stoermer & Håkansso*n*
		Stephanodiscus astrae (Ehrenberg) Grunow
	2.1.22- Surirellaceae	*Surirella angustata* Kützing
		Surirella biseriata Brébisson in Brébisson & Godey
		Surirella capronii Bréb.
		Surirella verrucosa Pantocsek
		Surrirella robusta Ehr.
		Cymatopleura solea (Brébisson & Godey) W. Smith
		Stenopterobia intermedia F.W.Lewis
2.2- Chrysophyceae	**2.2.1- Chromulinaceae**	*Dinobryon* sp.

Annexes Contd.

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

Annexes Contd.

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

Annexes Contd.

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

Annexes Contd.

	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	*Mastigocoleus* sp.
	3.1.16- Nostochopsidaceae	*Nostochopsis lobatus* Wood
	3.1.17- Oscillatoriaceae	*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.
		Oscillataria amphibia Agardh
		Oscillataria limosa Gom.
		Oscillataria 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 jenneri*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.

Annexes Contd.

		Oscillatoria sancta Kützing ex Gomont
		Oscillatoria sp.
		Oscillatoria tenuis Ag.
		Oscillatoria terebriformis C.Agardh ex Gomont
		Plectonema malayense Biswas
		Plectonema purpueum Gomont
		Plectonema sp.
		Rhizosolenia eriensis H.L.Smith
		Rhizosolenia longiseta O.Zacharias
		Rhizosolenia setigera Brightwell
	3.1.17- Phormidiaceae	*Ammatoidea* sp.
		Phormidium autumnale Kützing ex Gomont
		Phormidium luridum (Kützing) Gomont
		Phormidium chalybeum (Mertens ex Gomont) Anagnostidis & Komárek
		Phormidium formosum (Bory de Saint-Vincent ex Gomont) Anagnostidis & Komárek
		Phormidium hamelii (Frémy) Anagnostidis & Komárek
		Phormidium ornatum (Kützing ex Gomont) Anagnostidis & Komárek
		Phormidium sp.
		Phormidium tenue Anagnostidis & Komárek
	3.1.18- Pseudanabaenaceae	*Planktolyngbya limnetica* (Lemm.) J.Komárk-Legnerová & G.Cronberg
		Schizothrix sp.
		Pseudanabaena catenata Lauterborn
		Pseudanabaena sp.
	3.1.19- Rivulariaceae	*Calothrix braunii* Bornet and Flahault
		Calothrix gypsophila (Kütz.) Thuret
		Gloeotrichia echinulata P.Richter
		Gloeotrichia sp.
		Rivularia aquatica De Wildeman
	3.1.20- Scytonemataceae	*Tolypothrix roberti-lamii* Bourrelly in Bourrelly & Manguin.
	3.1.21- Spirulinaceae	*Spirulina gigantea* Schmidle
		Spirulina maxima Setch.
	3.1.22- Symphyonemataceae	*Iyengariella tirupatiensis* Desikachary
	3.1.23- Synecchoccocaceae	*Synechococcus vantieghemi* Pringsheim
		Synechococcus nidulans Largerh.
		Synechococcus leopoliensis (Raciborski) Komárek
		Synechococcus linearis (Schmidle & Lauterborn) Komárek
		Synechococcus major f. crassior Lagerheim
		Synechococcus sp.
		Synechococcus aeruginosa Nägeli
IV- Euglenophyta		
4.1- Euglenophyceae	**4.1.1- Astasiaceae**	*Distigma* sp
		Gyropaigne lefevrei Bourrelly & Georges
		Rhabdomonas incurva Fresenius
		Rhabdomonas sp.
		Rhabdomonas tortuosum (Stockes)
		Sphenomonas sp.
	4.1.2- Euglenaceae	*Cryptoglena pigra* Ehrenberg
		Euglena acus 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	*Eutreptia thiophila* Skuja
	4.1.4- Glenodiniopsidaceae	*Sphaerodinium polonicum*Woloszynska
	4.1.5- Peranemataceae	*Peranema tortuosum* (Christen).
	4.1.6- Petalomonadaceae	*Dylakosoma pelophilum* Skuja
	4.1.7- Phacaceae	*Lepocinclis acuminatum* Deflandre
		Lepocinclis caudata A.M. Cunha
		Lepocinclis colligera Deflandre
		Lepocinclis fusiformis (H.J.Carter) Lemmermann
		Lepocinclis marsonii Lemm. Waikato R., Mercer (T).
		Lepocinclis ovum Lemm.
		Lepocinclis sp.
		Lepocinclis stenii Lemm.
		Lepocinclis texta (Dujardin) Lemmermann.
		Phacus acuminatus Stokes
		Phacus agilis Skja.
		Phacus applanatus Poch
		Phacus caudatus Hübner
		Phacus ephipion Ehrbg.
		Phacus gamsii Bourrelly
		Phacus inflexus Conard
		Phacus longicauda (Ehr.) Dujardin
		Phacus mentaweiensis Conrad
		Phacus meson Ehrbg.
		Phacus minutus (Playfair) Pochmann.
		Phacus onyx Pochmann
		Phacus orbicularis Hűbn.
		Phacus oscillans Klebs
		Phacus pulcher Y.V.Roll
		Phacus sp.
		Phacus tortuosum (Lemmermann) Skvortzov
		Phacus tortus (Lemmermann) Skvortzov
V- Rhodophyta		
5.1- Florideophyceae	**4.1.1- Wrangeliaceae**	*Ptilothamnion richardsii* Skuja
	4.1.2- Rhodomelaceae	*Bostrychia scorpioides* (Hudson) Montagne
	4.1.3- Caulacanthaceae	*Sterrocladia amnica*(Montagne) F.Schmitz
5.2- Rhodophyceae	**4.1.5- Acrochaetiaceae**	*Andouinella violacea* (Kütz.)
5.3- Stylonematophyceae	**4.1.6- Stylonemataceae**	*Chroodactylon* sp.

