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Assessment of water quality and trace metal contaminations in Mondolkiri province in the Northeastern part of Cambodia

Kongkea Phan · Samrach Phan · Soknim Se · Huy Sieng · Laingshun Huoy · Kyoung-Woong Kim

Abstract The aim of the present study is to investigate water quality and potential trace metal contaminations in the Northeastern part of Cambodia. Tube well ($n = 35$), hand-dug well ($n = 18$), channel ($n = 10$) and lake/pond ($n = 8$) water samples were randomly collected from Mondolkiri province which is located in the Northeastern highland of Cambodia. A water sample was collected in two different bottles. One was filled in 30-mL polyethylene bottle after which was acidified to pH < 2 with concentrated HNO_3. Another was filled in 250-mL polyethylene bottle. The collected water sampled was stored in a cooler during fieldwork and transferred to a fridge where they are stored at 4 °C for analysis. The measurement of pH, ORP, dissolved oxygen (DO), turbidity, conductivity, total dissolved solids (TDS) and salinity was taken at laboratory following standard procedures. All chemical measurement of trace metals were taken by inductively coupled plasma mass spectrometry (ICP-MS). Analytical results reveal that tube well (47.1%), hand-dug well (77.8%) and channel water (20%) have pH < 6.5. Turbidity of tube well (32.4%), hand-dug well (5.6%), lake water (12.5%) and all channel water samples are exceeded Cambodia regulation of 5 NTU. Mean As, Cd, Cr, Cu, Ni, Pb and Zn concentrations in Mondolkiri's water sources are below Cambodian drinking water quality standard and WHO's drinking water quality guideline. However, the upper range of Pb in tube well and channel water and Zn in tube well are exceeding Cambodia regulation. Concurrently, the mean concentrations of Fe and Mn in tube well and channel water are exceeded Cambodian aesthetic guideline of 300 μg L^{-1} and 100 μg L^{-1}, respectively. This study suggests that appropriate treatment technologies are necessary for residents in the Mondolkiri province to access to clean water and minimize their potential health risks.

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Introduction

Heavy metal contamination in groundwater is of concern among environmental health scientists. Although some elements are essential for normal growth of humans and animals, high intake and low

intake of essential trace elements could lead to toxicity and nutritional deficiency, respectively (Goldhaber 2003). Trace elements in the drinking water (Muhammad et al. 2011; Kavcar et al. 2009) and food grown in contaminated soils (Huang et al. 2008) could pose adverse health effects to their consumers. In general, trace elements in groundwater could be derived from either natural or anthropogenic sources (Chen et al. 2007; Mondal et al. 2010). Ecological communities and living organisms in receiving water are also affected by direct discharge of effluents from various industries into aquatic systems (Krishna et al. 2009). Some of these trace elements in groundwater have been well documented in Vietnam (Agusa et al. 2006), Lao PDR (Chanpiwat et al. 2011) and China (Chen et al. 2007). A general population census in 2008 revealed that 80% percent of Cambodians live in rural areas (NIS 2012). It was estimated that 89.6% and 61.5% of populations in urban and rural areas had access to improved drinking water sources, which was equivalent to about 67.1% of the total populations (UNICEF 2017). Although many populations lived alongside surface waters in Cambodia, shallow groundwater was the main source for drinking water (Phan et al. 2010). Unfortunately, shallow groundwater in the Mekong River basin of Cambodia is naturally enriched by arsenic and other trace elements (Kim et al. 2011). Ministry of Industry, Mines and Energy (2013) has indicated that copper, gold, iron ore, zinc, lead, tin, bauxite, sapphire, ruby, kaolin and limestone are the potential mineral resources in Cambodia. Analysis of Chemical and mineralogical compositions of the natural laterite soils which is predominant in the northern part of Cambodia revealed high level of Fe, Al, Si, Mn and Ti (Pich et al. 2011). There are a large number of artisanal miners has been reported to run small operations recovering gold and gemstones (ODC 2016). Some artisanal small-scale gold mining has been reported in Mondolkiri (Murphy et al. 2013). In general, miners leave the abandoned mine pits and tailings in which some heavy metals could be released to the surrounding environment and the downstream. To date, there is a little known about heavy metal contaminations in the water sources in Mondolkiri province of Cambodia. The overall goal of the present study is to investigate water quality and potential trace metal contaminations in Mondolkiri province of Cambodia. The objectives are to (1) determine physio-chemical properties of water sources in Mondolkiri province, (2) assess trace metal contaminations in water sources in Mondolkiri province and (3) assess quality of drinking water sources in Mondolkiri with Cambodian drinking quality standard and WHO's drinking water quality guideline.

