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Original Research Article

Status of Good Manufacturing Practices (GMP) of Small and Medium – Scale 20-Liter Bottled Water Plants in Cambodia: Case Studies in 4 Provinces

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ABSTRACT

The United Nations' Sustainable Development Goal 6.1 on clean water and sanitation is quite challenging for most developing countries including Cambodia. Most Cambodians still rely on drinking water packed in 20-L containers that are bottled by at least 700 small- and medium-scale producers around the country; however, their GMP status requires evaluation. In this study, 16 small- and medium-scale bottled water plants were sampled from four provinces, i.e., Phnom Penh, Siem Reap, Banteay Meanchey, and Prey Veng. The sampled plants were audited by an expert using the modified GMP principle in the Codex Alimentarius (CODEX). Waters from different production steps were analyzed for total dissolved solids (TDS), residual chlorine, hardness, and iron content by using test kits on site. Samples were also sent to laboratories for chemical analysis (Fe, Cl, nitrate, nitrite, F, Mn, As, pH) and microbiological qualities (coliforms and Escherichia coli). All audited bottled water plants were equipped with softening and reverse osmosis (R.O.) systems as well as ultraviolet and/or ozone. Water sources included municipal water (from surface water) and ground water. Banteay Meanchey possessed the worst water quality, while Siem Reap had the best water quality regarding total hardness and TDS. None of the producers had a treatment system designed regarding with their raw water's qualities. The results from test kit analysis also indicated that all plants did not properly maintain their softening system, which could directly shorten their R.O. membranes' operating life.

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However, treated water quality from every plant could pass the World Health Organization's Guideline for Drinking Water 2011. The implementing treatment systems were efficient enough to treat water from various sources.

However, post contamination still remained as a problem since 56% of the studied plants had coliforms-contaminated products (ranged from 1 to 46 CFU/100 mL). Over 80% of the plants failed in the topic of cleaning and disinfecting and 75% of them failed in the topic of records and reporting. More than 60% of the plants passed the requirements on location and buildings. GMP status was poor in most plants and it was also the main cause of post contamination in the finished products.

INTRODUCTION

Accessibility to safe drinking water is a United Nations Sustainable Development Goal (SDG 6.1) that member countries need to achieve by 2030 (United Nations, 2016). Unsafe water can directly affect a population's quality of life, since it can cause acute and chronic diseases. With support from the World Health Organization (WHO), the Royal Government of Cambodia's Ministry of Industry, Mines and Energy has established a standard guideline for drinking water known as the Cambodian National Drinking Water Quality Standard (CNDWQS), which is used for monitoring the quality and safety of drinking water (Ministry of Industry, Mine and Energy, 2004). However, the problem of unsafe water is still found widely in the country. For instance, contaminated water in Kratie province has caused 10 deaths and 140 hospitalizations (Phnom Penh Post, 2018). Consequently, bottled drinking water is a preferred alternative drinking water source for the population, especially during the dry season (White et al., 2013).

In Cambodia, bottled drinking water is normally produced from surface and ground water sources. A survey in Cambodia indicated that the chemical qualities of raw water used to produce bottled drinking water from most sources were reasonably good (Feldman et al., 2007). However, certain natural health-related contaminants (i.e., As, NO3, NO2, F and Mn) were still found in some sources. Other parameters, such as Cl, Fe, hardness, and microbiological quality, could affect consumer acceptance and play a critical role in the long-term sustainability of that water supply (Feldman et al., 2007).

The surface water used for bottled drinking water production comes mainly from municipal tap water. Based on a study in Phnom Penh, the quality and safety of this water met the CNDWQS and WHO (2004) drinking water standards. Consequently, the tap water quality was safe for consumption. However, its quality could deteriorate due to poor distribution system maintenance that could result in microbial contamination, especially coliforms (Vanny et al., 2015).

