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Chemical, physical and microbiological analyses of different drinking water sources among diverse governorates in Lebanon

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Multiple sources of drinking water are commonly used in Lebanon, including bottled water, tap water, potable water, spring, artesian wells and station filtered water. The quality of these waters is of great concern, as its contamination could lead to waterborne outbreaks. We aimed to investigate the quality of drinking water in Lebanon, considering different sources and geographic distributions, and to compare their profiles across diverse governorates. A total of 200 samples (133 potable water, 28 station filtered water, 18 tap water, 8 spring water, 7 artesian well water and 6 bottled water) from five Lebanese governorates (Nabatieh, Beqaa, Mount Lebanon, Baalbek-Hermel and South Lebanon) were analyzed for physico-chemical and bacterial properties. The results indicated elevated phosphate concentrations in all areas (>1.35 mg/L). Additionally, all analyzed bacteria were present in all regions, highlighting the lack of contamination-free sources. While in Baalbek-Hermel, followed by Nabatieh, exhibited the highest chemical levels, microbiological contamination particularly total and fecal coliforms, was consistent across governorates, showing no significant difference ($p > 0.05$). However, the distribution of *Streptococcus* and *Pseudomonas Aeruginosa* varied significantly among the different zones ($p < 0.001$ and $p < 0.01$, respectively). All drinking water sources in various Lebanese governorates were found to be contaminated with multiple contaminants. Based on these findings, the sources used for drinking in Lebanon are not entirely safe and require monitoring.

Keywords Drinking water, Lebanon, Physico-chemical, Quality of water

Abbreviations

EHRL	Environmental Health Research Lab
FC	Fecal coliforms
LIBNOR	Lebanese Standards Institution
p	p-value
TC	Total coliforms
WHO	World Health Organization

Water, often referred to as the elixir of life, is a fundamental necessity for all individuals. Defined by the World Health Organization (WHO) in its guidelines for Drinking Water Quality as "the water used for domestic purposes, including consumption, bathing and food preparation"[1], it is a vital resource. Bottled water, on the other hand, is water sealed in bottles or containers, typically with no added ingredients except optional safe and suitable antimicrobial agents[2]. Regrettably, the global community faces a significant challenge due to drinking

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water pollution. Despite increasing access to bottled water, its quality has declined due to the presence of toxic elements, even in trace amounts, posing serious health risks[3]. Pollution of aquatic sources largely results from human actions such as inadequate waste management, industrial waste discharge and agricultural runoff. This issue not only threatens human health but also poses substantial risks to ecosystems and endangers aquatic life.

Unsafe water consumption has severe implications on human health[4]. The lack of water and sanitation services increases the incidence of diseases such as cholera, trachoma, schistosomiasis and helminthiasis[3]. Furthermore, poor environmental hygiene can lead to gastrointestinal infections, inhibiting nutrient absorption and malnutrition, particularly affecting children and vulnerable individuals[5,6].

The quality of water in a building's distribution system can be affected by many factors, leading to both microbial and chemical contamination of drinking water. Cross-connections between sewer and water pipes are a major source of fecal contamination in buildings[7,8]. Additionally, contamination can arise from disease-causing pathogens originating from landfills and septic systems, improper disposal of hazardous household products, leaky underground storage tanks and agricultural chemicals leaching into the water table (e.g., pesticides and fertilizers)[9]. These factors can affect the physical, chemical and microbial properties of water, altering its natural composition through chemical and microbial matter deposited on land surfaces and into soils, or via waste injections directly into groundwater[10]. Ensuring the quality of drinking water is vital for promoting optimal health and wellness within any community. Evaluating its quality is essential to assess the effective operation of treatment facilities, focusing on physical, chemical and biological properties of water that determine its suitability for consumption.

In Lebanon, a small Middle Eastern country, is divided into eight governorates, each possessing special geographic and demographic features. By law, drinking waters (bottled and unbottled) should comply with the Lebanese Standards Institution) LIBNOR) guidelines to be licensed by the concerned authorities. Lebanon's economic collapse, political instability, and healthcare struggles have hampered regular water quality testing[11]. Lebanon's water sector faces a multitude of challenges, an inadequate legal and regulatory framework for water usage, lax enforcement of existing regulations, and widespread pollution. In an old Lebanese case study conducted in 2007 aimed to investigate the domestic water quality variation of one of Beirut sectors (Ras Beirut), the results of this study showed the deterioration pattern in domestic water quality[12]. In a recent study conducted by Dib et al. to evaluate the quality of domestic water in 70 samples of households and schools at Nabatieh district, their findings reported a high phosphate levels in all the samples, with important bacterial and parasitological contaminations[13]. Other studies have focused on the quality of various water sources across Lebanon[14–16]. Though valuable, these researches were limited to selected Lebanese governorates, highlighting the need for further studies to assess water quality throughout the whole country, in order to inform policymakers about the effectiveness of sanitation interventions in improving water safety. This study aimed to investigate and to compare the physico-chemical and the microbiological qualities of several sources of drinking water in different governorates in Lebanon.

Materials and methods
Study area and sampling
The study was conducted at five different Lebanese governorates (Mount Lebanon, Nabatieh, South Lebanon, Beqaa and Baalbek-Hermel). The water samples were collected from July 1, 2023 to October 6, 2023 and analyzed in the Environmental Health Research Lab (EHRL) for physical (conductivity and total dissolved solids), chemical (nitrate, phosphate, magnesium, calcium and sulfate) and bacterial (total (TC) and fecal coliforms (FC)) parameters.

