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ORIGINAL ARTICLE

Determination of concentration of total sodium and potassium in surface and ground water using a flame photometer

Payal Banerjee[1] · Bably Prasad[2]

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Abstract
In this paper, we have investigated 18 water samples collected from various sources, e.g., surface, underground and river water, as specimens for their sodium and potassium ions content in and around Dhanbad, a mining town, using the flame photometry. We have plotted the contour maps to show the spatial distributions of the dissolved sodium and potassium cations in the groundwater and surface water sources in and around the Dhanbad city to identify the relative contributions of human and natural phenomena to it. Along with it, water quality index (WQI) is calculated to evaluate whether the collected surface, ground and river water samples are fit for human consumption for the residents of those areas. The water of Maithan Dam has been observed to have the least sodium and potassium concentrations of 16 mg/l and 7 mg/l, respectively, which make it most suitable for human consumption. The water of Rani Talab Pond has the highest sodium and potassium contents of 49 mg/l and 24 mg/l. WQI values of all the samples are found to be less than 50, which indicates they are safe to consume by the humans. Reduction in the use of pesticides, potassium permanganate and water softeners is recommended to maintain WQI of the Dhanbad city within safe limit.

Keywords Flame photometer · Sodium · Potassium · Surface water · Underground water

Introduction

The possibility of employment of characteristic emission from excited atoms in quantitative analysis of elements for analytical chemical science was first experimentally studied by Bunsen and Kirchhoff. This very principle was actually employed for the development of instruments such as flame photometer for analytical chemical science experiments for quantitative analysis of potassium and sodium alkali metal ions. For the detection of trace metals all across the world, atomic emission is considered as an effective tool. In order to develop a robust and quantitative atomic emission-based method, there are many considerations that need to be taken into accounts such as proper selection of atomization and excitation source, proper wavelength along with slit width selection, minimization of outside chemical and spectral interference and techniques to standardization. Progress in the development of flame photometer is accelerated with the introduction of nebulizer, which enables the introduction of the sample in the form of aerosol inside the air/acetylene flame. At that time, emission was dispersed by quartz prism spectrograph, and emission was recorded photographically. As a result of this, a low-cost, highly sensitive instrument such as flame photometer was developed for the precise determination of alkali metal ions content in the samples.

Other precise techniques such as atomic absorption spectroscopy (Parker 1972) (AAS), inductively coupled plasma atomic emission spectroscopy (ICP-AES) were also developed alongside to increase the resolution of other metal ions detection. Flame photometer has a high resolution for the detection of alkali metal ions such as sodium (Na^+) and potassium (K^+). Later in the field of analytical spectrophotometers, the concept of the introduction of photomultiplier tube in the grating-based spectrophotometers to AAS was significant.

Flame photometer actually works by atomizing a solution sample into a flame and separates the characteristic spectra of an element along with measurement of emission. Low

✉ Bably Prasad
drbablyprasad@yahoo.com

1 Department of Applied Chemistry, Central University of Jharkhand, Ranchi, Jharkhand 835205, India

2 Natural Resources and Environment Management, CSIR-CIMFR, Dhanbad Jharkhand-826015, India

excitation is obtained from flame-based devices ranging from the temperature of 1000–3000 °C. Due to low excitation temperature from flame than arc flame, this method is well suited for alkali metal at best, i.e., sodium and potassium to alkali earth metals including calcium, barium, etc. The Flame photometer has unique advantages in detecting above-mentioned alkali and alkaline earth metals to a great extent over AAS and ICP-AES, which are expensive techniques. ICP-AES enjoys an overwhelming superiority in metal ions detection over flame photometry technique, but the efficiency of sodium and potassium detection by this technique is very low compared to flame photometry, which makes flame photometry technique the most suitable candidate. On the introduction of group II compounds consisting of alkaline earth and alkali metals into the flame, they dissociate into separate atoms. On dissociation, the atoms get excited to higher states. But at higher states, they are not stable, so they return back to the ground state with the emission of characteristics wavelength. As they return back to the ground state, they emit color in the range of visible spectrum. It is also worth to note that each alkali metal and alkaline earth metals have a characteristic wavelength.

