



INFLUENCE OF WATER QUALITY AND POLLUTION ON BROILER'S PERFORMANCE, VACCINE AND ANTIBIOTIC EFFICIENCIES – A REVIEW

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Abstract

Good water quality for livestock is critical for preserving animal health, ensuring the quality of animal products, supplying safe food, and increasing food production economics. Higher water levels of toxic compounds than permitted can impair meat, fat, eggs, and milk production, lower fertility, and represent public health hazards. Water picks up pollutants from its surroundings and those caused by animal and human activities. Many physicochemical parameters were used to ensure water quality, including pH, salt, taste, color, alkalinity, odor, and hardness. Water quality, directly and indirectly, impacts livestock performance and, thus, the poultry industry. Employing drinking water as a carrier of drugs still faces substantial barriers. The effectiveness of vaccinations and drugs is affected by inadequate water quality. Furthermore, contaminated water and poor nutrition negatively affect broiler chicken immunity, survival, and production. Antibiotics are widely utilized in poultry production to preserve animal health and growth. They can eliminate harmful bacteria in the gut, reduce the load on the immune system, optimize the digestive system, and boost growth performance. However, the abuse of antibiotics in animal agriculture has resulted in antibiotic-resistant infections threatening people and animals. As a result of its positive impact on the metabolome and gut microbiome, the natural antimicrobial combination could be used as an alternative; improving broiler chicken growth performance without negatively affecting the environment is currently paramount.

Key words: antibiotic, broiler performance, water pollution, water quality, water stabilizer, vaccine efficiency

Many developing countries have adopted the intensive poultry production system in the last few decades to meet the needs of their populations, which has made modern broilers less tolerant of stressors and resulted in a dynamic disease situation in which several new infectious diseases have emerged. As a result, the poultry sector has faced two major obstacles: infectious diseases prevention and control and the safety of poultry products. Various measures may be applied to control and prevent disease spread successfully. Some diseases can be controlled through vaccination, while others require proper biosecurity measures (Kpomasse et al., 2021). Every metabolic process in poultry involves water, which is crucial for digestion, controlling body temperature, and eliminating waste. Under typical conditions, poultry drink at least twice as much water as they feed, and water

use will double or even triple when heat stress is present (Ashworth et al., 2023; Hussien et al., 2023). Therefore, a secure and sufficient water supply is crucial for effective poultry production. Water has special chemical properties due to its polarity and hydrogen bonds, which allow it to dissolve, absorb, or suspend various compounds (Singh et al., 2023). As a result, water is not really clean because it picks up pollutants from its surroundings and those caused by animal and human activities (WHO, 2007 a).

Several physical-chemical factors may determine water quality, including taste, color, pH, hardness, odor, alkalinity, and salt. These factors can impact chickens' health and productivity (Halls 2008; Elsaidy et al., 2015). Since water quality may directly or indirectly impact performance, it should concern all poultry businesses. High-

er levels of hazardous or mineral-containing substances might harm physiological functions and subsequently subpar performance (Bejan et al., 2013). Many pharmaceutical therapies involve drinking water. The oral drug taken with drinking water has various benefits, including fast action, achieving effective doses at a low cost, and requiring little to no handling. However, due to water solubility and medication stability, there are substantial barriers to employing drinking water as a “carrier of drugs” (Scandurra, 2013). When water quality is inadequate, the effectiveness of vaccinations and drugs delivered through water lines may be affected (Fairchild and Ritz, 2006).

Furthermore, broiler chicken production and immune system are negatively affected by drinking water contaminants and poor nutrition, and long-term exposure to contaminants can harm immunity, behavior, reproduction, nutrition, and survival (Avigliano et al., 2015). Water quality control is crucial to ensuring broiler performance. Additionally, there is no one or simple way to assess water quality. Therefore, based on the circumstances, water may be tested for a few features or many natural chemicals and pollutants (Serrenho et al., 2012). This review article aimed to highlight the effects of water quality and pollution on growth performance and vaccine efficiency in broilers.

Poultry farm water sources

Drinking water comes from two main sources: surface water and groundwater. It was believed that groundwater was a great source because of the purification action of the soil (Odeyemi et al., 2011). The presence of high concentrations of certain compounds in borehole, rain, and pipe-borne fluids capable of inhibiting or lowering the absorption of nutrients from feedstuffs was the cause of the birds’ decreased body weight (Irandoost and Mohammadzadeh, 2017). However, groundwater contamination is a critical challenge since it is a very important resource for agricultural, poultry, animal production, and drinking water sources. Leachates from animal and human wastes and other chemical contaminants were among the biggest dangers to groundwater sources for drinking water. Several water sources are used as safe drinking water in poultry farms, including tap water, filter water, roof tank water, and groundwater (Elsaidy et al., 2015).

Chemical composition of broiler farm water

pH

Water pH might affect palatability and taste, as well as cause problems with regular absorption and digestion. Low pH reduces the performance and decreases shell quality while making water unpalatable and corroding metal components of the watering system (Mullen et al., 2011; Ravindran and Abdollahi, 2021). The pH range for well water is typically between 6.5 and 7.5. However, 16% of the 95 wells used to provide drinking water for poultry in southern North Carolina had acidic water with values lower than 6.0. They also emphasized how acidic

water might impair birds’ digestion, damage the watering apparatus, and interfere with medications and immunizations (Taiwo and Arowolo, 2017). Water pH is a crucial factor where the ideal pH range for drinking water is between 5 and 7, and if the pH falls below 5, less water will be consumed, which might result in parasitic infections. In contrast, the higher pH levels may imply potential salt contamination (such as sodium bicarbonate), which would lead to reduced absorption of dietary elements, including calcium, phosphorus, potassium, and magnesium (Vermeulen et al., 2002). Also, broilers that were given acidic drinking water performed better, but broilers given alkaline drinking water performed poorly (Veeramani et al., 2003).

Lower water pH was shown to reduce *Salmonellae* survival and growth in birds and water systems, according to Watkins et al. (2004). Moreover, broiler production favored a pH range of 6.0 to 6.8. It was also mentioned that birds could endure pH levels between 4 and 8 (Fairchild and Ritz, 2006). Although water pH has no direct impact on consumers and also no health-based standards have been established, it is nevertheless one of the most significant operational water quality indicators. The ideal pH was between 6.5 and 9.5 (WHO, 2007 b). Low pH values impair shell quality, corrode metal components of water systems, and impact broilers’ performance (Gerber et al., 2020). However, alkaline water with a pH above 7.5 might harm equipment, and one above 8.5 could cause mineral incrustation (Idrissa et al., 2020). According to Chanthirasekaran (2008), an alkaline pH promotes harmful microbes’ growth, multiplication, and development. The pH range considered acceptable for animal drinking water is 6 to 8.

Additionally, they stated that although pH is not chemical or particular contamination, it can affect water quality by influencing the efficiency of disinfectants like chlorine. Watkins (2008) mentioned that a pH of 5 or lower could corrode metal and birds were tolerant of pH values of 2 to 3 for short periods. Also, water outside the maximum allowed ranges for both high and low pH can significantly impact chicken performance. A pH between 6.2 and 6.8 seems to work well with chickens (Tabler et al., 2017).

