Ions composition of waste water after reverse osmosis filtration of drinking water: risk analysis and contribution to mineral nutrition

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ABSTRACT
This work aimed to investigate the ions composition of wastewater produced after reverse osmosis and the suitability of using wastewater as a drinking source for different farm animals, especially in poultry, the most sensitive/intolerant farm animals. Ten samples of wastewater (three replicates) were obtained from different water filtration stations in Jordan and were analysed for their cations: sodium (Na), potassium (K) and calcium (Ca) and anions; fluorine (F), chlorine (Cl), nitrite (NO₂), nitrate (NO₃), phosphate (PO₄) and sulfate (SO₄) concentrations. The highest variation was found in both K (CV% = 99.7) and F (CV% = 90.78). With mineral concentration in extreme/highest cases, analysed wastewater samples can provide a negligible contribution to poultry (broilers) requirements, as the case in K (0.27%) or can supply excessive amounts as in Na (150.0%). In all wastewater samples, CI and F levels were above the safety guidelines recommended for poultry drinking water. In some of the selected samples, presence of Na (9 out of 10 samples) and sulfate (5 out of 10 samples) was higher than the recommended limits for broilers. Other analysed minerals were found tolerable by poultry. Results suggest the feasibility of re-using wastewater directly or indirectly after mixing it with public water as a source of drinking water for farm animals.

Introduction
In arid and semi-arid regions like Jordan, water availability can be considered as one of the main challenges. Management/treatment and reuse of wastewater, produced after reverse osmosis treatment, for animal production and agricultural applications can save drinking water resources. As well, processed wastewater can be reused for planting and to reduce desertification in arid regions. The wastewater treatment sector needs development even without considering population growth, which puts more pressure on the existing treatment capacity (Al Zahiri 2015).

High-quality drinking water is very important for poultry because of its important role in digestion, absorption, production, thermal regulation, metabolism, enzymatic and chemical reactions, and mineral nutrient contribution (NRC 1994). The tolerance of poultry to minerals in water is dependent on many factors such as water requirement, physiological status, environmental conditions, mineral content in the diet and poultry age (Mirsalimi and Julian 1993; NRC 1994; Kellems and Church 2002). Poultry is considered the most sensitive/intolerant species among farm animals. Therefore, testing the suitability of using wastewater as a source of drinking water for poultry can give an indication of its suitability for other farm purposes.

In Jordan, reverse osmosis treated drinking water became more extensively used because of the rapid increase in population, elevated living standards, industry development and the expansion of tourism sector. Reverse osmosis is a water purification technology that benefit of a semipermeable membrane to eliminate ions, molecules and big particles from low-quality water. Depending on the size of the filtration system, the pressure and the water quality, reverse osmosis systems waste significant quantities that range between 50% and 90% of the water (Olkowski 2009). In Jordan as the case in many countries, public water supplies are usually used by filtration shops to filterate water used for human consumption. Public water supplies are regularly monitored and treated as required under the supervision of government institutions such as Ministry of Health. However, there has been no study to quantify macrominerals and microminerals obtained from wastewater (rejected water) produced by reverse osmosis treatment by water filtration shops.

To best of our knowledge, this is the first study that aimed to evaluate the importance and suitability of wastewater produced after reverse osmosis as a source of drinking water in farm animals with particular focus on poultry.

