Environ Monit Assess (2012) 184:1325–1334
DOI 10.1007/s10661-011-2043-5

Composition and distribution of surfactants around Lake Chini, Malaysia

Mohd Talib Latif · Lim Wanfi · Norfazrin Mohd Hanif · Razarul Naim Roslan · Masni Mohd Ali · Idris Mushrifah

Received: 24 December 2010 / Accepted: 16 March 2011 / Published online: 7 April 2011

Abstract This study aims to determine the composition of surfactants in the lake surface microlayer, rainwater, and atmospheric aerosols in the area surrounding Lake Chini, Pahang. Surfactants in the lake surface microlayer were taken from seven different stations around the lake, while samples of rainwater were taken from five different sampling stations. The samples of atmospheric aerosols were collected from the Lake Chini Research Centre which is in close proximity to the lake. The colorimetric analysis method was used to determine the composition and concentration of anionic surfactants as methylene blue active substances (MBAS) and cationic surfactants as disulphine blue active substances (DBAS). The concentration of anionic surfactants, as MBAS, in the surface microlayer ranged between 0.08 to 0.23 µmol L^{-1}, while the range of concentration of cationic surfactants as DBAS ranged from 0.09 to 0.11 µmol L^{-1}. The concentration of MBAS was higher in rainwater when compared to surfactants in the lake surface microlayer. The high concentration of surfactants in the fine mode of atmospheric aerosols suggests that natural and anthropogenic sources of surfactants contribute to the atmospheric surfactants.

Keywords Surfactant · Lake-surface microlayer · Atmospheric aerosol · Rainwater · Lake Chini

Introduction

Wetland is often considered as the sink for pollutants which traps a variety of dissolved organic matter (DOM) that constitutes a large proportion of the total organic matter in many freshwater ecosystems (Haitzer et al. 1998). According to Pogorzelski and Kogut (2003), DOM is a very complex mixture of substances with diverse physicochemical properties. A large fraction of DOM has surface-active properties which have the ability to influence mass and energy transfer between the air–water interfaces (Hunter and Liss 1981; Leko et al. 2004). Although surfactants play a significant role in the environment (Latif and

M. T. Latif (✉) · L. Wanfi · M. M. Ali · I. Mushrifah
School of Environmental and Natural Resource Sciences, Faculty of Science and Technology, Universiti Kebangsaan Malaysia, 43600 Bangi, Selangor, Malaysia
e-mail: talib@ukm.my

N. M. Hanif · R. N. Roslan
School of Chemical Sciences and Food Technology, Faculty of Science and Technology, Universiti Kebangsaan Malaysia, 43600 Bangi, Selangor, Malaysia

Brimblecombe 2004; Kiss et al. 2005; Latif et al. 2005; Mungray and Kumar 2008; Masakorala et al. 2010), surfactants in wetlands are poorly quantified and have yet to be fully characterized in terms of their chemical composition and distribution.

Lake ecosystems are increasingly affected by surfactants derived from various natural and anthropogenic sources. Volatile organic compounds emitted from soil and vegetation have been found to act as a precursor of surfactants (Librando and Tringali 2005). Through chemical oxidation, volatile organic compounds generate semi-volatile organic compounds which eventually condense to form secondary organic particles. It is reported that these secondary organic particles comprise of molecules with the hydroxyl and carboxyl group that display surface-active properties (Seinfeld and Pankow 2003).

Several studies report that the introduction of surfactants may have an influence on lake ecosystems (Boulanger et al. 2004; Pavlić et al. 2005). According to Hyun-Hee et al. (2002), surfactants in aquatic systems may serve to cause deterioration of water quality and it is noted that surfactants in wetlands are capable of increasing the solubility of organic and inorganic pollutants (Almeida et al. 2009). The ability of surfactants to reduce surface tension, leads to other pollutants accumulating on the surface of the water and eventually dissolving, thus entering the water bodies (Warne and Schifko 1999). Surfactants released are also likely to negatively impact flora and fauna as reported by Pavlić et al. (2005) and El Shimy et al. (2007). Generally, however, surfactants have been observed to denature bind proteins from the cell walls of plants and consequently alter membrane permeability, hence, affecting aquatic food chains (Kimerle 1989; Lewis and Hamm 1986; Dyer et al. 1997). The flux of surfactants into the atmosphere will also increase the amount of cloud condensation nuclei, increase the number of water droplets and the albedo effect (Asa-Awuku et al. 2008) and therefore lead to changes in the microclimate around the lake ecosystem.

This study aims to determine the composition and distribution of surfactants around lake ecosystems, given their ability to affect the various functions of the lake ecosystem.

