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Eukaryotic Algal Flora of Surface Water and Wells Derived from Groundwater in the Astir Region, Including 13 New Records for Saudi Arabia

الفلورا الطحلبية لمجموعات الطحالب حقيقية النواة في المياه السطحية وآبار المياه الجوفية بمنطقة عسير، مع 13 نوعاً جديداً للمملكة العربية السعودية

Zakaria Atia Mohamed and Abdurrahman Mohy Al-Shehri

زكريا عطية محمد و عبد الرحمن محي الشهري

Department of Biological Sciences, Faculty of Science, King Khalid University,Abha, 9019, Saudi Arabia
E-mail: mzakaria_99@yahoo.com

Abstract: Algal flora Chlorophyta, Euglenophyta and Xanthophyta groups were surveyed in six surface water bodies and six ground water wells between August and December 2003. A total of 29 taxa were recorded during this study, of which 27 belonged to the Chlorophyta, one to the Euglenophyta and one to the Xanthophyta. Most species of Chlorophyta showed diversity in their distribution among all surface water and groundwater sites. However, some species occurred only in surface water sites. On the other hand, one species, Coelastrum microsporum, was recorded only in ground water sites. The Xanthophycean Tribonema utriculosum was found in both surface water and groundwater sites. The results also showed that some species of belonging to the Chlorophyta and Euglenohphyta species were restricted only to a certain site. Compared to the results of previous studies on freshwater algae in Saudi Arabia, thirteen species were new records for Saudi Arabia, of which, 11 belonged to the Chlorophyta, one to the Euglenophyta and one to the Xanthophyta.
Keywords: *Chlorophyta, Euglenophyta, Xanthophyta, freshwater algae, surface water, groundwater, new records, Saudi Arabia.*

المستخلص: المستخلص: تم خلال هذه الدراسة القيام بمسح شامل للطحالب الخضراء و اليوجلينية والخضراء المصفرة في ستة مواقع للمياه السطحية وستة مواقع للمياه الجوفية في منطقة عسير في الفترة من اغسطس إلى ديسمبر 2003. ولقد تم تسجيل 29 نوعا من الطحالب خلال هذه الدراسة، 27 نوعا منها تنتمي إلى الطحالب الخضراء و نوعا واحدا لكل من الطحالب اليوجلينية والخضراء المصفرة. ولقد اظهرت الدراسة ايضا بان الطحالب الخضراء امتلكت انتشارا واسعا بين مواقع الدراسة. وبالرغم من ذلك فإن بعض انواع الطحالب تواجدت في المياه السطحية فقط دون الجوفية والعكس، كما ان بعض الانواع تقيدت في تواجدها بموقع معين. وبمقارنة نتائج هذه الدراسة بنتائج الدراسات السابقة التي اجريت علي طحالب المياه العذبة في المملكة العربية السعودية، تم تسجيل 13 نوعا جديدا من الطحالب للملكة العربية السعودية، 11 منها تنتمي إلى الطحالب الخضراء وواحدا إلي اليوجلينية وواحدا إلى الخضراء المصفرة.

كلمات مدخلية: *طحالب خضراء، طحالب يوجلينية، طحالب خضراء مصفرة، طحالب المياه العذبة، مياه سطحية، مياه جوفية، أنواع جديدة، المملكة العربية السعودية.*

Introduction

The algal flora in tropical and arid regions, such as Saudi Arabia, are still poorly known. Most permanent and semi-permanent water bodies in Saudi Arabia are found in the Asir region because of its relatively large and more frequent rainfall. A number of studies have been carried out on the algal flora of water bodies in different regions of Saudi Arabia. Abdelmohsen and Backhary (1969) studied the algal flora in Riyadh area. Khoja et al. (1984) studied the

freshwater algae in Al-Kharj and Al-Baha areas. Whitton et al. (1986) studied the algal vegetation in some streams in the Asir Mountains. Al-Amoudi (1988) reported the algal vegetation in four streams in Mekkah Province. Khoja (1993) studied the filamentous green algae in irrigation and drainage networks of the Al-Hassa Oases. Al-Homaidan (1994a) studied the algal vegetation of reservoirs in southwestern Saudi Arabia. Al-Homaidan (1994b) reported new records of freshwater green algae in reservoirs in southwestern Saudi Arabia. Al-Homaidan and Arif (1998) study recorded bloom-forming algae in semi-permanent rain-fed pool at Al-Kharj.