Abd-El-Kader et al. (2009) noticed that the mean pH values in main water supplies were 7.32 ± 0.04 . Meanwhile, in the water of drinkers, the mean pH value was 7.16 ± 0.04 . They clarified nearly similar pH mean values for both ground and treated surface water, although variations in pH values were higher in drinkers than in main water supplies. Low pH values were due to the high content of humic acids and carbon dioxide saturation in the groundwater or water, which contains mineral acids (HCl, H_2SO_4 , and HNO_3). On the other hand, high pH may be caused by the presence of high levels of magnesium and calcium. It was revealed that the appropriate pH range is between 6.5 and 8.5 (Van Heugten, 2000; Scandurra, 2013). Using water samples from pig, chicken, and duckling farms, Makaroon et al. (2013) investigated the

chemical condition of livestock drinking water used in poultry farms in Thailand. Results showed that the median pH of underground water was 6.85, substantially lower than the median pH of surface water (7.23).

Interestingly, poultry preferred acidic water to alkaline water. They noted that potable water in Alabama might have a pH range of 6 to 9 based on their water systems, whereas the water pH in wells ranged from 5 to 6.5 (Tabler et al., 2017). Kamal (2015) assessed the water quality of ground and commercial tap water supplies in 82 Egyptian broiler farms, with pH values ranging from 6.1 to 8.9. The adverse effect of high and low pH on poultry production is illustrated in Figure 1.

TDS (Total Dissolved Solids)

The total dissolved solids (TDS) comprised inorganic salts (principally calcium, magnesium, potassium, sodium, bicarbonates, chlorides, and sulfates) and small amounts of organic matter dissolved in water. TDS in drinking water originates from natural sources, sewage, urban runoff, and industrial wastewater, and its concentrations in water vary considerably in different geological regions due to differences in mineral solubility. In addition, it was stated that high levels of TDS in drinking water might be objectionable to consumers (WHO, 2003 a). TDS levels over 3,000 mg/L can cause diarrhea, reduce economic performance, and raise chicken death rates (Sumano et al., 2004). TDS were not closely associated with poultry health concerns, but they might negatively impair equipment efficiency and water supply, influencing bird performance (Fairchild and Ritz, 2006; Ayoub et al., 2017).

Drinking water becomes considerably more unpleasant at TDS levels larger than 1000 mg/L (WHO, 2006).

The TDS levels in subsurface water varied from 240 to 1650 mg/L (Suresh and Kottureshwara, 2009). In the El-Ibrahimia canal, El-Wasta Center, Beni-Suef, Egypt, Melegy et al. (2014) found high TDS values surpassing 600 mg/L in raw surface water. In addition, the avian species exhibit lower water and food consumption due to high salinity, which affects body weight and fertility rates (Umar et al., 2014; Grossi et al., 2021).

Hardness

Water hardness is a measurement of the salts amount in the water, primarily divalent ions like magnesium, calcium, and/or iron. It is expressed as mg calcium carbonate (CaCO_3) per liter (ppm), which represents the total amount of divalent salts. There is no recommended level of magnesium in potable water for animals. However, a concentration of 6,000 mg/L was observed to inhibit development and trigger bone formation in immature chickens (Bleich et al., 2006). Both magnesium and calcium salts produce water hardness, which lowers the efficacy of detergents and soaps and disrupts the application of some drugs (Fairchild and Ritz, 2006; Manning et al., 2007). The highest concentration of minerals in water that is hard to extremely hard, with a hardness range of III and IV, respectively, owing to magnesium and calcium carbonate, chlorides, or sulfates, can cause precipitation in the water lines and impair the performance of the drinker's nipple (Lucke et al., 2017). The mean value of total hardness in main water supplies was 118 ± 6.27 mg/L, and 420.11 ± 31.39 CaCO_3 mg/L in drinker's water. This increase in the total hardness of drinkers was considered evidence of heavy contamination and drew attention to the need for frequent cleaning and disinfection (Abd-El-Kader et al., 2009).

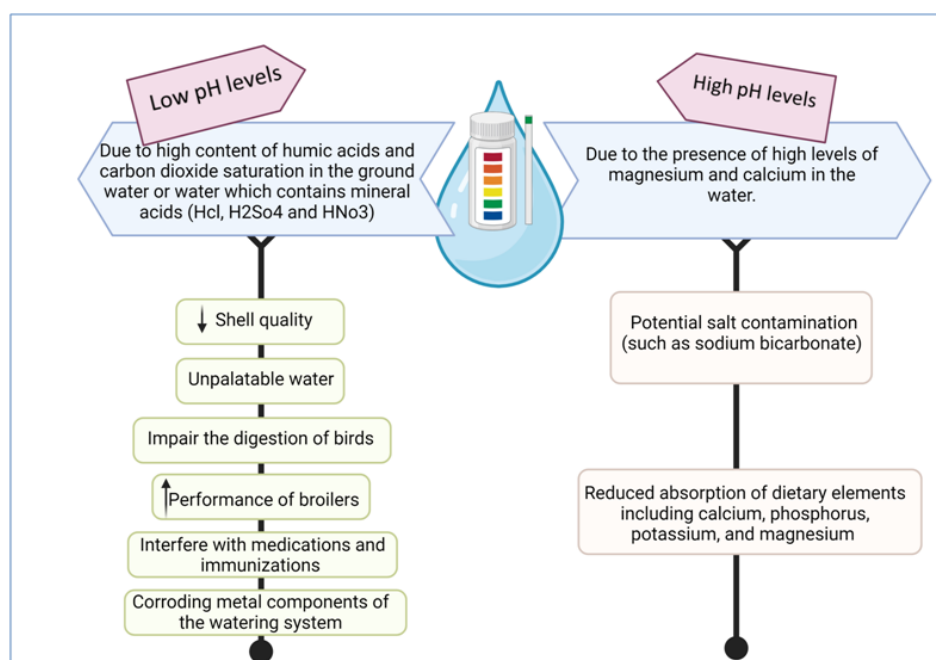


Figure 1. The adverse effect of high and low pH on poultry production

Moreover, the excessive mineral concentrations can cause salt to precipitate in watering equipment, which can impede water flow or, in rare cases, cause water lines to become entirely clogged. This might result in insufficient water availability and then water deprivation, negatively affecting the development rates of meat-type poultry and egg formation in laying chickens and increasing bird death and morbidity (Olkowski, 2009). In groundwater samples taken from livestock farms in Thailand, the median hardness level was 169.5 ppm, which was substantially higher than surface water. Hardness levels were also noticed to exceed the recommended drinking water limit in all samples because of the elevated amounts of manganese and iron (Makaroon et al., 2013). Hard water that contains iron (>3 mg/L) might plug drinking pipes and valves, as well as encourage the spread of bacteria (ROSS, 2018). When Kamal (2015) surveyed the water hardness in Egyptian broiler farms, he found a variation from 160 to 860 mg/L. The birds' performance metrics, such as the water/feed (W/F) ratio, dressing percentage, and performance index (PI), were shown to be negatively impacted by water hardness (800 ppm and 200 ppm) when compared to control groups. In addition, he observed that drinking water consumption rose at higher hardness levels (1.92 W/F ratios) than at lower levels (1.98 W/F ratios).

