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Handheld monitoring of lead level in drinking water in Rajasthan

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Abstract: Long-term exposure and accumulation of environmental heavy metals in the human body increases the susceptibility to various diseases and thus an accessible and ready-to-use device for increased surveillance of heavy metal exposure should be of immediate action. This paper highlights the development of a robust and handheld device, called 'DEPSOR', for the in-house and on-site electrochemical detection of heavy metals level in drinking water. Tap water samples from all over the Rajasthan in India were collectedto determine the level of lead (Pb)if any exceeded the World Health Organisation (WHO) stipulated permissible limits of 10 ppb. The results showed a total of 31% of the samples exceeded the limit up to 4-times above the stipulated WHO limits. We demonstrated that 'DEPSOR' device could be used as a potential tool for regular and in-house monitoring of traces of heavy metal contamination in drinking water.
Keywords: Heavy metals, lead poisoning, screen-printed electrodes, electrochemical sensor

I. MAIN BODY TEXT:

India covers the largest number of human population worldwide without access to safe drinking water and the country registers near 37.7 million people affected by water-borne diseases annually. Municipal tap water consisting of untreated groundwater that may contaminated by the accumulation of heavy metals from environment is commonly used for drinking by the majority of the population in India. Heavy metals exist as natural constituents of the earth curst, however, their concentrations have increased several-fold because of anthropogenic activities including the rapid growth and uptake of ICT that has led the exponential growth in global production of electronic devicesand so thus simultaneously to an early obsolescence and generation of huge amounts of end-to-life electronic devices, so called e-waste. The most common malpractice of e-waste management in many low- and middle-income countries involves dumping of e-waste into landfill disposal sites or composting in residential areas, which releases high amount of heavy metal pollutants into the groundwater. Direct exposure of contaminated groundwater results in unintended toxicities in vulnerable human populations including pregnant women and children. In a recent comprehensive review, a relationship between e-waste exposure pathways for pollutantsand human health hazards in India was evaluated with an emerging threat to the environment of urban India.

The major toxic environmental impact associated with leaching of heavy metals from e-wasteis the persistent release of lead, cadmium,mercury, and chromium. Of many hazardous heavy metals, lead is the most widely used in electronics devices, e.g., 0.3% by weight in mobile phone, and leaching of lead from e-waste into soil and groundwater at rates that exceed permissible range can create dangerous cumulative effects resulting in a variety of health hazards. Elevated levels of lead in the environment are recently reported in a coastal city of India10. A long-term exposure of drinking lead-contaminated water results in slowly deposition of leadin the body tissues, which may lead to the most deleterious effects on the hemopoetic, nervous, reproductive and urinary systems.Lead is permeable through placenta and thus during the pregnancy it is associated with intrauterine deaths, premature and stillbirths. Children exposed to lead are at high risk for impaired development. Many other possible risks includes anorexia, sleeplessness, restlessness, behavioural disturbances, diminished intellectual capacity, and hypochromic anaemia and in long terms, it can be as dangerous as renal tubular damage. International Agency for Research on Cancer has classified lead as possible human carcinogen. Therefore, a regular monitoring solution that is simple, affordable, portable and capable of rapid on-site detection of heavy metal concentrations below the permissible range in the exposure drinking water should be an immediate concern to ensure the dietary safety and protect human health. Electrochemical methods offer several advantages when compared to other conventional methods in terms of rapidness, cost effectiveness, simplicity and possibility of on-field application. Recently, we reported a screen-printed electrochemical-based 'DEP-On-Go' sensing platform as a valuable tool for simultaneous sensing of multiple heavy metals pollutants in environmental samples11. In this work, we extended the potential integration of 'DEP-On-Go'system onto a handheld and ready-to-use sensing device, called 'DEPSOR', for mobile, simple and rapid monitoring of heavy metals like lead and zinc in drinking groundwater.

