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Role of Diatom Flora in the Forensic Diagnosis of Drowning Cases from some Water Bodies in the Delta Region

Abdelfattah A. Zalat[1], Mostafa M. El-Sheekh[2*], Rania A. El-Shenody[2], Mohamed S. El-Hashash[2]

[1]Geology Department, Faculty of Science, Tanta University
[2] Botany Department, Faculty of Science, Tanta University
[*]Corresponding author: mostafaelsheikh@science.tanta.edu.eg

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ABSTRACT

In forensic studies of death issues, the body of victims have been found in the water, and by using the diatom test, it could be determined whether the cause of death is related to drowning or not. One more critical problem occurs, when the victim was killed and thrown into the water, was he/she alive at the time of drowning? Therefore, the diatom species in the water of six different sites from two canals (Mit-Yazid and Tanbara Haweis canals, the Delta region, El-Gharbia government, Egypt) were analyzed and the physicochemical parameters for these sites were measured to diagnose the cause of death of ten cases found in the studied canals, and determining the accurate site of death. In the present research, the water samples from six different sites of Mit-Yazid and Tanbara Haweis canals were collected during the time of victim's collection in 2021. The diatom frustules were extracted by the acid digestion of the lung tissue of the ten cases, and from the water samples of the studied canals according to the standard methods of diatom separation. A total of 65 diatom species belonging to 31 genera were recognized from the water samples of Mit-Yazid and Tanbara Haweis canals and the lung tissue of ten victims, which included 5 males, 3 females, and 2 children aged between 5- 63 years. The relative abundance of the recognized diatoms varied between the studied sites. The reports indicated seven positive cases of drowning and three negative cases. The results obtained in this research may attain an exact clarity of the obscurities related to the death linked to drowning and can be helpfully used as reference data for verifying the correct site of drowning.

INTRODUCTION

Phytoplankton are photosynthetic organisms that are present in all aquatic habitats, and they have several forms, dimensions and colors. These characters give them individualism so their existence in the water has the ability for distinguishing the site of drowning and may aid in forensic research. Because of their microscopic natural environment and lateness, the phytoplankton could stand on the suspicious, wounded, or victim’s clothes or the crime’s weapon. Additionally, the different species of phytoplankton are existing throughout different seasons, which helps in associating the suspicious to a particular crime place during a certain season **(Thakar *et al*., 2018).** Moreover, **Díaz-Palma *et al.* (2009)** indicated that, besides the use of the diatom test to identify drowning, other groups of phytoplankton can be used for diagnosis of drowning such as dinoflagellates and some chlorophytes because of their existence in tissues of drowned victims.

Diatoms are phytoplankton forms that develop when it adheres to surfaces, floats in water, or live on macrophytes. They have robust silicious skeletons and are present in moist and all aquatic ecosystems, including fresh and marine waters **(Verma, 2013)**. The diatom test can be used in forensic research by identifying the examined sites of human beings, clothings and properties. Continuous checking of the freshwater locations and comprehensive examination of species-level supplies of diatoms at these places may be helpful in the medical-official inquiry in drowning deaths **(Ajay & Sakshi, 2018; Thakar *et al*., 2018)**. Various studies have revealed that diatoms can be present in immersed victims when the reason for death is attributed to causes other than drowning. In five drowning cases, **Levkov *et al.* (2017)** found some *Cyclotela* species, and both drowned and non-drowned people had a lot of freshwater diatoms on them.

Several organs of the immersed victims can be tested for diatoms such as the lungs, kidney, liver, brain and cardiac blood or bone marrow. The presence of diatoms in the victim's lungs can confirm the identification of antemortem water targets and may provide evidence about the nature of examined water (marine or freshwater) **(Kakizaki *et al*., 2009)**. In this ecosystem, the numbers, and types of detected diatoms in drowned victims' lungs are usually rich **(Hurlimann *et al*., 2000)**. In an earlier case, a significant effort has been created to link up the suspects and victims to the crime incident by the way of examining the residues-coated sneakers from both attackers and victims along with various types of diatoms **(Thakar *et al*., 2018)**. It has been observed that diatoms present in tap water may enter individuals passing through three ways: the respiratory tissues, the digestive tract or the outer wounds **(Yen & Jayaprakash, 2007)**. The existence of diatoms in the lung should be evaluated in all immersed victims due to using only the infomercial components to hasten and streamline diatom extraction from the alleged drowning victims because of deprivation during long-standing immersion of the body in the water **(Krstic *et al.*, 2002)**. Various diatoms could enter through the lungs with water during the immersion, but they wouldn't immediately enter the periphery of the lungs, except for some situations such as the strong pressure of water or superior decomposition (**Bortolotti *et al*., 2011**). In contrast, few diatoms can be identified from the walled organs such as the kidneys and liver even though the concentration of diatoms in the drowning site was down **(Kakizaki *et al*., 2011)**. Furthermore, a few numbers of diatoms in the victim's organs indicates the opportunity for infection during post-mortem examination, making the sample's results false due to the presence of contamination during the victim's life unrelated to water examination so that in such organs, the investigation cannot be completely ruled out **(Kakizaki *et al*., 2012)**.

Description of study sites

Mit-Yazid canal is an irrigation canal; it is an off- take from Bahr Shebeen canal (km 96.500) (Figs. 1, 2). This canal passes into the Delta to reach Kafr El Sheikh City, and then it is disributed into various small canals. It is 63.00km long with an average depth of 3m, and it serves 197,000 feddans. There is drainage water as a source just downstream of the head. Besides the head regulator, the studying area in Mit-Yazid canal has four regulators: Beltag, El-Wasat, El-Zawia, and El-Mofty cross regulator. Its UTM coordinates are located between latitudes 31°05′11.6800 to 31°22′0.5500 N and longitudes 30°46′400 to 31°08′24.9400 E **(Abou El- Hassan *et al*., 2015)**.

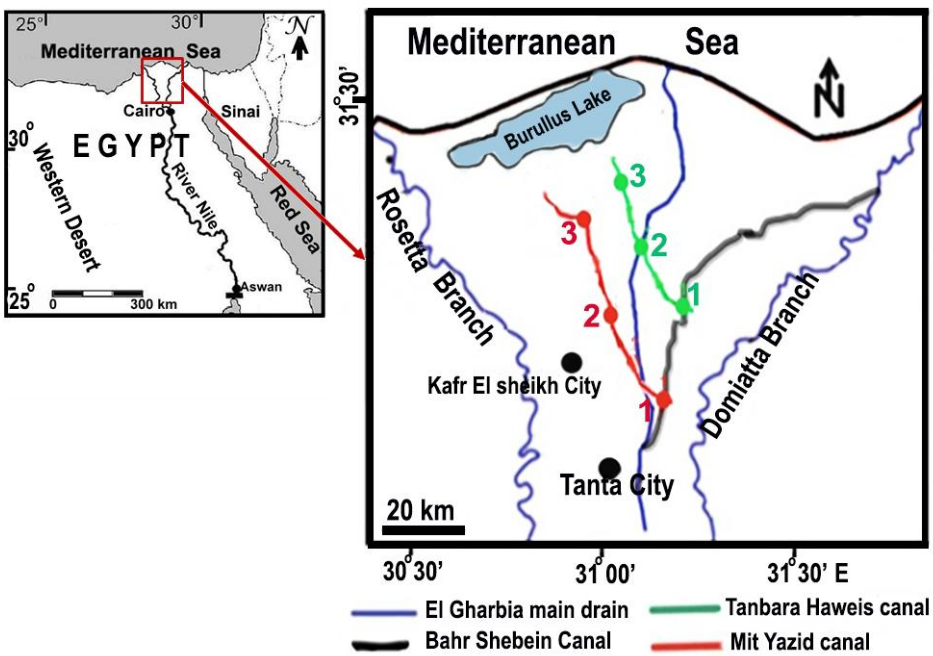

Fig 1. Location map of the Nile Delta showing the sampling sites of Mit-Yazid and Tanbara Haweis canals