A total of 200 water samples were collected from six different water sources including potable water ($n=133$), filtration water station ($n=28$), tap water ($n=18$), spring water ($n=8$), artesian well ($n=7$) and bottled water ($n=6$). Samples were aseptically collected from each sampling site in sterile plastic bottles and transported to laboratory in ice box and analyzed within 24 h. of sample collection. In the absence of a comprehensive inventory of water sources, a convenience sampling approach was employed. The location of sampling area is shown in Fig. 1.

Micro-biological analysis
Aliquots of the drinking water samples were examined for total and fecal coliforms, *Pseudomonas Aeruginosa*, and *Streptococcus* using aseptic methods through membrane filtration techniques. The subsequent culture media were employed: MacConkey agar for total coliforms (TC) and fecal coliforms (FC), Mannitol salt agar for Streptococcus, and Cetrimide agar for Pseudomonas Aeruginosa. A volume of 100 mL of filtered samples were incubated during 24 h in a temperature of 37 °C for TC and 44 °C for the remaining bacteria.

Physico-chemical analysis
The physical characteristics of the 200 samples were assessed using electrometric techniques. The conductivity of each sample was measured, and a TDS-meter was employed to determine the TDS. For the chemical analysis, the samples were filtered through a Millipore cellulose membrane with a pore size of 0.45 µm. The levels of nitrate, phosphate, sulfate, magnesium, and calcium were determined using the classical spectrophotometric method. The recorded values were compared to the recommendations of LIBNOR for drinking water.

Data analysis
Results of physico-chemical analysis and microbial counts of the investigated water samples were presented. Water quality results were compared with the World Health Organization drinking water standards. To obtain a quantitative summary of the data, descriptive statistics were obtained for all observations of the parameters

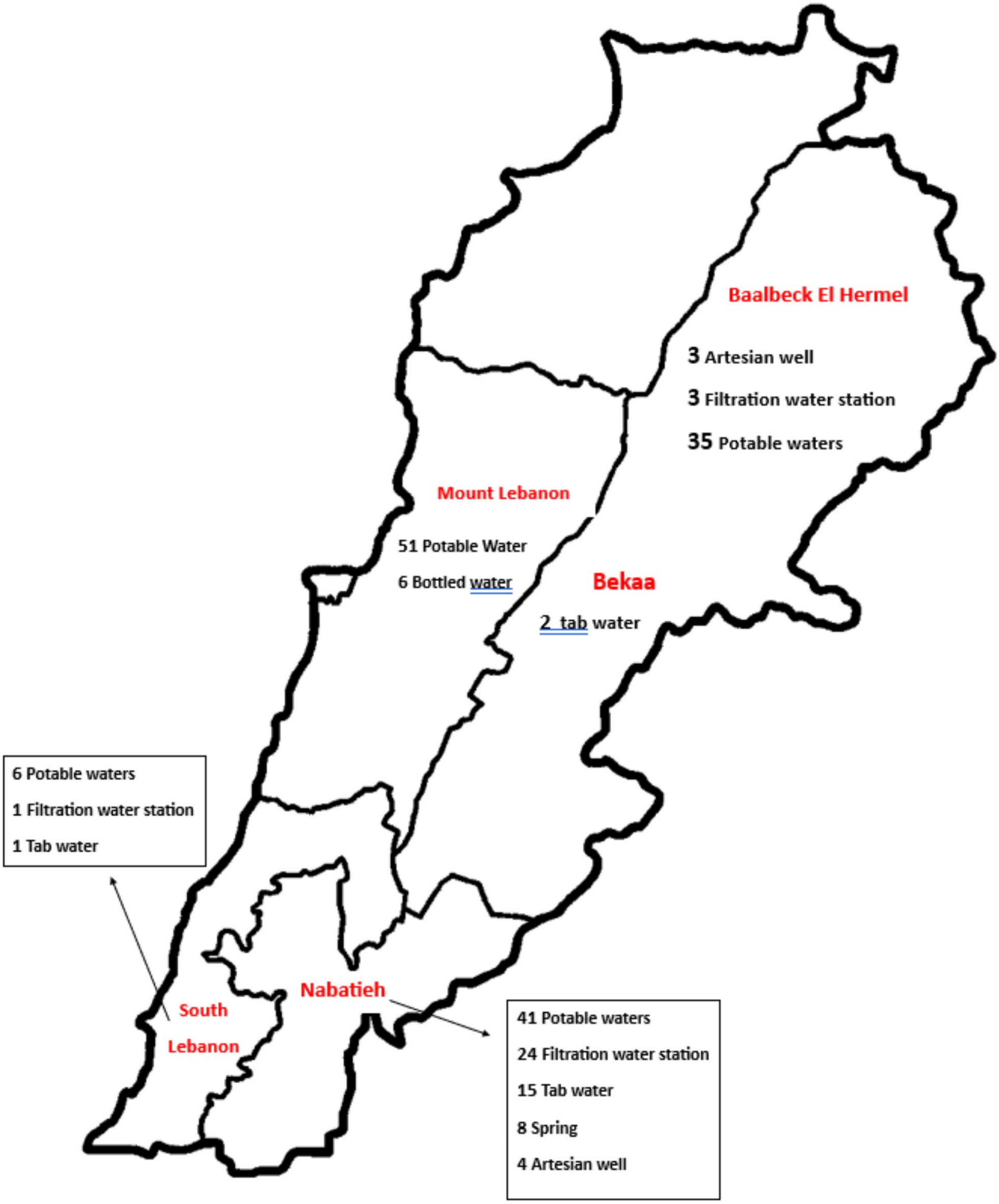

Fig. 1. Regional distribution of the water samples.

analyzed, including the mean, 95% confidence interval, median and range. The Shapiro-Wilk test was used to check the normality of data. To identify potential differences in the physio-chemical characteristics and bacterial contaminations of drinking water among the five Lebanese governorates under study, the Kruskal-Wallis and Chi-square tests were employed, subsequently. The statistical analyses were performed by using SPSS version 26 (SPSS, Inc.; Chicago, IL, USA) and Graph-Pad Prism version 5.0 (GraphPad software, Inc.; San Diego, CA). A significance level of p-value < 0.05 was established.