Chlorides

Abd El Hamid (1995) noted that while 93.1% of tap water samples were within the limit, where it varied from 29 to 299 mg/L for tap water samples, only 76.92% of the studied groundwater samples in Kalyobia Governorate, Egypt was below the allowed level of WHO (200 mg/L) for chloride. Broilers were shown to be negatively affected by chloride concentrations as high as 25 mg/L, while salinity levels were within the usual range. The chloride level of 14 mg/L was regarded as typical for well water; however, absorbing too much chloride negatively impacted metabolism (Carter and Sneed, 1996). The average and standard deviation of chloride in poultry drinking water in the Western Cape was 326.9 ± 1813 mg/L, with a low value of 87 mg/L and a high of 703.5 mg/L. It was shown that excessive chloride levels could lead to metabolic disturbances (Coetzee et al., 2000). High chloride levels increase water intake, reduce feed consumption, and have a digestive impact (Ayoub et al., 2017).

Furthermore, the chlorides in potable water may come from sewage, industrial effluents, or natural sources. Additionally, it was noted that high chloride levels accelerated the deterioration of metals in the distribution network. This process is influenced by water alkalinity, which might raise metal contents in the supply. Also, it was shown that chloride concentrations greater than 250 mg/L might cause a noticeable taste in water (WHO, 2003 b).

When producers in some areas of southern Arkansas complained of issues like poor feed conversion and weight gain, wet litter, weak droppings, and footpad-related problems, it was determined that the drinking water contained high levels of chlorides and sodium, ranging

from 268–470 and 367–450 mg/L, respectively. These issues were thought to be related to the excessive consumption of chlorides and sodium (Watkins et al., 2005). When Atta et al. (2007) examined the well water quality, they discovered that the average chloride concentration was 1.015 mg/L (178 to 2,840 mg/L). While, a reduction in the water/feed consumption ratio was observed in broilers due to the high chloride content in water (Abbas et al., 2008). Abd-El-Kader et al. (2009) estimated the mean value of chlorides in main water supplies and water of drinkers was 113.35 ± 8.22 mg/L and 193.1 ± 10.22 mg/L, respectively, where the increase in chloride levels of drinker's water was considered indication on water pollution by birds' droppings and feed particles.

According to Schlenker et al. (2010), broiler chicken feed consumption can decrease when chloride levels in water surpass 1000 mg/L. However, values underneath this level did not create any issues. When Taiwo et al. (2011) studied samples of underground water in Nigeria, they found that the chloride contents varied from 18 to 158 mg/L, below the WHO limit of 250 mg/L for drinking water. Water that contains more chloride than 250–500 ppm may taste bad to humans and undesirable to animals. It may also be contaminated since it frequently coexists with organic debris of animal origin. Besides, the excessive chloride levels are kidney-damaging for bird species (Van Heugten, 2000; Scandurra, 2013). Chloride concentrations above 250 mg/L were most likely to cause a salty taste or metal corrosion (Swistock and Clark, 2012). Also, the chloride concentration varied from 43 to 430 mg/L in the water used for broiler farms. In his experimental trial, the author recorded that high and low chloride-treated experimental groups (500 and 150 mg/L) recorded the lowest values of W/F ratio, dressing percentage, and PI as compared to control groups, which indicated the negative effect of chloride on birds' performance parameters (Kamal, 2015). The adverse effect of chloride on poultry production is illustrated in Figure 2.

Ammonia

The ammonia levels in the water samples taken from chicken farms in the Kalyobia Governorate were higher than the allowable limit (0.5 mg/L), ranging from 0.98 to 9.04 mg/L in groundwater and 0.92 to 5.26 mg/L in tap water samples (Abd El Hamid, 1995). The concentration of ammonia in unpolluted surface or groundwater is often less than 0.1 mg/L and depends mostly on pH and temperature (Kotb and Ahmed, 2019). Ammonia ions were found to be extremely low in groundwater, ranging from 0.02 to 0.1 mg/L on average (Atta et al., 2007). The high ammonia concentrations in groundwater are mostly seen in areas with extensive agricultural activity, fertilizer runoff, and septic tanks that discharge into the groundwater through the soil (Liu et al., 2020). The main water supply studied by Abd El-Kader et al. (2009) had an average ammonia level of 0.14 ± 0.02 mg/L. On the other hand, it was observed that the ammonia content in the water consumed by broiler farm workers (0.85–0.11 mg/L) was greater than that consumed by layer farm workers (0.46–0.08 mg/L).