Tanbara Haweis canal is an irrigation canal branched from the Bahr Shebeen canal. It has a length of about 23.200km, and an average depth of 3m. This canal penetrates into the Delta starting from Haweis of El-Mahalla El-kubra to Kafr El-Sheikh city, and then it is diverted into several small canals passing through two small villages (Mahallet Abu Ali, and Damrou village). Its UTM coordinates are between latitudes 31°05′11.6800 to 31°22′0.5500 N and longitudes 30°46′400 to 31°08′24.9400 E. It is away from Mit-Yazid canal with a distance of 10.5 Km **(Farig *et al*., 2022)**. (Fig. 3)

Fig 2. Photograph of Mit-Yazid canal

Fig 3. Photograph of Tanbara Haweis canal

MATERIALS AND METHODS

Collection of water samples

In the present study, water samples were collected from six different sites of Mit-Yazid and Tanbara Haweis canals, which are branched from the Bahr Shebeen canal in the middle of the Nile Delta and extend from El-Mahalla El-Kubra City to Kafr El-Sheikh City. Water samples were collected during the time of the victim's collection in 2021. Two liters were collected in a clean polyethylene flask from the surface and bottom of the sampling sites. The samples were mixed by adding 10ml of Lugol's iodine (iodine dissolved in potassium iodide) during the sampling time and transferred in an ice box to the laboratory.

Diatom analysis

The diatom test for collected water samples at the crime sites was done by the acid digestion method **(Ludes *et al*., 1994**). The samples were collected from the upper and lower sites of the lungs of the drowned victim. Approximately, 250ml of water was mixed with 100ml of concentrated nitric acid in a sterilized beaker, then the mixture was shaken carefully before analyzing. After 2 hours, samples were centrifuged at 5000rpm for 10 minutes. The supernatant was removed, and the pellets materials were suspended in distilled water and centrifuged twice to remove all traces of acid then used for diatoms examination **(Peabody, 1978; Hurlimann *et al*., 2000)**.

Detection and identification of diatoms (microscopic examination)

From the final cleaned materials of 50ml, about 0.1ml was taken from the center of the homogenized suspension and dried on the coverslips (22 × 50 mm) at a low temperature and then mounted onto a glass slide with Naphrax (R.I. = 1.75) for microscopic observation. Diatoms were quantitatively examined and identified to the species level using an Optika light photomicroscope, with a digital camera and under oil immersion with differential interference contrast at 1000x magnification. Diatom identification was based on extensive reviews and comparison with the most up-to-date literatures **(Krammer & Lange-Bertalot 1986-1991; Hofmann *et al*., 2011; Houk *et al*., 2014; Zalat *et al*., 2022)**. Diatom assemblages were quantitatively examined by counting 500 valves in transverse scans of each slide. The diatom analysis was done in the Environmental and Paleobotany Lab., Geology Department, Faculty of Science, Tanta University.

Detection of diatoms in the drowning victim's samples

The case studies were conducted in the Biology Division, Forensic Science Laboratory, Anatomical center of Public Tanta Hospital, and Al-Menshawy Hospital, and all cases were freshwater drowning cases. After the postmortem of dead bodies, the internal organs from the bodies were sent as crime exhibits to the laboratory. All the tools were single used and washed before sample collection. All samples were separated in the specified chronological sequence at the examination as follows: liver, kidney and lungs.

Preparation of the victim's sample for the diatom test

Two groups of 10 grams of collected tissues of the lungs were washed with distilled water and transferred into a test tube for the acid digestion process **(Ludes *et al*., 1994)**. The acid digestion method was carried out as follows:

1. Tissues of the lung were removed using clean instruments at autopsy and washed with distilled water, and then tissues were placed into a boiling flask using a clean spatula.
2. About 50mL of concentrated nitric acid was added to the boiling flask, and the solution of the examined tissues was boiled for 48 hours.
3. Following, the digested tissues were boiled for half an hour until the color of the solution changed to yellow then left for cooling. The upper layer (fats) was removed, and the yellow supernatant was centrifugated three times at 4000 rpm for about 15 minutes, and the supernatant was removed every time. Pellets were washed with distilled water and again centrifuged with the removed supernatant, and the subsequent acid-resistant substances were dropped onto clean microscope slides for examination.

RESULTS AND DISCUSSION

Diatoms community

The microscopic examination for diatoms inhabiting Mit-Yazid and Tanbara Haweis canals revealed that the diatom community is the most dominant group of phytoplankton. They constitute 71 and 59%, respectively, of the number of the total phytoplankton standing crop; Chlorophyta contributed 20 and 32%, respectively; Bluegreen-algae shared 7.0 %, and Euglenophyta constituted 2.0% in both canals (Fig. 4). The mean average of diatoms counting explained 369 x 10^4 cell/l and 61 spp., and 89 x 10^4 cell/l and 40 spp. respectively. Altogether, 65 diatom species belonging to 31 genera were recognized from the studied canals.