academicJournals

Vol. 9(22), pp. 959-965, 30 November, 2014
DOI: 10.5897/SRE11.528
Article Number: 3AAD50E48778
ISSN 1992-2248 © 2014

http://www.academicjournals.org/SRE

Scientific Research and Essays

Full Length Research Paper

Design considerations for a sustainablepower energy system in Khartoum

Abdallah Z. M. E.[1,2]*, M. F. M. Zain[1] and Sopin K.[3]

[1]Department of Architecture Engineering,Faculty of Engineering and Built of Environment, Universiti Kebangsaan Malaysia, 43600, UKM, Bangi, Selangor D. E., Malaysia.
[2]Department of Architecture, Faculty of Engineering Science, Omaurman Islamic University, Sudan.
[3]Solar Institute (SERI), Universiti Kebangsaan Malaysia, 43600, UKM, Bangi, Selangor D. E., Malaysia.

Received 11 March, 2011; Accepted 11 November, 2014

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

*Correspondence author. E-mail: zeinab3007@yahoo.com. Tel: +6143296490.

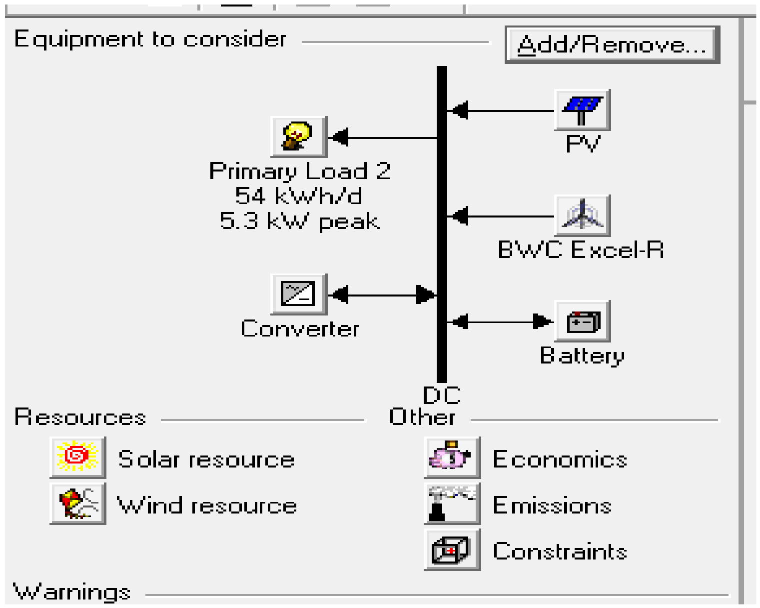


Figure 1. Schematic diagram of hybrid power system.