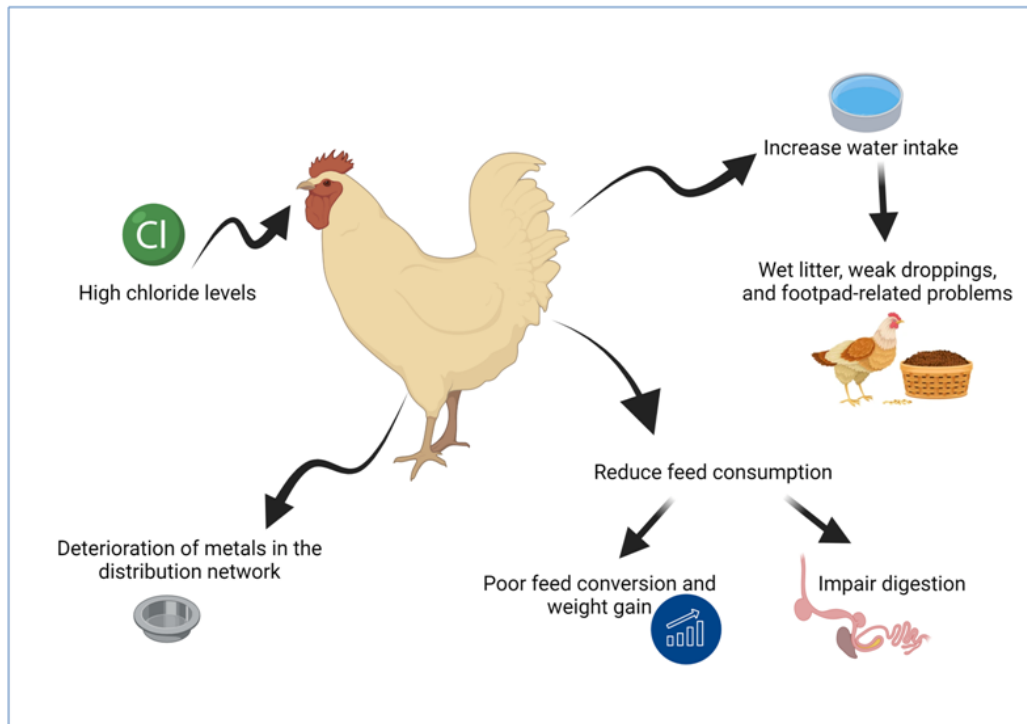


Figure 2. The adverse effect of chloride on poultry production

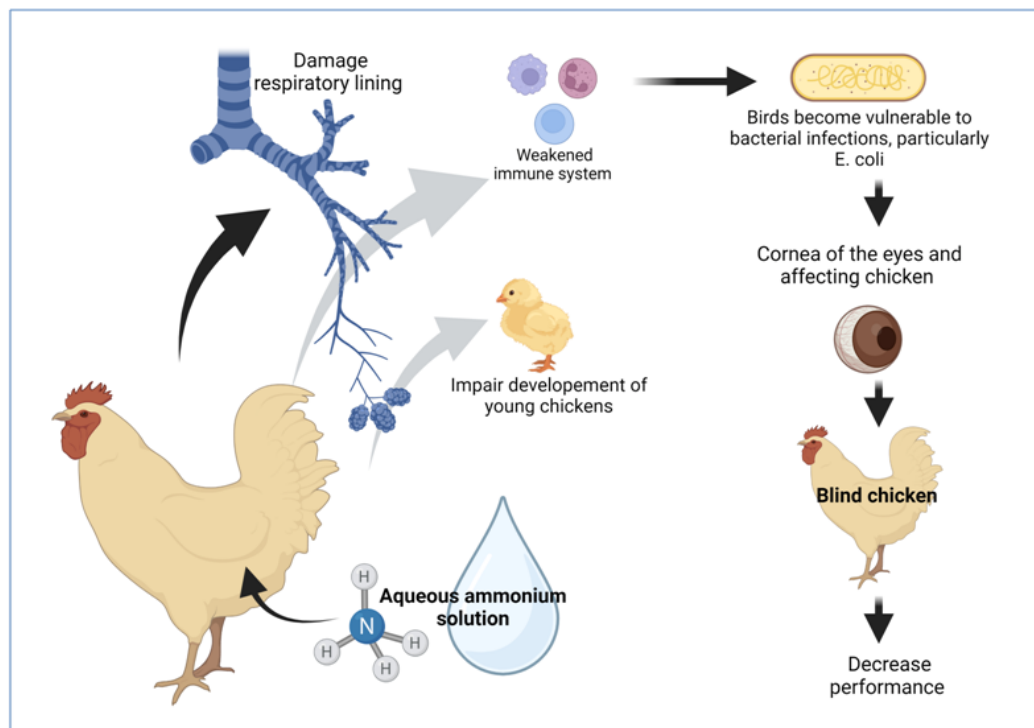


Figure 3. The adverse effect of high levels of ammonia on poultry health

The damaged chicken's respiratory lining was eroded by the resulting aqueous ammonium solution, which also weakened the animal's immune system and left it vulnerable to bacterial infections, particularly *E. coli*. As well as harming the cornea of the eyes and affecting chicken

eyes, excessive ammonia concentrations harmed poultry development, especially in young birds (Hofmann et al., 2020). In samples taken from hand-dug wells in the peri-urban region of Obantoko, Nigeria, ammonia (in the form of ammonium nitrate) was found in concentrations

ranging from 0.00 to 0.59 mg/L (Mohammed, 2014; Liu et al., 2020). In addition, birds are particularly sensitive to ammonia levels, and long-term exposure to high quantities of ammonia can make chickens blind. As a result, their performance suffered (Bobinienė et al., 2014).

The maximum mean value of ammonia was in surface water and then in tap water. However, the lowest mean values of ammonia recorded in underground water samples from Beni-Suef, Egypt, were attributed to fecal contamination, as well as the excessive use of nitrogen fertilizer (urea, ammonia, and nitrate) in the agricultural lands where the mean values of turbidity, ammonia, alkalinity, nitrate, and nitrite of surface water at values of 6.2 ± 1.0 NTU, 0.5 ± 0.18 mg/L, 301.7 ± 0 mg/L, 9.0 ± 1.7 mg/L, and 1.3 ± 1.3 mg/L, respectively (Mohammed, 2014). Kamal (2015) states that the detected ammonia levels varied from 0.01 to 15 mg/L. He observed that the performance metrics of experimental chicks exposed to high and low amounts of ammonia (15 mg/L and 5 mg/L) were decreased. At the same time, findings revealed lower values of dressing % and the greatest value of the W/F ratio. The adverse effect of high ammonia levels on poultry health is illustrated in Figure 3.

Nitrites

According to Salem et al. (2001), 64.1% of the water samples from Assiut, Egypt, that were examined had nitrite concentrations that were higher than the WHO-recommended limit of 0.01 mg/L. When Abd El Hamid (1995) conducted a survey on the water quality in poultry farms in Kalyobia, Egypt, he discovered that all of the samples' nitrite levels were higher than the permissible level for poultry water supply (zero mg/L), ranging from 0.14 to 1.16 mg/L for groundwater sources and 0.13 to 0.98 mg/L for tap water (Mortada and Shokeir, 2018). Since nitrate was the most stable oxidation state, Carter and Sneed (1996) claimed that nitrite was formed during intermediate stages of the breakdown of organic molecules, where it was not often present in substantial proportions other than in a reducing environment. *Nitrosomonas* bacteria might chemically produce nitrite in distribution pipes when nitrate-containing and oxygen-poor drinking water stagnates in galvanized steel pipes or if chlorination is utilized to provide a residual disinfectant (Ajayi et al., 2002; Zendehbad et al., 2022). The appropriate amounts of nitrites in water for livestock should be 10 mg/L nitrites (3.0 mg/L as nitrite-N) following current Canadian standards for livestock drinking water (Ajayi et al., 2002). While the nitrite levels in drinking water often fall below a few mg/L in most nations (WHO, 2007 c).

In drinking water, the mean nitrite concentration was 0.12 ± 0.01 mg/L, compared to 0.03 ± 0.005 mg/L in main water sources (Abd-El-Kader et al., 2009). The mean nitrite level in drinkers of broiler birds was greater than that in drinkers of layer birds, which might be explained by the increased motility and feeding behaviors of broiler birds and the ensuing continual contamination of drinkers' water (Abd-El-Kader et al., 2009). The amounts of nitrites

in groundwater from various livestock farms were up to 0.13 mg/L, making it clear that there was no issue with the nitrite content in groundwater utilized for animal production and consumption (Stefanova et al., 2012; Mortada and Shokeir, 2018). In water samples from broiler farms, nitrite concentrations ranged from 0 to 15 mg/L, whereas nitrate concentrations ranged between 1 and 30 mg/L. At the same time, reducing the W/F ratio, dressing percentage, and PI in nitrite groups, revealed evidence of the negative effects of nitrite in water on bird performance indicators (Kamal, 2015; Zendehbad et al., 2022).

Phosphates

Phosphate concentration varied from 8 to 6.22 mg/L for groundwater samples. In contrast, tap water samples ranged from 38 to 5.59 mg/L in the Kalyobia Governorate survey on poultry farms' drinking water quality (Abd El Hamid, 1995). Besides, phosphorus was naturally present in groundwater or may be added as part of corrosion control treatment, where it was found in a wide range at 0.1 µg/L and 300 µg/L in low and high levels, respectively (Geldreich, 2020). The high phosphate levels in the water indicate sewage contamination (Ayoub et al., 2017). It was recommended that 10 mg/L be the standard phosphate value in drinking water (WHO, 2003 c).

Phosphates combined with bacterial pollution rendered the water unfit for human consumption. Phosphates may be utilized as chemical fertilizers or organic manures (Ayoub et al., 2017). Also, he recommended that the MAL for phosphorus be 5000 µg/L. On the other hand, phosphate is harmful to people and animals at very high concentrations, which can lead to stomach disturbances (D'Amelio, 2007). In well water samples taken from Obantoko, Nigeria, Taiwo et al. (2011) found that the phosphate levels ranged from 12 to 86 g/L. Kamal (2015) stated phosphate concentrations varied from 0.5 to 16 mg/L. Furthermore, he found that water phosphate concentrations of 15 mg/L and 2 mg/L harmed the performance ratings of birds.