In spite of the above studies on freshwater algae in the Asir region, many water bodies have still not been surveyed for the presence of algae. Therefore, the present study was undertaken to contribute to our knowledge of the freshwater algae of Saudi Arabia in water bodies of areas other than those previously surveyed and described in the literature. Furthermore, the present study aimed to investigate for the first time the algal flora in groundwater wells in Saudi Arabia.

Materials and Methods

1. Study Sites

All water bodies chosen for the study are located within the Asir region. The six surface water bodies are reservoirs and streams which fall between latitudes 18° and 19° N, and longitudes between 42°and 43°30 E, while the six groundwater wells lie between latitudes 18° and 20° N, and longitudes 42°30 and 43° E (Fig. 1).

The six surface water sites were assigned as S1-S6 and the groundwater wells were assigned as G1-G6 as marked in the map.

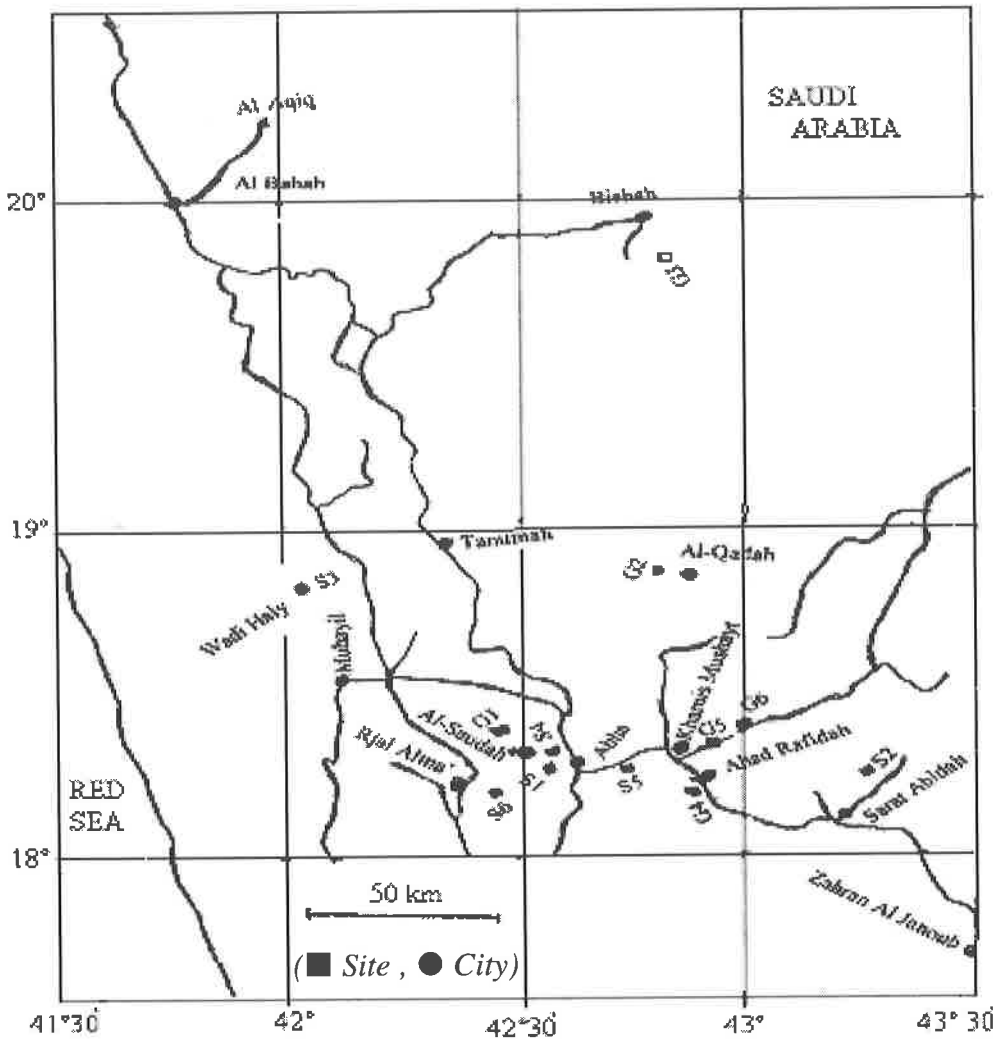

Fig. 1. Map showing location of study sites of surface and groundwater bodies studied.

S1: Abha Dam Lake, about 8 km northwest of Abha downtown. The lake is one of the most popular tourist places in Abha city. The lake contains huge population of the aquatic plant Lemna *minor* L. and *Raunnculus* sp.

S2: Wadi Ghanum, stream located near Sarat Abidah city and about 60 km Southeast of Abha city.