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 3º N 23ºN and longitude 21º.45/E and 39ºE. 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

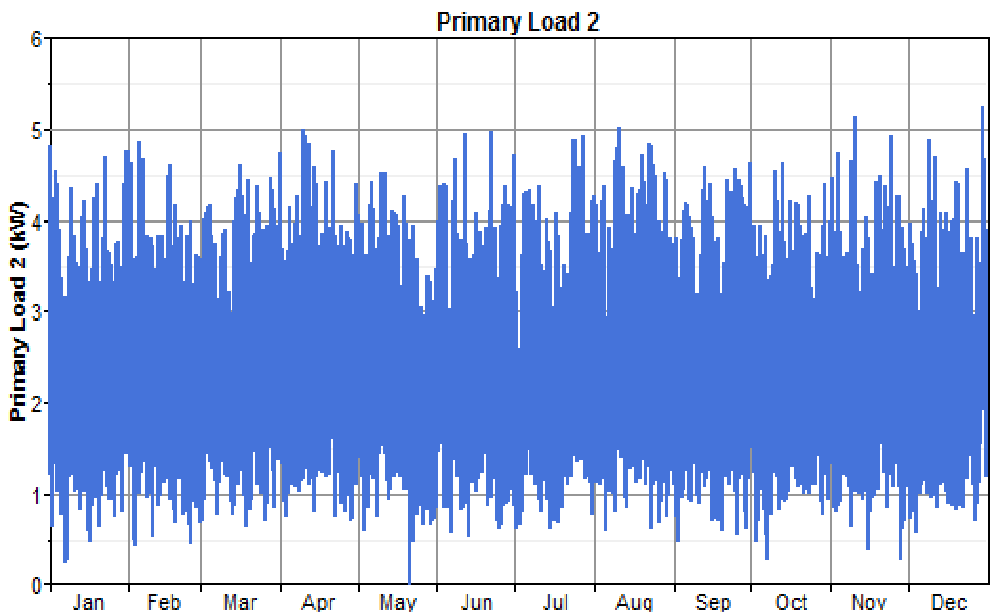


Figure 2. Primary load 2.

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

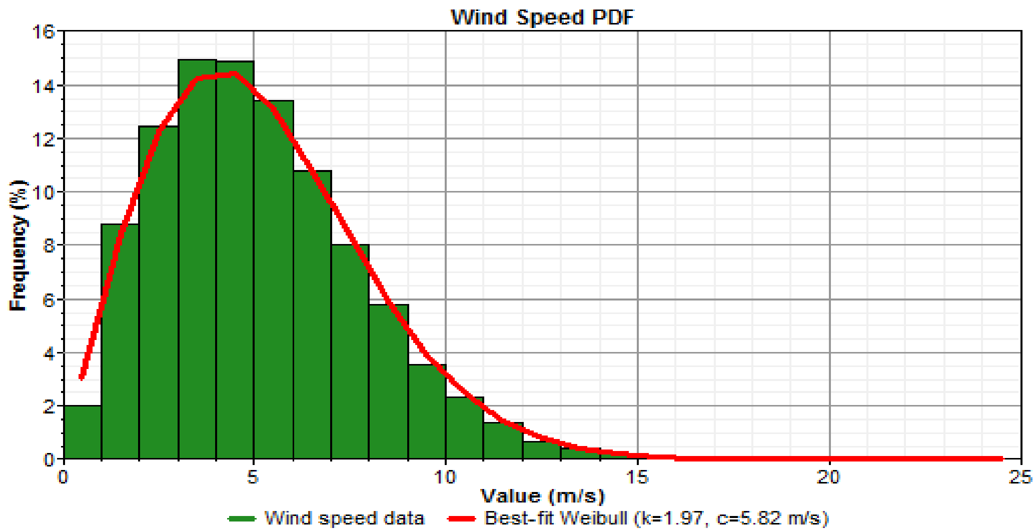


Figure 3. Solar analysis diagrams.