Figure 1 illustrated the three simple operating steps to test heavy metals in drinking groundwater using handheld DEPSOR that uses the anodic stripping voltammetry (ASV) technique. First, collect the water sample and mix with equal amount of electrolyte buffer solution. Second, apply the mixture onto a disposable electrode-printed chip (DEP chip) connected to a USB-powered palm-sized potentiostat (BDT miniStat100, BioDevice Technology Co. Ltd.). Third, run a proprietary software (KME_USBStat_v2, BioDevice Technology Co. Ltd.) that was loaded on a Pocket PC with installed DPV parameters. Other characteristic features of DEPSOR include affordability (the running cost per sample is less than one US dollar), minutes analysis (sample-to-answer in less than 10 minutes), and a simple-to-use and low-cost setup for minimally trained users. Figure 2 shows a picture of the handheld DEPSOR device.

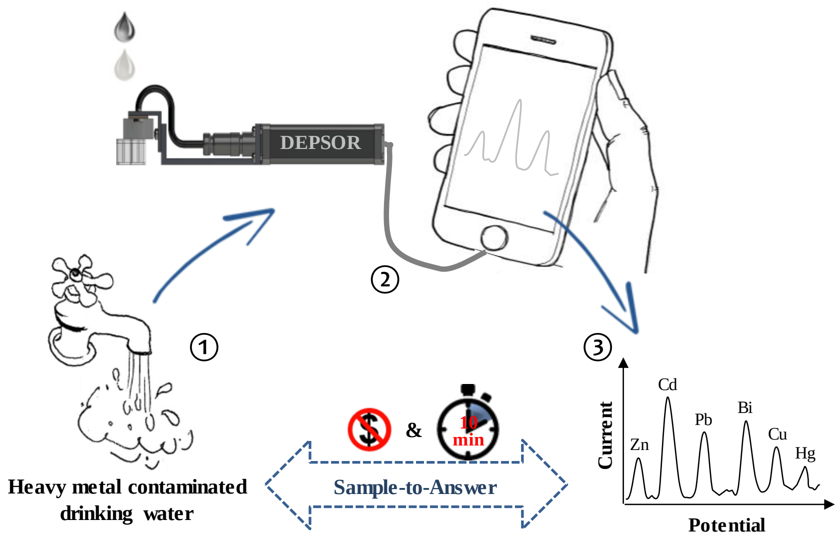

Figure 1. Schematic drawing of the three simple operating steps for rapid and simultaneous testing of multiple heavy metal level in drinking water sample using DEPSOR.

Figure 2. Photographs of handheld DEPSOR unit and components including palm-sized USB-powered potentiostat, Screen-printed disposable electrode chips, and PC tablet with semi-automatic software for on-site voltammetric analysis.

As shown in Figure 3 and Table 1, sixteentap water samples were collected from various districts of Rajasthan, India. Water samples collected from the only stream in the community that is used for drinking and other domestic chores. Tap water was collected in clean bottles after rinsing the bottle 3–5 times with tap water, followed by

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measuring the pH. The collected tap water was then mixed with 0.2 M acetate buffer (pH 4.6) in ratio of (1:1). After following the pre-treatment, water samples were processed for DPV analysis. The DEP chips with working area of 2.64 mm2were fabricated and provided by BioDevice Technology Co. Ltd. (Ishikawa, Japan). The DEP chip was attached to a miniStat100 potentiostat connector. The miniStat100 potentiostatis supplied with power via a USB-connected tablet. For measurement, a4-5 drops (comprises near 250-µL volume) of pre-treated water sample solutionwas dropped onto a well of microtiter plate and a cleaned DEP chip was inserted into the sample solution. The heavy metal detections were performedby differential pulse voltammetry (DPV) after deposition of heavy metals using a potentiostat(miniStat100) run by KME software with optimized DPV parameters11. DP voltammogramswere collected at a potential range from -1500 mV – 500 mV at a scan rate of 20 m V/s, respectively. The electrode was pre-treated for 300 seconds at a potential of -1400 mV, respectively. All the experiments were conducted at ambient temperature and clean conditions.