Materials and methods

Study area

The design of the present study is a cross-sectional sampling which has been conducted in Mondolkiri province of Cambodia (Fig. 1). Mondolkiri is located in the Northeastern part of Cambodia and has population approximately 60,811 people (NIS 2012). It is mountainous area and covered by natural laterite soils. The people in Mondolkiri rely on different types of the available water sources such as tube well, hand-dug well, channel and lake/pond for their daily living and agricultural activities.

Field sampling

Sampling was conducted in May 2017 across Mondolkiri province. However, sample collection depended on our accessibility to water sources. Water samples from tube well ($n = 35$), hand-dug well ($n = 18$), channel ($n = 10$) and lake/pond ($n = 8$) were collected into two different bottles. One was filled in a 30 mL polyethylene bottle after which was acidified to pH < 2 with 65% HNO_3 for trace metal analysis. Another was filled in 250 mL polyethylene bottle for measuring physio-chemical properties. Groundwater was collected from tube well after 5 min pumping of the standing water in the tube. Hand-dug well water was sampled using a bucket to bring water sample from well to the ground and then water was filled into the 250 mL acid-cleaned polyethylene bottle. Channel and lake/pond water were collected using grab sampling method at depth about 0–30 cm. A composite sample was filled into the respective polyethylene bottles. All collected water samples were kept in a cooler during fieldwork and stored at 4 °C in a fridge till analysis.
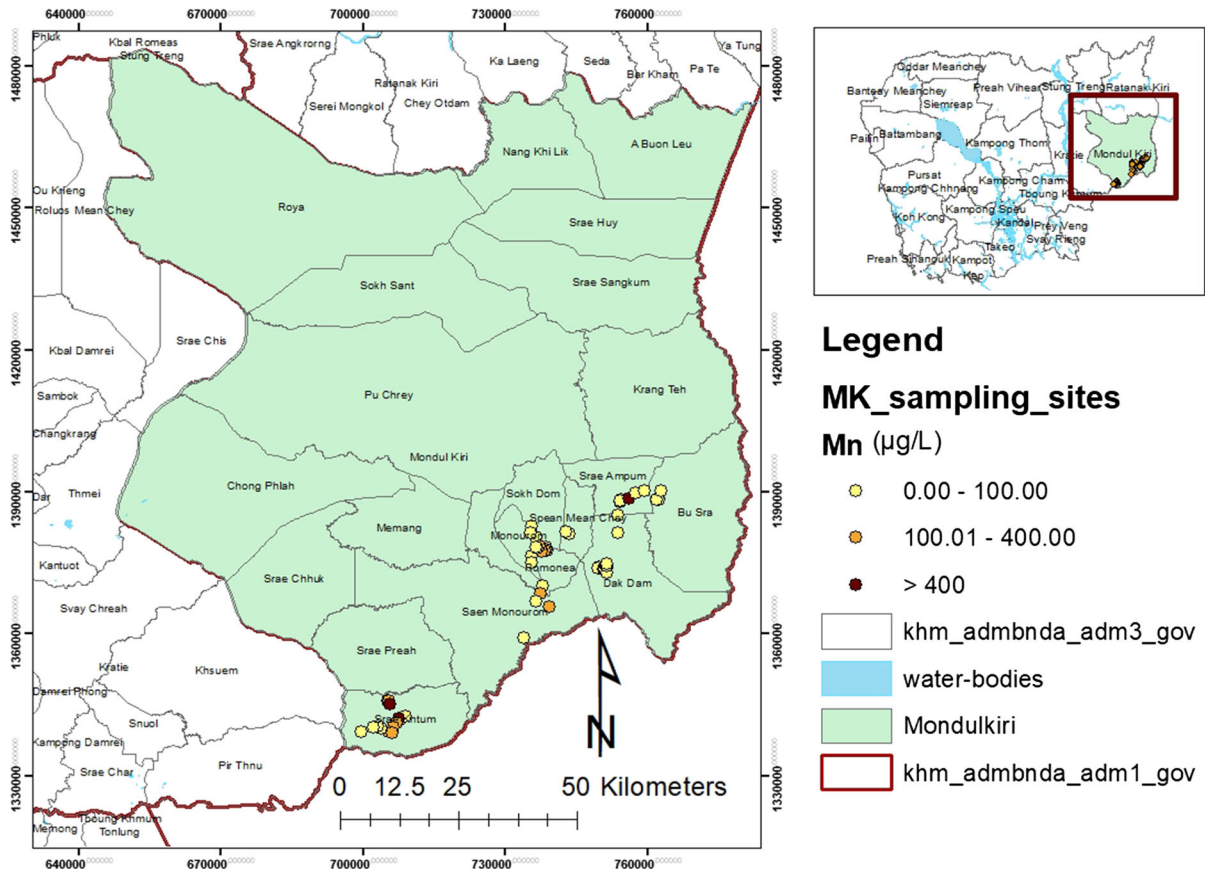
Fig. 1 Map of sampling area