Materials and method

Study area

Lake Chini is the second largest natural lake in Malaysia, located at 03°24′40″ N to 03°26′42″ N and 102°54′18″ E to 102°55′54″ E in the state of Pahang in the Malaysian Peninsular. Lake Chini is comprised of a series of 12 inter-connecting water bodies referred to as "Laut" (sea) in the Malay language spoken by the locals. The water bodies which form Lake Chini are Laut Gumum, Laut Pulau Balai, Laut Cenahan, Laut Tanjung Jerangking, Laut Tengkuk, Laut Mempiteh, Laut Kenawar, Laut Serodong, Laut Melai, Laut Batu Busuk, Laut Labuh, and Laut Jemberau (Shuhaimi-Othman et al. 2007).

The Chini River, which drains from the lake, flows into the Pahang River. This river is dammed to maintain the lake's depth during the dry season. However, this has disrupted the natural ecology of the lake and resulted in the death of trees on its shores due to elevated water levels. According to the Malaysian Nature Society (1999), this area is richly endowed with biological resources and some 288 species of plants, 21 species of aquatic plants, 92 species of birds, and 144 species of freshwater fishes have been found here.

The lakeshores themselves are inhabited by the Jakun branch of the Orang Asli. Most of these people survive through a combination of fishing in the lake, rubber tapping, harvesting forest products such as rattan, and making blowpipes and other handicrafts for tourists. They are also involved in the logging industry and agricultural activities on the palm oil plantations.

Sampling locations

Several stations were selected to determine the concentration of surfactants around the lake ecosystem (Fig. 1). The seven stations used for sampling lake water surface microlayer were: Laut Gumum, Laut Cenahan, Laut Kenawar, Laut Melai, Laut Batu Busuk, and Laut Jemberau dan Chini River mouth (Table 1). Sampling stations for rainwater are shown in Table 2. Lake Chini Research Centre (3°25′32″ U, 102°55′34″ T) was