S3: Wadi Haly, a large stream in Muhayil Province, and about 85 km Northwest of Abha city.

S4: Al-Moqadda Dam, reservoir, at Al-Saudah area, and about 9 km north of Abha city. The stream is covered with the aquatic plant *Ceratophyllum* sp. and surrounded with other wild plants.

S5: Wadi Gohan, a small stream located on the Abha-Khamis Mushayt road, about 12 km East of Abha city. The stream is covered with huge mats of the green alga, *Cladophora glomerata*, and the aquatic plant *Potamogeton* sp.

S6: Wadi Ashran, a small stream located near Rjal Alma', and about 20 km Southwest of Abha city.

G1: Groundwater well, located at Al-Saudah area, and about 23 km Northwest of Abha city.

G2: Groundwater well, located at Al-Qadah city, and about 64 km Northeast of Abha city.

G3: Groundwater well, located at Bishah city, and about 152 km Northeast of Abha city.

G4: Groundwater well, located at Ahad Rafidah city, and about 50 km East of Abha city.

G5: Groundwater well, located in Khamis Mushayt city, and about 16 km East of Abha city.

G6: Groundwater well, located in Tandaha ciy, and about 40 km East of Abha city.

2. Sampling

Three water samples were collected in 500-ml polyethylene bottles from each site during the period from August to December 2003. Samples from groundwater wells were taken by lowering the bottles into the surface layer of deep-water column. The phytoplankton samples from of each site were divided into two parts; one of them was preserved in Lugol's solution (1% final concentration), while the other part was kept under conditions of illumination conditions (about 25 μmol/m^2/s) and at a room temperature of 25±2oC°. Benthic algae present on the substrates of each site were also collected and included in the survey list during the present study. Taxonomic identifications were made using according to Prescott (1982) and John *et al.* (2002). The new records of Chlorophyta, Euglenophyta and Xanthophyta species were photographed with a camera connected to an Olympus research microscope.

3. Physio-chemical Analysis

Physical parameters (temperature, pH, conductivity) were measured in the field using a thermometer, pH-meter, and conductivity meter, respectively. Water samples for chemical analyses were collected in pre-sterilized polyethylene bottles and transferred to the laboratory within 2 hours. Water samples were filtered through GF/C filter paper, and stored in a freezer at -20 C° until worked up. Chemical analyses were carried out according to Standard methods (APHA, 1995), briefly, nitrate by the Na-salcylate method, ammonia by Nesseler's reagent, and soluble reactive phosphate by the Ascorbic Acid method.

Results

The physical and chemical properties differed significantly between surface and ground waters ($p < 0.05$). In general, nitrate and soluble phosphate concentrations are much greater in surface waters than in groundwaters (Table 1).

Atotal of 30 taxa were recorded in the surface and ground water sites, of which 28 belonged to the Chlorophyta, one to the Euglenophyta and one to the Xanthophyta (Table 2). Most chlorophycean species showed high diversity in their distribution among in all surface and ground water sites. However, six species, namely, *Actinochloris terrestris*, *Chara vulgaris*, *Chlorella vulgaris*, *Cladophoa glomerata*, *Odeogonium*

Table 1. Some physio-chemical parameters of the surface and ground water sites s of studied sites.

Sites	Temp.(C^0)	pH	Conduct.($\mu s\ cm^{-1}$)	NO_3^- (mg/L)	NH_4^+ (mg/L)	PO_4^{-3} (mg/L)
S1	25	8.2	700	13	27.5	8.3
S2	23	8	645	19	2.4	18.2
S3	24	7.7	650	3.4	1.3	1.2
S4	25	8	687	4.5	1.5	1.3
S5	25	8.1	628	6.5	1.9	0.9
S6	23	7.8	623	5.3	2	0.3
G1	19	7.5	654	2.1	2.6	0.04
G2	18	7.8	589	6.4	2.3	0.03
G3	19	7.7	501	3.4	2.1	0.02
G4	17	8	543	3.6	1.8	0.03
G5	18	7.9	567	4.4	1.9	0.04
G6	18	7.8	595	4.3	1.2	0.04

microgonium and *Pandorina morum*, were identified only in surface water sites and were not found in groundwater sites. On the other hand, *Coelastrum microsporum* was recorded only in ground water sites. The Xanthophycean *Tribonema utriculosum* was found in both surface and ground water sites.