Sample preparation and analysis

All measurements of physio-chemical properties were performed at a laboratory of the Faculty of Science and Technology, International University, Phnom Penh. The pH and ORP were measured by Hanna pH and ORP meter (HI 2211, Italy). Conductivity and TDS and salinity were measured by Hanna conductivity meter (HI2300, Italy). Dissolved oxygen was measured by Hanna DO meter (HI 9147, Italy). All laboratory equipment and instruments were checked and calibrated with the respective standard solutions prior to analysis. All chemical measurements of trace metals were conducted at laboratory of the International Environmental Research Center (IERI), Gwangju Institute of Science and Technology (GIST), Republic of Korea. The acidified water samples were air shipped to GIST for trace metal analysis. Water samples were analyzed following a method described

by Phan et al. (2010). All chemical measurement of trace metals were performed by inductively coupled plasma mass spectrometry (ICP-MS, Agilent 7500ce). The concentration of As, Cd, Co, Cr, Cu, Ni, Pb and Zn was analyzed using the original water samples. Water samples were filtered using 0.45 μm syringe filter prior to analysis. However, dilution with 2% HNO_3 (prepared by 18.2Ω MilliQ deionized water with 65% HNO_3) was made for measuring Fe and Mn to make sure the final concentration of aliquots to meet the standard calibration curve as recommended by ICP-MS analytical technique. Standard reference material (trace element in water, SRM 1643e) was analyzed every 20 samples during analysis to check instrument accuracy and precision. All recovery rates were in a good agreement with the recommended range of 90–110%.

Table 1 Summary of physio-chemical properties of tube wells and hand-dug wells in Mondolkiri province