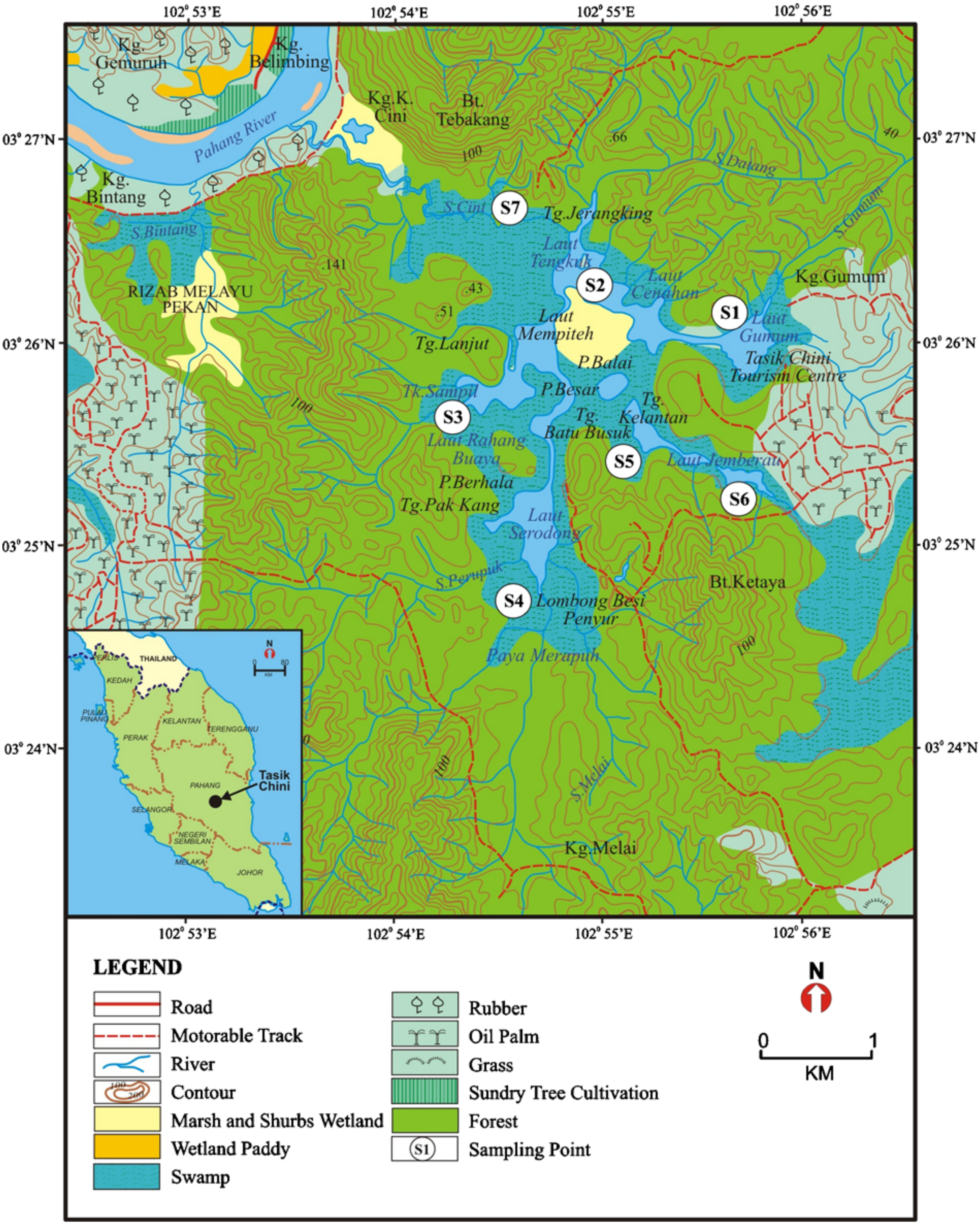

Fig. 1 Location of sampling stations around Lake Chini

Table 1 Sampling stations for lake water surface microlayer

Station	Area	Coordination	
S1	Laut Gumum	03°26.12′ N	102°55.69′ E
S2	Laut Cenahan	03°26.16′ N	102°54.90′ E
S3	Laut Kenawar	03°25.61′ N	102°54.38′ E
S4	Laut Melai	03°24.69′ N	102°54.57′ E
S5	Laut Batu Busuk	03°25.41′ N	102°55.05′ E
S6	Laut Jemberau	03°25.10′ N	102°55.71′ E
S7	Chini River	03°26.41′ N	102°54.68′ E

selected as a sampling station for atmospheric aerosol (near to S1).

Sampling procedure

Sampling for the lake surface microlayer ($n = 15$) and rainwater (monthly, $n = 6$) was conducted between August (2009) to January (2010); while atmospheric aerosol samples were taken between 28 and 30 January 2010.

Lake-surface microlayer

Samples of the lake's surface microlayer were collected using a rotation drum as recommended by Harvey (1966) for collecting samples from the sea-surface microlayer. The rotation drum has a smooth surface which is readily wet by water and used to collect the sample through its rotation on the surface water (Roslan et al. 2010). This method is ideal for obtaining a sample of a thin and less disturbed layer of surface water. Samples were stored in a vial at 4°C prior to surfactant analysis.

Rainwater

Samples of rainwater were collected in a dark bottle, attached with funnel, and wrapped in aluminum foil. Samples were collected every fortnight for surfactant analysis. Samples of rainwater were filtered using 47 mm diameter cellulose acetate filter paper with a 0.2-μm pore size (Whatman), before being analyzed.

Table 2 Sampling station for rainwater

Station	Area	Coordination	
S1	Laut Gumum	03°26.12′ N	102°55.69′ E
S2	Laut Cenahan	03°26.16′ N	102°54.90′ E
S3	Laut Kenawar	03°25.61′ N	102°54.38′ E
S4	Laut Melai	03°24.69′ N	102°54.57′ E
S7	Chini River	03°26.41′ N	102°54.68′ E

Fine and coarse mode aerosols

Samples of aerosol were collected using a high-volume air sampler (HVAS) with a two-stage Cascade Impactor (Staplex) with slotted filter paper (Westech Instrument) were used to collect coarse mode aerosols samples (diameter size >1.5 μm) and backup filter paper (Whatman EPM 2000) to collect fine mode aerosols samples (diameter size <1.5 μm). In order to remove organic matter, slotted filter papers and backup filter papers were packed in aluminum foil and pre-fired at 500°C in a muffle furnace for 4 h prior to use. The filter papers were then conditioned in desiccators for 24 h before being weighed with an electronic balance and stored in a refrigerator (4°C) until analysis. The HVAS with prepared filter papers was placed in an open field to avoid any disturbance of material to the flow of aerosols entering the instrument. The sampling was carried out for 24 h with a flow rate of 1.13 m^3 min^{-1}. After the aerosol sampling, the filter papers were once again carefully packed in aluminum foil and conditioned in a desiccator prior to weighing. Blank filter papers were treated in the same manner as the filter paper used to collect aerosol samples. The filter paper was fitted to the high-volume air sampler for 24 h without the high-volume sampler being switched on. To extract the aerosol samples from the filter paper, 1/4 of filter paper, containing aerosol particles, was cut into small pieces (1 × 1 cm) with clean scissors and forceps. Approximately 40 mL of deionised water was measured into the centrifuge tube with the filter paper and sonicated for 45 min. The mixed solution was then filtered through Whatman 0.45 μm GF/C glass microfiber filters using a vacuum pump (850 Air Compressor). The resulting filtered solution was diluted to 100 mL in a volumetric flask and kept at 4°C until analysis (Latif and Brimblecombe 2004).

Surfactant analysis

The principal of the methodology of the surfactants analysis is based on the formation of a chloroform extractable ion-association complex between the anionic or cationic surfactants and cationic (disulfine blue) or anionic (methylene blue) dyes, followed by spectrophotometric measurement of the intensity of the extracted colored complex as applied by Chitikela et al. (1995), Oppo et al. (1999), Latif and Brimblecombe (2004), Hanif et al. (2009), and Roslan et al. (2010).