Hence, bottled drinking water producers must know the quality of raw water from different sources that they use for drinking water production in order to select a proper and economical treatment system in terms of safety and quality. Unfortunately, the majority of Cambodian drinking water producers, similar to food producers in most developing countries, lack appropriate knowledge and expertise on good food hygiene and handling practices, which can cause unsafe food (and water) problems in the population (FAO and WHO, 2003).

Responding to this problem, the CODEX provides a Code of Hygienic Practice for Bottled/Packaged Drinking Waters other than natural mineral waters (namely, CAC/RCP 48-2001) for member countries to use as a guideline for monitoring the quality and safety of drinking water within their country contexts (Codex Alimentarius, 2001). This Code recommends general techniques for collecting, processing, packaging, storing, transporting, distributing, and offering for sale a variety of drinking water types (other than natural mineral water) for direct consumption. In this study, the good manufacturing practices (GMP) and the control of critical points of 16 small- and medium-scale 20-L bottled water plants were evaluated regarding the CODEX guideline for the appropriateness of their treatment, maintenance, and quality assurance system. These plants were located in four provinces of different development levels and were using different sources of raw water.

MATERIALS AND METHODS

Production plant auditing

The 16 production plants from four provinces were selected with regard to their raw water sources as follows:

- More developed: Capital Phnom Penh and Siem Reap,
- Less developed: Banteay MeanChey and Prey Veng, and
- Water sources: ground and surface.

The selected plants were visited, evaluated for their production processes, and audited for their GMP statuses. Each visit was conducted over a 2-3 hours period, during which plant staff members were interviewed and the production process was recorded. An expert on bottled drinking water production and quality assurance conducted an audit on GMP and critical point controlling processes using a developed checklist. During each visit, certain chemical analyses were performed in-line by using simple measurement techniques. For laboratory analyses, raw water and finished products were analyzed for chemical qualities, while both samples as well as treated water before packing were analyzed for microbiological qualities.

Auditing checklist

The auditing checklist for bottled water production was developed using the concept from the CODEX guideline (Codex Alimentarius, 2001), as well as pre-Hazard Analysis and Critical Control Points (pre-HACCP). It contained sections on location and production buildings; tools, machinery, and equipment; water source, water quality adjustment, quality control; containers; cleaning and disinfection processes; packaging; sanitation; personal hygiene; records and reporting. Each checklist section could be interpreted quantitatively into a point (based on score x weight). The weights for scoring the pre-HACCP points were higher than for those of the general GMP.

Chemical and microbial analyses

Raw water, waters from certain production steps, and finished products were tested for quality in-line using simple techniques and sampled for laboratory analysis.

In-line analysis

Water samples from different production steps were analyzed on site for TDS, residual chlorine, hardness, and iron content. The TDS of raw water and finished products was determined by using a TDS Meter 3 Water Quality Tester (HM Digital Inc., Culver City, CA, USA), where results are reported as mg/L. Residual chlorine and iron were semi-quantitatively analyzed using a LovibondTM CHECKITTM Comparator-Kit (Lovibond, Dortmund, Germany), for which the reagents Chlorine-DPD no. 1 (0-1.0 mg/L range) and Iron LR

(0.05-1.0 mg/L range) were used in the analysis, respectively. Total hardness was semi-quantitatively determined on the LovibondTM and TintometerTM MINIKITTM AF424 (Lovibond, Dortmund, Germany) at a range of 0-250 mg/L.