Results and discussion

Study design and sampling

A total of 200 drinking water samples were gathered from five distinct Lebanese governorates. The distribution and origins of the examined samples are detailed in Table 1. The majority of samples were obtained from Nabatieh (46%), followed by Mount Lebanon (28.5%), Baalbek-Hermel (20.5%), South Lebanon (4%) and Beqaa (1%). As shown in Table 1, the main sources of drinking water in each area were taken into account during the sampling process. Potable water was the most frequently collected water in the studied regions, with the exception of Beqaa, while the remaining samples were sourced from tap water, filtration stations, artesian wells, bottled water and spring water. To the best of our knowledge, this is the first study in Lebanon that addresses the quality of drinking water across various geographical zones and comprehensively considers all sources of drinking water in the country.

Physico-chemical and bacterial qualities of drinking water in different Lebanese governorates

A total of 200 drinking water samples were subjected to physico-chemical and bacterial examinations. As shown in Table 2, the results indicated that the TDS values fell within the acceptable range according to the drinking water guidelines set by LIBNOR (600 mg/L) in all five zones under investigation. However, the raw data showed that elevated TDS levels exceeding 600 ppm were detected in five water treatment plants (unpublished data). This highlights the importance of regularly replacing and maintaining filters in the water purification facilities to ensure their effectiveness. Unfortunately, this behavior is not consistently followed in Lebanon, where outdated filters are still in use.

In terms of chemical composition, the concentrations of nitrate and sulfate in all samples met the recommended limits set by LIBNOR (nitrate: 45 mg/L; sulfate: 250 mg/L). However, the average of phosphate concentration exceeded the recommended value (1.35 mg/L) in the five study areas, which can contribute to increased microbial growth[17]. These findings align with the recently published data about tap water quality in Nabatieh district, indicating elevated phosphate levels in domestic water[13]. Additionally, our data revealed that several samples exhibited high nitrate concentrations surpassing Lebanese standards (45 mg/L), particularly in Baalbek-Hermel region, possibly due to groundwater contamination from agricultural fertilizers[18]. It is important to highlight that elevated levels of nitrates in drinking water can pose health risks, especially for gastric cancer[18].

Otherwise, the microbiological analyses confirmed the presence of TC in samples collected from Beqaa and South Lebanon. This observation could be attributed to soil contamination. Coliforms were previously identified in previous studies carried out in Lebanon, either in tap water or in surfaces water[13,15]. More importantly, *Streptococcus* was detected in these two zones. This contamination necessitates serious consideration since safe drinking water must be devoid of any pathogens.

General physico-chemical and bacterial qualities of all collected drinking water samples

The physico-chemical and bacterial properties of the total of collected drinking water samples are shown in Fig. 2. In terms of physical quality, the measured TDS values fell within the safe interval as per the LIBNOR drinking water standards (600 ppm). Regarding chemical quality, the concentrations of nitrate and sulfate in all samples were below the recommended threshold set by LIBNOR (nitrate: 45 mg/L; sulfate: 250 mg/L). However, the reported median of phosphate concentration exceeded the recommended limit (1.35). This data indicates that the overall physico-chemical quality of drinking water is satisfactory, except for phosphate contamination, which is a widespread issue across the country rather than being localized to specific regions.

In general, all the tested microorganisms were identified as contaminants in the drinking water samples when aggregated from various sources. The presence of FC indicates a fecal contamination of water. Otherwise, the *Pseudomonas Aeruginosa*bacteria were identified. Even this minor level of contamination necessitates a rapid intervention to mitigate the health risks it poses to humans, as it can lead to a variety of infections and is a primary cause for sickness in immunocompromised individuals[19].

	Source of water					
	Artesian well	Tap water	Filtration water station	Potable water	Bottled water	Spring water
Governorate	*n* (%)	*n* (%)	*n* (%)	*n* (%)	*n* (%)	*n* (%)
Nabatieh ($n=92$)	4 (4.3)	15 (16.3)	24 (26.1)	41 (44.6)	0 (0.0)	8 (8.7)
Mount Lebanon ($n=57$)	0 (0.0)	0 (0.0)	0 (0.0)	51 (89.5)	6 (10.5)	0 (0.0)
Baalbek-Hermel ($n=41$)	3 (7.3)	0 (0.0)	3 (7.3)	35 (85.4)	0 (0.0)	0 (0.0)
South Lebanon ($n=8$)	1 (12.5)	0 (0.0)	1 (12.5)	6 (75.0)	0 (0.0)	0 (0.0)
Beqaa ($n=2$)	0 (0.0)	2 (100.0)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)

Table 1. Distribution of drinking water samples in the governorates and according to source of water.