Sodium is not harmful to a human being if it does not exceed the normal levels, which is sourced from drinking water and foods. But sodium intake turns into a cause of concern for those who are suffering from heart and kidney problem or insomnia. They are advised to take low sodium content food. Potassium is the sodium's partner. Potassium stays inside the cells with cell barrier at the other side. Potassium is considered as an electrolyte which does not enjoy free circulation inside the human body. Concentration of potassium is responsible for withstanding gate pressure of sodium and the pressure generated due to water movement. Sodium/potassium pumps (Smith 1988) inside a cell are inseparable, which help our body in controlling neural transmission and contraction of muscles. Potassium level in the body is vital as it maintains a balanced water level inside the body, controls blood pressure and plays a pivotal role in neural transmission and contraction of muscle, which includes involuntary cardiac muscle. In the present work, different drinking water samples of mining area have been analyzed and discussion has been carried out. Dhanbad city has a large population as it is one of the most important coal mining belts of India. So, it is important to study the sodium and potassium content in the water as the water bodies in and around Dhanbad city are primary and secondary source of drinking water for the city population. It is important to study the amount of sodium and potassium contents in the water of the water bodies to rule out health hazards in school-going children and old-age people suffering from the kidney-related problem due to the presence of potassium and sodium in drinking water. Water quality index (WQI) of the collected water samples is calculated later to understand the compiled influence of different water quality, i.e., presence of dissolved solute, e.g., sodium and potassium in our case on the overall quality of the water. So, WQI calculation for all the water samples has been done to get the idea of quality of drinking water, i.e., whether it is fit for human consumption in reference to the presence of sodium and potassium in it.

Materials and methods

Study areas

Surface water samples were collected from the various sources as shown in Fig. 1, which are situated in and around Dhanbad city of Jharkhand, India. These areas hold the highest concentration of population of Dhanbad city along with villages around Dhanbad city. So, these areas were chosen for the study. The surface waters were collected from sources, namely Baker Badh Pond, Duba Badh Pond, Kali Mandir Mandal Talab Pond, Dhaiya Basti Thakur Puli Pond and Rani Talab Pond, all of which are freshwater ponds situated in the Dhanbad city of Jharkhand, India, while one surface water sample was collected from Maithan Dam build over the flowing River Damodar. The underground waters were sourced from different places of Dhanbad city which are Hirapur, Housing Colony tube well-61/28, CSIR-CIMFR Campus bore well, Housing Colony tube well-62/28, Chandra Vihar Colony tube well, Bartand, Housing Colony bore water, Bank More tube well, Housing Colony tube well-28/413DMC (20/18/19), Steel Gate tube well, Govindpur tube well, while two underground water samples were collected from Gopalpur (Asansol)—a place which is nearly 52 km away from Dhanbad city bore water—and Chittaranjan (bore water)—a town nearly 60 km away from Dhanbad. All the above-mentioned collected water samples were examined using a flame spectrophotometer for the detection of sodium and potassium ions contained in the water samples.

Experimental procedure

Eighteen water samples were collected from various water bodies in and around Dhanbad city, of which five were surface water of ponds, while 12 were underground water comprising of four shallow and eight deep aquifers, wells, bore water (Meena and Hosamani 2004; Radha et al. 2007), tube wells along with one water sample collected from Maithan Dam built on the banks of Barakar River (biggest reservoir of Damodar Valley Corporation). For spectroscopic analysis of these water samples, a flame photometer was employed (American Public Health Association 1985).