Laboratory testing

Laboratory analyses were performed by using the standard methods of the American Public Health Association (2012) for examining water and wastewater. A pH meter was used to analyze pH levels (Mettler Toledo model Seven Easy from Columbus, Ohio, United States). Iron, nitrate, nitrite, fluoride, manganese, and arsenic were analyzed using the standard methods stated in the Standard Methods for the Examination of Water and Wastewater, APHA, AWWA, WEF 22nd ed., 2012 parts 3120 B, 4500-NO3 E, 4500-NO2 B, 4500F D, 3120 B, 3114C, respectively. Iron and manganese levels were determined by using the inductively coupled plasma (ICP) method with ICP-OES (Perkin Elmer model 7300 DV from Waltham, Massachusetts, United States). For nitrate determination, the cadmium reduction method was employed using a spectrophotometer (at 543 nm, light path ≥ 1 cm) and filter photometer (light path ≥ 1 cm and equipped with a filter having maximum transmittance near 540 nm). Nitrite was determined by the colorimetric method and using a spectrophotometer (at 543 nm, light path ≥ 1 cm) and filter photometer (light path ≥ 1 cm and equipped with a green filter having maximum transmittance near 540 nm). For fluoride determination, the SPADNS colorimetric method was employed using a spectrophotometer (at 570 nm, light path ≥ 1 cm) and filter photometer (light path ≥ 1 cm and equipped with a greenish yellow filter having maximum transmittance at 550 to 580 nm). Arsenic was determined by the electrothermal atomic absorption spectrometric method using an atomic absorption spectrometer (Perkin Elmer model 900F from Waltham, Massachusetts, United States) and graphite furnace. Microbial analysis for total coliforms and E.coli was analyzed by following ISO 2000, ISO 9308-1. Tergitol 7-TTC agar was used as a growth medium. The presumptive coliform colonies were then confirmed by testing for the production of indole and oxidase activity. The colonies that were indole and oxidase negatives were presumed as non-E.coli, while colonies that were indole positive and oxidase negative were presumed as E.coli (ISO 9308-1, 2000).

Ethical consideration

The Cambodian Ministry of Industry and Handicraft approved this study and provided ethical clearance. For data collection during production plant audits, informed consent and participant information sheets for the study were prepared. Bottled water producers were clearly informed about the study's purpose and procedures in detail prior to data collection. Information regarding participants was kept confidential. They were also free to withdraw at any time during the study period.

RESULTS AND DISCUSSION

Table 1 shows that 50% of the audited plants used municipal water produced from surface water in their bottled water production process. The remaining plants used ground water from nearby areas. Regardless of raw water quality, the treatment systems used by all audited plants were designed more or less similarly and consisted of softening and reverse osmosis (R.O.) systems in sequence. None of the treatment systems was designed to assess raw water quality. None of the plants checked the chlorine content in the incoming raw water. In addition, chlorine was never added to the ground water used for production. Chlorine is normally used for killing contaminated microorganisms in raw water, especially pathogens,

Table 1. Production processes used in the production plants used as the case studies

Water source	Province	Plant	Production process
Tap water	Phnom Penh (PP)	1	Tap water →Softening System [Anthracite – Activated Carbon – Cation Resin] → Storage tank → Cartridge filter → Ceramic filter → Storage tank → Reverse Osmosis → Storage tank → Packing
		2	Tap water →Softening System [Anthracite – Activated Carbon – Cation Resin] → Microfilter→ Ultraviolet → Storage tank → Reverse Osmosis → Cation Resin → Microfilter→ Storage tank → Packing
		3	Tap water →Softening System [Anthracite – Activated Carbon – Cation Resin] → Cartridge filter → Reverse Osmosis → Storage tank → Packing
		4	Tap water →Storage tank with small opening → Softening System [Anthrahcite – Activated Carbon – Cation Resin] → Microfilter x2 → Reverse Osmosis → Ultraviolet → Storage tank → Ozonation → Packing
	Banteay Meanchey (BM)	2	Tap water →Aeration → Softening System [Anthracite, Activated Carbon, Cation Resin] → Cartridge filter → Cation Resin → Reverse Osmosis x 3 → Ultraviolet (not working) → Storage tank → Ozonation → Ultraviolet (not working) → Microfilter → Packing
		3	Tap water → Storage tank → Softening System [Cation Resin – Unknown – Activated Carbon – Cation Resin] → Cartridge filter x 2 → Storage tank → Reverse Osmosis x 7 (vertically arrangement) → Storage tank → Ozonation → Packing
	Prey Veng (PV)	2	Tap water →Sand filter → Storage tank → Softening System [Anthracite – Activated Carbon – Cation Resin] → Microfilter → Ceramic filter → Storage tank → Reverse Osmosis → Storage tanks → Ultraviolet → Storage tank → Ozonation → Titanium filter → Storage tank → Packing
		3	Tap water → Softening System [Anthracite – Activated Carbon – Cation Resin] → Microfilter → Reverse Osmosis x 4 → Cation Resin → Storage tank → Microfilter → Ultraviolet →Packing