Statistics	Tube well ($n = 35$)					Hand-dug well (18)				
	Mean	Median	SD	Min.	Max.	Mean	Median	SD	Min.	Max.
Depth (m)	52.20	50.00	15.16	28.00	85.00	13.38	14.00	4.38	5.00	20.00
pH	6.44	6.55	0.47	5.48	7.26	6.24	6.22	0.43	5.60	7.17
Turb (NTU)	12.09	0.00	27.02	0.00	107.00	0.67	0.00	2.83	0.00	12.00
DO (mg L^{-1})	7.34	7.30	0.33	6.80	8.20	7.47	7.55	0.32	6.70	7.90
EC (μS cm^{-1})	207.08	138.90	173.46	12.65	566.00	48.86	31.40	47.39	6.54	157.40
TDS (mg L^{-1})	103.60	69.45	86.84	6.32	283.00	24.44	15.72	23.71	3.27	78.70
Salinity (%)	0.41	0.30	0.34	0.00	1.10	0.10	0.10	0.10	0.00	0.30
ORP (mV)	190.57	196.75	49.02	62.60	318.20	179.71	171.35	49.34	104.00	254.70

SD, standard deviation; Min., minimum; Max., maximum

Statistical data analysis

All statistical data analyses are employed by SPSS for windows (version 15.0). A t test is used to evaluate the differences in physio-chemical properties [well depth, pH, turbidity, dissolved oxygen (DO), electrical conductivity (EC), total dissolved solid (TDS), salinity and oxidation–reduction potential (ORP)] between tube well and hand-dug well. The t test is also used to ascertain the differences in physio-chemical properties between channel water and lake/pond water. In addition, t test is applied to certify the differences in trace metals (As, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb and Zn) between tube well and hand-dug well and between channel and lake/pond water sources. One-Way ANOVA is performed to verify the differences in physio-chemical properties among the four water sources. Concurrently, one-way ANOVA is also performed to certify the differences in trace metal concentrations among all water sources. Significance is considered in a circumstance where $p \leq 0.05$.

Results and discussion

Physio-chemical properties of water sources in Mondolkiri province

A summary of physio-chemical properties of tube wells and hand-dug wells in Mondolkiri province is presented in Table 1. The depth of tube wells ranges from 28 to 85 m (mean $\pm$ SD, 52.20 $\pm$ 15.16 m), whereas that of the hand-dug wells range from 5 to 20 m (13.38 $\pm$ 4.38 m). Analysis indicates that mean depth of tube well is significantly higher than that of hand-dug well (t test, $p < 0.05$). The pH of tube wells range from 5.48 to 7.26 (mean $\pm$ SD, 6.44 $\pm$ 0.47), whereas it ranges from 5.60 to 7.17 (6.24 $\pm$ 0.43) for hand-dug well. There is no significant difference in pH between tube well and hand-dug well in Mondolkiri province (t test, $p > 0.05$). Mean turbidity of tube well is 12.09 $\pm$ 27.02 NTU which is significantly higher than that of hand-dug well of 0.67 $\pm$ 2.83 NTU (t test, $p < 0.05$). Our field observation indicated that there are a lot of iron precipitations on the surface of the tube of tube well comparing to the open and large surface of the dug well. Mean dissolved oxygen (DO) of tube well is 7.34 $\pm$ 0.33 mg L^{-1} (range from 6.80 to 8.20 mg L^{-1}), whereas that of hand-dug well is 7.47 $\pm$ 0.32 mg L^{-1} (range from 6.70 to 7.90 mg L^{-1}). A comparison revealed that there are no significant differences in DO between tube well and hand-dug well (t test, $p > 0.05$). Mean EC of tube well is 207.08 $\pm$ 173.46 μS cm^{-1} while it is 48.86 $\pm$ 47.39 μS cm^{-1} for hand-dug well. The mean TDS of tube well is 103.6 $\pm$ 86.84 mg L^{-1}, whereas that of hand-dug well is 24.44 $\pm$ 23.71 mg L^{-1}. Salinity of tube well range from 0.00 to 1.10%, whereas that of hand-dug well range from 0.00 to 0.30%. Comparisons show that EC, TSD and salinity of tube well are statistically significant higher than those hand-dug well in Mondolkiri province (t test, $p < 0.05$). Tube well and hand-dug well water in Mondolkiri province are in an oxidizing condition. Groundwater in Mondolkiri is consistent with that in Kampong Cham province (Phan et al. 2010).