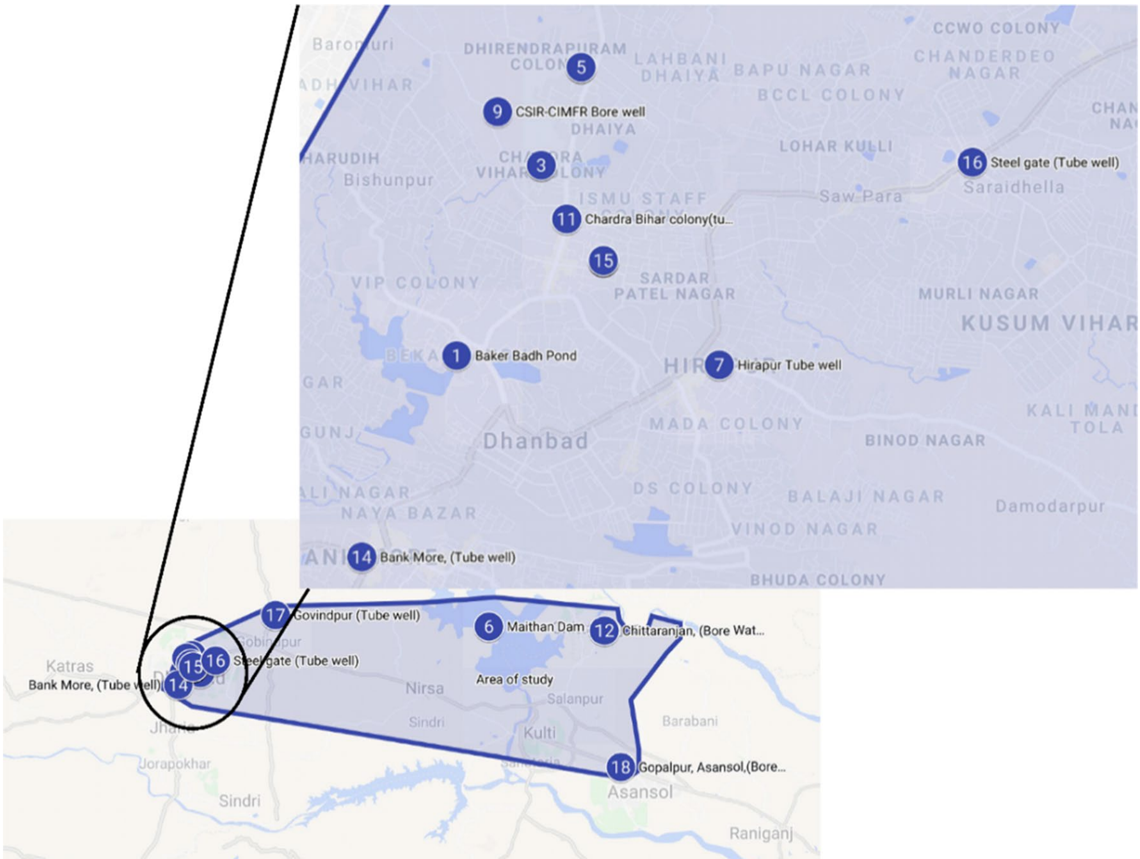

Fig. 1 Map showing the locations of collected water samples in and around Dhanbad city

Table 1 Characteristic emission color from alkali metals under the flame

Alkali metals	Characteristic wavelength	Flame color
1. Sodium	589 nm	Yellow color
2. Potassium	766 nm	Violet color

The flame photometer was calibrated using the standard stock solution of sodium and potassium having 30 ppm concentration. Various other instrumental parameters were adjusted to fine-tune the flame. After instrumental calibration, it was run to examine the collected water samples. For examination, 100 ml of water from each collected sample was taken in standard laboratory plastic bottles and then the water samples were poured inside the flame photometer. All the samples were collected during the dry winter season in the month of December when the average temperature was 20 °C. All the samples were collected once for analysis from the water sources.

Results and discussion

Analysis results as obtained from the flame photometer data are summarized below in Tables 1, 2:

The results indicate that the sodium and potassium contents in all the water samples are well within the permissible limit as per guideline laid down by World Health Organization (WHO 1984), (BIS 1991) and guidelines by other groups (Udo and Ogunwale 1978). But there are observed fluctuations in the sodium and potassium contents between different sources of water, i.e., surface water, aquifers and underground water (Maliniet al. 2003). The cause of the presence of sodium in the surface water can be attributed to time-dependent wear-out of mineral rock that contains sodium and salt deposit erosion along with infiltration of surface (Abowei 2010) water contaminated by road salt, irrigation (Erton 1950; Singh and Ram 1971; Boyd 1979; Ayers and Westcot 1985; Yadav and Khera 1993) and precipitation leaching through soils high in sodium, groundwater pollution (Ghose and Basu 1968; Turner 1981; Chatterjee 1996; Patil and Tijare 2001; Singh and Mathur 2005; Gupta and Shukla 2006) by sewage effluent (Theroux et al. 1943; Manivasakam 1996; Jakhrani 2009) and infiltration