Table 1. Production processes used in the production plants used as the case studies (cont)

Water source	Province	Plant	Production process
Ground water	Siem Reap (SR)	1	Ground water → Softening System [Unknown] → Reverse Osmosis → Ultraviolet → Storage tank → Packing
		2	Ground water → Aeration of raw water → Softening System [unknown] → Cartridge filter → Reverse Osmosis → Ultraviolet → Cartridge filter → Storage tank → Ultraviolet →Cartridge filter → Packing
		3	Ground water → Softening System [Anthracite – Activated Carbon – Cation Resin] → Storage tank →Cartridge filter → Ceramic filter → Storage tank → Reverse Osmosis → Storage tank →Packing ⇩ Waste water →Packing as 2nd grade
		4	Ground water → Aeration → sand/carbon filter →Storage tank → Softening System [unknown] → Cartridge filter x2 → Ceramic filter (no use-empty) → Storage tank → Cartridge filter x 2 → Reverse Osmosis x 3 → Storage tank → Ozonation → Ultraviolet → Packing
	Banteay Meanchey (BM)	1	Ground water from 2 sources → Cation Resin x 2 → Chlorination (Used Calcium hypochlorite 70%, used directly as powder form and causes blockage to the dosing pump but now no use) → Cartridge filter x 2 → Zeolite x 2 → Ceramic filter x 2 → Softening System [Manganese sand – Activated Carbon – Cation Resin] → Cartridge filter x 2 → Reverse Osmosis → Ultraviolet ⍰ Storage tank → Ozonation → Cartridge filter x 2 → Ultraviolet → Packing
		4	Well water → Softening System [Manganese sand – Activated carbon – Cation Resin] → Cartridge filter → Reverse Osmosis x 3 → Storage tank →Reverse Osmosis x 3 → Storage tank → Activated Carbon → Cartridge filter x 2 → Ultraviolet → Packing
	Prey Veng (PV)	1	Ground water → Softening System [Activated Carbon – Manganese sand– Cation Resin] → Cartridge filter x 2 → Ceramic filter → Storage Tank → Reverse Osmosis → Cartridge filter → Cation Resin → Storage tank → Ozonation → Storage tank → Cartridge filter x 2 → Ultraviolet → Packing
		4	Well water → Softening System [Unknown] → Microfilter → Reverse Osmosis x 2 → Ultraviolet → Storage tank → Ozonation → Packing

before treatment. Even though membrane filtration, such as the R.O. system, can potentially remove all contaminated microorganisms, the high initial load of microorganisms could shorten the life of filtering materials in the softening system and the R.O. membrane due to microbial growth and accumulation during production breaks.

Other than major water treatment systems (i.e., softening and R.O.), differences existed in the installation sequences of minor treatments, such as microfilters, cartridge filters, and ceramic filters. Inappropriate installation of these filters could affect water safety and quality due to post-treatment contamination if they were installed after the R.O. system. Since the R.O. system is the final process for removing all water contaminants (physical, chemical and biological), post treatment after passing the R.O. system should only rest on disinfection, which, in fact, was found in most audited plants, except for audited plants PP 1, PP 2, PP 3, and SR 3.

Most plants used ultraviolet as their disinfection system and half of them also had installed ozonation. Nonetheless, none of the plants recorded the operating life of their UV lamps, which is normally less than 10,000 hours (Parrotta and Bekdash, 1998). Consequently, there was the risk of inefficient disinfection due to an expired UV lamp.