The results also showed that some Chlorophycean and Euglenohphycean species were restricted only to a certain site, namely, *Chara vulgaris* was recorded only in S4 site (Al-Moqadda Dam reservoir), *Pediastrum boryanum var. cornutum* in G1 site (groundwater well at Al-Saudah area), and *Euglena proxima* in S1 site (Abha Dam lake). Compared to the results of previous studies on freshwater algae in Saudi Arabia, thirteen species were reported as new records for Saudi Arabia, of which, 11 belonged to the Chlorophyta, one to the Euglenophyta and one to the Xanthophyta. Descriptions and microphotographs of newly reported species are given below, (see table 2):

Chlorophyta

a. Order: Chlorococcales

***1. Characium angustum* A. Braun** (Fig. 2-a).
Synonym: *Characium apiculatum* Rabenhorst.
Cells, about 32.5μm long, up to 6 times longer than wide, narrowly lance-shaped; apex short, acute and thick-walled. The species was identified in two surface water sites (S1 & S2) and four ground water sites (G2, G4, G5 & G6).

***2. Monoraphidium pusillum* (Printz) Komarkova-e Legnrova** (Fig. 2-b).
Basionym: *Anksitrodesmus braunii* (Nageli), *collins Collins var. pussilla* Printiz
Cells, 1.7-5.9 μm wide, 23.2μm long, broadly spindle-shaped, with two apices at ends; each apex, bluntly rounded and gfinder-like, straight. The species was investigated in three surface water sites (S1, S2 & S5) and two groundwater sites (G2 & G4).

***3. Pediastrum boryanum var. cornutum* (Rcaiborski) Sulek** (Fig.2-c).
Basionym: *Pediastrum duplex var. cornutum* Raciborski
Coenobia 32.5μm wide, marginal cells 4.3 x 3.4μm with two projections almost equal to cells bearing them. Inner cells, polygonal, 3.3 x 3.9μm. The species was identified only in one groundwater site (G1).

***4. Scenedesmus bernardii* G. M. Smith** (Fig. 2-d)
Synonym: *Scenedesmus acuminatus var. bernardii* (G. M. Smith) Denusenko.
Coenobia of 2-8 cells in a zigzag, alternate arrangement. Cells adjoined alternatively by the apex of one cell1 to the mid-region of the next in series; cells 3-4.3 μm in wide, 11-13.8μm long, spindle-shaped to arc-like, tapering to acute apices. The species was investigated in four surface water site (S1, S2, S4 & S6) and one groundwater site (G1).

5. Schroederia setigera (eSchroder) Lemmermann (Fig. 2-e).
Basionym: *Reinschiella setigera eSchroder.*

Table 2. List of algal species identified in surfacesites (S) and groundwater sites (G) in the Asir region.

Species	S1	S2	S3	S4	S5	S6	G1	G2	G3	G4	G5	G6
Chlorophyta												
Characium angustum Braun	+	+						+		+	+	+
Characium gracipes Lambert				+		+			+	+	+	
Chlorococcum infusionum Meneghini				+	+		+					
Cladophora glomerata (L.) Kutz					+	+						
Closterium dianae Ehr. ex Ralfs	+		+				+					
Coelastrum microporum Nag.									+	+		+
Cosmarium contratum var. rotundatum O. Borge			+	+	+							+
Cosmarium cyclicum var. articum Nordstedt			+	+	+	+						+
Cosmaruim pseudopyramidatum P. Lundell			+	+	+	+						+
Haematococcus pluvalis Flot. en Wille				+				+				+
Microspora amoena (Kutz.) Rabenh			+			+			+			
Monoraphidium pusillum Komarkov	+	+			+			+		+		
Oedogonium microgonium Prescott	+			+	+	+						
Pandorina morum (Mul) Bory				+	+							
Pediastrum integrum Nag.	+	+		+	+	+	+		+	+	+	
Pediastrum boryanum (Turp.) Menegh.					+	+	+					
Pediastrum boryanum var. cornutum (Racibors.) Sulek							+					
Pediastrum tetras (Eher.) Ralfs	+			+			+					
Rhizoclonium hieroglyphicum (C. Ag) Kutz.			+						+	+	+	
Scenedesmus bernardii G.M. Smith	+	+		+		+	+					
Scenedesmus communis E.H.Hegewald	+	+				+			+	+		
Chlorophyta												
Scenedsmus dimorphus (Turp.) Kutz.	+	+		+		+	+					
Schroderia setigera (Schrod.) Lemm.	+			+	+	+	+	+			+	+
Spirogyra parva (Hass.) Kutzing	+							+				
Tetraedron minimum (A.Braun) Hansg.		+		+		+			+	+		+
Charophyta												
Chara vulgaris L.				+								
Euglenophyta												
Euglena proxima P.A. Dangeard	+											
Xanthophyta												
Tribonema utriculosum (Kutz.) Hazen	+									+	+	