The determination of anionic surfactants such as methylene blue active substances comprises two extraction stages. Approximately 20 mL of the sample solution was put into a 40-mL vial (vial A) equipped with a screw cap and Teflon liner. Then 2 mL of alkaline buffer and 1 mL of neutral methylene blue solution, followed by 5 mL of chloroform, were added to vial A in that order. The vial was tightly closed with a holed screw cap and Teflon liner before being vigorously shaken for 2 min using a vortex mixer. After shaking, the vial was left for phase separation. The screw-cap was loosened to release the pressure inside. Once the two phases were separated, a Pasteur pipette was used to transfer the chloroform layer into a new vial (vial B) that contained 22 mL of deionised water and 1 mL of acid methylene blue solution. Vial B was then shaken for 2 min using a vortex mixer. The cap was loosened for a few seconds and then re-tightened. Once the chloroform had completely separated from the water (after about 2 min), the chloroform layer was collected using a Pasteur pipette and put into a 10-mm quartz cell. The absorbance of the chloroform phase was measured with an ultraviolet-visible spectrophotometer at a wavelength of 650 nm. The lower limit of detection was estimated at 0.05 μM SDS for a blank solution.

Disulphine blue (anionic) dyes were used to determine cationic surfactants. About 20 mL volume of the sample solution was put into a 40-mL vial equipped with a screw cap and Teflon liner. First, 2 mL of acetate buffer and 1 mL of disulphine blue solution were added to the solution. After the addition of 5 mL of chloroform, the solution was shaken vigorously for 1 min using a vortex mixer. The cap was loosened for a few seconds to release pressure and then re-tightened. The vial was left for approximately 2 min until the two phases had completely separated. The chloroform layer was then removed from the vial using a Pasteur pipette and placed into a 10-mm quartz cell. The light absorbance was measured at a wavelength of 628 nm. The lower limit of detection was 0.04 μM Zephiramine standard solution.

Statistical analysis

All data collected was statistically analysed using the Student's Version of Statistical Package for the Social Sciences. An analysis of variance test was performed with a 95% confidence among the concentrations from all the sampling stations after the data was found to be in normal distribution.

Trajectory analysis

A trajectory diagram of simulations of pollutant transport in the atmosphere was developed using the Hybrid-Single Particle Lagrangian Integrated Trajectory (HYSPLIT) model run on the Realtime Environmental Applications and Display system website (www.arl.noaa.gov/ready.html). The model calculation method is a hybrid between a Lagrangian approach for transport calculations and an Eulerian approach for the dispersion calculations.

Results and discussion

Surfactants in the lake surface microlayer

The concentration of surfactants as MBAS in the lake surface microlayer was recorded as being between 0.08 ± 0.06 and 0.23 ± 0.25 μmol L^{-1} while surfactants, such as DBAS, were recorded at a range of 0.09 ± 0.02 to 0.10 ± 0.03 μmol L^{-1} (Table 3). Both the surfactants MBAS and DBAS were found in higher quantities in S6 (Laut Jemberau), while the lowest level of the surfactants as MBAS was recorded at S3 (Laut Kenawar). The lowest surfactants as DBAS were recorded at S1 (Laut Gumum), S4 (Laut Melai), S5 (Laut Batu Busuk), and S7 (Chini River).

There are significant differences in the level of MBAS recorded between stations ($p < 0.05$) but this is not the case for DBAS. Our early findings demonstrate that the level of surfactants in the

Table 3 Concentration of surfactant as MBAS and DBAS in lake surface microlayer

Station	Area	Concentration	
		MBAS (μmol L^{-1})	DBAS (μmol L^{-1})
S1 ($n = 15$)	Laut Gumum	0.11 ± 0.06	0.09 ± 0.03
S2 ($n = 15$)	Laut Cenahan	0.13 ± 0.06	0.10 ± 0.02
S3 ($n = 15$)	Laut Kenawar	0.08 ± 0.06	0.10 ± 0.02
S4 ($n = 15$)	Laut Melai	0.11 ± 0.10	0.09 ± 0.01
S5 ($n = 15$)	Laut Batu Busuk	0.19 ± 0.10	0.09 ± 0.02
S6 ($n = 15$)	Laut Jemberau	0.23 ± 0.25	0.10 ± 0.03
S7 ($n = 15$)	Chini River	0.16 ± 0.11	0.09 ± 0.02
Average		0.15 ± 0.13	0.10 ± 0.02

lake surface microlayer, particularly at S6 (which is in close proximity to the palm oil plantation) are significantly related to anthropogenic sources as a result of soil erosion and the movement of chemical from the soils.