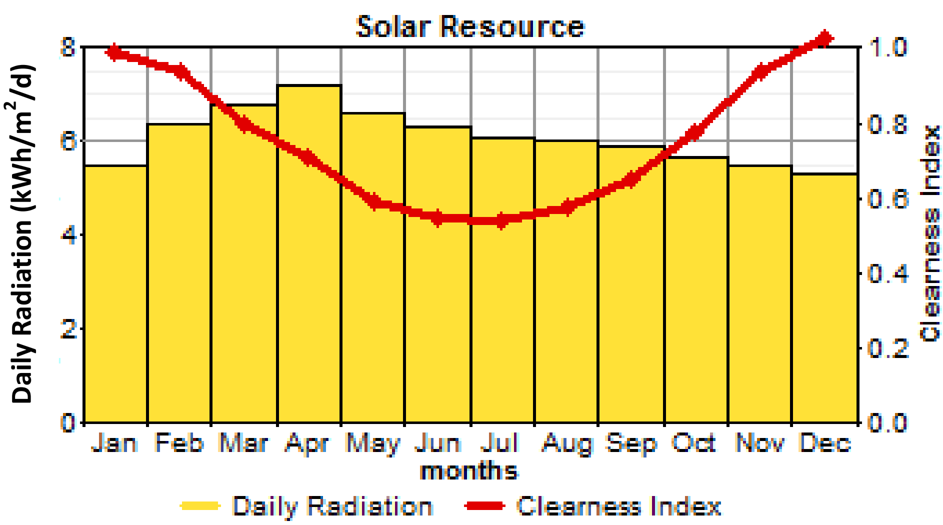


Figure 4. Daily wind speed.

(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

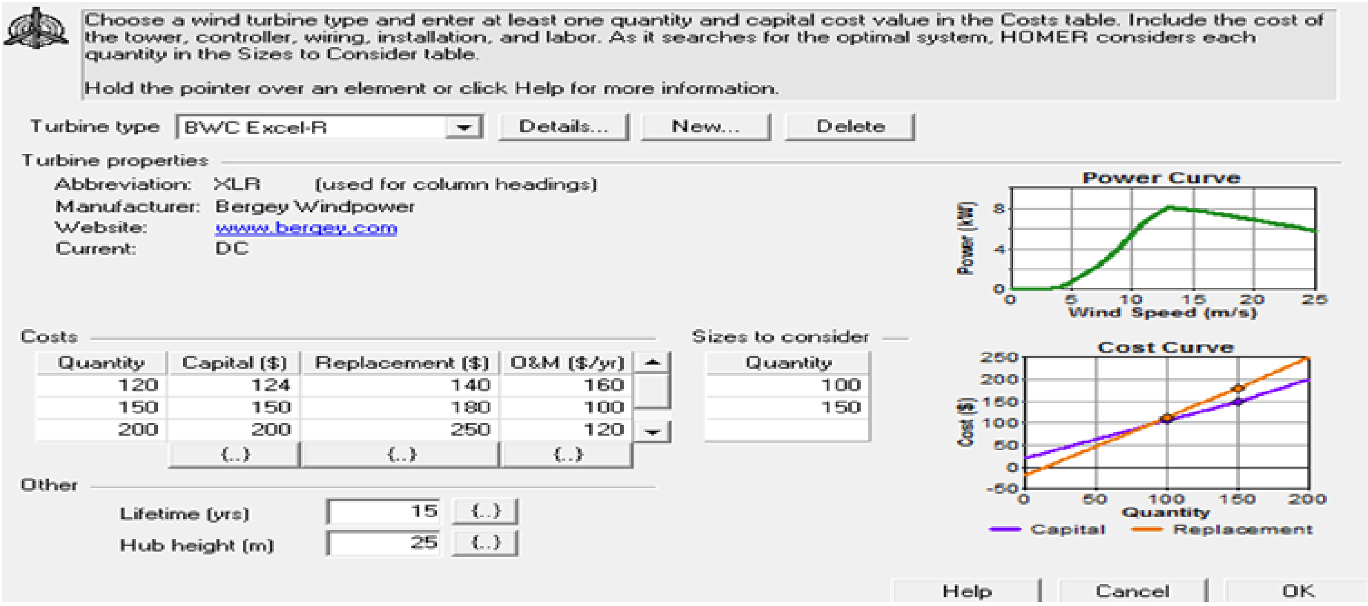


Figure 5. Wind turbine input.