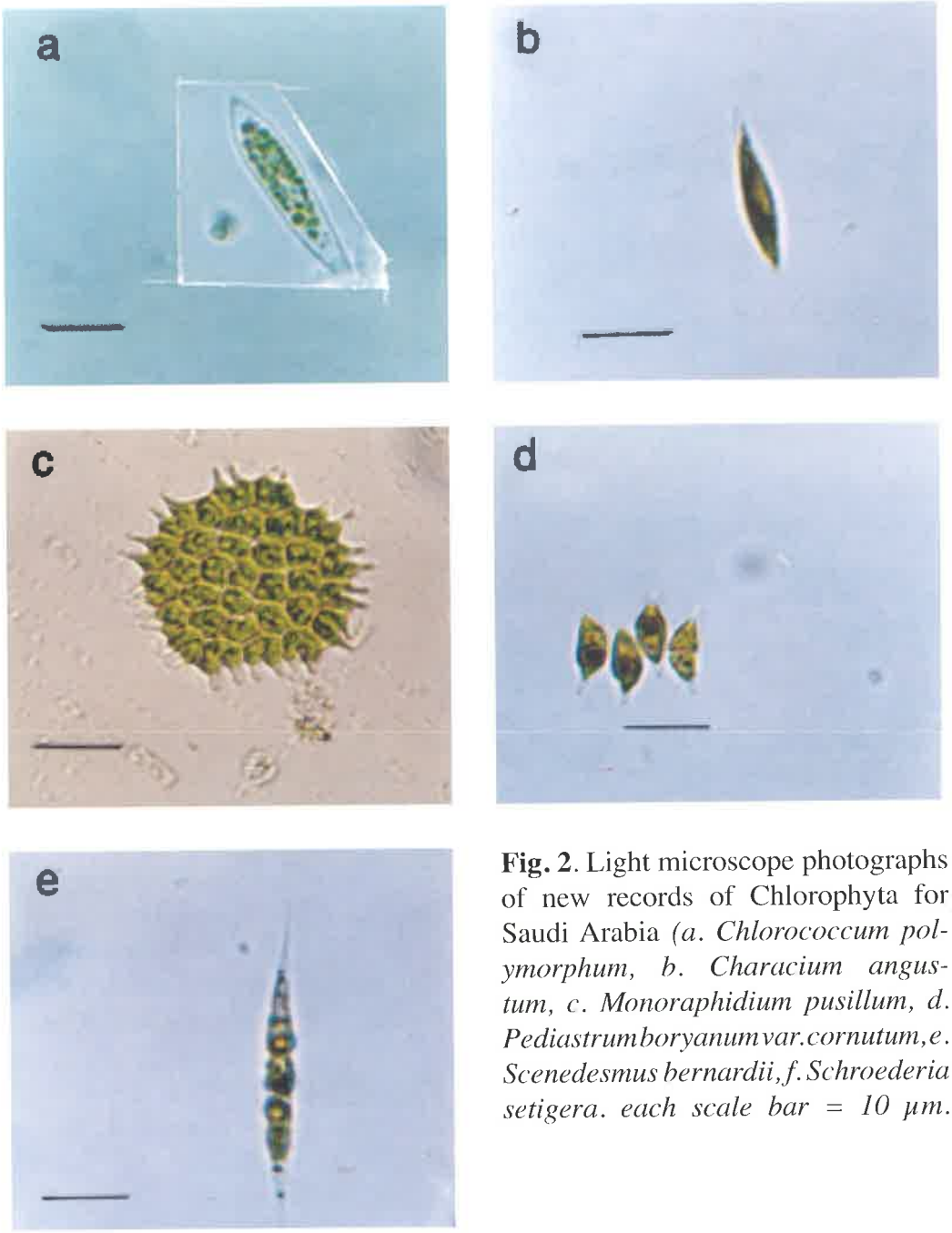

Fig. 2. Light microscope photographs of new records of Chlorophyta for Saudi Arabia *(a. Chlorococcum polymorphum, b. Characium angustum, c. Monoraphidium pusillum, d. Pediastrum boryanum var. cornutum, e. Scenedesmus bernardii, f. Schroederia setigera. each scale bar = 10 µm.*

Synonyms: *Ankistrodesmus setigerus (e*Schroder) G.S. West,
Characium setigerum (eSchroder) Bourrelly. Cells, 5.2 µm wide, 32.5 µm long, straight, narrowly spindle-shaped. Each apex terminating in a delicate straight spine, 11 µm long. Chloroplast with two pyrenoids. The species was identified in one surface site (S1) and three groundwater sites (G2, G5 & G6).