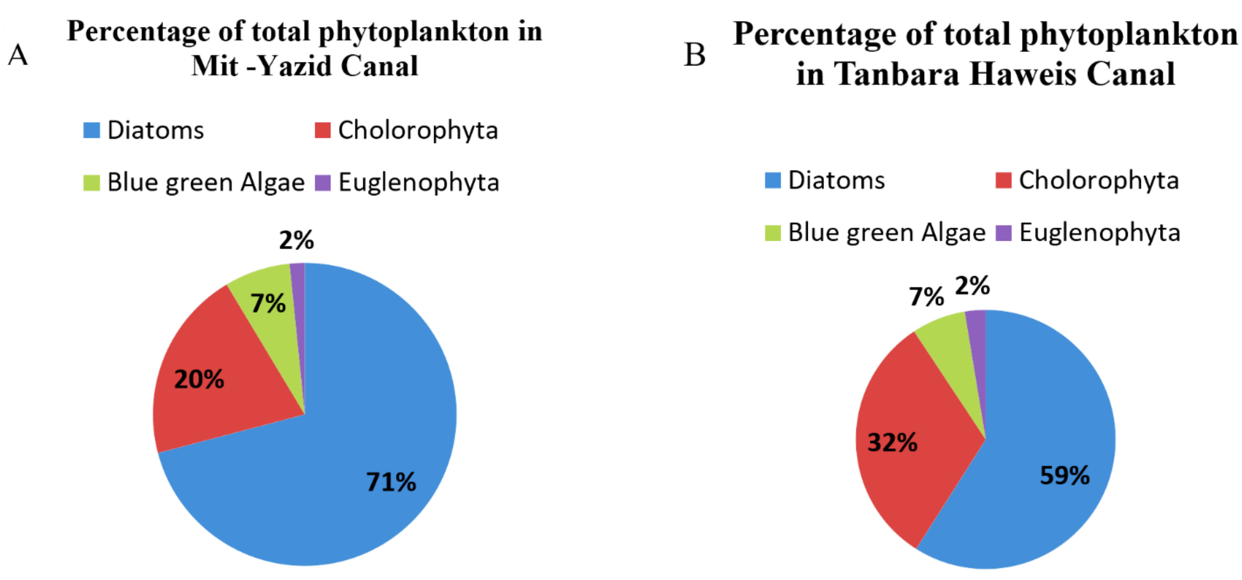

Fig. 4. Percentage of total phytoplankton species (Diatoms, Chlorophyta, Blue-green algae, and Euglenophyta) recorded in Mit-Yazid (A) and Tanbara Haweis (B) canals

The relative abundance of diatom species in the studied canals

The results indicated that the most dominant species of diatoms at all sites of the Mit-Yazid canal according to their number of cells per liter were *Pantocsekiella ocellata* (864.7 x 10^3), *Ulnaria ulna* (499.7 x10^3), *Aulacoseira granulata* (218.3 x10^3), *Ulnaria danica* (159.2 x10^3), *Aulacoseira ambigua* (123.6 x10^3), *Staurosira construens* (115.2 x10^3), *Staurosira venter* (101.3 x10^3), *Ulnaria acus* (78.6 x10^3), *Ulnaria delicatissima* (78.2 x10^3), *Pantocsekiella kuetzingiana* (68.1 x10^3), *Ulnaria biceps* (66.5 x10^3), *Aulacoseira granulata* var. *angustissima* (66.4 x10^3), *Stephanocyclus meneghiniana* (59.5 x10^3), *Cocconeis placentula* (48.5 x10^3), *Nitzschia frustulum* (48.3 x10^3), *Planothidium minutissimum* (45.1 x10^3), *Navicula cari* (45.1 x10^3), *Navicula menisculus* (42.1 x10^3), *Navicula rhynchocephala* (37.7 x10^3), *Nitzschia fonticola* (34.5 x10^3), *Nitzschia linearis* (34.2 x10^3), *Encyonema cespitosum* (34.1 x10^3) and *Pseudostaurosira brevistriata* (33.5 x10^3) (Fig. 5A).

On the other hand, the diatoms species in Tanbara Haweis canal were *Staurosira construens* (172.9 x10^3), *Pantocsekiella ocellata* (120.8 x10^3), *Aulacoseira granulata* (114.3 x10^3), *Staurosira venter* (79.5 x10^3), *Aulacoseira ambigua* (41.8 x10^3), *Ulnaria danica* (39.3 x10^3), *Pseudostaurosira brevistriata* (35.9 x10^3), *Ulnaria ulna* (30.3 x10^3), *Fallacia pygmaea* (22.1 x10^3), *Staurosira leptostauron* (20.9 x10^3), *Nitzschia fonticola* (20.3 x10^3), *Navicula cari* (19 x10^3), *Staurosirella pinnata* (17.6 x10^3), *Stephanocyclus meneghiniana* (17 x10^3), *Encyonema silesiacum* (16.8 x10^3), *Planothidium minutissimum* (16.7 x10^3), *Ulnaria delicatissima* (16.4 x10^3), *Cocconeis placentula* (15.8 x10^3), *Ulnaria acus* (12.6 x10^3) and *Ulnaria biceps* (10.7 x10^3) (Fig. 5B).

The variations in the relative abundance of diatom flora in the two studied canals may be attributed to the differences in the biological and physiochemical parameters of water. This variation in physiochemical parameters and their mean average in the studied Mit- Yazid and Tanbara Haweis canals are displayed in Table (1). The minimal number of genera and low relative abundance of diatom species recorded in the Tanbara Haweis canal than the Mit-Yazid canal can mostly be ascribed to the constant flow of wastewater, managing to increase the nutrient enhancements, thus diminishing the principal genera and species. This finding coincides with those of **Ludsin *et al.* (2001)** and **Prepas and Charette (2005)** who postulated that, the variety of microorganisms is reversibly proportional with the nutrient content because of the increased eutrophication state of the water body, and the frequently polluted water with flowing waters including chemicals, fertilizers and industrial wastes from drains. **Fathi *et al.* (2000)** found that the maximum count was found during winter and the minimum one was harvested in summer, which affected greatly the hydrography and physicochemical assets of water as revealed by the extreme quantity of the organic material, unusual concentrations of nutrient salts, which produce some rise in stages of eutrophication.