Governorate	Physical parameters				Chemical parameters										Bacterial parameters							
	Conductivity (µs/cm)		TDS (ppm)		Sulphate (mg/L)		Phosphate (mg/L)		Nitrate (mg/L)		Magnesium (mg/L)		Calcium (mg/L)		Total coliforms (CFU/mL)		Fecal coliforms (CFU/mL)		Pseudomonas (CFU/mL)		Streptococcus (CFU/mL)	
	Median (range)	Min-Max	Median (range)	Min-Max	Median (range)	Min-Max	Median (range)	Min-Max	Median (range)	Min-Max	Median (range)	Min-Max	Median (range)	Min-Max	Median (range)	Min-Max	Median (range)	Min-Max	Median (range)	Min-Max	Median (range)	Min-Max
Nabatieh ($n=92$)	73 (236)	36–272	118 (623)	33–656	32 (218)	0.5–218	8(230)	0–230	6 (35)	0.1–35	7 (69)	0.1–35.8	39 (92)	6–98	0 (470)	0–470	0 (300)	0–300	0 (25)	0–25	0 (280)	0–280
Mount Lebanon ($n=57$)	87 (206)	48–254	132 (530)	48–578	26 (264)	1–265	8 (32)	0–32	2.7 (15)	0.1–15	3 (38)	0–38	14 (218)	0–218	0 (782)	0–782	0 (300)	0–300	0 (16)	0–16	0 (280)	0–280
Baalbek-Hermel ($n=41$)	57 (25)	40–65	130 (440)	61–501	22 (243)	3–246	11 (48)	0–48	11 (137)	0.3–137	8 (28)	0–28	48 (156)	4–160	0 (470)	0–470	0 (300)	0–300	0 (16)	0–16	5 (280)	0–280
South Lebanon ($n=8$)	43 (20)	40–60	102 (87)	42–129	43 (92)	8–100	18 (28)	2–31	6 (20)	2–22	10 (19)	0–19	28 (22)	16–38	37 (470)	0 –470	0 (0)	0–0	0 (22)	0–22	71 (193)	0–193
Beqaa ($n=2$)	162 (49)	138–187	157 (29)	143–172	34(17)	26–43	20 (3)	18–22	3 (4)	1–6	1 (1)	1–2	76 (16)	68–84	41 (82)	0–82	0 (0)	0–0	0 (0)	0–0	0 (2)	0–5

Table 2. Physical, chemical and bacterial parameters of drinking water samples collected from different regions ($n=200$).

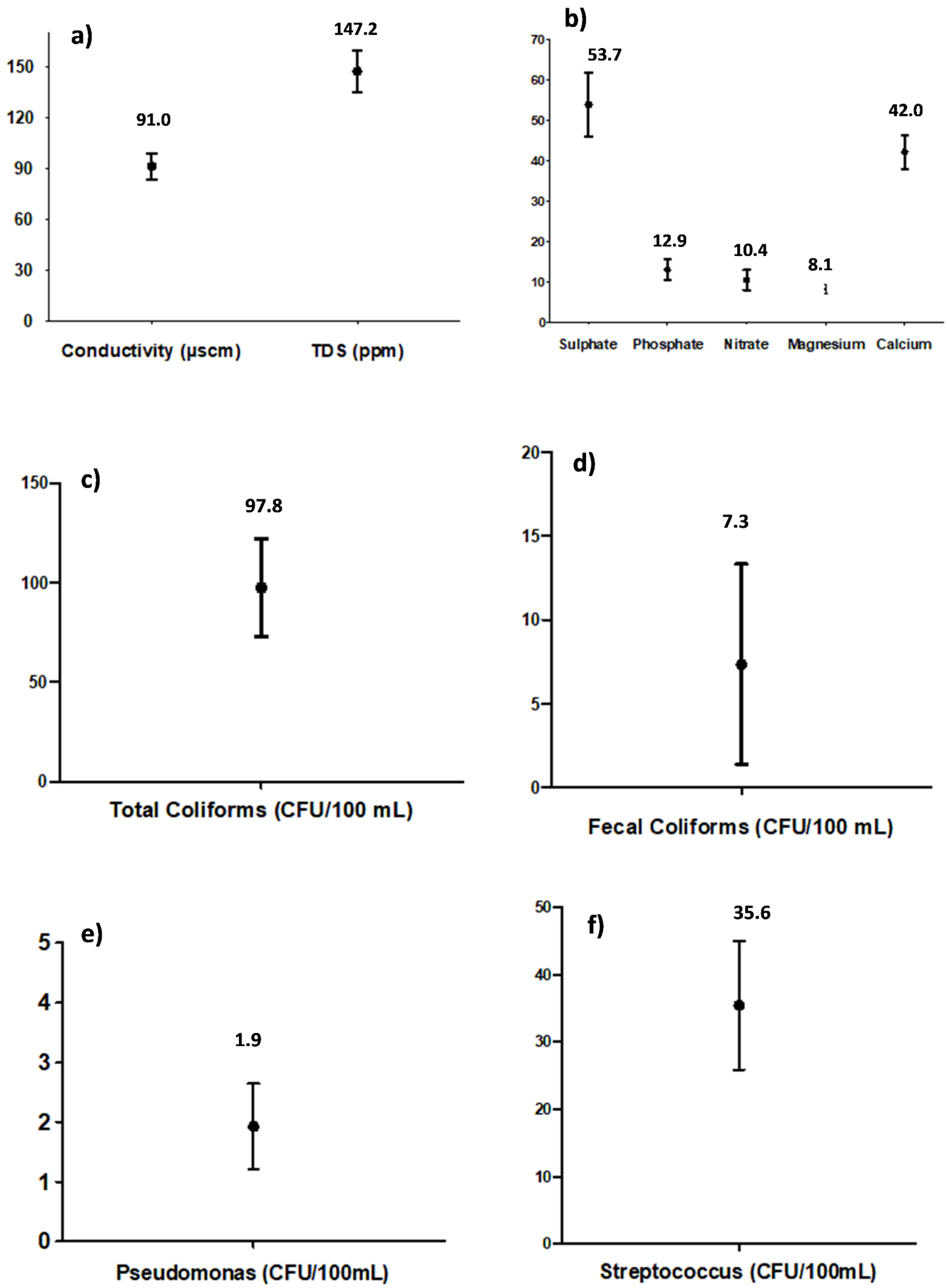

Fig. 2. Mean of physical (**a**, **b**) and chemical (**c**, **d**, **e**, **f**) parameters of drinking water samples obtained from different sources.