The concentration of anionic surfactants is far greater when compared to the concentration of cationic surfactants. These results correlate with other findings from previous studies on the concentration of surfactants in the environment, thus indicating the domination of anionic surfactants in the environment (Latif and Brimblecombe 2004; Latif et al. 2005; Hanif et al. 2009; Halim et al. 2010; Roslan et al. 2010).

A comparison of the concentration of surfactants from the sea surface microlayer as undertaken by Roslan et al. (2010) found that the concentration of MBAS and DBAS taken from the lake microlayer were within the same concentrations of surfactants found in the sea surface microlayer. Based on the results from this study, it is expected that natural sources, e.g., the degradation of soil humic substances contribute to the quantity of surfactants in the lake surface microlayer. Nevertheless, the amount of other chemicals, particularly those used in agricultural activities (for example: pesticides, fertilizers, and oil palm residues), contribute to the quantity of organic substances which in turn contain surfactants (Tann 1997). In addition, the quantity of surfactants in the lake surface microlayer can also be contributed to the level of detergent used by those living in the surrounding areas (Hanif et al. 2009).

Surfactants in rainwater

The range of surfactants as MBAS, recorded in rainwater was given as being between 0.06 ± 0.10 and 0.41 ± 0.28 μmol L^{-1}, while surfactants as DBAS were recorded as being between 0.14 ± 0.03 and 0.28 ± 0.21 μmol L^{-1} (Table 4). The highest concentrations of both surfactants MBAS and DBAS were recorded at Chini River (S7), while samples collected at S3 (Laut Kenawar) showed the lowest concentration of surfactants as MBAS. Samples collected at S1 (Laut Gumum) and S4 (Laut Melai) showed the lowest concentrations of the surfactants as DBAS. As surfactants in lake surface microlayer, there is a significant difference between surfactants as MBAS in rainwater between stations ($p < 0.05$) but this is not the case for DBAS.

Table 4 Concentration of surfactant as MBAS and DBAS in rainwater

Station	Area	Concentration	
		MBAS (μmol L^{-1})	DBAS (μmol L^{-1})
S1 ($n = 6$)	Laut Gumum	0.18 ± 0.20	0.14 ± 0.03
S2 ($n = 6$)	Laut Cenahan	0.11 ± 0.13	0.17 ± 0.08
S3 ($n = 6$)	Laut Kenawar	0.06 ± 0.10	0.18 ± 0.10
S4 ($n = 6$)	Laut Melai	0.28 ± 0.07	0.14 ± 0.07
S7 ($n = 6$)	Chini River	0.41 ± 0.28	0.28 ± 0.21
Average		0.21 ± 0.22	0.19 ± 0.13

Table 5 Concentration of surfactant as MBAS and DBAS in aerosol

Station	Particle size	Concentration	
		MBAS (pmol m^{-3})	DBAS (pmol m^{-3})
S1 ($n = 2$)	Coarse (>1.5 μm)	50.92 ± 0.01	51.21 ± 0.10
	Fine (<1.5 μm)	81.54 ± 13.76	30.40 ± 17.80
	Total	132.46 ± 13.76	81.61 ± 17.80

The results showed that the concentration of surfactants in rainwater, for both MBAS and DBAS, are higher when compared to concentrations in the lake surface microlayer (Tables 3 and 4). There is no significant correlation ($p > 0.05$) between the concentration of surfactants MBAS and DBAS from the lake surface microlayer and the concentration of surfactants in rainwater. The evaporation of organic substances in the atmosphere from the lake ecosystem contributes to the high amount of surface active molecules entering the atmosphere. These molecules