Table 2 Summary of physio-chemical properties of channel and lake/pond in Mondolkiri province

Statistics	Channel ($n = 10$)					Lake ($n = 8$)				
	Mean	Median	SD	Min.	Max.	Mean	Median	SD	Min.	Max.
pH	6.80	6.88	0.40	6.17	7.48	7.04	7.02	0.07	6.96	7.15
Turb (NTU)	47.90	28.50	49.67	6.00	162.00	1.13	0.00	2.47	0.00	7.00
DO (mg L^{-1})	7.34	7.30	0.21	7.00	7.70	7.58	7.65	0.42	6.90	8.30
EC (µS cm^{-1})	78.59	72.70	63.11	8.81	215.80	57.96	59.10	13.60	26.90	69.10
TDS (mg L^{-1})	39.30	36.35	31.56	4.39	107.90	28.98	29.55	6.79	13.47	34.60
Salinity (%)	0.16	0.15	0.13	0.00	0.40	0.10	0.10	0.00	0.10	0.10
ORP (mV)	153.51	149.15	36.16	101.40	207.30	97.21	76.00	48.73	53.80	194.30

SD, standard deviation; Min., minimum; Max., maximum

However, the mean ORP of tube well (190.57 ± 49.02 mV) is not significantly different from that of hand-dug well (179.71 ± 49.34 mV) in Mondolkiri province (t test, $p > 0.05$). The summary of physio-chemical properties of channel and lake/pond water sources in Mondolkiri is presented in Table 2. The range of pH in channel water is from 6.17 to 7.48, whereas it ranges from 6.96 to 7.15 in the lake. Statistical analysis reveals that pH of channel water is significantly lower than that of lake/pond water (t test, $p < 0.05$). The turbidity, EC, TDS and salinity of channel waters are significantly higher than those of lake waters (t test, $p < 0.05$). High turbidity in the channel is caused by water movement that is the water flows in the channels. Nevertheless, there is no significant difference in DO levels and ORP between channel and lake water (t test, $p > 0.05$).

Trace metals in water sources in Mondolkiri province

The summary of trace metals in groundwater in Mondolkiri province is presented in Table 3. The concentration of As in tube well ranged from 0.10 to 4.96 µg L^{-1} (mean $\pm$ SD, 1.72 ± 0.99 µg L^{-1}), whereas it ranged from 0.76 to 2.66 µg L^{-1} (1.62 ± 0.59 µg L^{-1}). A comparison reveals that there is no statistically significant difference in As concentrations between tube well and hand-dug well in Mondolkiri (t test, $p > 0.05$). As in tube well in Mondolkiri is much lower than the As-affected areas in the Mekong River basin in previous studies (Buschmann et al. 2007; Sthiannopkao et al. 2008; Luu et al. 2009; Phan et al. 2013). In contrast, there are

statistically significant difference in Cd, Co, Cr between tube well and hand-dug well (t test, $p < 0.05$). Cu concentration in tube well ranges from 0.24 to 148.30 µg L^{-1}, whereas it ranges from 0.09 to 612.10 µg L^{-1} in hand-dug well. However, Cu concentrations in tube wells do not significantly differ from those in hand-dug well (t test, $p > 0.05$). Iron concentrations range from 2.8 to 36,150.0 µg L^{-1} and 41.5 to 37,360.0 µg L^{-1} in tube well and hand-dug well, respectively. There is no statistically significant difference in Fe between tube well and hand-dug well (t test, $p > 0.05$). The mean Mn concentration in tube well is 138.34 ± 161.12 µg L^{-1}, which is statistically significant higher than hand-dug well of 33.26 ± 62.46 µg L^{-1} (t test, $p < 0.05$). The mean Mn concentration in tube well in Mondolkiri is much lower than other provinces of the Mekong River basin such as Kratie (Phan et al. 2013), Prey Veng (Buschmann et al. 2007; Sthiannopkao et al. 2008) and Kandal (Buschmann et al. 2007; Luu et al. 2009; Phan et al. 2013). High concentrations of Fe and Mn could be associated with geological characteristics of the study area. Laterite soil which is predominantly found in peneplain and terrace deposits in the Northeastern parts of Cambodia contain more Fe, Si, Mn, Al and Ti (Pich et al. 2011). Lead concentration range from 0.01 to 59.66 µg L^{-1} and 0.08 to 9.65 µg L^{-1} in tube well and hand-dug well, respectively. However, there are no significantly differences in Ni, Pb and Zn concentrations between tube well and hand-dug well (t test, $p > 0.05$). The summary of trace metals in surface water in Mondolkiri province is presented in Table 4. Arsenic concentration in channel water ranged from 0.13 to 4.25 µg L^{-1} (mean $\pm$ SD,