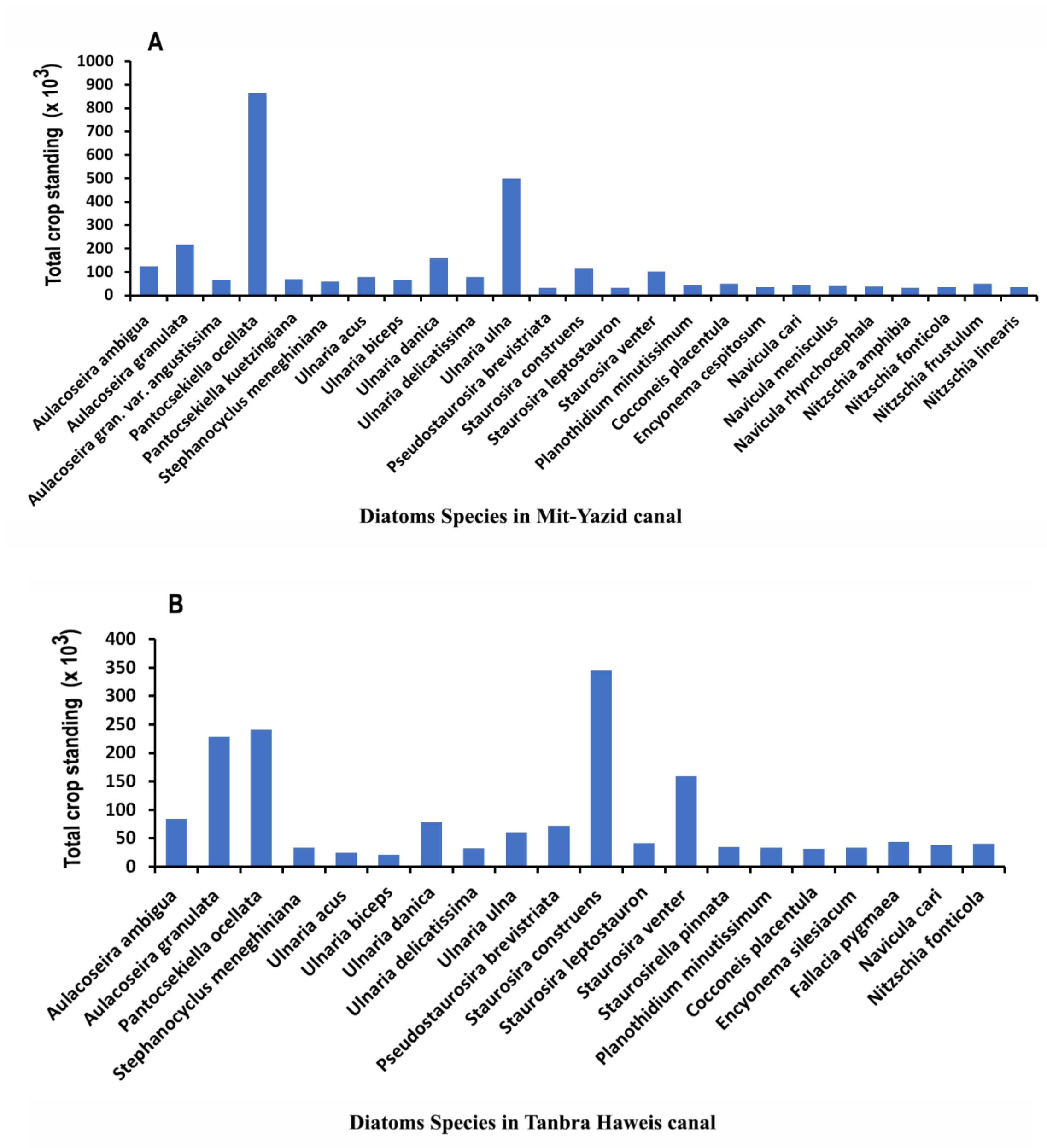

Fig. 5. Total standing crop of diatom species at different sites of Mit-Yazid (A) and Tanbara Haweis (B) canals during the study period

The forensic analysis of diatoms (Diagnosis of drowning victims)

The most important aim in the forensic field is to distinguish the death cases of the immersed bodies found in both seawater and freshwater via laboratory investigations, which may expose the occurrence of diatoms in the victim's body due to their silica-based skeletons which don't decay and can be distinguished even in the severely decomposed ones **(Li *et al.*, 2011)**. If the individual is killed before thrown into the water with no blood circulation, the transfer of diatoms to organs is prevented due to the absence of circulation preventing diatoms from entering the body's organs **(Horton *et al.*,**

2006). While, if the victim is thrown into the water, there is generally a doubt whether it was an issue of antemortem or post-mortem drowning, whether the dead body was submerged before or after being thrown in the water. In these medical-legal issues, the existence of diatoms in the body tissues is an extremely effective proof **(Takeichi & Kitamura, 2009)**. In the cases related to drowning, a strong relationship is recorded between the diatoms extracted from lung tissues and the water samples taken from the drowning site for the successful detection of drowning sites in Forensic laboratories **(Ago *et al.*, 2011)**. Nevertheless, it is crucial to remember that the non-existence of diatoms does not directly rule out drowning; the diatom test does not confirm the negative, and a comprehensive investigation is constantly required. **Rohn and Frade (2006)** reported that, diatoms retrieving from the bone marrow of victims can be matched with those discovered at the supposed drowning site; this result might associate with a specific location of submersion and help in identifying the death site. In contrast, when the dead body is thrown into water, or when the reason for death is other than drowning, diatoms may move to the lungs by passive clarification; in addition, the absence of heart beats prevents the circulation of diatoms to reach distant organs **(Saukko *et al*., 2004)**.

In the present study, ten cases were received for the recognition and diagnosis by diatom test; there were 5 males, 3 females, and 2 children aged between 5-63 years (Fig 9).

Case1: The dead body of a male of 54 years of old; it was found with a floating face down in the Tanbara Haweis canal in the summer season, about 10km from the main canal branching (near Site No. 3. The water samples were obtained from this site and other sites 1 & 2 for diatom analysis. The diatom investigation showed the presence of eight species (*Aulacoseira granulata, Pantocsekiella ocellata, Staurosira construens, Cymbella neoleptoceros, Encyonema cespitosum, Gomphonema affine, Navicula capitatoradiata, Nitzschia amphibia*) in tissue samples, which were compared with diatoms detected in water samples of sites 1 2 and 3. It was observed that the eight recognized diatom species were recorded in site 1, but only *Aulacoseira granulata, Pantocsekiella ocellata, Staurosira construens Cymbella neoleptoceros,* and *Navicula capitatoradiata* were detected in Site No. 2. However, *Cymbella neoleptoceros, Gomphonema affine, Navicula capitatoradiata, Nitzschia amphibia* were absent in Site 3. This finding revealed that it was a case of death due to asphyxia drowning in Site No.1 and the water moved the body near Site No.3.

Case 2: The dead body of a male aged 59 years was discovered a week later, drowned in the water of the Mit-Yazid canal in the winter season, about 20 km from the area of the main canal branch (near Site No. 2). The diatom analysis explained the presence of nine species (*Aulacoseira granulata, Stephanocyclus meneghiniana, Ulnaria danica, Ulnaria biceps, Anomoeoneis sphaerophora, Planothidium hauckianum, Caloneis subsalina*, *Gomphonema gracile*, and *Pleurosira laevis*) in lung tissue sample, which was compared TO diatoms noticed in water samples from Sites No.1 and 2. The result showed the occurrence of *Stephanocyclus meneghiniana, Ulnaria biceps, Anomoeoneis sphaerophora, Planothidium hauckianum, Caloneis subsalina, Gomphonema gracile* and *Pleurosira laevis* characteristic of Site No. 2 and their absence in Site No.1, which reflects the case of death from asphyxia drowning at Site No.2.

Case 3: The dead body of a male aged 35 years was retrieved from the Tanbara Haweis canal in the summer season near Site No. 2 in a highly decomposed conditions. The examination revealed no diatom detected in the lung tissue sample. However, 28 diatom species were detected from the water samples, and the most dominant species were *Aulacoseira granulata, Pantocsekiella ocellata, Ulnaria danica, Ulnaria ulna, Staurosira construens, Staurosira venter, Staurosirella pinnata, Planothidium minutissimum, Navicula cari* and *Nitzschia fonticola.* Therefore, the reason for death was ascribed to other causes than drowning.

Case 4. The dead body of a female aged 42 years was recovered after three weeks from the Mit-Yazid canal in the winter season at Site 3. The diatom examination showed the existence of ten species *Aulacoseira ambigua*, *Aulacoseira granulata, Pantocsekiella ocellata, Pantocsekiella kuetzingiana, Stephanocyclus meneghiniana, Ulnaria delicatissima, Amphora ovalis, Caloneis bacillum, Neidium apiculatum,* and *Tryblionella hungarica* in the lung tissue sample. By comparing with the recorded diatom from the water samples, *Aulacoseira ambigua, Aulacoseira granulata, Pantocsekiella ocellata, Pantocsekiella kuetzingiana, Stephanocyclus meneghiniana, Ulnaria delicatissima* were noticed in Sites No. 1 and 2; however, *Amphora ovalis, Caloneis bacillum, Neidium apiculatum,* and *Tryblionella hungarica* were only detected at Site No. 1. Consequently, the case of death proved to be the asphyxia drowning diagnosis at Site No. 1, and the water moved the victim near Site No. 3.