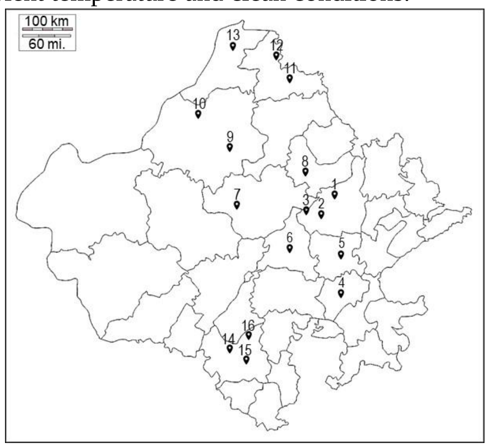

Figure 3. Map of Rajasthan state illustrating various locations from where water sample was collected.

Table 1: Detected values of heavy metals in sample of water (groundwater, tap water). PEL: Permissible exposure limit given by WHO standards.

S. No.	Sample #	Sample location		Lead (ppb)	Zinc (ppb)
		District	Town/Tehsil	PEL 10 ppb	PEL 3 ppm
1	6	Ajmer	Sarwar	8.0 ± 0.4	27.0 ± 2.3
2	9	Bikaner	Shri Dungargadh	7.7 ± 0.8	15.0 ± 0.7
3	10		Suratgarh, Uncha Tibba	7.5 ± 2	23.0 ± 1.9
4	4	Bundi	Hindoli	7.0 ± 0.9	10.0 ± 1.5
5	5	Tonk	Bisalpur Dam	6.6 ± 0.2	50.5 ± 39.8
6	11	Hanumangarh	Kherwala	7.2 ± 0.6	26.5 ± 4.4
7	12		Talwara Jheel	9.3 ± 1.6	NA
8	1	Jaipur	Badhal	**36.1 ± 5.8**	20.0 ± 1
9	2		Phulera	9.4 ± 0.4	30.0 ± 5.2
10	3		Sambhar	7.4 ± 0.3	25.0 ± 4.9
11	7	Nagaur	Kuchaman City	**14.5 ±0.8**	NA
12	8	Sikar	Khatu	**10.4 ± 2.7**	45.0 ± 5.9
13	13	Ganganagar	Ganganagar	7.5 ± 0.6	26.0 ± 2.1
14	14	Udaipur	Ameth	**15.6 ± 5.7**	18.0 ± 0.8
15	15		Kaladwas	**10.9 ± 2.7**	20.0 ± 5.6
16	16		Sardarpura	8.9 ± 1.5	15.0 ± 1.5

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Each metal is specific towards its oxidation at a particular potential and thus we can observed a clear and single separated peak current response for zinc, cadmium, lead and copper at average potentials of approximately -1.423, -1.178, -0.889, and -0.321 V, respectively11. Figure 4 shows the DP voltammograms for few of tested samples observed with well-defined and separated peaks for lead and zinc. As described in Supplementary Figure S1, the calibrated results were used to calculate the concentrations of observed metals in the water samples11.The results showed that water samples collected from Jaipur (#1), Nagaur (#7), Sikar (#8), and Udaipur (#14, 15) cities contained high levels of lead. As shown in Table 1, we detected high amount of lead from Jaipur city, i.e., 36.1 µg·L-1which is near four times above the permissible safe limitgiven by WHO standards. Two other samples from Nagaur and Udaipur cities were also observed with lead above the permissible limit. Interestingly, all other samples were observed with lead near the permissible limit and thus are indicating the early alarming signs of lead poisonings. The high content of lead in the groundwater could be due to weathering and leaching of lead from the industries located nearby or dump sites of electronics waste materials. This study suggests that direct drinking of tap water can be deleterious to the communities as the levels of lead were above the WHO stipulated limits. Based on the findings in this paper, it is recommended that DEPSOR can be efficiently used to assess and monitor contamination of heavy metals in the drinking water samples and other related samples.We are now advancing a pocket-sized version of DEPSOR device for remote monitoring that uses Bluetooth technology and will be able to send a detailed report using telecommunications technology.