Physico-chemical and bacterial qualities of drinking water according to their sampling sources

The physical and chemical characteristics of water gathered from diverse origins in Lebanon are illustrated in Fig. 3. Although the TDS, nitrate, and sulfate levels demonstrated satisfactory readings, the phosphate content surpassed the threshold in all drinking water sources (1.35 mg/L). Notably, the maximal concentration was detected in the water sourced from a treatment facility (Fig. 3, d). This finding underscores the critical need to enhance the efficiency and effectiveness of water treatment facilities throughout the country.

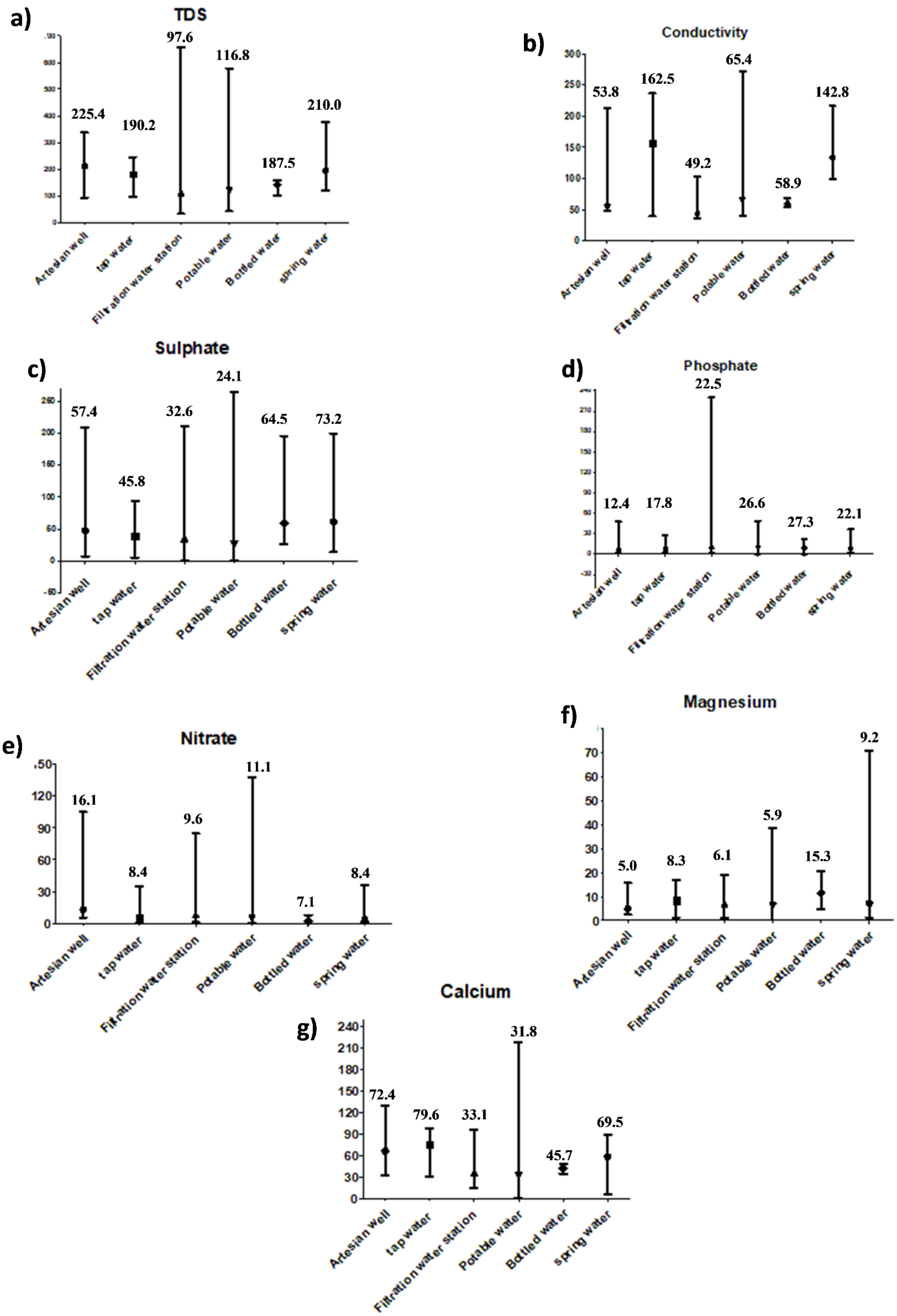

Fig. 3. Mean of physical (**a**, **b**) and chemical (**c**, **d**, **e**, **f**, **g**) parameters of drinking water samples obtained from different sources.