Table 3 Summary of trace metals (μg L^{-1}) in groundwater in Mondolkiri province, Cambodia

Statistics	Tube well (n = 35)					Hand-dug well (n = 18)					WHO's DWQ guideline	CDWQS
	Mean	Median	SD	Min.	Max.	Mean	Median	SD	Min.	Max.		
As	1.72	1.60	0.99	0.10	4.96	1.62	1.68	0.59	0.76	2.66	10	50
Cd	0.01	0.01	0.01	0.002	0.032	0.02	0.01	0.02	0.001	0.065	3	3
Co	1.93	1.21	1.94	0.03	7.02	0.68	0.22	0.85	0.03	2.53		
Cr	1.71	0.34	2.58	0.04	8.63	1.10	0.32	1.52	0.01	5.24	50	50
Cu	16.36	2.32	32.84	0.24	148.30	41.35	1.08	152.27	0.09	612.10	2000	1000
Fe	4069.2	357.9	9228.0	2.8	36,150	2751.9	102.6	9262.4	41.5	37,360		300
Mn	138.34	46.97	161.12	0.27	578.00	33.26	14.61	62.46	1.37	259.70		100
Ni	3.68	2.68	3.07	0.02	11.82	3.14	1.65	3.16	0.01	10.08	70	20
Pb	3.23	0.36	10.62	0.01	59.66	1.35	0.28	2.69	0.08	9.65	10	10
Zn	312.44	15.87	1119.62	0.10	5600	49.49	17.72	86.95	2.20	345.50	3000	3000

DWQ, drinking water quality; CDWQS, Cambodian drinking water quality standard; SD, standard deviation; Min., minimum; Max., maximum

1.85 ± 1.22 μg L^{-1}) while it ranges from 0.97 to 3.55 μg L^{-1} in lake water (1.90 ± 0.79 μg L^{-1}). A comparison indicates that there is no significant difference in As concentration between channel and lake water (t test, $p > 0.05$). Mean Co concentration in channel water is 2.25 ± 3.92 μg L^{-1} which is significantly higher than that of lake water, 0.39 ± 0.26 μg L^{-1} (t test, $p < 0.05$). There are no significant differences in Cd, Cr and Cu concentrations between channel water and lake water (t test, $p > 0.05$). Fe concentrations in channel water range from 74.8 to 23,530 μg L^{-1}, whereas it ranges from 100.9 to 650.9 μg L^{-1} in the lake. Statistical analysis reveals that Fe concentrations in channel water are significantly higher than those of lake water (t test, $p < 0.05$). The concentrations of Mn, Ni and Zn in channel water do not differ from those in the lake (t test, $p > 0.05$). Pb concentration in channel water range from 0.25 to 58.40 μg L^{-1} (mean ± SD, 6.82 ± 19.34 μg L^{-1}), whereas it ranges from 0.17 to 0.49 μg L^{-1} (0.27 ± 0.12 μg L^{-1}). A comparison indicates that Pb concentration in the channel water is significantly higher than that of the lake water (t test, $p < 0.05$). Although some heavy metals are released into aquatic environment by human activities most of them may occur through natural processes. The higher concentration of Co, Fe and Pb in channel water might be due to the movement of water in the channels. Our field observation indicated that the water in the channels flew during field sampling while lake water stayed still. The flow of water in channel might induce the erosion of some heavy metals into channel water body.