Sulfates

According to Coetzee et al. (2000), the Western Cape survey's minimum and maximum sulfate levels were 4.9 mg/L and 87.00 mg/L, respectively, with a mean SD of 27.3 ± 25.4 mg/L. This indicates that excessive sulfate levels can have a laxative impact on chickens and lower egg production. Mullen et al. (2011) attributed the development of scale in the watering system to high concentrations of or combinations of sulfate, calcium, or magnesium because high concentrations of magnesium and sulfate resulted in the formation of Epsom salt, which in turn caused scale formation and restricted water flow. In addition, sulfate was released into the water by atmospheric deposition and industrial by-products. However, the highest concentrations are typically found in groundwater and come from natural origins. Additionally, it was shown that sulfates, when present in drinking water at levels over 250 mg/L, induce corrosion of distribution

networks and have a laxative impact on people at concentrations of 1000–1200 mg/L (WHO, 2003 d).

Sulfate levels in well water samples ranged from 192 to 1,416 mg/L, with an average of 824 mg/L (Atta et al., 2007). Due to loose droppings, moderate amounts of sulfate can result in moist litter and unclean eggs, but the levels must be exceedingly high to harm growth rate and egg production. To prevent problems with sulfate in drinking water, effective barn ventilation is required to keep the manure and litters dry (Halls, 2008). Abdel-Kader et al. (2009) recorded the mean value of sulfate in main water supplies and the water of drinkers as 98.1 ± 14.36 mg/L and 200.58 ± 31.88 mg/L, respectively, where it was anticipated that there would be an excess of sulfate in drinkers' water due to bird droppings and feed-related pollution. At the same time, the concentrations of sulfate ranged between 5.0 and 340 mg/L for samples collected from Obantoko, Nigeria (Taiwo et al., 2011).

Chickens exposed to various doses of sulfate in the form of copper sulfate exhibited various clinical symptoms, such as enteritis with a higher frequency of coccidiosis infection, poor feather growth, and loose feces (Iqbal et al., 2012). Sulfates, which were dissolved from the bedrock or brought on by neighboring coal mining, may be the reason for the bitter, scaly deposits and medicinal taste in the water; laxative effects on livestock (Swistock and Clark, 2012; Idrissa et al., 2020). The highest suitable amount of water sulfates was recorded as 200:250 ppm according to ROSS (2018), who stated that sulfate water content at 50–200 ppm was satisfactory but could have a laxative impact if Mg or Na were greater than 50 ppm. It was discovered that water sulfates at concentrations of 500–1000 ppm might interfere with copper absorption and have a laxative effect. However, birds may adapt, whereas water with sulfates at concentrations greater than 1000 ppm endangers the health of chicks by raising water consumption and wet dropping. Water with a high sulfate level had a sulfurous odor, while water containing iron or manganese sulfates tasted bitter (Tabler et al., 2017). Kamal (2015) recorded that sulfate levels varied from 1 to 600 mg/L for water samples collected from broiler farms. Moreover, he found that high and low sulfate (600 mg/L and 200 mg/L) treated groups recorded the lowest values of W/F ratio, dressing %, and PI.

Iron

Broiler performance has not been demonstrated to be negatively impacted by high iron levels up to 25 mg/L, though drinkers were stained at considerably lower levels (Carter and Sneed, 1996). High iron concentrations promote the development of bacteria that might cause diarrhea (Ayoub et al., 2017). Iron content has been found to reduce water consumption via a negative feedback loop on the brain's appetite region. In addition, elevated iron levels may promote the development of bacteria, which can cause diarrhea in chickens. Additionally, they discovered that the ferrous form of iron found in well water changes to ferric hydroxide, also known as rusty water,

when exposed to air (Pajarillo et al., 2021). Water samples from Upper Egypt had iron concentrations that were less than the U.S. EPA's maximum permitted contaminant value of 0.3 mg/L (Salem et al., 2001). Water for poultry should have 0.3 ppm of iron.

Systems with high iron levels may enhance the formation of microbial films in water lines (Bhardwaj et al., 2021). Iron was found to be a secondary or aesthetic contaminant but was not determined to be harmful to health (Nartey et al., 2009). Furthermore, increased iron concentrations in poultry drinking water posed no direct health risks (Fairchild and Ritz, 2006). Fairchild et al. (2006) investigated the effects of elevated iron content on the performance of Cobb male broilers and discovered that there was no difference in water and feed consumption, body weight, or mortality rate in any of the trials at different levels of iron (0, 2, 20, 200, 400, and 600 ppm $\text{FeSO}_4 \cdot 7\text{H}_2\text{O}$ supplement). They concluded that increasing the iron content of the water did not affect broiler performance.

Olkowski (2009) observed that groundwater contained a higher iron level than surface water. Iron dissolved from mining or bedrock can result in brown, reddish, or orange streaks or silt, as well as metallic-tasting water (Swistock and Clark, 2012; Idrissa et al., 2020). Makaroon et al. (2013) investigated the drinking water quality in several Thai animal farms. They discovered that iron levels in surface water surpassed drinking water standards and were substantially higher than in groundwater sources. Haggag et al. (2016) assessed the prevalence of iron in the water quality of chicken farms in two Egyptian provinces, Behera and Kafr El-Sheikh. The results for 36.37%, 55.17%, and 29.63% of the ground, surface, and tap water samples examined were not following WHO-recommended levels.

Manganese

Manganese is essential for proper immunological activities in broiler chickens (Kidd, 2004). According to Salem et al. (2001), more than 0.05 mg/l of manganese was present in 58.97% of the water samples taken from Assiut, Egypt. Excessive manganese levels have been linked to water flavor issues (Carter and Sneed, 1996; Sun et al., 2021). Coetzee et al. (2000) discovered that manganese levels in poultry drinking water in the Western Cape survey ranged from 27.15 g/L to 2204.7 g/L. They linked its excess to hardness, turbidity, bitterness, and deposits in pipes. Manganese chloride in drinking water may impact reproduction or fertility (Elbetieha et al., 2001). Salem et al. (2001) reported that manganese levels in all water sources were between the highest acceptable level (0.05 mg/L) and the WHO maximum permissible level (0.5 mg/L); however, 30% of samples surpassed the WHO MCL.

Organic manganese (30 mg/kg) supplementation to broiler hen diets boosted hatchability and fertility while decreasing embryo death in comparison to inorganic manganese (100 mg/kg) (Lyons and Jacques, 2003). The

Chao Phraya River in Thailand has 0.13 ± 0.01 ppm of manganese and 11.60 ppm of iron, whereas the ground-water surrounding the river has 0.062 ± 0.007 ppm and 0.035 ± 0.035 ppm of manganese and iron, respectively (Kruawal et al., 2005). Interestingly, manganese exposure was linked to decreased sperm density and motility (Wirth et al., 2007). Manganese can be found as dissolved or suspended particles in natural surface waters; however, it is more frequent in groundwater than in surface water sources due to the reduced circumstances that occur underground. Water is just a minor component of total manganese intake. Furthermore, the Canadian aesthetic guideline of 0.05 mg/L for distribution networks was based on probable difficulties in limited flow devices in water lines rather than toxicity incidence (Olkowski, 2009). However, there are no Canadian criteria for manganese in livestock.