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.

REFERENCES

Ahmed AZ, Nayar CV (2008). Integrating Sustainable Energy in Buildings: A Case Study in Malaysia. Copenhagen: FAU Conference, May.

Ahmad AS, Nayar CV (2004). Department of electrical and computer Engineering Curtin University of Technology-article from article from Homer Energy.

Alnaser WE, Trieb F, Knies G (2007). Solar energy technology in the Middle East and North Africa (MENA) for sustainable energy, water and environment. Adv. Solar Energy: An. Annu. Rev. Res. Dev. 17:261-304.

Alnaser WE, Eliagoubi B, Al-Kalak A, Trabelsi H, Al-Maalej M, El-Sayed HM, Alloush M (2004). First solar radiation atlas for the Arab world.

Renew. Energy 29:1085-1107. http://dx.doi.org/10.1016/j.renene.2003.10.007

Alnaser WE, Eliagoubi B, Al-Kalak A, Trabelsi H, Al-Maalej M, El-Sayed HM (2004). First solar radiation atlas for the Arab world. Renew. Energy 29(7):1085-1107. http://dx.doi.org/10.1016/j.renene.2003.10.007

Anonymous (1996). Review of ultra-low energy homes. Information Report.

Anonymous (1998). European Countries Set to Agree on Greenhouse Targets. Nature 393:616. http://dx.doi.org/10.1038/31316

AWEA (1999). Global Wind Energy. The Wind Energy Production Tax Credit. http://www.awea.org/pubs/documents/globalmarket1999.html

Benemann J, Chehab.O (2000). Building-Integrated PV Modules. Building-Integrated PV Modules, Solar International Gmbh, Muehlengasse 7, D-50667 Cologne, Germany November 2000 Ministry Energy (a).

Benemann J, Chehab O, Schaar-Gabriel E (2001). Building-integrated PV modules. Solar Energy Mater. Solar Cells 67(1-4):345-354. http://dx.doi.org/10.1016/S0927-0248(00)00302-0

Graham VA, Hollands KGT (1990). A method to generate synthetic hourly solar radiation globally. Solar Energy. Blackwell. Nayar CV, Phillips SJ, James WL, Pryor TL Remmer D (1993). Novel wind/diesel/battery hybrid energy system, Solar Energy 51(1):65-78.

HOMER (2005). Homer version history. Version 2.14.

IEA (International Energy Agency) (2002). Trends in photovoltaic applications, survey report of selected IEA countries between 1992 and 2002. Report IEA-PVPS T1-12:2003.

Indradip M, GonChaudhuri SP (2008). Remote Village Electrification Plan Through Renewable Energy in the Islands of Indian Sundarbans. The Energy and Resources Institute, IHC Complex, Lodhi Road, New Delhi, India. Article from Homer energy.

ISE (2008). Solar Photovoltaic Energy. Solar Radiation in Khartoum, Khartoum Final Report of Solar Energy, pp. 29-32.

James & James (2005). Planning and Installing Photovoltaic Systems Guide for-Installers, Architects and Engineers. SciTech Book News, Earthscan Publications, London, pp. 88-89.

Malika A (2009). Renewable energy systems for rural health clinics in Algeria: Homer application. Renewable Energy Research Centre Algeria.http://homerenergy.com/webcast-downloads/Malika_Amini/health.pdf

NASA (2008).Surface meteorology and solar energy, released. 5.1

Roaf S, Fuentes M (1999). Demonstration project for a 4 KW domestic photovoltaic roof in Oxford, p. 1.

Rohinton EM (2009). An Urban Approach to Climate-Sensitive Design. SPON Press, Taylor and Francis Group, London.