Table 2 Concentration of sodium and potassium ions in the analyzed water samples

Sample details	Sample locations (coordinates)	Concentration of Na^+ (mg/l)	Concentration of K^+ (mg/l)
1. Baker Badh Pond (surface water)	23.8012° N, 86.4248° E	47	20
2. Duba Badh Pond (surface water)	23.8136° N, 86.4308° E	49	14
3. Kali Mandir Mandal Talab Pond (surface water)	23.8136° N, 86.4308° E	59	15
4. Dhaiya Basti Thakur Puli Pond (surface water)	23.8200° N, 86.4336° E	43	15
5. Rani Talab Pond (surface water)	23.8200° N, 86.4336° E	49	24
6. Maithan Dam (surface water)	23.8503° N, 86.7778° E	16	07
7. Hirapur (tube well) shallow aquifer	23.8006° N, 86.4434° E	63	06
8. Chandra Vihar Colony (tube well), Bartand, shallow aquifer	23.8101° N, 86.4326° E	46	08
9. Bank More (tube well), shallow aquifer	23.7881° N, 86.4181° E	17	08
10. Govindpur (tube well), shallow aquifer	23.8627° N, 86.5306° E	49	08
11. CSIR-CIMFR (bore water), deep aquifer	23.8171° N, 86.4277° E	27	08
12. Chittaranjan (bore water), deep aquifer	23.8460° N, 86.9111° E	41	09
13. Housing Colony (bore water)	23.8074° N, 86.4352° E	24	07
14. Gopalpur, Asansol (bore water), deep aquifer	23.7003° N, 86.9299° E	27	08
15. Housing colony (tube well)-28/413DMC 20/18/19	23.8074° N, 86.4352° E	56	15
16. Steel gate (tube well)	23.8138° N, 86.4613° E	46	10
17. Housing colony (tube well)-61/28	23.8074° N, 86.4352° E	35	07
18. Housing colony (tube well)-62/28	23.8074° N, 86.4352° E	42	07

Table 3 Quality of water classification range and water type based on WQI value

Range	Type of water
<50	Excellent water
50–99.99	Good water
100–199.99	Poor water
200–299.99	Very poor water
≥ 300	Unsuitable for drinking/irrigation

of leachate from landfills or industrial sites (Dwivedi and Pandey 2002; Chaurasia and Pandey 2007). The source of potassium in groundwater may come from hard water treatment by ion exchange treatment, or it may be sourced from accidental discharge of a large amount of potassium. Treatment of water by potassium permanganate is another major source that adds to enhanced potassium level in the water. Water softeners used to reduce the hardness of water are another way by which potassium gets introduced inside the water bodies. The sodium and potassium ions content in the analyzed samples as shown in Fig. 2a, b for collected surface and underground water give us the relative weightage of sodium and potassium ions contained in the water collected from different sources in and around the Dhanbad city.

The trend observed in experimental values of sodium and potassium contents in the water of ponds, (Bronmark and Hansson 2005; Kiran 2010), surface water and underground water as given in Table 2, 3 is that underground water has a much higher content of sodium present in it compared to surface water, which may be ascribed to the fact that there is a high probability of the presence of salt rock bed very near to underground water bed, which leads to dissolving of the sodium ions with it, whereas potassium content in surface water is higher than surface water due to the human activities mentioned above.

In order to get a glimpse of variation of sodium (Rajesh and Murthy 2004) and potassium content in the entire region over which the sources of sample water are distributed will help us in understanding the interplay of role of human activity contribution to sodium, potassium ions present in water versus underground rock bed geology contribution to alkali metal ions in water. It showed that in and around the heart of Dhanbad city, sodium and potassium ions content is in the higher range, while as we move away from the city area where human habitation is negligible, a drop in potassium ion content, which is solely due to human activity, and sodium ion content in the water, which is due to the role of earth rock bed geology, is noticed (Madhuri et al. 2004; Narayan and Prasad 2006).