Materials and methods
Wastewater was collected from 10 filtration shops in Jordan in October 2016. All wastewater samples were collected from outlet port using 1.5-l plastic bottles and were stored directly in refrigerator (4°C) until mineral analysis. The ions composition of all wastewater samples was determined at the Department of...
Chemistry, Faculty of Science at Mutah University, Alkarak, Jordan. The concentration of sodium (Na), potassium (K) and calcium (Ca) were determined by flame photometry (Microprocessor Flam Photometer Model (FP902-5) PG Instruments limited, UK). Fluorine (F), chlorine (Cl), nitrite (NO2), nitrate (NO3), phosphate (PO4) and sulfate (SO4) were determined by using ion chromatography (DX-100 Ion Chromatograph, Dionex Corp, USA). The concentration of both cations and anions in wastewater were measured in triplicate and presented as mg/L. The data were presented as descriptive statistics (means ± standard deviation). To compare concentration heterogeneity between different ions, coefficient variation (CV%) was used and calculated as follows:

\[
CV\% = \frac{\text{standard deviation}}{\text{mean}} \times 100
\]

## Results

### Ions levels in wastewater

Table 1 and Table 2 show cation and anion concentration of the 10 collected samples obtained from different filtration shops distributed in Jordan, respectively. Sodium had the highest average concentration (558.95 mg/L) and ranged from 136.33 to 1213.33 mg/L. Whereas, K had the lowest average concentration (2.20 mg/L) and ranged from 0.15 to 7.20 mg/L. Ca had intermediate average concentration (123.15 mg/L) and ranged from 53.5 to 212.0 mg/L. Although K had the lowest concentration among other analysed cations (i.e. Ca and Na), it had the highest variation (CV% = 99.70) (Table 1).

Among analysed anions, Cl had the highest average concentration (357.67 mg/L) and ranged from 188.30 to 600 mg/L. Whereas, NO2 and PO4 were not detected in all collected wastewater samples. Furthermore, F were not detected in some of wastewater samples. Both NO3 and SO4 had an intermediate average concentrations (11.61 and 218.98 mg/L, respectively) and ranged from 7.85 to 13.47 mg/L, 75.66 to 504.41 mg/L, respectively. Among analysed anions, F had the highest variation (CV% =90.78).

### Discussion

#### Variation in ions composition and suitability of wastewater for poultry

Different concentration levels within the same ion in wastewater may be attributed to the initial differences in ion content in public water before the start of reverse osmosis filtration process (Al-Rabadi 2017). Poultry is considered the most sensitive/intolerant farm animals. Therefore, testing the suitability of using wastewater as a source of drinking water can give an indication of its suitability for other farm purposes. Table 3 shows the minimum and maximum ion concentration levels (mg/L) measured in wastewater samples and comparison to maximum acceptable concentration level of drinking water for poultry. K, Ca and NO3 of wastewater samples were below the upper limit guidelines. Nine out of 10 wastewater samples showed Na concentration levels above the safety guidelines recommended by Watkins (2008). Na concentration above 150 mg/L have been reported to enhance harmful bacterial growth in poultry (Watkins 2008). Na concentration above 250 mg/L have been reported to cause wet litter and loose dropping as a result of the increase in water intake (Balnave 1988; Kamphues et al. 2007). However, Watkins et al. (2005) reported that a combination of 500 mg/L in water with 0.25% Na in the diet did not adversely affect body weight gain, feed conversion or mortality in broilers. In laying hens, addition of 796 mg Na/L to the drinking water negatively affected eggshell breaking strength and the concentration of calcium-binding proteins (Balnave and Zhang 1993). Higher level of Na

### Table 1. Cation concentration (mg/L) of wastewater after reverse osmosis filtration treatment.

| Filtration/sample | Na   | K    | Ca   |
|-------------------|------|------|------|
| 1                 | 590.00 | 2.88 | 104.66 |
| 2                 | 1213.33 | 1.20 | 212.00 |
| 3                 | 638.33 | 2.26 | 113.0 |
| 4                 | 516.66 | 0.92 | 107.00 |
| 5                 | 750.00 | 4.13 | 193.00 |
| 6                 | 185.66 | 2.55 | 53.50 |
| 7                 | 136.33 | 7.20 | 122.83 |
| 8                 | 516.67 | 0.50 | 100.83 |
| 9                 | 650.00 | 0.167 | 129.17 |
| 10                | 392.50 | 0.15 | 92.5 |