Only one plant used a standard ozonation system that could efficiently monitor the level and homogeneity of the ozone gas. For effective disinfection, ozone concentration in water must be between 0.1-0.2 ppm and contact time of 1-5 minutes (Department of Primary Industries, 2018).

As mentioned above, the softening system was similarly installed as the primary treatment prior to the R.O. system, which mainly consisted of anthracite/manganese sand, activated carbon, and cation resin. Among these, four plants (BM 2, PV2, SR 2, and SR 4) were installed with additional pretreatment systems, i.e., either aeration or sand filtration, prior to the softening system. Interviews during plant visits revealed that most producers did not know the needs for such water treatment systems and some even could not identify the filtering tanks within the softening system. Such problems could lead to ineffective maintenance programs, which is quite significant for the safety and quality of drinking water production.

Table 2 gives the results of test kit analyses performed at the plants. By comparing the degree of contamination between raw water, softened water, and the finished product, key parameters, namely, residual chlorine, iron, total hardness, and TDS, were expected to be improved, especially for the first three parameters after passing the softening system. Unfortunately, the contents of some parameters still remained the same as raw water or even worse than before passing through the system. These results indicated that the existing softening systems are not working properly in all plants. Moreover, the filtering materials that require regular maintenance had been neglected especially in terms of cation resin. The test-kit on hardness indicated no improvement in the hardness of raw water after passing the cation resin in all audited plants.

Table 2. Results from the in-line quality analysis

Water source	Province	Plant	Residual Cl (ppm)			Iron (ppm)			Hardness (ppm)			TDS (ppm)		
			Raw water	Soften water	R.O. water	Raw water	Soften water	R.O. water	Raw water	Soften water	R.O. water	Raw water	Soften water	R.O. water
Tap water	Phnom Penh (PP)	1	0.7	0	0	0	0	0	90	90	< 20	83	83	16
		2	0.7	0	0	0	0	0	90	90	< 20	100	100	1
		3	0.8	0	0	0	0	0	70	70	< 20	94	92	6
		4	0.2	0	0	0	0	0	70	70	< 20	94	93	8
	Banteay Meanchey (BM)	2	0	0	0	0	0	0	110	150	< 20	158	232	9
		3	0	0	0	0	0	0	> 170	> 170	< 20	195	179	10
	Prey Veng (PV)	2	0	0	0	0	0	0	150	150	< 20	249	250	3
		3	1.0	0	0	0	0	0	130	150	< 20	249	250	15
Ground water	Siem Reap (SR)	1	0	0	0	0.5	0	0	< 20	< 20	< 20	14	13	2
		2	0	0	0	0	0	0	< 20	< 20	< 20	10	10	0
		3	0	0	0	0.21	0	0	< 20	< 20	< 20	21	20	3
		4	0	0	0	0	0	0	< 20	< 20	< 20	27	26	4
	Banteay Meanchey (BM)	1	0	0	0	0	0	0	> 170	> 170	< 20	376	378	46
		4	0	0	0	0	0	0	> 170	> 170	< 20	648	661	11
	Prey Veng (PV)	1	0	0	0	0	0	0	130	130	< 20	291	288	5
		4	0	0	0	0.15	0	0	150	150	< 20	199	203	13

Since the iron level was quite low in the raw water of all plants, the efficiency of anthracite could not be determined. Aeration process and anthracite filtration for iron removal from raw water were, in fact, unnecessary for most of the plants.

Adequate residual chlorine (> 0.2 ppm) was found in the municipal water from plants PP 1-4 and PV 3 but not from PV 2, BM 2, and BM 3. The chlorine could have been lost from the incoming tap water due to the pretreatment processes and storage period. Without chlorine content monitoring, the operating life of the R.O. membrane could be shortened due to growth and accumulation of microorganisms. The activated carbon at plants PP 1-4 and PV 3 was still efficient enough to remove the residual chlorine. Residual chlorine, if remaining, could destroy the R.O. membrane.