The microbial characteristics of water sourced from different locations in Lebanon are illustrated in Fig. 4. The documented findings indicated minimal contaminations of artesian wells, tap water, filtration water stations, potable water and spring water by TC, FC, *Pseudomonas Aeruginosa* and *Streptococcus*. Despite the generally low contamination levels, it is crucial for safe drinking water to be devoid of any pathogens. This information suggests a lack of adequate water treatment facilities and highlights the potential risks of consuming untreated tap or spring water by the public. While bottled water exhibited favorable

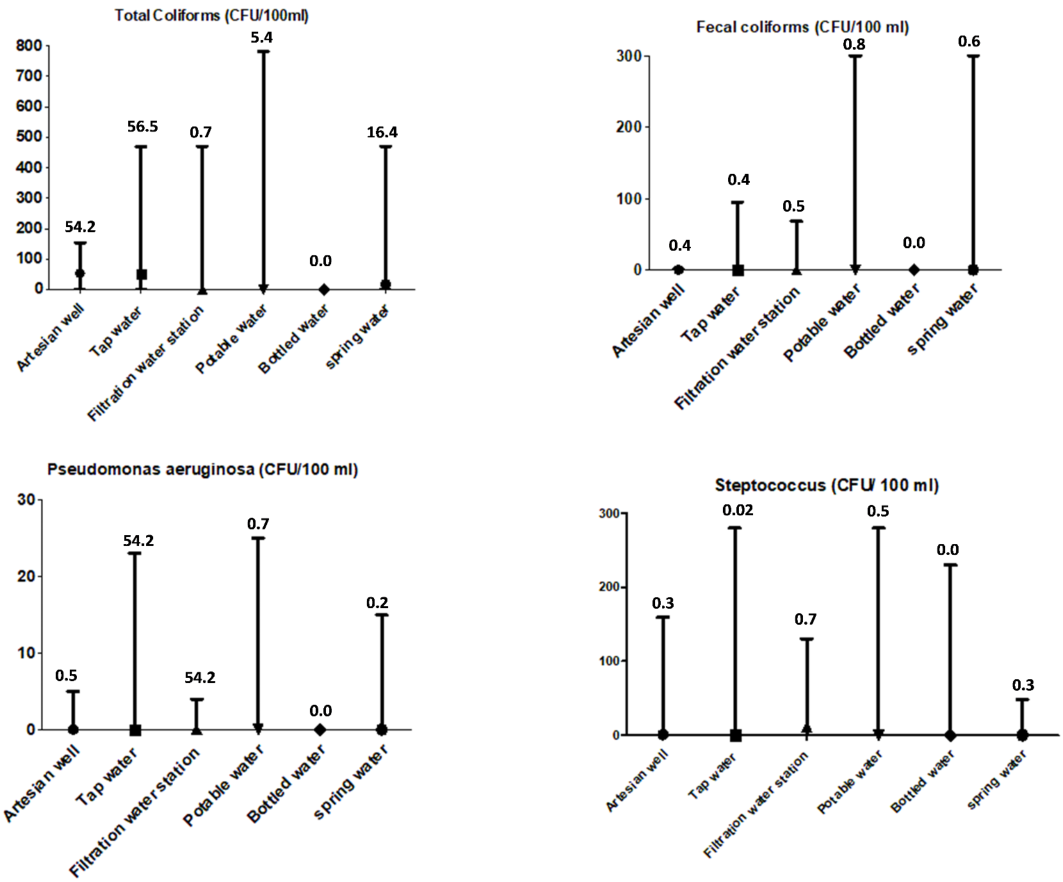

Fig. 4. Mean of bacterial parameters of drinking water samples collected from different sources.

outcomes in terms of TC, FC and *Pseudomonas Aeruginosa*, the presence of *Streptococcus*indicates that the sterilization and/or storage procedures may be ineffective or unsafe, respectively. Lately, there has been a rise in the consumption of bottled drinking water under the belief that it is more secure than tap water and can safeguard against waterborne illnesses[20]. However, our data confirmed that bottled water could be a main contributor to the spread of water-borne diseases.

Comparison of physical parameters of drinking water in different Lebanese governorates

A comparative analysis was conducted among physical, chemical and bacterial parameters of drinking water in different Lebanese regions. The Beqaa governorate was excluded from this analysis due to its small sample size (n = 2). The comparative results of physical data were shown in Fig. 5. Interestingly, significant differences were observed in the conductivity and TDS measurements among the various regions ($p < 0.001$). Nabatieh exhibited the highest levels of conductivity and TDS, although they remained within the acceptable limits and did not exceed them.

Comparison of chemical parameters of drinking water in different Lebanese governorates

The comparison of the chemical profiles among the four regions is shown in Fig. 6. The results demonstrated significant variations in nitrate, magnesium and calcium concentrations ($p < 0.001$). The highest levels of contamination were observed in Baalbek-Hermel, followed by Nabatieh. This data should act as a benchmark to evaluate the efficacy of local treatment facilities.

Comparison of drinking water bacterial contaminations between Lebanese governorates

The average contamination levels of TC, FC, *Streptococcus* and *Pseudomonas Aeruginosa* in four different governorates are summarized in Fig. 7. A comparison of these outcomes revealed high contamination by TC and low levels of FC without significant variations, suggesting similar contamination levels of these bacteria in all areas. It is important to note that according to the Lebanese recommendations, the presence of these contaminants in drinking water is not permitted, indicating that this water is not safe for human consumption. The contamination of TC could be attributed to contact with soil in wells, springs and streams, while FC is likely originates from fecal materials discharged into rivers.