This trend may have arisen from the fact that in and around Dhanbad city, there exists a huge volume of a coal bed that may have inside hidden sodium rock salt bed that continuously gets mixed with the water due to the erosion of sodium rock salt bed. This explanation gets firm footing as can be seen in Fig. 2b: as we move away from

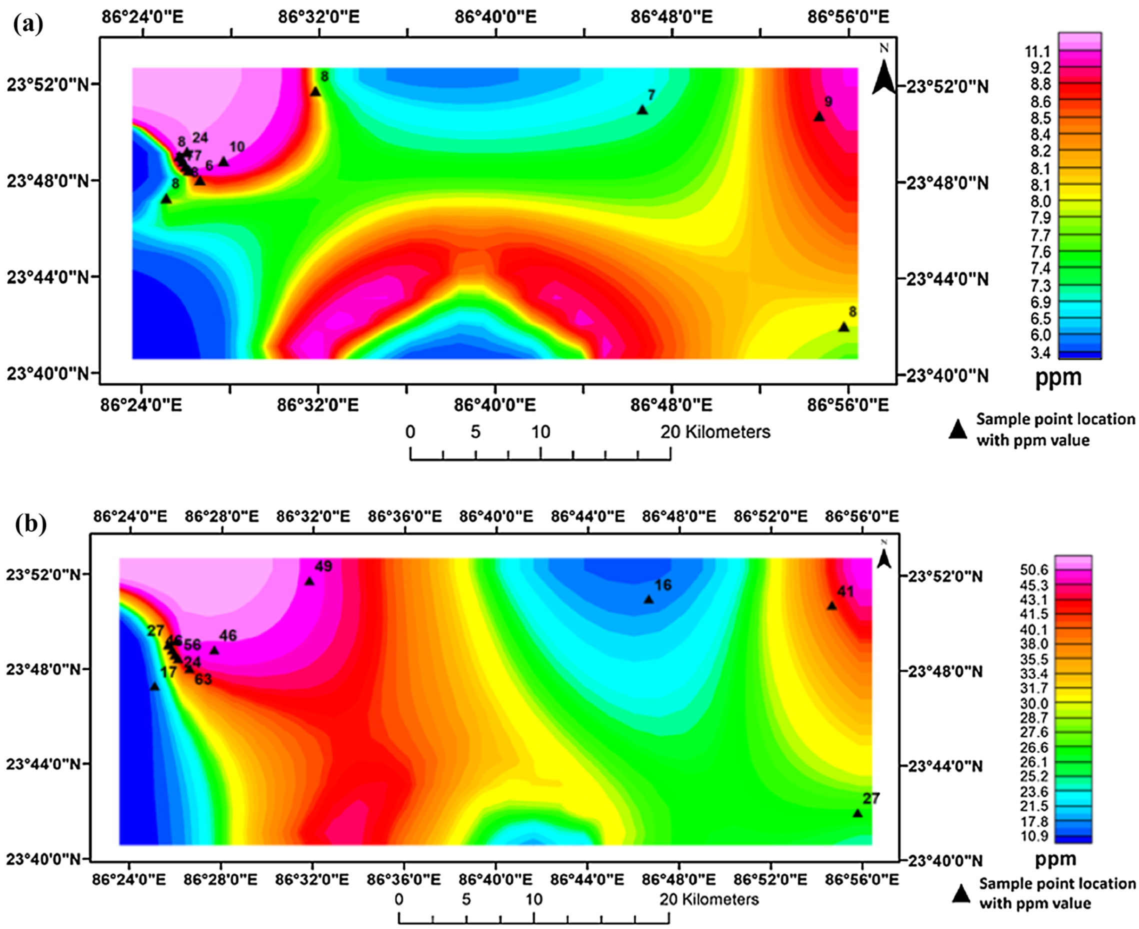

Fig. 2 **a** Spatial distribution of potassium ions (K^+) in the pond, surface water and underground water bodies in ppm, in and around the Dhanbad district of Jharkhand represented by contour mapping, **b** Spatial distribution of sodium ions (Na^+) in the pond, surface water and underground water bodies in ppm, in and around the Dhanbad district of Jharkhand represented by contour mapping

Dhanbad, still we can find high content of sodium in the water bodies as the coal bed is spread across large areas away from the Dhanbad city. So, to get the insight into the quality of water qualitatively and quantitatively, water quality index (WQI) is calculated using relative weightage of parameters starting from 1 and so on based on the significance of a particular dissolved solute in the water; i.e., the most important one will get higher values like 5,6, etc., while the less relevant one will get values like 1, 2, etc., respectively.