Case 5: The dead body of a 63-year-old lady was found in the Tanbara Haweis canal in the summer season near Site No. 3. No specific reason for death was found at the autopsy. The examination proved the absence of diatom species in the lung tissue sample. However, water samples proved the presence of 31 diatom species recognized in the Tanbara Haweis canal, and the most dominant were *Aulacoseira granulata*, *Pantocsekiella ocellata*, *Ulnaria danica, Ulnaria ulna, Staurosira construens, Staurosira venter, Staurosirella pinnata*, *Planothidium minutissimum* and *Navicula cari*. The reason of death was assigned to reasons other than drowning.

Case 6: The dead body of a male aged 30 years was found floating face down in the Tanbara Haweis canal in the winter season at Site No. 2. The diatom analysis proved the occurrence of *Aulacoseira granulata*, *Pantocsekiella ocellata*, *Staurosira construens,* *Craticula ambigua, Encyonema cespitosum, Navicula rhynchocephala,* and *Gomphonema affine* in the lung tissue sample. *Aulacoseira granulata*, *Pantocsekiella ocellata*, and *Staurosira construens* were dominant in both Sites 1 and 2; however, *Craticula ambigua, Encyonema cespitosum, Navicula rhynchocephala,* and *Gomphonema affine* were characteristics referring to Site No.1. Therefore, the analysis revealed that it was a case of death due to asphyxia drowning at Site No.1.

Case 7. The dead body of a boy aged 5 years was lost for 3 days and found in the Mit-Yazid canal in the winter season, and no indication of wounds was found on the body. The body was found in front of Segein ElKom village before Site No.3. The recognized diatom species from the lung tissue sample were *Aulacoseira granulata*, *Pantocsekiella ocellata, Ulnaria biceps*, *Anomoeoneis sphaerophora, Cymbella neoleptoceros, Gomphonema gracile, Nitzschia amphibia* and *Nitzschia frustulum*. This diatom assemblage, except for *Aulacoseira granulata* and *Pantocsekiella ocellata*, was noticed in the water samples of both Sites No.2 and 3 while absent at Site No.1. Therefore, the case of death from asphyxia drowning at Site No.2, and the water moved the body near Site No.3.

Case 8: The dead body of a male with 37 years of old was recovered floating face down in the Tanbara Haweis canal in the summer season near Site No.1 and is fully dressed. The diatom analysis from the lung tissue sample defined six species, which included *Aulacoseira granulata, Pantocsekiella ocellata, Pseudostaurosira brevistriata, Staurosira construens, Staurosira venter* and *Navicula cari*. These diatom florae were distinguished from the water sample of Site No.1. This finding verified it to be a case of asphyxia drowning at the same site.

Case 9: The body of a girl aged 12 years old was found in the Mit-Yazid canal during the winter season, close to Site No.2. No diatom species were recognized from the lung tissue sample. However, the water samples proved the presence of 64 diatom species at Sites No.1 and 2, and the most dominant species were *Aulacoseira ambigua*, *Aulacoseira granulata, Pantocsekiella ocellata, Pantocsekiella kuetzingiana*, *Stephanocyclus meneghiniana*, *Ulnaria danica*, *Ulnaria delicatissima*, *Ulnaria ulna, Staurosira construens, Staurosira venter* and *Cocconeis placentula*. The cause of death was assigned to reasons other than drowning.

Case 10: The dead body of a 53-year-old lady was recovered from the Mit-Yazid canal close to Site 3. The diatom examination from the lung tissue sample proved the presence of nine diatoms species, which were represented by *Aulacoseira granulata, Pantocsekiella ocellata*, *Pantocsekiella kuetzingiana, Discostella stelligera, Ulnaria biceps, Staurosirella pinnata, Epithemia sorex, Navicula ventralis* and *Nitzschia palea*.

A comparison with water samples reflects the occurrence of *Staurosirella pinnata*, *Epithemia sorex*, *Navicula ventralis*, and *Nitzschia palea* that characterize Site No. 2. Consequently, the reason of death was assigned to asphyxia drowning at Site No.2, and the water moved the body towards Site No.3.

CONCLUSION

The current study explained that the diatoms test is considered a clear tool when indisputable diatoms are present on the examined slides. A total of 65 diatom species belonging to 31 genera were identified from the water, and the tissue samples and photographed. The diatoms were present in the lung tissue samples of the seven corpses, which were found submerged in the water of Mit-Yazid and Tanbara Haweis canals, whilst they were absent in the three corpses, which died from other causes of death. The relative abundance of the recognized diatoms varied between the studied sites in the two canals. The diatom composition and abundance were high in the Mit-Yazid canal than Tanbara Haweis canal. This may be attributed to the variation in the physicochemical characteristics of the water of both canals. The amount and species of the diatoms in each studied case were different, depending on the diatoms that were present at the drowning site. In terms of a comparison of the diatoms taken from the tissue samples and those collected from the water samples at the drowning sites, nearly the dominant species were the same, but there are other species' characteristics of each site. The findings of this research provide evidence of diatoms as an excellent standard tool to solve critical cases and differentiated the difference between postmortem and antemortem drowning.

Table 1. Average of the measured physicochemical parameters of the collected water samples from six different sites of Mit-Yazid and Tanbara Haweis canals

Mit-Yazid Canal						
Season	**Winter**			**Summer**		
	Min	**Max**	**Average**	**Min**	**Max**	**Average**
Parameters						
pH	7.54	8.91	8.225	7.26	8.36	7.81
EC (mhos/cm)	744	1012	878	720	1234	977
TDS (mg/l)	250	612	431	458	590	524
Temp. (°C)	12	15	13.5	30.2	33.1	31.65
T. A (mg/l)	158.5	180.0	169.25	164.2	192.3	178.25
COD (mg/l)	2.70	4.65	3.675	2.30	4.63	3.465
BOD (mg/l)	1.6	3.5	2.55	1.2	2.4	1.8
Mg^{++} (mg/l)	11.5	42.0	26.75	11.5	39.0	25.25
Ca^{++} (mg/l)	21	31	26	24	33	28.5
Cl (mg/l)	33.4	46.8	40.1	30.5	46.8	38.65
Tanbara Haweis canal						
Season	**Winter**			**Summer**		
	Min	**Max**	**Average**	**Min**	**Max**	**Average**
Parameters						
pH	7.17	8.99	8.08	7.33	8.26	7.795
EC (mhos/cm)	922	1121	1021.5	823	1312	1067.5
TDS (mg/l)	562	691	626.5	584	680	632
Temp. (°C)	11	16	13.5	29.5	31.5	30.5
T. A (mg/l)	129.2	195.2	162.2	129.2	195.1	162.15
COD (mg/l)	3.10	5.10	4.1	3.10	4.91	4.005
BOD (mg/l)	2.53	3.15	2.84	2.16	3.41	2.785
Mg^{++} (mg/l)	21.4	44.1	32.75	29.0	46.3	37.65
Ca^{++} (mg/l)	22	29	25.5	24	30	27
Cl (mg/l)	30.4	40.8	35.6	32.8	43.5	38.15

{pH, Electrical Conductivity (EC), Total Dissolved Solids (TDS), Temperature (Temp.), Total Alkalinity (T.A.), Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD), Magnesium (Mg), Calcium (Ca), and Chlorine (Cl)}.