The quality of water sources in Mondolkiri province

Analytical results indicate that 47.1%, 77.8%, 20% of tube well, hand-dug well and channel water, respectively have pH < 6.5, less than Cambodian drinking water quality standard (MIME 2004). Concurrently, analytical results reveal that 32.4% of tube well, 5.6% of hand-dug well, 100% of channel water and 12.5% lake water samples are exceeded the turbidity of 5 NTU regulated by Cambodia drinking water quality standard (MIME 2004). However, the total dissolved solid of all water sources are below Cambodian drinking water quality standard of 800 mg L^{-1} (MIME 2004). Comparisons show that there are

Table 4 Summary of trace metals (µg L^{-1}) in surface water in Mondolkiri province, Cambodia

Statistics	Channel ($n = 10$)					Lake ($n = 8$)					WHO's DWQ guideline	CDWQS
	Mean	Median	SD	Min.	Max.	Mean	Median	SD	Min.	Max.		
As	1.85	1.86	1.22	0.13	4.25	1.90	1.80	0.79	0.97	3.55	10	50
Cd	0.01	0.00	0.01	0.00	0.03	0.01	0.00	0.01	0.00	0.02	3	3
Co	2.25	0.22	3.92	0.11	10.28	0.39	0.39	0.26	0.10	0.94		
Cr	1.98	1.15	1.91	0.05	5.99	1.06	0.14	2.02	0.03	5.92	50	50
Cu	6.90	1.44	12.80	0.11	39.93	1.11	0.62	1.09	0.29	3.09	2000	1000
Fe	4128.8	328.0	7813.5	74.8	23,530	310.9	250.9	186.2	100.9	650.9		300
Mn	106.13	24.13	182.76	3.56	552.60	59.83	49.73	54.74	9.74	154.30		100
Ni	5.71	2.40	10.59	0.25	31.60	0.45	0.24	0.52	0.01	1.16	70	20
Pb	6.82	0.30	19.34	0.25	58.40	0.27	0.22	0.12	0.17	0.49	10	10
Zn	33.41	12.25	68.55	2.74	215.40	39.33	23.75	38.58	3.10	102.70	3000	3000

DWQ, drinking water quality; CDWQS, Cambodian drinking water quality standard; SD, standard deviation; Min., minimum; Max., maximum

Fig. 2 Distribution of As, Cd, Co and Cr in Mondolkiri's water sources. Cambodian drinking water quality standards for As, Cd and Cr are 50 µg L^{-1}, 3 µg L^{-1} and 50 µg L^{-1}, respectively. There is no regulation level for cobalt
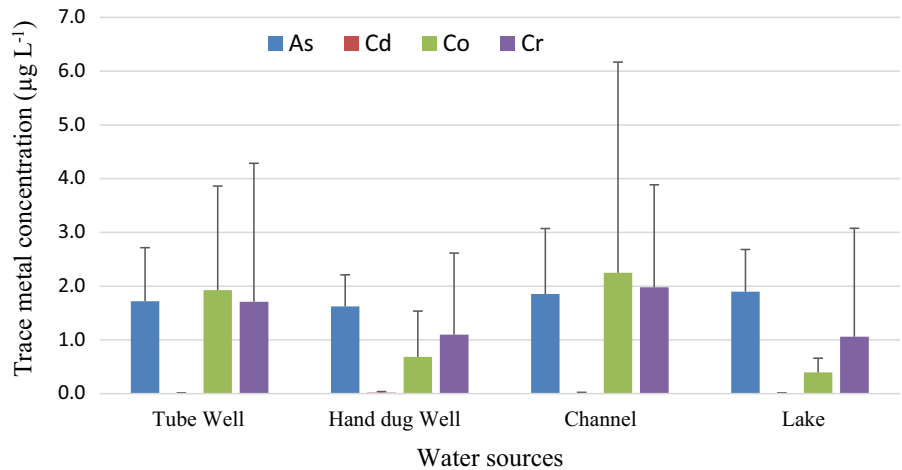
significant differences in pH, EC, Turbidity, TDS, Salinity and ORP among these four water sources (one-way ANOVA, $p < 0.05$). However, there is no significant difference in DO among all water sources (one-way ANOVA, $p > 0.05$). Analytical results revealed that mean As, Cd, Cr, Cu, Ni, Pb and Zn concentrations in all water sources in Mondolkiri province are below Cambodian drinking water quality standard (MIME 2004) and WHO's drinking water quality guideline (WHO 2011). However, the upper range of Pb in tube well (6.3%) and channel (11.1%) water and Zn in tube well (6.3%) are exceeding