b. Order: *Oedogoniales*

***6. Oedogonium microgonium* Prescott** (Fig. 3-a). Vegetative cells distinctly capitellate, 6-6.8 µm wide, 8.5-11µm long. Oogonium, single, terminal, depressed-spherical, little wider than vegetative cells, 10 µm wide, 11.7 µm long, opening with superior operculum. The species was investigated in four surface water sites (S1, S4, S5 and S6).

c. Order: *Zygnematales*

***7. Spirogyra parva* (Hassall) Kutzing** (Fig. 3-b)
Synonym: *Zygnema flavescens var. parva* (Hassall) Cleve.
Cells, 11 µm wide, 63.7 µm long. End walls plane; chloroplast, single, making 6-8 turns of cell. The species was identified in four surface

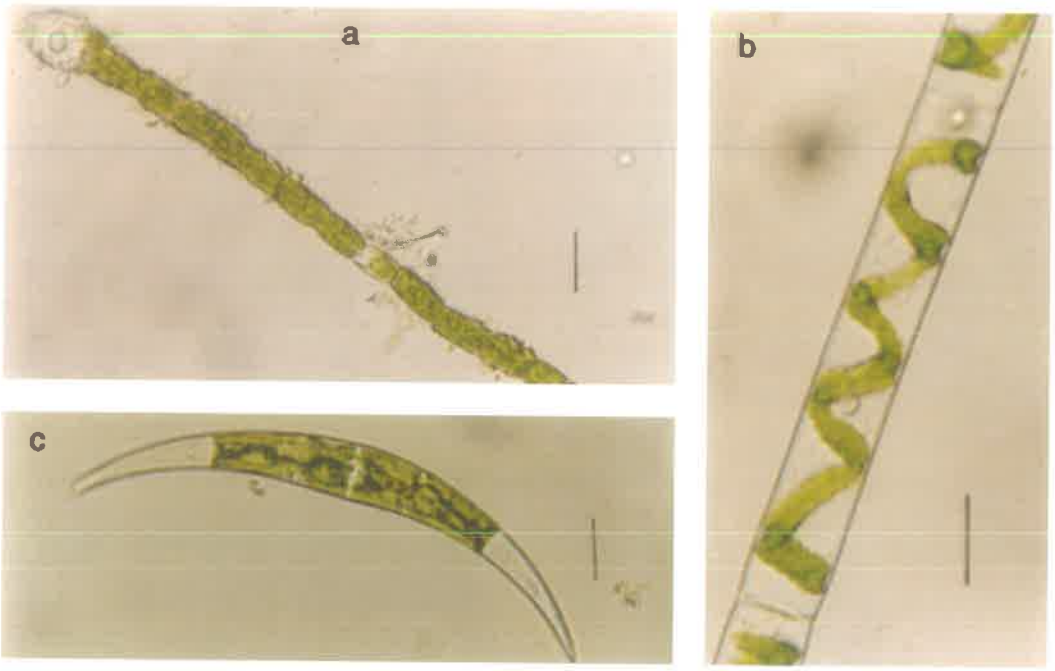

Fig. 3. Light microscope photographs of new records of Chlorophyta to Saudi Arabia *(a.Oedogonium microgonium, b. Spirogyra parva, c. Closterium dianae) (each scale bar=10 μm).*

water sites (S1, S4, S5 & S6) and two sites of groundwater (G1 & G2).

8. *Closteriumdianae* Ehrenberg ex. Ralfs (Fig. 3-c)
Cells, curved, mid-region slightly tumid, 11 μm wide, 118 μm long, tapering from mid-region to narrow extended ends. Apices, 4.3-6.8 μm wide. Chloroplasts with 3-5 longitudinal ridges, 2 visible in face view. Wall, smooth and brown. The species was identified in two surface water sites (S1 & S3) and one groundwater site (G1).

***9. Cosmarium contractum var. rotundatum* O. Borge** (Fig. 4-a).
Cells, 10.5 μm wide, 26.7 μm long; sinus, deep and wide; isthmus, 9.4 μm wide; semi cells, circular, with smooth wall. The species was investigated in three surface water sites (S3, S4 & S5) and one ground water site (G6).

***10. Cosmarium cyclicum var. arcticum* Nordstedt** (Fig. 4-b).
Cells with extended basal angles, 41-μm wide, and 42.3 μm long. i Semocells with slightly flattened apex, having 4 crenulations. The species was identified in four surface water sites (S, S4, S5 7 S6) and one groundwater site (G6).