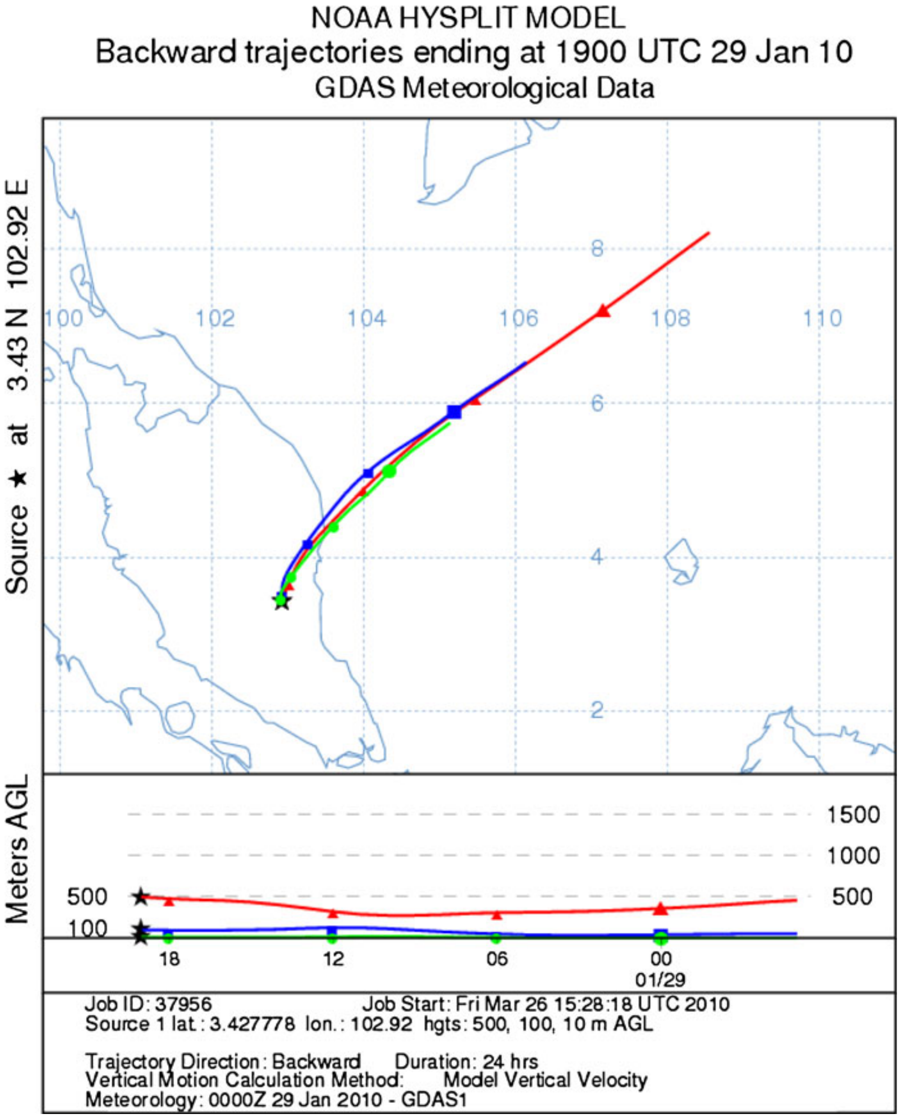

Fig. 2 Backward trajectory of wind direction during atmospheric aerosols sampling on 29 January 2010

interact with atmospheric aerosols and dissolve in rainwater before being washed out onto the lake surface. The high evaporation processes and the interaction of high molecular weight molecules from humic substances are believed to generate a high level of surfactants into the atmosphere from the lake ecosystem (Latif and Brimblecombe 2007; Klavins and Purmalis 2010).

Surfactants in atmospheric aerosols

The concentration of anionic surfactants as MBAS in atmospheric aerosols (132.46 ± 13.76 pmol m^{-3}) was found to be higher when compared to cationic surfactants as DBAS (81.60 ± 17.80 pmol m^{-3}; Table 5). The results showed that the anionic groups in organic substances are more dominant in atmospheric surfactants. This is expected to be due to the presence of organic acids around Lake Chini and the amount of various types of humic acids. These findings correspond to the study previously undertaken by Hanif et al. (2009), which reported that anionic surfactants found in the lake ecosystem correlate with humic-like substances (HULIS) found in soil. This statement is made based on the comparison of UV/VIS spectra of aerosol with the spectra of HULIS, whereby the aerosol extract exhibited similar patterns to the HULIS spectra as reported in other studies (Havers et al. 1998). In the natural ecosystem, soil acts as the main contributor for organic matter load in the atmosphere (Krivácsy et al. 2008). It was noted that the humic substances contained in soil have the potential to generate surfactants through the process of photo-oxidation (Tegen and Fung 1995).

Through a comparison of the data on fine mode and coarse mode aerosols, surfactants as MBAS were also found to be dominant in fine mode aerosols, ranging between 71.81 and 91.27 pmol m^{-3}. There is a possibility that anthrophogenic activities, for example, open burning by the local community and agricultural activities (particularly those relating to the palm oil industries), contribute to the load of negatively charged surfactants in fine mode aerosols. According to Bascom et al. (1996), aerosol generated from the combustion process are highly distributed significantly in a fine mode aerosols. These results suggest the need for further investigation into the ability of biomass burning (especially from the palm oil industries in the Chini area) to contribute to the quantity of surfactants around lake ecosystems. The results from the HYSPLIT Model (Fig. 2) also indicate the possibility of surfactants originating from the sea surface microlayer as a result of wind direction.

With relation to cationic surfactants, DBAS was found to be dominant in the coarse mode aerosols, and ranged between 51.14 and 51.28 pmol m^{-3}. Cationic surfactants such as DBAS are expected to originate from soil emissions which contain a high amount of cationic charge due to the amount of nitrogen substances, e.g., amine fatty acid and ammonium quartenary as suggested by Latif (2006). It has been found that the decomposition of plants and insects would convert large organic nitrogen molecules into water-soluble salts containing ammonium ions (Miller 1982). In addition, the use of fertilizers containing ammonium salts, as used in agricultural activities, is also considered to be a likely contributing factor to the high concentration of cationic surfactants.