Relative weight age of each parameter is calculated

as: $$W_i = \sum \frac{W_i}{\sum_{i=1}^{n} W} \tag{1}$$

Quality rating of water based on the ith parameter: $$q_i = \left(\frac{c_i}{s_i}\right) \times 100 \tag{2}$$

where C_i denotes chemical parameter concentration in each and every water sample in mg/L and S_i stands for standard for each parameter of chemical in mg/L as per the guidelines issued by the BIS (BIS 1991).

$$SI_i = W_i \times q_i \tag{3}$$

is the subindex of ith parameter.

$$WQI = \sum_{i=1}^{n} SI_i \tag{4}$$

is the water quality index which classifies water into five types from unsuitable for human use to excellent; the table of which is given below.

The water quality index of the water samples has been calculated for sodium and potassium, and inference has been drawn regarding whether they are fit for drinking (WHO 1984) or not in Table 4. So, water quality index gives us a tentative idea about the quality, (Rao and Devadas 2005) of the water.

Table 4 Water quality classification based on WQI values of the study area

Sl. no.	Sample details	Na (mg/l)	K (mg/l)	WQI	Water quality
1	Baker Badh Pond (surface water)	47	20	21.90884	Excellent
2	Duba Badh Pond (surface water)	49	14	11.63111	Excellent
3	Kali Mandir Mandal Talab Pond (surface water)	59	15	13.8444	Excellent
4	Dhaiya Basti Thakur Puli Pond (surface water)	43	15	12.73571	Excellent
5	Rani Talab Pond (surface water)	49	24	31.01887	Excellent
6	Maithan Dam (surface water)	16	7	2.67391	Excellent
7	Hirapur (tube well), shallow aquifer	63	6	4.53307	Excellent
8	Chandra Vihar colony (tube well), Bartand, shallow aquifer	46	8	4.70281	Excellent
9	Bank More (tube well), shallow aquifer	17	8	3.46164	Excellent
10	Govindpur (tube well), shallow aquifer	49	8	4.89642	Excellent
11	CSIR-CIMFR (bore water)	27	8	3.76055	Excellent
12	Chittaranjan (bore water), deep aquifer	41	9	5.27464	Excellent
13	Housing Colony (bore water)	24	7	2.8913	Excellent
14	Gopalpur, Asansol (bore water), deep aquifer	27	8	3.76055	Excellent
15	Housing Colony (tube well)-28/413DMC 20/18/19	56	15	13.61003	Excellent
16	Steel gate (tube well)	46	10	6.53954	Excellent
17	Housing Colony (tube well)-61/28	35	7	3.3322	Excellent
18	Housing Colony (tube well)-62/28	42	7	3.69837	Excellent

Although the sodium and potassium contents in all the water samples are well within permissible limit fit for human consumption, the results hint toward the fact that human activities such as the use of too much water softeners, pesticides, deep penetration of used waste water (Foppen 2002) and application of potassium permanganate in water bodies for treatment must be controlled in and around the Dhanbad city.

Conclusions

The analysis of sodium and potassium ions present in 18 water samples collected from three types of water sources, e.g., surface, ponds and underground, in and around the Dhanbad city showed variable cation concentrations. The cation concentrations of water bodies of the Dhanbad city are within the safe limits and are fit for drinking, agricultural and industrial purposes. The water of Maithan Dam is found to have the least concentration of sodium and potassium, which is built on the banks of the River Barakar so we can say that because of being away from marine areas, the water of the rivers flowing in this region is much safer and not saline. The presence of a good concentration of sodium in underground waters taken from tube wells depicts that the aquifers are attached to the mineral bed of strata which contains a large amount of dissolved sodium. Although flame photometry is not a very reliable analytical technique for metal cations analysis, it has a high efficiency of sodium and potassium ions detection. Human activities in and around the Dhanbad city must also be kept under control to keep potassium ions content under control. Maithan water may be concluded to be the best fit for daily consumption based on sodium and potassium ions content. In a general sense, the water of all the water bodies is safe for human consumption and use from the point of view of sodium and potassium contents in it. So, the human beings should be careful before dumping toxins in the barren landscape, in water bodies such as rivers and ponds. We should minimize synthetic inputs to the entire food chain and optimize the management of waste disposal so that we leave a world that can sustain future generations to come.

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Conflicts of interest There are no conflicts to declare.

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