Table 2. The diatoms checklist and their relative abundance in the studied water samples from Mit-Yazid and Tanbara Haweis canals. – absent, R= Rare (1-10 valves in one scan traverse), F= Frequent (>10-25 valves in one scan traverse), C= Common (>25-40 valves in one scan traverse), A= Abundant (>40 valves in one scan traverse).

	Tanbara Haweis			Mit-Yazid		
Sites	**1**	**2**	**3**	**1**	**2**	**3**
Diatom species						
Aulacoseira ambigua (Grunow) Simonsen 1979	C	C	C	A	A	A
Aulacoseira granulata (Ehrenberg) Simonsen 1979	A	A	A	A	A	A
Aulacoseira granulata var. *angustissima* (O. Müller) Simonsen 1979	-	-	R	F	C	A
Pantocsekiella ocellata (Pantocsek) Kiss & Ács 2016	A	A	A	C	A	A
Pantocsekiella kuetzingiana (Thwaites) Kiss & Ács 2016	-	-	R	C	C	A
Discostella stelligera (Cleve & Grunow) Houk & Klee 2004	-	-	-	R	F	F
Stephanocyclus meneghiniana (Kützing) Skabichevskii 1975	F	F	R	R	F	F
Cyclostephanos dubius (Hustedt) Round 1988	-	-	R	R	R	F
Melosira varians Agardh 1827	-	-	-	R	R	R
Ulnaria acus (Kützing) Aboal in Aboal *et al*. 2003	F	R	F	F	C	A
Ulnaria biceps (Kützing) Compère 2001	R	F	F	-	A	A
Ulnaria danica (Kützing) Compère & Bukhtiyarova 2006	F	C	C	R	A	A
Ulnaria delicatissima (W. Smith) Aboal & Silva 2004	F	F	F	F	C	A
Ulnaria ulna (Nitzsch) Compère 2001	F	C	C	F	A	A
Pseudostaurosira brevistriata (Grunow) Williams et Round 1987	C	C	F	R	F	F
Staurosira construens Ehrenberg 1843	A	A	A	A	A	A
Staurosira leptostauron (Ehrenberg) Kulikovskiy & Genkal 2011	F	F	F	R	F	F
Staurosira venter (Ehrenberg) Cleve & Möller 1879	A	A	C	F	A	A
Staurosirella pinnata (Ehrenberg) Williams & Round 1987	F	F	F	R	F	-
Planothidium hauckianum (Grunow) Bukhtiyarova 1999	R	R	-	-	R	F
Planothidium minutissimum (Krasske) Lange-Bertalot 2006	F	F	F	F	F	C
Amphora ovalis (Kützing) Kützing 1844	-	-	-	F	-	-
Anomoeoneis sphaerophora Pfitzer 1871	-	-	-	-	F	F
Caloneis bacillum (Grunow) Cleve 1894	-	-	-	F	-	-
Caloneis subsalina (Donkin) Hendey 1951	-	-	-	-	R	R
Cocconeis pediculus Ehrenberg 1838	-	-	-	R	R	F
Cocconeis placentula Ehrenberg 1838	F	F	F	R	C	C
Craticula ambigua (Ehrenberg) D.G.Mann 1990	R	-	-	R	R	R
Craticula cuspidata (Kutzing) D.G.Mann 1990	-	-	-	R	-	F
Cymatopleura solea (Brébisson) W.Smith 1851	-	-	-	R	R	R
Cymbella neoleptoceros Krammer 2002	R	R	-	-	R	C
Encyonema silesiacum (Bleisch) D.G.Mann 1990	F	F	F	-	F	C
Encyonema cespitosum Kützing 1849	R	-	-	F	F	C
Epithemia sorex Kützing 1844	-	-	-	R	R	-
Fallacia pygmaea (Kützing) Stickle & D.G.Mann 1990	F	F	F	F	F	F
Gomphonema affine Kützing 1844	R	-	-	-	R	F

Gomphonema gracile Ehrenberg 1838	-	-	R	-	F	R
Gomphonema parvulum (Kützing) Kützing 1849	-	-	R	R	F	C
Navicula capitatoradiata Germain ex Gasse 1986	R	R	-	F	-	F
Navicula cari Ehrenberg 1836	F	F	F	F	C	C
Navicula lanceolata Ehrenberg 1838	-	-	R	R	R	-
Navicula menisculus Schumann 1867	R	R	-	F	C	F
Navicula rhynchocephala Kützing 1844	R	-	-	F	F	C
Navicula trivialis Lange-Bertalot 1980	-	-	-	R	R	F
Navicula ventralis Krasske 1923	-	R	R	F	C	-
Navigeia modica (Hustedt) Bukhtiyarova 2013	-	-	-	R	R	F
Neidium apiculatum Reimer 1959	-	-	-	F	-	-
Neidium dubium (Ehenberg) Cleve 1894	-	-	-	R	R	F
Nitzschia amphibia Grunow 1862	R	R	-	-	F	F
Nitzschia fonticola (Grunow) Grunow 1881	F	F	F	F	F	C
Nitzschia frustulum (Kützing) Grunow 1880	R	R	R	-	C	C
Nitzschia linearis W.Smith 1853	R	R	R	F	F	F
Nitzschia palea (Kützing) W.Smith 1856	-	-	-	F	F	-
Nitzschia pura Hustedt 1954	-	-	-	R	R	F
Nitzschia recta Hantzsch ex Rabenhorst 1862	R	R	R	F	F	F
Placoneis gastrum (Ehrenberg) Mereschkowsky 1903	-	-	-	-	R	R
Placoneis clementis (Grunow) E.J.Cox 1988	-	-	-	R	R	R
Pleurosira laevis (Ehrenberg) Compère 1982	-	-	-	-	F	-
Rhoicosphenia abbreviata (Agardh) Lange-Bertalot 1980	R	R	-	R	F	F
Sellaphora pseudoventralis (Hustedt) Chudaev & Gololobova 2015	R	-	R	F	R	F
Sellaphora pupula (Kützing) Mereschkovsky 1902	-	-	-	R	R	-
Tryblionella calida (Grunow) D.G.Mann 1990	-	-	-	-	R	R
Tryblionella granulata (Grunow) D.G.Mann 1990	-	-	-	R	R	R
Tryblionella hungarica (Grunow) Frenguelli 1942	-	-	-	R	-	F
Tryblionella marginulata (Grunow) D.G.Mann 1990	-	-	-	R	R	R