Noticeably, manganese concentrations are positively associated with the quantity of iron in the groundwater in Scotland (Homoncik et al., 2010; Sun et al., 2021). Manganese levels greater than the SMCL of 0.05 mg/L will result in black flecks or stains, metallic-tasting water, and standing water that appears gray or black (Swistock and Clark, 2012). When Makaroon et al. (2013) investigated the quality of drinking water used on various livestock farms in Thailand, they discovered that surface water had manganese amounts that were higher than the recommended limits for personal usage and substantially higher than groundwater sources at levels of 0.183 ppm. Additionally, they stated that although manganese and iron do not directly influence an animal's health when present in water resources in concentrations above 0.05 and 0.3 ppm, they can alter the water's color and flavor and deter animals from drinking it, especially young piglets. Additionally, the silt development at manganese concentrations greater than 0.02 ppm can plug pipelines. Iron levels in the water were assessed in Behera and Kafr El-Sheikh, Egypt (Haggag et al., 2016). Most of the water samples were found unfit because their manganese content was higher than the allowed limit (0.05 mg/L), and the highest manganese level ever recorded was 99 mg/L (Haggag et al., 2016).

Effects of polluted water on broiler performance

When broilers were given 5.25% sodium hypochlorite (NaClO) solution as a source of chloride in water, water intake was decreased at a chloride level of 100 ppm and body weight was similarly reduced at a level of 300 ppm (Damron and Flunker, 1993). The effects of TDS in water on broiler chicken performance were investigated, wherein birds were divided into six groups with three replications per group depending on the water's TDS concentration, which was less than 1000, 1000–2000, 2000–3000, 3000–4000, 4000–5000, and more than 5000 ppm (Pourreza et al., 2000). Water demand and bedding moisture were highly and positively correlated with TDS at $r = +0.74$ and $+0.65$, respectively. It was discovered that water with various TDS contents had the most harm-

ful impact on the mortality rate in the growing cycle, with up to 56.2% mortality recorded at the maximum TDS content. The highest level of the TDS group and the control group of chickens had significantly different body weights, and the effects of the various TDS concentrations on body weight and feed intake were similar (Pourreza et al., 2000).

According to Borges et al. (2003), broiler chicks' higher consumption of saline water to maintain plasma osmotic balance also increased the digesta's passage rate, which decreased the digestibility and nutrient absorption for growth. Rind et al. (2003) studied the impact of the hardness of two groundwater sources on the production of broiler chickens was assessed using two equal groups of birds; group A reared at the poultry experiment station at Tandojam and group B was reared at a private poultry farm at Mubashir farm at Rahuki and both groups had similar management conditions. While feed consumption was significantly higher in group B (11.711 and 5.33) than in group A (11.587 and 5.083 l/kg per broiler), it was discovered that water intake was not significantly different between the two groups. Furthermore, group A's mean live body weight (224) increased much more than group B's (1.851) kg b⁻¹, which improved live body weight/weight gain and dressed carcass recovery. Besides, water hardness indirectly impacted the performance by reducing the efficacy of enrofloxacin treatment in broilers (Sumano et al., 2004). Cornelison et al. (2005) found that water acidification, which became very popular in broiler production as a tool for improving bird performance, did not affect the performance of broilers. On the other hand, Fairchild et al. (2006) revealed that increased sulfate levels or decreased water pH did not affect broiler performance. While the increasing chloride intake linearly increases litter moisture and consequently decreases dressing and organs weights (Mushtaq et al., 2007).

According to Berghaus and Stewart-Brown (2013), water pH significantly impacts how much drinking water birds take. The effectiveness of antimicrobial drugs and antiseptics, vaccines, mineral accumulation in water lines, and mineral transfer to the gut are all impacted by the many chemicals used to adjust water pH. Additionally, he demonstrated that birds could tolerate a consistent pH range of 4 to 8 and advised that poultry water be kept between a pH of 6 and 6.5. Using drinking water from natural sources, Ahmed (2013) evaluated the effects of various TDS levels (265, 2610, 3154, and 3448 ppm) on the performance metrics in broilers under hot, arid conditions. According to the author, body weight gain and feed efficiency were only adversely impacted at the highest TDS level (3448 ppm), while the maximum weight gain was seen at a TDS level of 2610 ppm. However, water intake improved substantially as TDS levels rose. In contrast to the impacts of levels of 3154 and 3448 ppm, it was found that 265 and 2610 ppm of TDS in drinking water had no bad impacts on broiler performance. Additionally, it was claimed that a TDS level of 2610 ppm had

a better impact on broiler efficiency regarding weight gain than a TDS level of 265 ppm (Ahmed, 2013; Mostashari-Mohases et al., 2017).

Ibitoye et al. (2013) described how different drinking water sources affected broiler chicken performance, carcass characteristics, and hematology in Sokoto, North-West Nigeria. The birds were divided into three treatments: T1 drinking pipe-borne water, T2 getting water from a borehole, and T3 getting water from a well, from day-old to seven-week-old age. In physicochemical analyses, it was found that only well water had a fair taste and the highest turbidity level. In contrast, borehole water was the least turbid and had the highest total hardness. Nitrate, sodium, and calcium were higher in well water, while magnesium was absent in pipe-borne water.

Furthermore, it was discovered that water treatments had no discernible impact on broilers' performance, carcass features, or hematological indices (Mohamed et al., 2020). Nonetheless, birds kept on borehole water showed a significant improvement in feed intake and weight growth. These histological changes were consistent with several detected parameter biochemical abnormalities. In broilers that were given well water, Bowman's capsule had significant concentrations of cadmium, chromium, zinc, lead, manganese, mercury, and nickel (Karantika et al., 2016; Dobrzański et al., 2017). Lead poisoning negatively impacts broiler chicks' body weight and weight increase (Idrissa et al., 2020).

Additionally, Abdou et al. (2018) discovered that chemical contaminants from drinking water in chicken farms are partially preserved in muscles, kidneys, and liver, which then spread via the white meats to customers and negatively impact their health. Some water impurities, such as lead nitrate, ammonium chloride, microbial contaminants (*E. coli* O157: H7), and magnesium sulfate, have been shown to cause physiological disruptions such as reduced performance traits, decreased immunoglobulin concentrations, altered biochemical profiles, and irregular cell architecture when present in broiler microclimates at levels above the allowable limits. After the extreme challenge circumstances were lifted, certain contaminants were able to stimulate development (Mohamed et al., 2020).

Elsaidy et al. (2015) investigated how different water sources (farm tap water, filtered tap water, stored water at farm roof tanks, and groundwater) used as drinking water in Egypt affected broiler chicken performance, hematological responses, and carcass characteristics. They discovered no discernible variations between the treated groups in most performance metrics and carcass traits. Additionally, the filtered tap water treatment displayed higher values for body weight, body weight gain, and feed conversion ratio but lower values regarding water intake, liver weight, feed/water intake ratio, as well as serum uric acid, creatinine, glutamic oxaloacetic transaminase, and glutamic pyruvic transaminase.