The presence of Pseudomonas Aeruginosa bacteria was also detected in the drinking water collected from the four governorates. Its prevalence ranged between 5% and 11% across these areas, with the highest percentage recorded in Nabatieh (11%).and Mount Lebanon (11%). A noteworthy significant difference in contamination

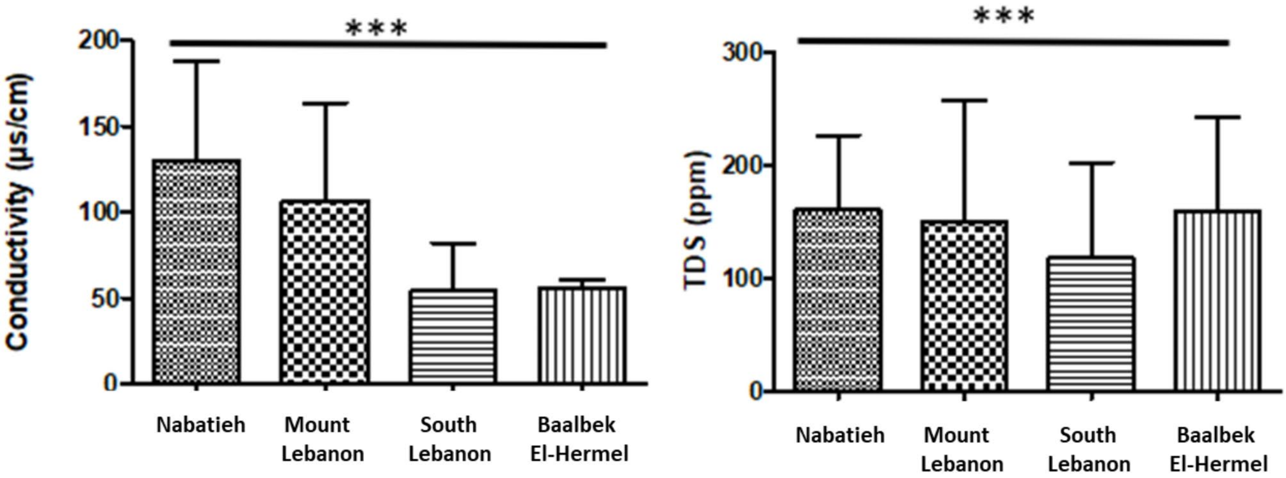

Fig. 5. Comparison of drinking water physical parameters between different Lebanese governorates.

levels among the examined regions was observed ($p < 0.01$). Nevertheless, even the small proportion of *Pseudomonas Aeruginosa* contamination in Baalbek-Hermel, similar to other Lebanese regions, warrants serious consideration. As per national and international guidelines, safe drinking water must be devoid of any pathogens.

Significant differences were noted in streptococcus contamination levels among samples collected from various areas ($p < 0.001$), with the highest levels found in South Lebanon and Baalbek-Hermel, while the lowest percentage of contaminated samples was observed in Nabatieh. Once again, the assessment of bacterial quality reaffirms that the majority of drinking water sources in various Lebanese governorates are unsuitable for consumption; this underscores the urgency to review and enhance the ineffective treatment procedures used in all examined regions.

Conclusions

In summary, while the physico-chemical characteristics of drinking water in Lebanon were deemed satisfactory across various regions, the presence of TC, FC, *streptococcus* and *Pseudomonas Aeruginosa* was confirmed in drinking water obtained from streams, wells and treatment facilities in all surveyed areas. Consequently, these drinking water sources are contaminated and unsafe for consumption. This highlights the importance of raising awareness and educating the Lebanese population about the significance and protocols of routine disinfection of dispensing systems. Additionally, it is advisable to reserve water in well-ventilated environments to minimize the proliferation of bacteria. By implementing these practices, hygienic conditions can be enhanced, ensuring the safe and high-quality dispensation of water.