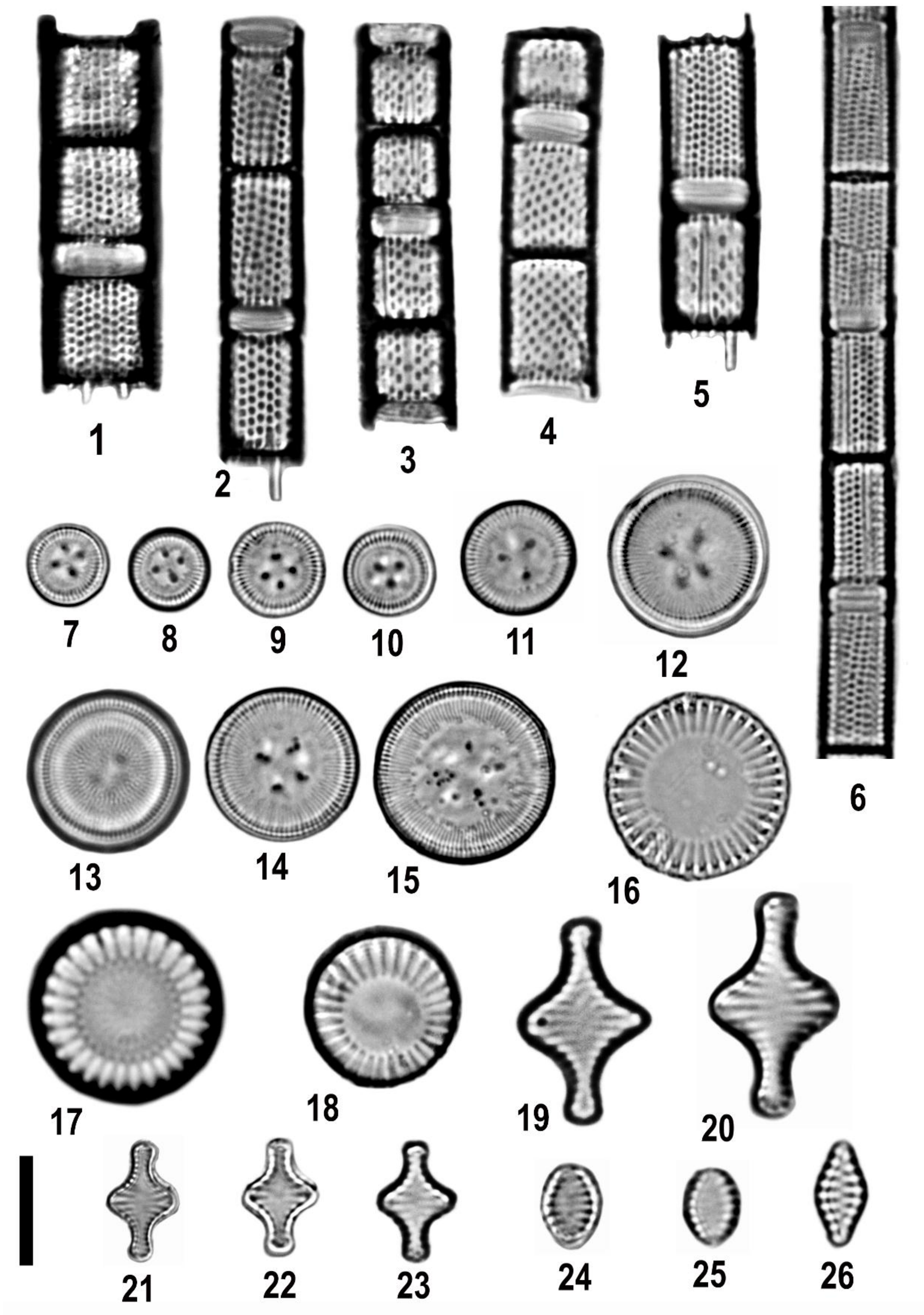

Fig. 6. Light microscopic photomicrographs of diatoms recovered from the studied canals: 1-6. *Aulacoseira granulata* (Ehrenberg) Simonsen; 7-14. *Pantocsekiella ocellata* (Pantocsek) Kiss & Ács; 15. *Pantocsekiella kuetzingiana* (Thwaites) Kiss & Ács; 16-18. *Stephanocyclus meneghiniana* (Kützing) Skabichevskii; 19-20. *Staurosira leptostauron* (Ehrenberg) Kulikovskiy & Genkal; 21-23. *Staurosira construens* Ehrenberg; 24-25. *Staurosira venter* (Ehrenberg) Cleve & Möller; 26. *Staurosirella pinnata* (Ehrenberg) Williams & Round.