Statistics
- Mean: 558.95
- SD: 303.58
- CV%: 54.31

### Table 2. Anion concentration (mg/L) of wastewater after reverse osmosis filtration treatment.

| Filtration sample | F    | Cl   | NO2  | NO3  | PO4  | SO4  |
|-------------------|------|------|------|------|------|------|
| 1                 | 0.63 | 439.52 | ND   | 13.47 | ND   | 258.65 |
| 2                 | 3.42 | 600.68 | ND   | 13.03 | ND   | 504.41 |
| 3                 | 0.52 | 424.03 | ND   | 10.87 | ND   | 224.05 |
| 4                 | ND   | 354.50 | ND   | 7.85  | ND   | 129.86 |
| 5                 | 1.70 | 328.86 | ND   | 11.75 | ND   | 181.61 |
| 6                 | ND   | 188.30 | ND   | 11.66 | ND   | 75.66  |
| 7                 | ND   | 267.38 | ND   | 12.58 | ND   | 135.44 |
| 8                 | ND   | 278.72 | ND   | 10.50 | ND   | 286.08 |
| 9                 | 0.58 | 423.86 | ND   | 11.92 | ND   | 249.74 |
| 10                | ND   | 270.88 | ND   | 12.38 | ND   | 144.31 |

Statistics
- Mean: 557.67
- SD: 118.31
- CV%: 90.78

### Table 3. Minimum and maximum cations and anions concentrations (mg/L) measured in wastewater, and comparison to maximum acceptable concentrations in poultry.

| Minerals | Minimum (mg/L) | Maximum (mg/L) | Maximum acceptable level (mg/L) | Reference |
|----------|----------------|----------------|---------------------------------|-----------|
| Na       | 136.33         | 1213.33        | 150                             | Watkins (2008)* |
| K        | 45.30          | 212.0          | 250                             | Kamphues et al. (2007)* |
| Ca       | 53.50          | 212.0          | 500                             | Kamphues et al. (2007)* |
| Cl       | 188.30         | 600.68         | 150                             | Watkins (2008)* |
| F        | 0.52           | 3.42           | 0.30                            | Watkins (2008)* |
| NO3      | 7.85           | 13.47          | 25                              | Watkins (2008)* |
| SO4      | 75.66          | 504.41         | 200                             | Watkins (2008)* |

*Not established.

*Adapted from Watkins (2008).

*Adapted from Beede (2006).
(1200 mg/L) in drinking water has been reported to enhance the risk occurrence of pulmonary hypertension syndrome (Xiang et al. 2004). All wastewater samples had Cl levels above the safety guidelines reported by Watkins (2008). Broilers body weight gain has been reported to be impaired when water contained 300 mg/L Cl (Damron and Flunker 1993). Water consumption of broiler chicks has been reported to decline as Cl concentration of the drinking water increased (Abbas et al. 2008). Concentration levels of both Na and Cl can influence broiler performance and body metabolism. Briton (1990) found that the best ratio of Na:Cl for the best body weight gain and efficiency was 1:1 (w/w) and any disturbance in this ratio will negatively reduce feed intake, body weight gain and disturbance in blood pH value of the birds (Hurwitz et al. 1973; Briton 1990; Balos et al. 2016). The detrimental effect of Cl seems to rely on other ions presence (Apha 1985). Euribird (1982) reported that high concentration of Cl in drinking water of poultry can cause wet dropping when combined with hard water and in the presence of sulphate.

In this study, all wastewater samples had F levels above the safety guidelines reported by Watkins (2008). F levels greater than 40 mg/L have been reported to cause soft bones in poultry (Halls 2008). Limited information in the literature is available on the influence of F level in drinking water on poultry health and production performance. Five out of 10 wastewater samples showed SO 4 concentration level above the safety guidelines. High SO 4 contents in drinking water increased (Abbas et al. 2008) and disturbance in blood pH value of the birds (Hurwitz et al. 1973; Briton 1990; Balos et al. 2016). The detrimental effect of Cl seems to rely on other ions presence (Apha 1985). Euribird (1982) reported that high concentration of Cl in drinking water of poultry can cause wet dropping when combined with hard water and in the presence of sulphate.