Table 2 also indicates that the BM plant possessed the worst water quality, while SR had the best water quality regarding total hardness and TDS. The results from test kits implied that the softening system or even the R.O. system might not be necessary for raw water in the SR plants. A simpler and more economical system, such as ultrafiltration, could be a more efficient alternative.

These in-line tests clearly revealed that all plants did not maintain their softening systems properly, which could directly shorten their R.O. membranes' operating life and end up frequently wasting their expenses on procuring and cleaning the membranes. It was fortunate that the operating R.O. systems were still working properly, which was confirmed by the R.O. water with TDS and total hardness values that were within acceptable limits.

From results shown in Tables 1 and 2, we found that majority of the plants installed a lot of unnecessary equipment in their production lines, which caused the unnecessary waste of investment funds and increased maintenance costs. At present, the improper maintenance of the softening system did not cause safety problems. However, increased costs for maintenance and procurement of the R.O. membrane were significant.

Table 3 gives the GMP scores for each audited plant for all 9 aspects that were rated by the expert. Most plants lacked information on raw water quality, which consequently affected the design of their treatment systems. However, this point did not affect the score, since the plants implemented systems that could cover all types of raw water quality (overuse of the treating equipment). Most production plants failed in the topic of cleaning and disinfecting the 20-L containers; none of them had a proper system. Most plants used a pressure pump to clean the used tanks, but they did not use any cleaning agents or disinfectants. This practice was quite inconsistent and unpredictable due to human error. Most plants also did not have a hygienic packing area or storage area for the 20-L containers, which could potentially cause contamination in the treated water.

All plants also failed the topic of records and reporting, which are required for monitoring production, quality assurance and distribution processes. This finding highlights ineffective operating conditions and a lack of a product recall system.

Table 3. GMP scores of the production plants used in the case studies

Water source	Province	Plant	GMP scores (as % of each part)										
			Part 1	**Part 2**	**Part 3**	**Part 4**	**Part 5**	**Part 6**	**Part 7**	**Part 8**	**Part 9**	**Total**	**Rank**
Tap water	Phnom Penh (PP)	1	60.00	43.00	30.00	10.00	0.00	0.00	60.00	28.00	25.00	256.00	11
		2	95.00	93.00	30.00	50.00	50.00	95.00	85.00	36.00	13.00	547.00	2
		3	45.00	26.00	30.00	5.00	0.00	9.00	18.00	13.00	13.00	159.00	16
		4	35.00	41.00	30.00	5.00	0.00	36.00	40.00	28.00	0.00	215.00	12
	Banteay Meanchey (BM)	2	61.25	58.75	7.14	20.00	0.00	77.27	40.00	18.75	12.50	295.66	10
		3	100.00	72.50	7.14	75.00	0.00	100.00	75.00	48.88	62.50	541.02	3
	Prey Veng (PV)	2	100.00	90.00	50.00	90.00	50.00	100.00	82.50	81.25	50.00	693.75	1
		3	40.00	30.00	33.93	30.00	50.00	22.73	40.00	31.25	25.00	302.91	9
Ground water	Siem Reap (SR)	1	23.75	25.00	33.93	5.00	0.00	22.73	22.50	21.88	12.50	167.29	14
		2	76.25	52.50	41.07	35.00	16.67	22.73	62.50	50.00	50.00	406.72	4
		3	62.50	77.50	33.93	50.00	0.00	72.73	60.00	31.25	12.50	400.41	6
		4	46.25	71.25	46.43	50.00	0.00	68.18	12.50	18.75	12.50	325.86	8
	Banteay Meanchey (BM)	1	63.75	65.00	30.36	60.00	0.00	68.18	35.00	43.75	37.50	403.54	5
		4	61.25	28.75	7.14	10.00	0.00	4.55	35.00	31.25	12.50	190.44	13
	Prey Veng (PV)	1	68.75	26.25	14.29	25.00	0.00	31.82	50.00	62.50	50.00	328.61	7
		4	26.25	27.50	23.21	5.00	0.00	13.64	20.00	39.06	12.50	167.16	15