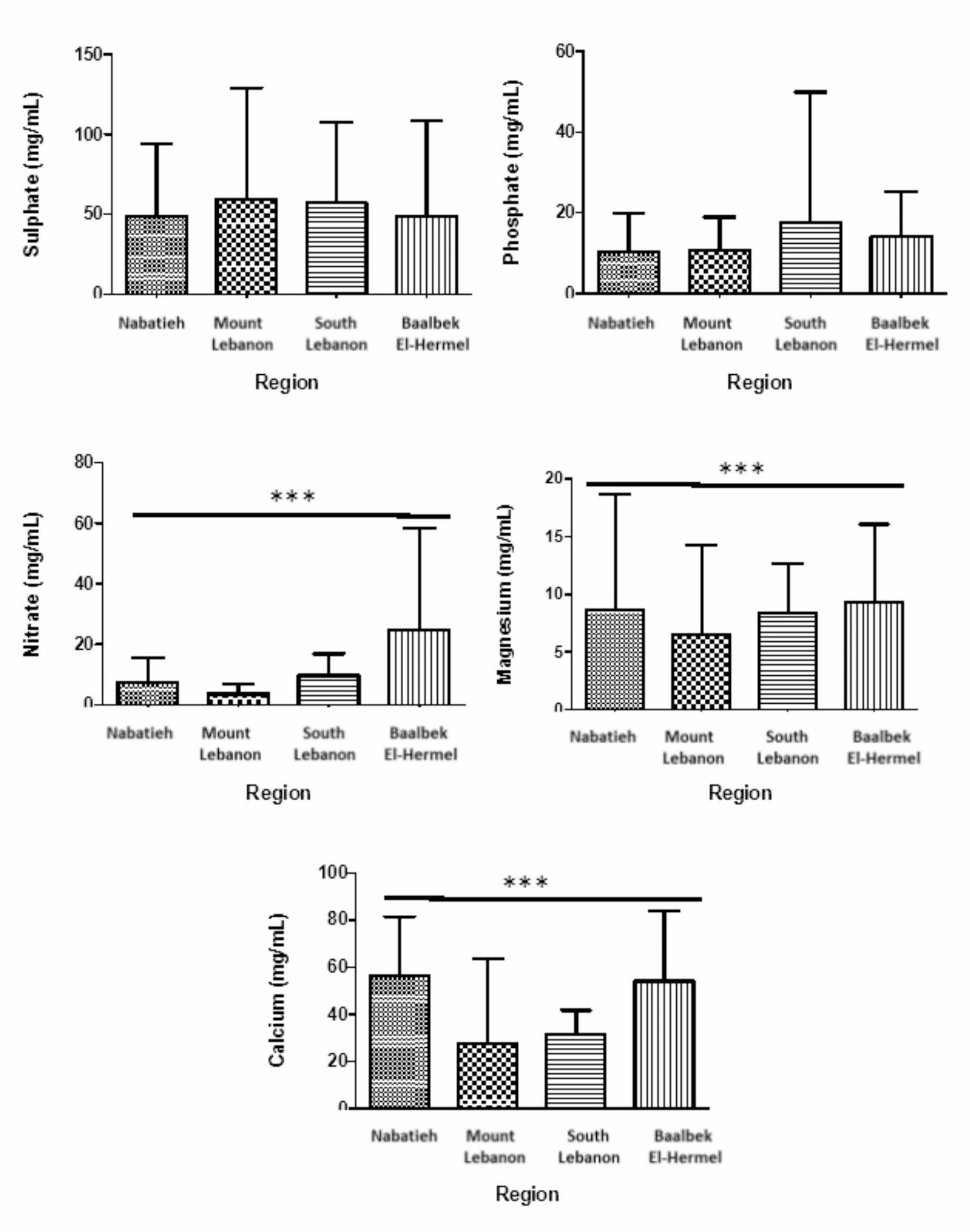

Fig. 6. Comparison of drinking water chemical parameters between different Lebanese governorates.

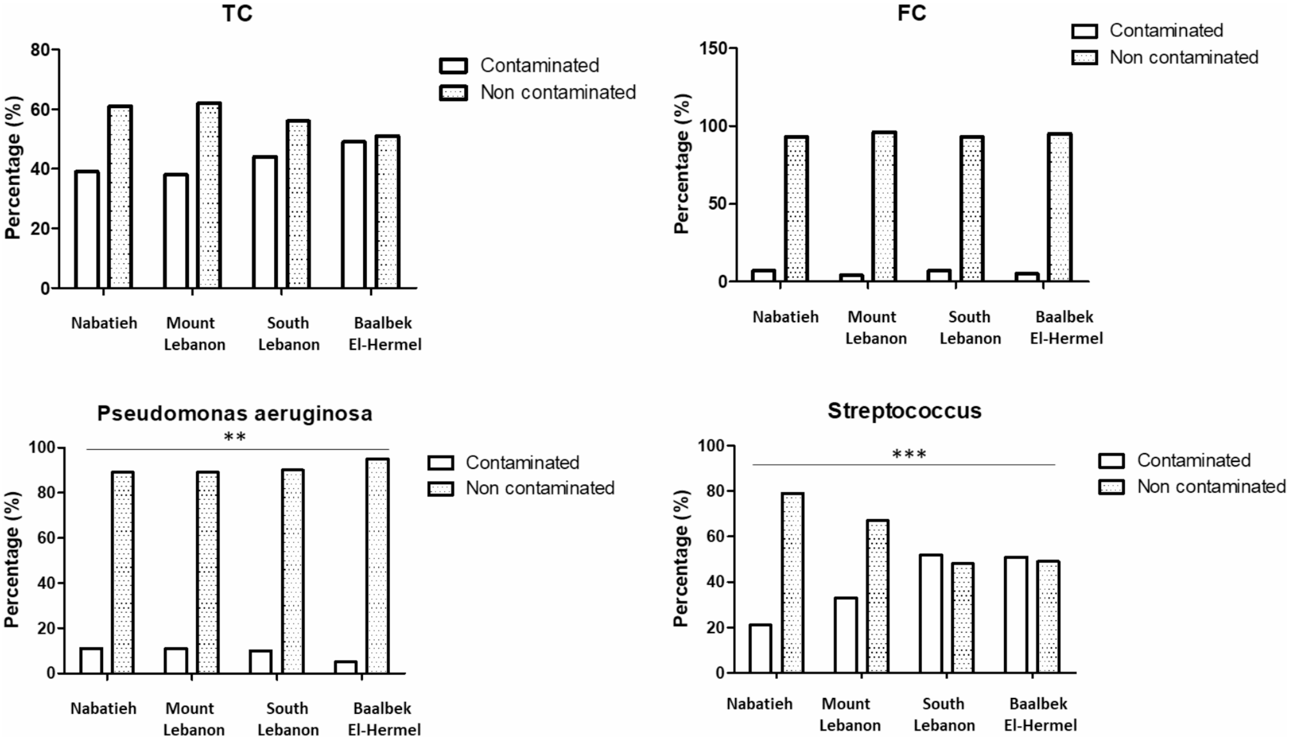

Fig. 7. Comparison of drinking water bacterial contamination between different Lebanese governorates.

Data availability

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

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Conceptualization, R.H, and S.M; methodology, F.F, I.D, F.N, R.H and M.F; software, I.D and RH; validation, M.F, K.B, S.M and A.H; formal analysis, I.D and R.H; investigation, F.F, I.D, F.N and M.F and R.H; resources, K.B, S.M and A.H; data curation, I.D; R.H; writing—original draft preparation, F.F, I.D, R.H, and F.N ; writing—review and editing, F.F, I.D, F.N, K.B and RH; visualization, F.F, I.D, F.N, and R.H; supervision, M.F; project administration, A.H and M.F. All authors read and approved the final manuscript.

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Consent for publication
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Competing interests
The authors declare no competing interests.

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