Dilution of wastewater with low mineral content of freshwater and/or rainwater could be a useful approach to prevent the increase of certain minerals in water (Manera et al. 2016). Alternatively, wastewater produced by reverse osmosis technology may be more suitable as drinking water for ruminates due to their higher tolerant levels to mineral content in the drinking water (National Research Council 1974; 1980; 2005) (Table 4) when compared to poultry.

**Macroions contribution of wastewater for broilers at different growth stages**

Broilers at 5, 6 and 7 weeks of age were used as an example to investigate the macroions contribution of wastewater to broiler requirements. Assuming daily water consumption at different production stages shown in Table 5, the highest contribution of Ca and K in wastewater was not enough to make a significant contribution to broilers nutrition at different growth stages. Maximum Ca and K contribution obtained from wastewater were 3.73% and 0.50% respectively. However, Na and Cl concentration of wastewater were relatively sufficient to make a significant contribution to broiler nutrition at different growth stages. Minimum Na and Cl contribution obtained from wastewater were 7.69% and 15.38% respectively. Maximum Na and Cl contribution obtained from wastewater were 3.73% and 0.50% respectively. It is estimated that 100 mg/L Na in the water can replace approximately 0.05% Na in the diet (Modather 2006). Watkins et al. (2005) reported that when drinking water contain medium level of Na (400–500 mg/L), no Na seems to be required by broilers diet. Resistant of broilers to saline water is dependent on age and previous exposure of broilers to salt. Broiler chickens less than 3 weeks of age are more vulnerable to saline water than those over 3 weeks of age, and that broilers given increasing concentrations of dietary salt

![Table 4. Minimum and maximum cations and anions concentrations (mg/L) measured in wastewater and comparison to maximum acceptable concentrations in some farm animals.](image)

![Table 5. Estimates of daily feed intake (gram/day), daily free water intake (kg/day), daily macroions requirement (g/day) and daily drinking water ions contribution (represented as g/day and/or as % of daily requirement) for broilers at different growth stages.](image)

**Notes:**

- *The data presented apply for environmental temperatures of about 21°C.
- *Estimate of daily feed intake, daily free water intake and ions requirements were obtained from Poultry (NRC 1994).
may withstand higher dietary salt than those that have no earlier adaptation (Mirsalimi and Julian 1993).

Although wastewater derived from public water sources is used in this study, more frequent analysis is required to measure pollutants (such as organic hydrocarbons), pesticides and other ions, e.g. magnesium and bicarbonate, to confirm the suitability of wastewater after reverse osmosis treatment as a drinking water for poultry.

Conclusion
Wastewater samples obtained after reverse osmosis treatment showed variation in ion levels with high proportion of Na, Cl, F and SO₄. Of all ions evaluated in different wastewater samples, Na and Cl made the greatest contribution for broiler nutrition at different growth stages; wastewater can be offered to supply part or all of broiler’s requirement. However, some samples showed potential risk of toxicity if wastewater offered as a drinking water for poultry. Thus dietary minerals should be adjusted with mineral level in wastewater. Drinking wastewater if used for poultry should be analysed periodically to ensure that ion concentration is not compromising poultry growth performance and health. More frequent analysis and bigger sample size are required to measure pollutants, pesticides and other ions to confirm the suitability of wastewater after reverse osmosis treatment as a drinking water for poultry. Finally, this study suggested that wastewater can be a suitable source as drinking water for more tolerant animals such as cattle, swine and fish. Using wastewater for agricultural purposes can save more of the drinking water for humans.

Disclosure statement
No potential conflict of interest was reported by the authors.

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