Part 1: location and production buildings; Part 2: tools, machinery, and equipment; part 3: water source, water quality adjustment, quality control; Part 4: container; Part 5: cleaning and disinfection; Part 6: packaging; Part 7: sanitation; Part 8: personal hygiene; Part 9: records and reporting

A general cleaning program and personal hygiene were problems for most plants. In addition, most plants could pass the requirements on location and buildings. Unexpectedly, the plants in less-developed areas, i.e., PV 2 and BM 3, had better GMP scores than many plants located in more developed areas. Training on basic knowledge for bottled drinking water production and GMP should be provided to the bottled water production plants in Cambodia in order to increase their capacity in the production investment and quality assurance processes.

Tables 4 and 5 show that the study provinces are blessed with good quality raw waters that, even untreated, could pass the World Health Organization's 2011 Guideline for Drinking Water standards and Cambodia's own standards. Only problems regarding pH and Mn were found in SR 1, PV 1 and PV 4 plants. After treatment, however, their chemical and microbial qualities could pass both standards, except for pH from certain plants that was < 6.5, which in fact is not a safety issue. The problem of low pH is normally found in R.O. treated water due to the carbonic acid formed by the solubility of carbon dioxide in the air entering into the water (Al-Mutaz and A. Al-Ghunaimi, 2001). Consequently, the water products had lower pH than their raw waters.

Table 5 shows the differences in microbial qualities for coliforms and E. coli of raw water, treated water before packing, and the finished product. Microbial contamination not found in the raw waters could be due to correct chlorination by municipal water plants as well as non-contaminated ground waters. Microbial-contaminated raw water, in fact, did not affect safety of the treated water, since the R.O. system could remove all of the microbial contamination. The treated waters before packing that contained no coliforms or E. coli showed the effectiveness of the R.O. system in all plants. However post-contamination remained as a problem, possibly due to the 20-L containers not being cleaned and/or handled properly as found in the GMP audits. The design of the 20-L container (Figure 1), which has a permanently installed faucet on the bottom and a large cap and tiny opening hole on the top of each bottle, could cause contamination at the faucet, but would limit contamination from the top, since the large cap is rarely opened. The main source of contamination, therefore, was environmentally related, rather than from humans, which can be seen from the results that re-contaminations were all from coliforms not E. coli. There were 9 out of 16 studied plants had coliforms-contaminated products. This post-contamination could result from the returned dirty containers not being cleaned properly as well as inappropriate handling of the cleaned containers. Deficiencies in applicable knowledge and skills regarding good food handling practices, food hygiene, and implementation of up-to-date agricultural practices are common among producers in many developing countries (FAO and WHO, 2003).

Table 4. Results from laboratory analyses of chemical qualities of raw waters and finished products