In addition, in Owerri, South Eastern Nigeria, broiler birds were separated into four treatments, according

to Etuk and Ukomadu (2019) evaluation of the performance and carcass metrics. For eight weeks, treatments involved four different types of water: rainwater, water from a borehole, water from a pipe, and river water. To determine how the various treatments affected weight increase, it was discovered that there were significant changes in the birds' water intake. While river water recorded the greatest final body weight and total body weight gain values compared to birds receiving other similar treatments, thus river water was significantly different from the other treatments.

Interaction between water quality and vaccine efficiency

When broilers were given water with extremely low $\text{NO}_3\text{-N}$ and pH, Grizzle et al. (1996) noticed that the weights of the liver, thymus, and spleen were reduced as water nitrogen raised and water pH lowered. This was contrary to what was expected to happen when organ weights decreased, indicating that immune resistance decreased. When providing experimental drinking water containing a mixture of cadmium, arsenic, and lead to birds with diets that included feed with 50% additional vitamins and minerals and feed without added vitamins and minerals. A natural, humoral, and cell-mediated immune response was found to be suppressed by rising drinking water pollutants when there were insufficient amounts of vitamins and minerals in the diet.

According to Bartlett and Smith (2003), phosphorus content and water hardness can both affect Zn absorption, which is necessary for animals to have healthy immune systems. Cellular and humoral immunity would decline as a result of the Zn shortage. In addition, ammonia harms the respiratory system of chicks. It also reduced the primary and secondary weight of lymphoid organs, spleen, and bursa of Fabricius (Carey et al., 2004).

Moreover, manganese is important for maintaining immunological systems in broiler chickens (Kidd, 2004). Interestingly, the broilers' and breeders' ability to absorb nutritional levels of zinc, manganese, copper, and selenium are linked to immunological responses from high levels of calcium or phosphorus in water (Park et al., 2004). An acid-base imbalance might prevent the occurrence of particular immunity in places with access to heavily salinized water (Siddique et al., 2005; Manzoor et al., 2013). Additionally, chlorinated water was harmful to vaccines and could significantly decrease the vaccine virus given to birds, reducing the vaccine's effectiveness. Fairchild et al. (2006) mentioned that elevated sulfate levels or decreased water pH did not affect serum protein synthesis in broiler chickens.

In turn, turbid water significantly reduces immune response through many phases of inflammation and cell-mediated immunity processes (Mohammed, 2008; Chen et al., 2018). Vaccines should be re-suspended in freshwater resources with a pH near neutral, medium hardness, and no chlorine or other disinfectant residues (Alvarado, 2008; Ahmad, 2022). Poor water quality for

dilution and delivery of live vaccines might negatively affect vaccine titers. AL-Mayah et al. (2009) employed live lentogenic strains, including the Hitchner B1 and LaSota strains, to study the effects of various diluents used during drinking water vaccination on the Newcastle disease (ND) vaccine. Birds were split into five categories as follows: A) received vaccinations mixed with distilled water, B) received vaccinations mixed with reverse osmosis (RO) water, C) received vaccinations mixed with tap water, D) tap water plus powdered skim milk (PSM) as a diluent for vaccines, and E) served as the negative control. The results of the HI test recorded that the mean $\pm$ SE for groups was 6 ± 0.25 , 5 ± 0.33 , 2 ± 0.33 , 6.5 ± 0.16 , and 0.0 ± 0.00 receptively. The findings also demonstrated that, compared to chicks vaccinated with ND vaccines made in tap water only, distilled water, tap water + PSM, and RO drinking water, ND vaccine-vaccinated chickens displayed a high HI titer. The study showed the significant benefit of RO as a diluent in drinking water vaccination of hens versus Newcastle disease even without the inclusion of PSM since tap water might suppress the vaccine owing to its impurity and also contain greater levels of chlorine than RO (5 mg/L).

According to Dorr et al. (2009 a), cleaning medications and waterlines in between treatments is crucial, and avoiding mixing therapeutic compounds can result in residue-forming reactions. They also viewed the buildup of residues or metabolic by-products throughout the delivery system as a potential health danger to the pigs because it may decrease the efficiency of oral altered live vaccines given through the water.

The effectiveness of the ND vaccination in hens in Sudan was examined by Khalil and Khalafalla (2011) concerning the water sources used as diluents. Their findings showed that the chicks' immune system was notably greater in birds that acquired the LaSota vaccine diluted in plastic bottles with a mean of 5.70 ($\log_2$), where the antibody amount began to increase from the first post vaccination week. It peaked at the third week, and then it declined slightly, but at a protective level at week four that is more than 3 $\log_2$, the protective level for the ND vaccine. The second-best group had a mean of 4.85, indicating a substantially weaker immune response to chlorine usage than the first group. They were immunized using tap water as a diluent. The lower immunological responses (4.0, 3.99, and 3.36 geomeans, respectively) from shallow wells, artesian wells, and surface water were likely caused by their higher TDS and turbidity levels. Accordingly, bottled water was preferred over tap water, shallow well water was preferred over artesian well water, and surface water came in last. It was also shown that using Sudanese tap water to dilute the ND vaccination had no negative effects on the immune response. The optimum water for the dilution of vaccines also had low turbidity and TDS (Khalil and Khalafalla, 2011; Ahmad, 2022).

According to research by Morsy et al. (2012), providing White Leghorn chickens with salty water (6000 and 4000 ppm TDS groups) significantly reduced globulin by

60.53 and 53.67%, total protein by 43.75 and 38.35%, and cholesterol concentrations by 25.41 and 252% as compared to those in the control group (using tap water containing 274 ppm TDS). Additionally, they found that when compared to the hens in the control group, those who drank salty water with 6000 ppm TDS had an increase in creatinine concentrations and alanine transaminase (ALT) of 130.0 and 23.68%, respectively. This increase in creatinine and ALT concentrations may indicate liver dysfunction, and the decrease in plasma albumin following SW consumption supported this theory. Moreover, plasma total protein and albumin levels significantly increased in the chicken groups that consumed the most TDS (3154 and 3448 ppm) compared to the other groups (265 and 2610 ppm), and the TDS level in the drinking water also significantly increased the H/L ratio. Additionally, it was shown that at ages 21 and 28, the chicks that drank water with TDS of 2610 and 265 ppm had much greater ND antibody titers than the other two groups. In contrast, at ages 28 and 35, the group who drank water with a TDS of 265 ppm had significantly lower ND antibody titers (Ahmed, 2013).

Notably, chickens that drank filtered tap water had better bursa weight, serum total protein, globulin (G), albumin (A), A/G ratio, and Ab titers against ND virus vaccine results than chickens in other groups that drank farm tap water, farm water that was stored in rooftop tanks, or chickens that had access to groundwater (Elsaidy et al., 2015). Additionally, there were substantial changes for the majority of performance and immunological metrics, with body weight, body weight increase, feed conversion ratio, and antibody response to the ND and AI (H9) virus vaccination demonstrating a much greater response (Hussein et al., 2022).

Kamal (2015) examined the effects of different levels of water chemicals (COD, hardness, chloride, ammonia, nitrite, sulfate, and phosphate) on the humeral immune response against IB and ND vaccines. ND vaccine results showed that the antibodies titer was decreased at 14 days in all treated groups compared to control groups, indicating the negative effect of previous water treatments on antibodies titer post vaccines and residual maternal antibodies. The highest antibody titer was produced using phosphate buffer saline (PBS) (6.33). When birds received a booster dose of ND vaccine (Clone 30) on the 17th day in drinking water followed by another booster dose of ND vaccine (Clone 30) on the 27th day, antibodies were gradually increased till they reached a peak at the 5th week with a significant decrease between treated water groups versus control groups.