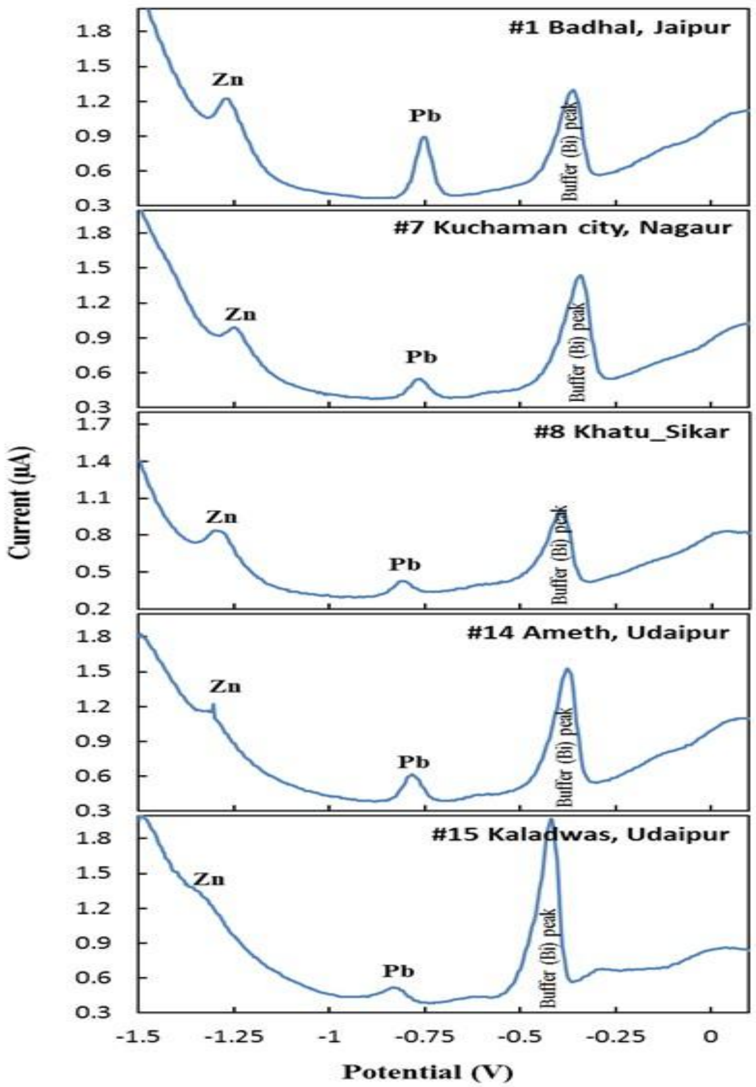
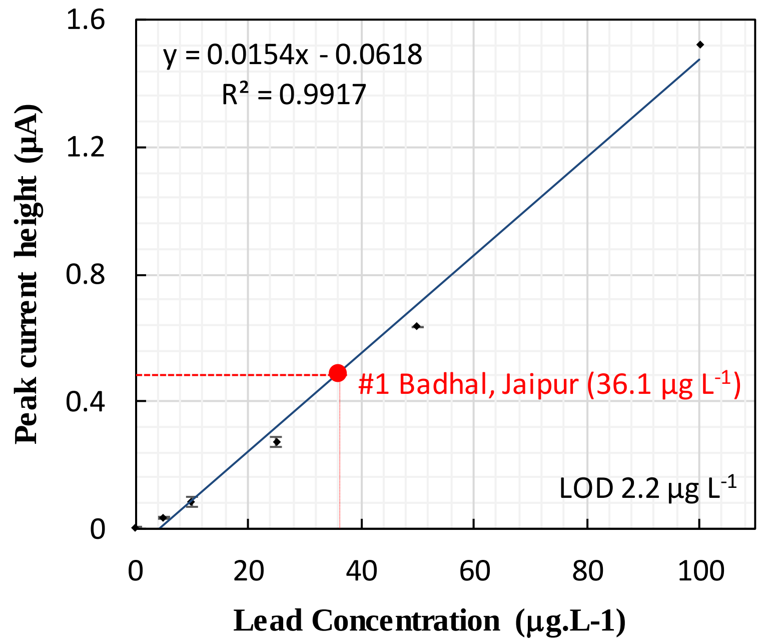


Figure 4. Individual DP voltammograms demonstrating detection of Zinc and Lead along with Bismuth using handheld DEPSOR unit. The data are the average of four independent experiments conducted for the given samples.



Supplementary Figure S1. Reference calibration curve for the detection of lead in water samples.

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