***11. Cosmarium pseudopyramidatum* P.Lundell** (Fig. 4-c).
Synonym: *Cosmariumpyramidatum* Brebissonex. Ralfs, *var. pseudocucumis* G.A. Klebs.
Cells, 19-21.2 μm wide, 30.6 μm long. Sinus, deep, narrows. Semi cells, truncate-pyramidate to semi-elliptic. Wall, smooth. The species was identified in four surface water sites (S, S4, S5 7 S6) and one groundwater site (G6).

Xanthophyta

***12. Tribonema utriculosume* (Kutzing) Hazen** (Fig. 4-d).
Basionym: *Tribonema bombycinum var. utriculosum* Hazen
Cells, 8.5 μm wide, 17.3 μm long, thick-walled. Chloroplasts, numerous and small. The species was identified in one site of surface water site (S1) and two sites of groundwater sites (G4 & G5).

Euglenophyta

***13. Euglena proxima* P.A. Dangeard** (Fig. 4-e).
Cells, 23 μm wide, 97.2 μm long, spindle-shaped. Anterior end slightly bluntly truncate, posterior end, tapering to a short with hyaline tail piece. Chloroplasts, numerous, disc-shaped, without pyrenoids. Flagellum, about 1.2 times cell length. The species was identified in one site of surface water site (S1), and was found to be forming a green waterbloom on the water surface of this site.