Sasitharanuwat A, Rakwichian W (2007). Performance Evaluation Of A 10 KW P PV Power System Prototype For Isolated Building In Thailand. Renew. Energy 32:1288-1300. http://dx.doi.org/10.1016/j.renene.2006.05.002

Sasitharanuwat A, Rakwichian W, Ketjoy N, Yammen S (2007). Performance evaluation of a 10 kWp PV power system prototype for isolated building in Thailand. Renew. Energy 32(8):1288-1300. http://dx.doi.org/10.1016/j.renene.2006.05.002

Shafiuzzaman KK (2005). Feasibility Study of Wind Home System in Coastal Region of Bangladesh. Renewable Energy Research Centre, University Of Dhaka, Dhaka – 1000, Bangladesh. Article from Homer energy website.

Steven S (2005). Building integrated photovoltaic. A White Paper on its Principles and Applications. Solar Design Associates. http://www.solardesign.com/library/pdf/Building-Integrated-Photovoltaics-Steven-Strong-2005.pdf.

van Roosmalen JAM, Lysen EH (2004). Modeling improvement of spectral response of solar cells by deployment of spectral converters containing semiconductor nanocrystals. Semiconductors 38:962-969. http://dx.doi.org/10.1134/1.1787120

van Sark WGJHM, Meijerink A, Schropp REI, van Roosmalen JAM, Lysen EH (2004). Modeling improvement of spectral response of solar cells by deployment of spectral converters containing semiconductor nanocrystals. Semiconductors 38:962. Available at: http://www.springerlink.com/content/11371u7541785v61, http://dx.doi.org/10.1134/1.1787120

academicJournals

Vol. 9(22), pp. 966-971, 30 November, 2014
DOI: 10.5897/SRE2014.6121
Article Number: 027087648781
ISSN 1992-2248 © 2014

http://www.academicjournals.org/SRE

Scientific Research and Essays

Full Length Research Paper

Modification of the adaptive Nadaraya-Watson kernel regression estimator

Khulood Hamed Aljuhani* and Lutfiah Ismail Al turk

Statistics Department, King Abdulaziz University, Kingdom of Saudi Arabia, Saudi Arabia.

Received 14 October, 2014; Accepted 14 November, 2014

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; $i = 1,2, \ldots, n$.

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.

*Corresponding authors. E-mail: khaljuhani@kau.edu.sa, lturk@kau.edu.sa

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 Toktamiş (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:

$$\hat{m}_{NW}(X_i) = \int y\, f(y|x)\, dy = \frac{\int y\, \hat{f}(x,y)\, dy}{\hat{f}(x)} = \frac{\sum_{i=1}^{n} Y_i K\left(\frac{x-X_i}{h}\right)}{\sum_{i=1}^{n} K\left(\frac{x-X_i}{h}\right)} \qquad (2)$$

where

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

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

i) $\int_{-\infty}^{\infty} \mathrm{K(u)du} = 1$

ii) $\int_{-\infty}^{\infty} \mathrm{u\,K(u)\,du} = 0$

iii) $\int_{-\infty}^{\infty} \mathrm{u^2K(u)du} = \mu_2 \neq 0$

iv) $\mathrm{V} = \int_{-\infty}^{\infty} \mathrm{K(u)^2du} < \infty$

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

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

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

$$\mathrm{ISE} = \int \left[\hat{f}(x) - f(x)\right]^2 dx \qquad (4)$$

and

$$\mathrm{MISE} = \mathrm{E(ISE)}$$

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

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

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

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

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:

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

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:

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

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:

$$h(X_i) = h\,\lambda_i \quad (9)$$

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:

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

Adaptive Nadaraya-Watson kernel estimator

Demir and Toktamiş (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

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

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:

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

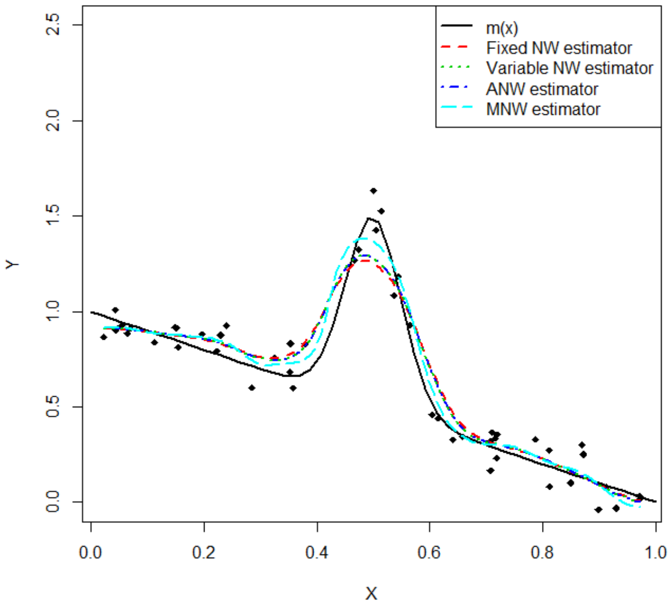


Figure 1. The real regression function and the NW kernel estimators of the regression function using sample size 50 and *h=0.16*.