Water source	Province	Plant	Raw water (mg/L)							Finished product (mg/L)						
			pH	As	F	Fe	Mn	NO3	NO2	pH	As	F	Fe	Mn	NO3	NO2
Tap water	Phnom Penh (PP)	1	8.0	0.001	0.130	< 0.020	< 0.010	ND	0.008	7.2	ND	< 0.050	ND	ND	ND	< 0.006
		2	8.0	0.001	0.070	ND	ND	ND	< 0.006	6.7	ND	ND	ND	ND	ND	< 0.006
		3	8.0	0.001	0.120	< 0.020	ND	ND	< 0.006	6.8	ND	< 0.050	ND	ND	ND	< 0.006
		4	7.9	0.001	0.150	ND	ND	ND	< 0.006	6.7	ND	0.050	ND	ND	ND	< 0.006
	Banteay Meanchey (BM)	2	8.2	0.002	0.130	ND	0.030	0.660	0.019	6.8	ND	ND	ND	ND	ND	< 0.006
		3	8.2	ND	0.130	< 0.020	ND	2.220	< 0.006	6.9	ND	ND	ND	ND	ND	< 0.006
	Prey Veng (PV)	2	8.3	< 0.001	0.460	ND	ND	ND	< 0.006	7.1	ND	0.050	ND	ND	ND	< 0.006
		3	8.3	< 0.001	0.470	ND	ND	ND	< 0.006	7.2	ND	0.080	ND	ND	ND	< 0.006
Ground water	Siem Reap (SR)	1	6.3	ND	0.060	ND	0.020	ND	< 0.006	6.0	ND	< 0.050	ND	ND	ND	< 0.006
		2	6.5	ND	ND	0.10	ND	ND	< 0.006	6.3	ND	ND	ND	ND	ND	< 0.006
		3	6.5	ND	< 0.050	0.140	ND	ND	< 0.006	6.5	ND	< 0.050	ND	ND	ND	< 0.006
		4	7.0	ND	< 0.050	< 0.020	< 0.010	ND	< 0.006	6.6	ND	ND	ND	ND	ND	< 0.006
	Banteay Meanchey (BM)	1	8.0	0.002	ND	ND	ND	3.720	< 0.006	6.9	ND	ND	ND	ND	2.340	< 0.006
		4	8.0	ND	0.340	ND	ND	5.190	0.013	6.1	ND	ND	ND	ND	ND	< 0.006
	Prey Veng (PV)	1	8.0	ND	0.450	0.020	7.420	ND	ND	7.2	ND	0.050	ND	ND	ND	0.010
		4	7.9	< 0.001	0.440	0.070	0.850	ND	< 0.006	7.3	ND	0.080	ND	ND	ND	< 0.006

A

B

Figure 1: The design of 20-L containers

CONCLUSIONS

This study revealed that the water treatment systems used by small-and medium-scale bottled drinking water plants in Cambodia are not designed to take into account the quality of raw water. Due to the use of R.O. system, however, finished products are safe, but not economical. Inadequate system maintenance, especially in terms of the softening system, is a major problem affecting production efficiency and cost-effectiveness. GMP status, especially in the production of drinking water in 20-L containers, was poor and the main cause of post treatment contamination in the finished products. Overall, therefore, bottled water producers should be given training on basic knowledge for bottled water production, especially in terms of taking into consideration raw water quality, maintenance, good handling practices, hygiene, record keeping and reporting to increase their investment and quality assurance processes.

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Table 5. Microbial qualities of waters from the different steps of production

Water source	Province	Plant	Raw water (CFU/100 mL)		Before Packing (CFU/100 mL)		Product 1 (CFU/100 mL)		Product 2 (CFU/100 mL)		Product 3 (CFU/100 mL)	
			(CFU/100 mL)	Product 1	Coliforms	E. coli	Coliforms	E. coli	Coliforms	E. coli	Coliforms	E. coli
Tap water	Phnom Penh (PP)	1	0	0	0	0	5	0	5	0	3	0
		2	0	0	0	0	0	0	4	0	0	0
		3	0	0	0	0	0	0	0	0	0	0
		4	0	0	0	0	0	0	0	0	0	0
	Banteay Meanchey (BM)	2	0	0	0	0	13	0	0	0	0	0
		3	0	0	0	0	0	0	0	0	0	0
	Prey Veng (PV)	2	0	0	0	0	0	0	0	0	0	0
		3	0	0	9	0	0	0	0	0	0	0
Ground water	Siem Reap (SR)	1	0	0	0	0	4	0	1	0	0	0
		2	0	0	0	0	0	0	0	0	0	0
		3	0	0	0	0	0	0	0	0	0	0
		4	0	0	0	0	0	0	0	0	0	0
	Banteay Meanchey (BM)	1	0	0	0	0	4	0	0	0	0	0
		4	0	0	0	0	0	0	0	0	10	0
	Prey Veng (PV)	1	0	0	0	0	46	0	29	0	0	0
		4	0	0	0	0	15	0	15	0	34	0

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