Conclusion

This study has shown that the concentrations of anionic surfactants were higher than those of cationic surfactants across all the sampling sites. Surfactants, particularly in the anionic form as MBAS, were found to be at the highest level at the sampling stations associated with various natural and anthropogenic sources. The presence of surfactants in the surface microlayer recorded sampling stations may be the result of agricultural activities specifically from palm oil plantations.

The concentrations of surfactants in rainwater are significantly higher when compared to those of surfactants in the lake surface microlayer. Evaporation processes are expected to contribute small molecules from the surface microlayer to the atmosphere to form surface active molecules in atmospheric aerosols. The dissolved surface active molecules or surfactants are washed out by rainwater to complete the cycle of surfactants in the atmosphere.

Based on the characteristics of surfactants in atmospheric aerosols, there are indications that surfactants in this lake ecosystem are generated from humic-like substances or HULIS. The cycle and interaction of surfactants in lake ecosystems are an important focus of research and should be studied further to determine the effect of surfactants on the solubility and accumulation of organic and inorganic pollutants in the lake ecosystem.

Acknowledgements We are very thankful to the Ministry of Science, Technology and Innovation of Malaysia (MOSTI) and National Oceanography Directorate (NOD) for the E-Science Fund 04-01-02-SF0515 grant and Universiti Kebangsaan Malaysia for UKM-GUP-ASPL-07-05-138 grant.

References

Almeida, C. M. R., Dias, A. C., Mucha, A. P., Bordalo, A. A., & Vasconcelos, M. T. S. D. (2009). Influence of surfactants on the Cu phytoremediation potential of a salt marsh plant. *Chemosphere, 75*, 135–140.

Asa-Awuku, A., Sullivan, A. P., Hennigan, C. J., Weber, R. J., & Nenes, A. (2008). Investigation of molar volume and surfactant characteristics of water-soluble organic compounds in biomass burning aerosol. *Atmospheric Chemistry and Physics, 8*(4), 799–812.

Bascom, R., Bromberg, P. A., Hill, C., Costa, D. L., Devlin, R., Dockery, D. W., et al. (1996). Health effects of outdoor air pollution. *American Journal of Respiratory and Critical Care Medicine, 153*, 477–498.

Boulanger, B., Vargo, J., Schnoor, J. L., & Hornbuckle, K. C. (2004). Detection of perfluorooctane surfactants in Great Lakes water. *Environmental Science and Technology, 38*, 4064–4070.

Chitikela, S., Dentel, S. K., & Allen, H. E. (1995). Modified method for the analysis of anionic surfactants as methylene blue active substances. *The Analyst, 120*, 2001–2004.

Dyer, S. D., Lauth, J. R., Morrall, S. W., Herzog, R. R., & Cherry, D. S. (1997). Development of a chronic toxicity structure activity relationship for alkyl sulphates. *Environmental Toxicology and Water Quality, 12*, 295–303.

El Shimy, A., Tantawy, N., El Tabi, A., & Omar, A. M. A. (2007). Biological activity and toxicity of some surfactants used in metal working fluids on scendesmus obliquus algae. *Journal of Applied Science Research, 3*, 245–250.

Haitzer, M., Höss, S., Traunspurger, W., & Steinberg, C. (1998). Effects of dissolved organic matter (DOM) on the bioconcentration of organic chemicals in aquatic organisms—A review. *Chemosphere, 37*, 1335–1362.

Halim, N. H. A., Hanif, N. M., Othman, M. R., & Latif, M. T. (2010). Colourimetric determination of features of an air sampling technique optimal for detection of surfactants. *Sains Malaysiana, 39*, 175–179.

Hanif, N. M., Latif, M. T., Ali, M. M., & Othman, M. R. (2009). Atmospheric surfactants around lake ecosystems. *European Journal of Scientific Research, 32*, 268–276.

Harvey, G. W. (1966). Microlayer collection from the sea surface: A new method and initial results. *Applied Oceanography, 11*, 600–613.

Havers, N., Burba, P., Lambert, J., & Klockow, D. (1998). Spectroscopic characterization of humiclike substances in airborne particulate matter. *Journal of Atmospheric Chemistry, 29*, 45–54.

Hunter, K. A., & Liss, P. S. (1981). Organic sea surface films. In E. K. Duursma, & R. Dawson (Eds.), *Marine Organic Chemistry* (pp. 259–298). New York: Elsevier.

Hyun-Hee, C., Jaeyoung, C., Goltz, M. N., & Jae-Woo, P. (2002). Combined effect of natural organic matter and surfactants on the apparent solubility of polycyclic aromatic hydrocarbons. *Journal of Environmental Quality, 31*, 275–280.

Kimerle, R. A. (1989). Aquatic and terrestrial ecotoxicology of "LAS". *Tenside, Surfactants, Detergents, 26*, 169–176.