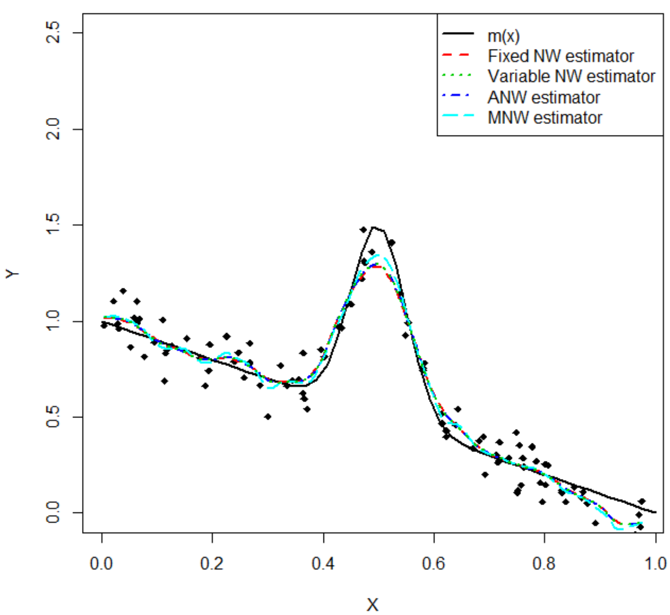


Figure 1. The real regression function and the NW kernel estimators of the regression function using sample size 100 and *h=0.08*.

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:

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

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:

$$Y_i = 1 - X_i + e^{\left[-200\,(X_i-0.5)^2\right]} + \varepsilon_i \qquad (14)$$

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.

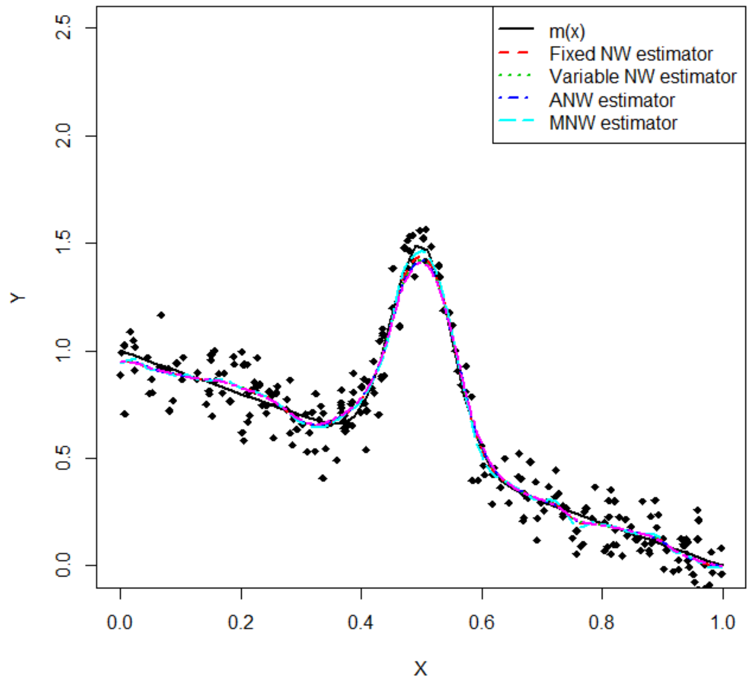


Figure 3. The real regression function and the NW kernel estimators of the regression function using sample size 250 and *h=0.06*.

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 Toktamiş 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 Toktamiş 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.