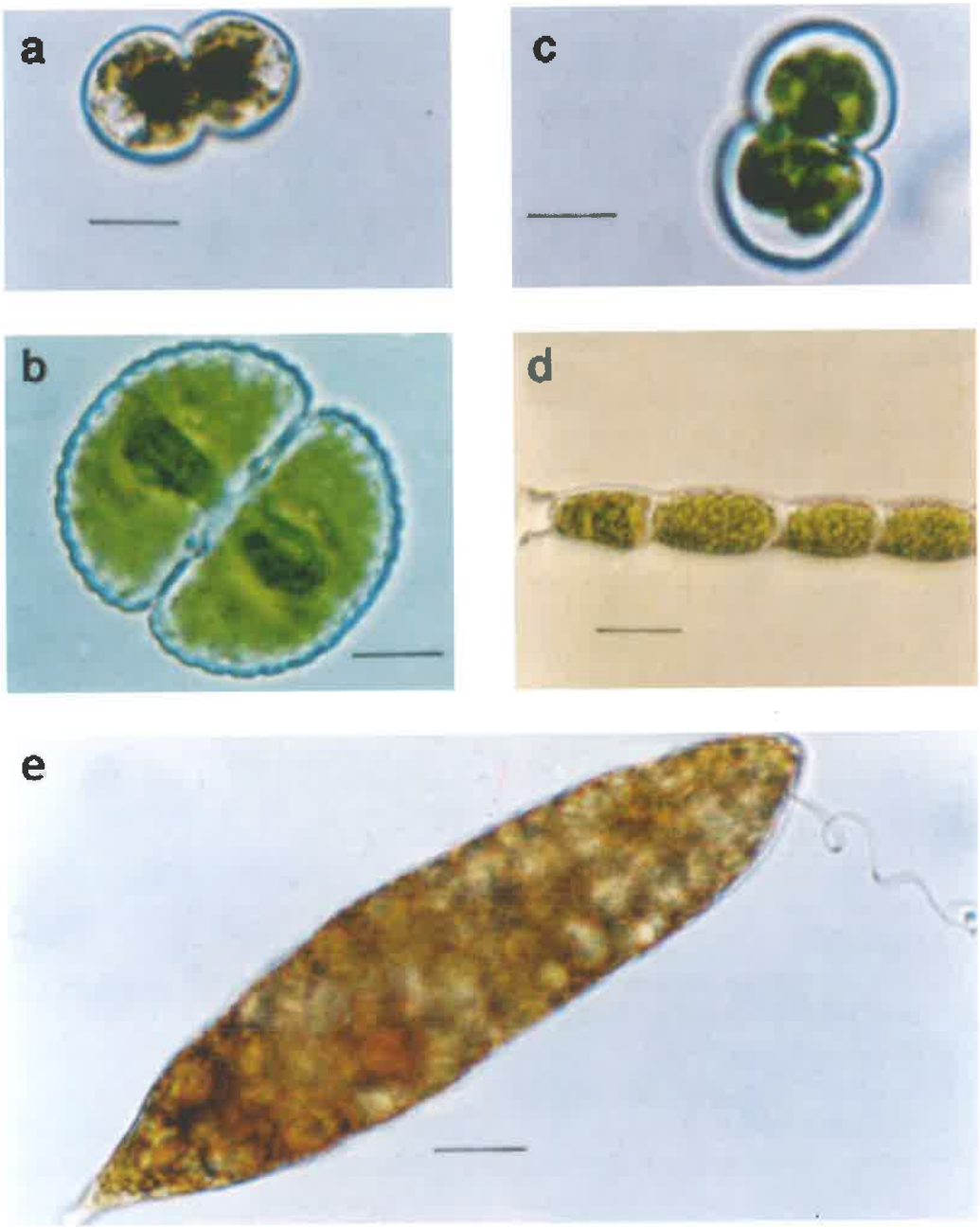

Fig. 4. Light microscope photographs of new records to Saudi Arabia of Chlorophyta *(a.Cosmarium contractum var. rotundatum, b. Cosmarium cyclicum var. arcticum, c.Cosmarium pseudopyramidatum; of Xanthophyta:, d. Tribonema utriculosum; and of Euglenophyta,: e. Euglena proxima (each scale bar=10 µm)).*

Discussion

Detailed information of the pollution status of any water body is of considerable importance because it ultimately helps in the proper management of such waters. Chemical analysis is valuable and necessary to monitor water pollution, but does not provide all the information required in pollution assessment. Thus, biological analysis and documentation of organisms such as algae in a water body are also required to give the whole picture (Henley, 2001)

Water and dissolved minerals are ubiquitous and essential resources for all life forms. Thus, limitation or excess dissolved minerals for one or both of these two factors could have an effect on algae (Bell, 1993, Johansen, 1993, Fletchner, 1999). Physical properties of surface and ground waters in our study did not differ markedly from those obtained in other studies on reservoirs and streams in the southeast of Saudi Arabia (Whitton, et al., 1986; Khoja,

1993; Al-Homaidan, 1994). However, some chemical parameters, such as ammonia, nitrate and soluble phosphate in the sites of our study, were detected with higher concentrations compared to those obtained in previous studies.

Since the Asir region is considered to be as a semi-arid region of Saudi Arabia, it is possible to find certain species of algae, which can withstand arid conditions. Despite the high concentration of nutrients, particularly nitrates and phosphates in the sites of our study, low numbers of chlorophycean, euglenophycean and xanthophycean species were recognized in these sites. Previous studies on the freshwater algae in Saudi Arabia also recorded low number of species. Whitton et al. (1986) recorded 37 chlorophycean species, one charophycean, two euglenophycean and one xanthophycean species in streams in the Asir Mountains. Khoja (1993) identified 51 chlorophycean and 4 xanthophycean species in irrigation and drainage networks of the Al-Hassa Oases, eastern region of Saudi Arabia. Al-Homaidan (1994) investigated 45 chlorophycean, two charophycean and two euglenophycean species in reservoirs in southwestern Saudi Arabia. Al-Homaidan and Arif (1998) recorded 18 chlorophycean and two euglenophycean species in semi-permanent rain-fed pools at Al-Kharj, central region of Saudi Arabia.

There are no barriers for algae to migrate since they can be transported by wind or water over long distances, and as a result they can settle on various substrates, and in reservoirs and groundwater wells (Dubovik, 1995). To a lesser extent, the algae are carried from water reservoirs by strong wind, which could blow off liquid drops from wave peaks (Vlodavets, 1960; Dubovik, 2002). Thus, the appearance of some of the algal species in both surface and ground waters during our study, might be wind, or transfer of these species by surface water flowing into groundwater wells. In this respect, Dubovik (2002), reported the migration of some species of Chlorophyta and Xanthophyta by rainwater to rainwater puddles.

The presence of algal species in both rainwater bodies and groundwater wells in the Asir region reflects their ability to populate any surface such as place, including tree trunks, granite, marble and buildings. Consequently, algae may contribute to the destruction of the surface of stone quays and old building (Petushkova and Koptiayeva, 1984; Andreoli and Rascio, 1986). Furthermore, during our study, we recorded very important species, namely *Closterium, Cosmarium, Pediastrum* and, *Euglena,* which could be useful indicators of the trophic status of these water bodies. *Pediastrum* is considered as a characteristic species of mesotrophic lakes (Rawson, 1956). *Closterium* and *Cosmarium* are considered to be as characteristic species of oligotrophic lakes (Hutchinson, 1967; Rosenström and Lepistö, 1996). Euglenophycean species serve as excellent bioindicators of environments high in organic matter content (Conforti, 1998). This should be taken into account during pollution assessment of the water resources in Saudi Arabia.

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