Kiss, G., Tombácz, E., & Hansson, H.-C. (2005). Surface tension effects of humic-like substances in the aqueous extract of tropospheric fine aerosol. *Journal of Atmospheric Chemistry, 50*, 279–294.

Klavins, M., & Purmalis, O. (2010). Humic substances as surfactants. *Environmental Chemistry Letters, 8*(4), 349–354.

Krivácsy, Z., Kiss, G., Ceburnis, D., Jennings, G., Maenhaut, W., Salma, I., et al. (2008). Study of water-soluble atmospheric humic matter in urban and marine environments. *Atmospheric Research, 87*, 1–12.

Latif, M. T. (2006). *Characteristics and Distribution of Surfactants in the Atmosphere*. Norwich: University of East Anglia.

Latif, M. T., & Brimblecombe, P. (2004). Surfactants in atmospheric aerosols. *Environmental Science and Technology, 38*, 6501–6506.

Latif, M. T., & Brimblecombe, P. (2007). Average molecular weight of surfactants in aerosols. *Atmospheric Chemistry and Physics Discussions, 7*(5), 13805–13838.

Latif, M. T., Brimblecombe, P., Ramli, N. A., Sentian, J., Sukhapan, J., & Sulaiman, N. (2005). Surfactants in South East Asian aerosols. *Environmental Chemistry, 2*, 198–204.

Leko, P. O., Kozarac, Z., & Ćosovć, B. (2004). Surface active substances (SAS) and dissolved organic matter (DOC) in atmospheric precipitation of urban area of Croatia (Zagreb). *Water, Air and Soil Pollution, 158*, 295–310.

Lewis, M. A., & Hamm, B. G. (1986). Environmental modifications of a photosynthetic response of lake plankton to surfactants significance to laboratory–field comparison. *Water Research, 12*, 1575–1582.

Librando, V., & Tringali, G. (2005). Atmospheric fate of OH initiated oxidation of terpenes. Reaction mechanism of α-pinene degradation and secondary organic aerosol formation. *Journal of Environmental Management, 75*, 275–282.

Malaysian Nature Society (1999). *A Survey of Vegetation and Avifauna of Chini*. Malaysia Nature Society.

Masakorala, K., Turner, A., & Brown, M. T. (2010). Toxicity of synthetic surfactants to the marine macroalga, *Ulva lactuca*. *Water, Air and Soil Pollution*. doi:10.1007/s11270-010-0641-4.

Miller, G. T. (1982). *Living in the Environment*. California: Wadsworth Publishing Company.

Mungray, A. K., & Kumar, P. (2008). Occurrence of anionic surfactants in treated sewage: Risk assessment to aquatic environment. *Journal of Hazardous Materials, 160*, 362–370.

Oppo, C., Bellandi, S., Innocenti, N. D., Stortini, A. M., Loglio, G., Schiavuta, E., et al. (1999). Surfactant components of marine organic matter as agents for biogeochemical fractionation and pollutant transport via marine aerosols. *Marine Chemistry, 63*, 235–253.

Pavlić, Ž., Vidaković-Cifrek, Ž., & Puntarić, D., (2005). Toxicity of surfactants to green microalgae Pseudokirchneriella subcapitata and Scenedesmus subspicatus and to marine diatoms Phaeodactylum tricornutum and Skeletonema costatum. *Chemosphere, 61*, 1061–1068.

Pogorzelski, S. J., & Kogut, A. D. (2003). Adsorptive properties of natural water surfactant films. Dead Vistula catchment water studies. *Oceanologia, 45*, 373–394.

Roslan, R. N., Hanif, N. M., Othman, M. R., Azmi, W. N. F. W., Yan, X. X., Ali, M. M., et al. (2010). Surfactants in the sea-surface microlayer and their contribution to atmospheric aerosols around coastal areas of the Malaysian Peninsula. *Marine Pollution Bulletin, 60*, 1584–1590.

Seinfeld, J. H., & Pankow, J. F. (2003). Organic atmospheric particulate material. *Annual Review of Physical Chemistry, 54*, 121–140.

Shuhaimi-Othman, M., Lim, E. C., & Idris, M. (2007). Water quality changes in Chini Lake Pahang, West Malaysia. *Environmental Monitoring Assessment, 131*, 279–292.

Tann, R. S. (1997). A review of surfactants used in novel agricultural applications. *ASTM Special Technical Publication, 1328*, 187–196.

Tegen, I., & Fung, I. (1995). Contribution to the atmospheric mineral aerosol load from land surface modification. *Journal of Geophysical Research D: Atmospheres, 100*, 18,707–18,726.

Warne, M. S. J., & Schifko, A. D. (1999). Toxicity of laundry detergent components to a freshwater cladoceran and their contribution to detergent toxicity. *Ecotoxicology and Environmental Safety, 44*, 196–206.