REFERENCES

Abramson IS (1982). On bandwidth variation in kernel estimates-a square root law. The annals of Statistics. 10(4):1217-1223. http://dx.doi.org/10.1214/aos/1176345986

Demir S, Toktamiş Ö (2010). On the Adaptive Nadaraya-Watson Kernel Regression Estimators. Hacettepe J. Math. Stat. 39(3):429-437.

Härdle W (1990). Applied nonparametric regression. Cambridge University Press, Cambridge. http://dx.doi.org/10.1017/CCOL0521382483

Härdle W, Werwatz A, Müller M, Sperlich S (2004). Nonparametric and semiparametric models: An Introduction. Springer, New York. http://dx.doi.org/10.1007/978-3-642-17146-8

Lidstone GJ (1932). 1023: The Arithmetic and Geometric Mean. Math. Gazette. 16(218):127-127.

Nadaraya EA (1964). On Estimating Regression, Theory of Probability & Its Applications. Soc. Ind. Appl. Math. 9(1):141-142.

Scott DW, Terrell GR (1987). Biased and Unbiased Cross-Validation in Density Estimation. J. Am. Stat. Assoc. 82(400):1131-1146. http://dx.doi.org/10.1080/01621459.1987.10478550

Silverman BW (1986). Density Estimation for Statistics and Data Analysis. Chapman & Hall, New York. http://dx.doi.org/10.1007/978-1-4899-3324-9

Wand MP, Jones MC (1995). Kernel Smoothing. Chapman & Hall, London. http://dx.doi.org/10.1007/978-1-4899-4493-1

Watson GS (1964). Smooth Regression Analysis. Indian J. Stat. Series A:359-372.

academicJournals

Vol. 9(22), pp. 972-975, 30 November, 2014
DOI: 10.5897/SRE2013.5717
Article Number: 0DCB71C48783
ISSN 1992-2248 © 2014

http://www.academicjournals.org/SRE

Scientific Research and Essays

Full Length Research Paper

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

M. Jayanthi[1]* and A. Vijayakumar[2]

[1]Department of Seed Science and Technology, Adhiparasakthi Agricultural, Horticultural college, G. B. Nagar, Kalavai, Vellore, Tamilnadu, India – 606 905, India.
[2]Department of Seed Science and Technology, Tamil Nadu Agricultural University, Coimbatore, India.

Received 24 October, 2013; Accepted 18 December, 2013

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

*Corresponding author. E-mail: kutima8@gmail.com.

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 record 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.

REFERENCES

Abdul-Baki AA, Anderson JD (1973). Vigour determination in soybean seed by multiple criteria. Crop Sci. 13:630-633. http://dx.doi.org/10.2135/cropsci1973.0011183X001300060013x

Al-Harbi MM, Qureshi S, Ahmed MM, Riza GA, Shah AH (1994). Studies on the Anti inflammatory antipyretic and analgestic activities of santanonin. Jap. J. Pharmacol. 64(3):135-139. http://dx.doi.org/10.1254/jjp.64.135

Ashraf M, Khalid A, Ali K (1999). Effect of seedling age and density on growth and yield of rice in saline soil. Pak. J. Biol. Sci. 2:860-862.

http://dx.doi.org/10.3923/pjbs.1999.860.862
ISTA (1999). International Rules for Seed Testing. Seed Sci. Technol. Suppl. Rules 27:25-30.
Naeem S, Muhammad M, Syed AW, Muhammad A-ul-H (2011). Impact of nursery seeding density, nitrogen, and seedling age on yield and yield attributes of fine rice. Chilean J. Agric. Res. 71(3):343-349. http://dx.doi.org/10.4067/S0718-58392011000300001
Narayana MR, Khan MNA, Dimri BP (1998). Davana and its cultivation in India. Farm Bull., No. 12, CIMAP, Lucknow, 11:1-10.
Safina N, Muhammad AA, Ishtiaq A (2006). Growth of chilli (Capsicum annuum l.) F1 Hybrid sky line-2 in response to different ages of transplants. J. Res. Sci. 17(2):91-95.
Shin YC, Tsao SJ, Tseng MS, Chen CC (1999). Effect of seedling age on dry matter and nitrogen content of transplanted chilli pepper 'Everflavor' (Capsicum annuum). J. Chin. Soc. Horticult. Sci. 45(3):263-272.