Cambodian drinking water quality standard of 10 µg L^{-1} and 3000 µg L^{-1}, respectively. The mean concentrations of Mn and Fe in tube well water were exceeded Cambodian aesthetic values (MIME 2004). The percentages of tube well, hand-dug well, channel and lake water samples which have Fe of 300 µg L^{-1} exceeded an aesthetic value in Cambodian drinking water quality standard (MIME 2004) are 53.1%, 31.3%, 55.6% and 37.5%, respectively. Likewise, tube well (40.6%), hand-dug well (6.3%), channel (22.2%) and lake water (25.0%) samples have Mn of 100 µg L^{-1} exceeded the aesthetic value in

Cambodian drinking water quality standard (MIME 2004). There are no significant differences in As, Cd, Co and Cr among all four water sources (one-way ANOVA, $p > 0.05$) in Mondolkiri province (Fig. 2). Likewise, there are no significant differences in Cu, Fe, Mn, Ni, Pb and Zn among these four water sources (one-way ANOVA, $p > 0.05$) in this province. Significant correlations have been observed between well depth and Mn ($r_s = -0.442$, $p < 0.05$) and As ($r_s = -0.500$, $p < 0.01$) in tube well. There is no significant correlation between well depth and other measured parameters of water quality in dug wells is found (Spearman's rho, $p > 0.05$). Regardless of well type, depth is significantly correlated with EC ($r_s = 0.341$, $p < 0.05$), TDS ($r_s = 0.339$, $p < 0.05$) and salinity ($r_s = 0.288$, $p < 0.05$).

Conclusions

The physical and chemical qualities of water sources in Mondolkiri province is evaluated in the present study. Analytical results revealed that pH of tube well (47.1%), hand-dug well (77.8%) and channel water (20%) do not meet Cambodian drinking water quality standard. There is no significant difference in pH between tube well and hand-dug well in Mondolkiri province. Concurrently, turbidity of tube well (32.4%), hand-dug well (5.6%), lake water (12.5%) and all channel water samples are exceeded Cambodian drinking water quality standard. Turbidity, EC, TSD and salinity of tube well are statistically significant higher than hand-dug well in Mondolkiri province. Nevertheless, TDS of all water sources are below Cambodian drinking water quality standard, 800 mg L^{-1}. The mean concentrations of As, Cd, Cr, Cu, Ni, Pb and Zn in Mondolkiri's water sources are below the Cambodian drinking water quality standard and WHO's drinking water quality guideline. However, the upper range of Pb in tube well (6.3%) and channel (11.1%) water and Zn in tube well (6.3%) are exceeding Cambodian drinking water quality standard of 10 µg L^{-1} and 3000 µg L^{-1}, respectively. Meanwhile, the mean Fe and Mn concentrations are exceeded Cambodian drinking water quality guideline. This study suggests that further study is warrant to investigate on the sources of Fe and Mn contaminations in drinking water sources in Mondolkiri province. The appropriate treatment technologies are necessary for residents in Mondolkiri province to access to clean water.

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