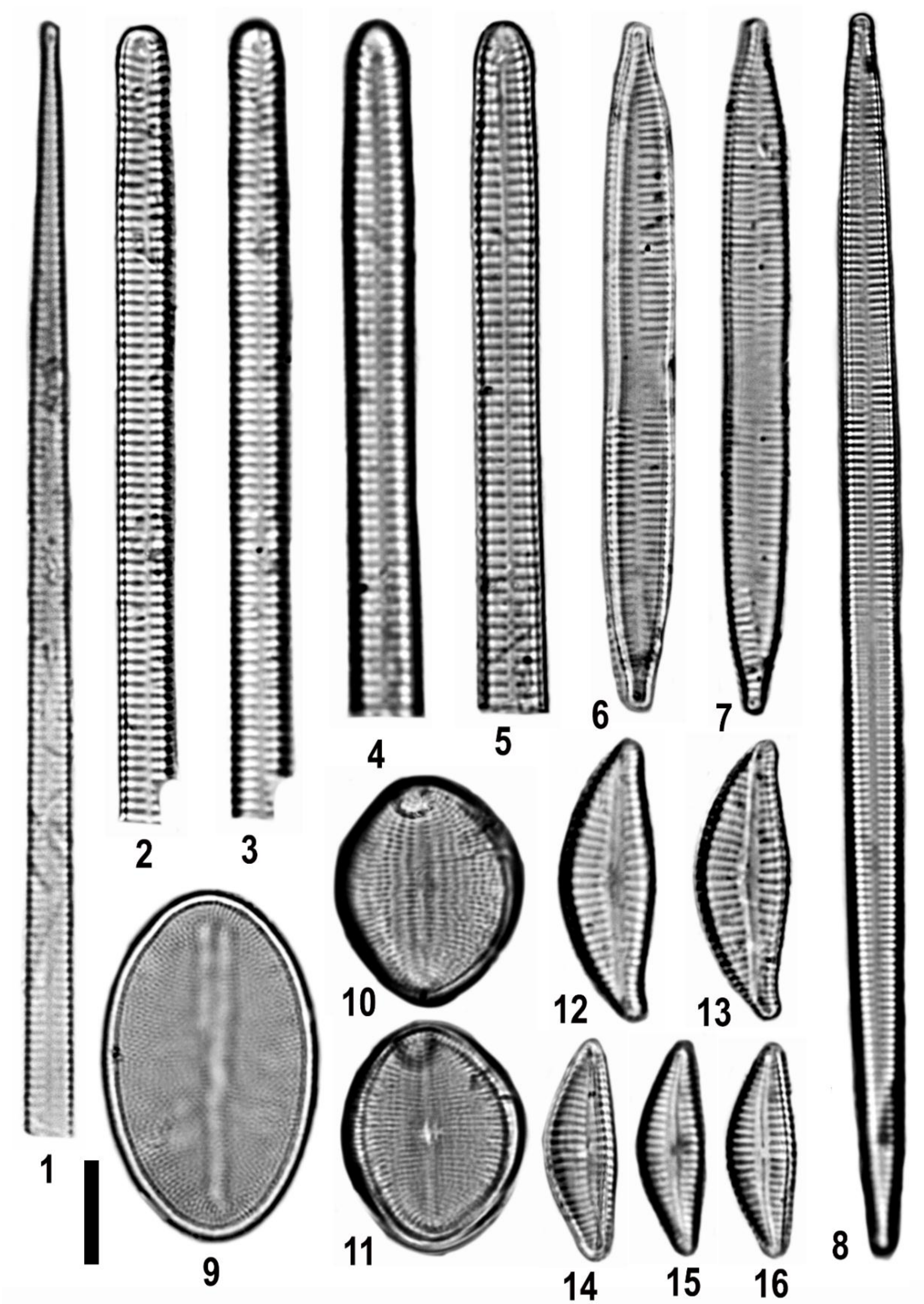

Fig. 7. Light microscopic photomicrographs of diatoms recovered from the studied canals: 1. *Ulnaria delicatissima* (W. Smith) Aboal & Silva; 2-5. *Ulnaria biceps* (Kützing) Compère; 6-8. *Ulnaria ulna* (Nitzsch) Compère; 9. *Cocconeis placentula* Ehrenberg; 10-11. *Cocconeis pediculus* Ehrenberg; 12-13. *Encyonema cespitosum* Kützing; 14-16. *Cymbella neoleptoceros* Krammer.

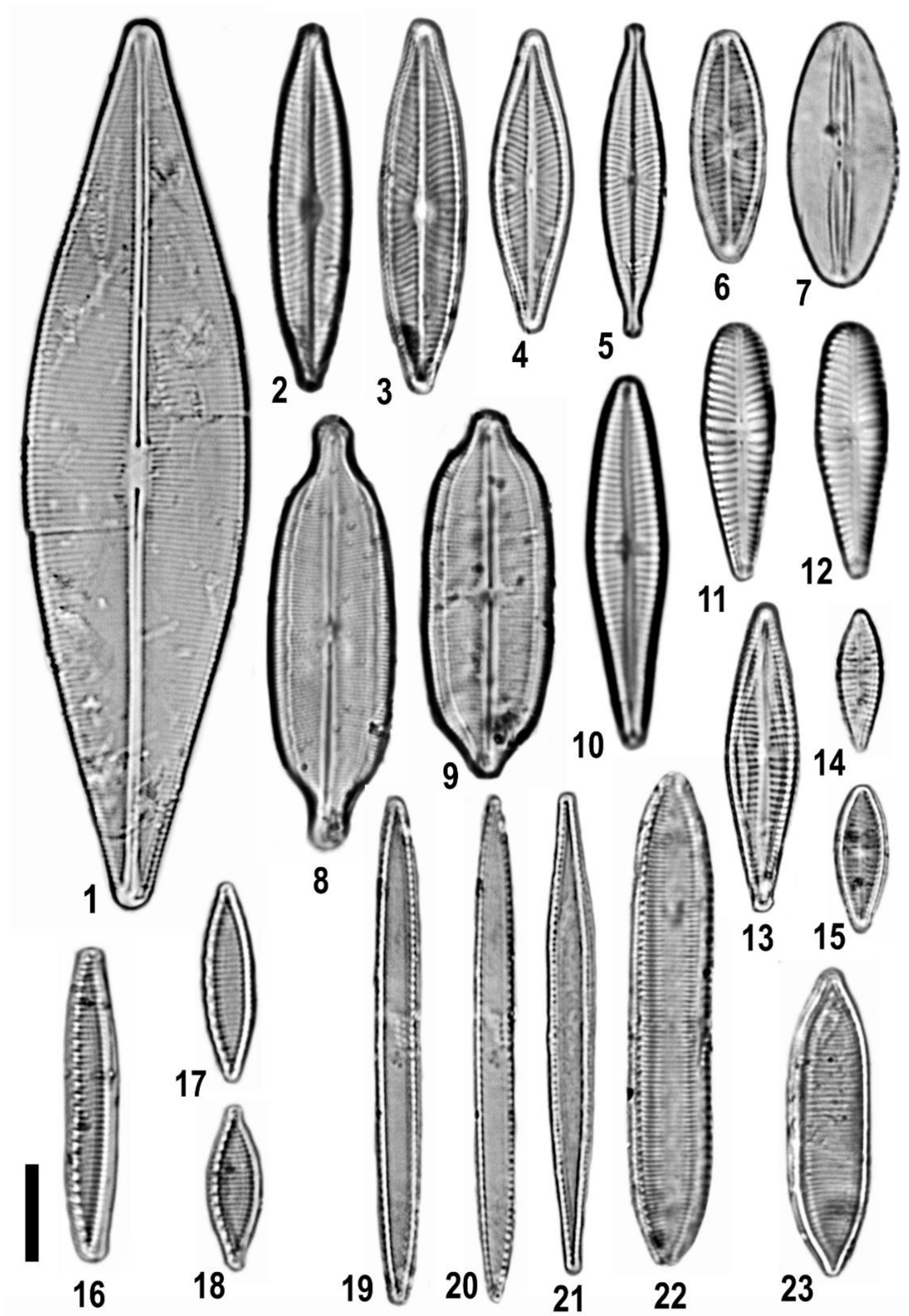

Fig. 8. Light microscopic photomicrographs of diatoms recovered from the studied canals: 1. *Craticula cuspidata* (Kützing) Mann; 2-3. *Navicula lanceolata* Ehrenberg; 4. *Navicula trivialis* Lange-Bertalot; 5. *Navicula capitatoradiata* Germain ex Gasse; 6. *Navicula cari* Ehrenberg; 7. *Fallacia pygmaea* (Kützing) Stickle & Mann; 8. *Neidium dubium* (Ehenberg) Cleve; 9. *Neidium apiculatum* Reimer; 10. *Gomphonema affine* Kützing; 11-12. *Gomphonema affine* Kützing; 13. *Gomphonema gracile* Ehrenberg; 14-15. *Gomphonema parvulum* (Kützing) Kützing; 16. *Nitzschia frustulum* (Kützing) Grunow; 17. *Nitzschia amphibia* Grunow; 18. *Nitzschia fonticola* (Grunow) Grunow; 19-20. *Nitzschia linearis* W.Smith; 21. *Nitzschia recta* Hantzsch ex Rabenhorst; 22. *Tryblionella marginulata* (Grunow) Mann; 23. *Tryblionella calida* (Grunow) Mann.

Fig 9. Photographs of some victims of cases study.

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