Effect of the addition of water stabilizer on improving water quality

Abd El Hamid (1995) studied the effect of drinking water quality (as a vaccinal diluent) on the humoral immune response of broilers to ND and Gumboro vaccines in poultry in Kalyobia Governorate. Regarding the Newcastle disease vaccine, he found that the highest mean

of HI antibody response was recorded in the group that received the vaccine diluted in distilled water with 1% skim milk, followed by the groups of distilled water and groundwater with milk. In contrast, the group that received the vaccine diluted in tap water recorded the lowest response. Besides, the reducing agents, such as sodium thiosulfate, sodium metabisulfite, sodium bisulfite, or ammonium thiosulfate can be used as water stabilizers to neutralize pollutants or oxidizing sanitizers found in farm water (Vertova et al., 2019).

Bovine serum albumin, glycerol, maltose, sucrose, sorbitol, and lactose, are among the most popular water and vaccine stabilizers that serve as thermal-stability-granting substances, according to Barbour et al. (2002). In addition, chickens that received the ND vaccine after being mixed with tap water and powdered skim milk (PSM) had the greatest HI titer (6.5 0.16) among all groups, showing that the use of PSM at a value of 1:400 w/v prevented the negative impact of using tap water alone as a diluent for the vaccine (Al-Mayah et al., 2009). Modern commercial stabilizers are an easy, affordable alternative to milk with a longer shelf life than skim milk (Bernardi and Johnson, 2011). Also, Frame et al. (2022) recommended using water stabilizers which contain a natural reducing agent, a buffer, and a coloring agent or dye. While it was recommended to add vaccine stabilizers to neutralize the chlorine in the water before reconstituting live vaccines in this water as chlorine can either inactivate the vaccine or reduce vaccine titer so decreasing vaccine efficiency (ROSS, 2018). Moreover, the chicks that received PBS in water at the time of vaccination recorded the highest antibody titer compared to other groups, as described by Kamal (2015) and Frame et al. (2022).

Relationship between antibiotic effectiveness and water quality

Water quality must be considered to maximize the benefits of most antibacterial medications (Ledesma et al., 2018). In addition, certain antimicrobials, such as tetracyclines, are most stable and soluble in water with a low pH (3–5). Also, the water temperature was considered a significant factor impacting medication solubility and stability, particularly for poorly soluble medicines (Vermeulen et al., 2002). Sumano et al. (2004) investigated enrofloxacin bioavailability in broilers under different hard water levels (very hard water at 195 ppm; hard water at 175 ppm; moderately hard water at 120 ppm; low hard water at 35 ppm and sweet water at 16.5 ppm hardness content). The findings revealed significant variations in various pharmacokinetic characteristics, including the maximal serum levels (C_s max), the area under the time vs. concentration curves, and the elimination phase half-lives. When water hardness increased, the averages of such values demonstrated a linear decline in C_s max from one group to the next. Additionally, a chemical analysis of the calcium and magnesium ions in water indicated the existence of cooperative groups,

and enrofloxacin diluted in hard water did not affect the microbiological activities *in vitro*, suggesting that decreased absorption may be partially to blame for the decrease in bioavailability (Sumano et al., 2004).

Additionally, it was discovered that the pH considerably changed the steady-state rejection of several antibiotics by various nanofiltration (NF) membranes with variable pore sizes. Trimethoprim (TMP), an antibiotic, showed a recognizable trend from pH 3–10, with the weakest rejection (50.1%) seen close to circumneutral pH settings but increasing both above and below that pH to get close to 91%. However, clearance of the antibiotic sulfamethoxazole (SMX) rose considerably to >97% at pH 8.0 as a result of repulsive effects between the negatively charged membrane and the negatively charged SMX species, dropping as low as 37.4% at pH 4.8 (Kem et al., 2022). In particular, amoxicillin was found to degrade more rapidly when diluted in high-pH water, and utilizing water with a higher pH level also diminished the efficiency of chlorination (Jerzsele and Nagy, 2009).

To identify issues with water delivery systems that might lead to subtherapeutic dosing, Dorr et al. (2009 b) researched different drinker types and water flow rates that varied with medication delivery and among farms, barns within a farm, and pens within a barn. He also examined the correlation between drinking water flow rate and plasma tetracycline levels. Blood was drawn from 50 pigs per barn, 40 healthy and 10 sick, in two farms that were given tetracycline HCl by water at a dose of 22 mg/kg body weight. Plasma tetracycline concentrations were then determined using ultra-performance liquid chromatography. Significant variations in flow rates were identified depending on the type of drinker and in plasma tetracycline concentrations between the two farms but not between healthy and sick pigs. The average plasma tetracycline dose was 0.3 g/m. The variations in plasma tetracycline concentrations were caused by differences in drinker flow rates and the amount of antibiotic consumed by the pigs.

Rodgers and Furones (2009) reported that the bioavailability of some aquaculture drugs decreased when they were applied in seawater, where the bioavailability was recorded as 1% for oxytetracycline, 2% for amoxicillin, 2% for sarafloxacin, 30% for oxalonic acid, 45% for flumequine, 50% for sulfadiazine, 96% for trimethoprim, and 97% for florfenicol. Di Martino et al. (2018) explained that the solubility of medication depends on the product (active substance and excipients) and the water quality, where the product's active substance must be capable of ionizing to be water soluble; otherwise, it would precipitate out to form sediments. Numerous studies have suggested adding water additives to enhance the quality of drinking water. These include ionized alkaline water (Jassim and Aqeel, 2017), water soaking with sweet orange (Orayaga et al., 2016), silicon (Sgavioli et al., 2016), potassium chloride (Yosi et al., 2017), and amino acid-chelated trace minerals (Baxter et al., 2020).

In addition, fluoroquinolones can interact with cations and produce a complex that cannot cross the intestinal barrier, reducing their bioavailability (Simon et al., 2010). Furthermore, Oladele et al. (2010) examined the impact of water hardness on the absorption of ciprofloxacin in bath-treated African catfish. Catfish were categorized into three groups with varying calcium hardness levels, as defined by Group A's calcium hardness of 15 mg/L, Group B's calcium hardness of 215 mg/L, and Group C's calcium hardness of 415 mg/L, respectively. All of the groups were given baths containing ciprofloxacin at a concentration of 25 mg/L of water and treated water with an optimized pH of 6.6. The amount of ciprofloxacin was measured within 8 hours in the collected samples using ELISA. The serum area under the curve (AUC) values were 17,938.13 g/hr, 18,883.75 g/hr, and 12,273.75 g/hr, for groups A, B, and C, respectively. This data showed that ciprofloxacin uptake decreased at the greatest amount of calcium in medicated water (Group C), resulting in decreased bioavailability. The AUC values for tissue and the amount of calcium hardness in the water likewise had a straight, linear connection. This study thus indicated a need to seriously take into account the impact of key chemical factors within fish culture water, such as hardness, alkalinity, and pH, which might decrease the efficacy or raise the toxicity of medications given to fish using the bath method (Oladele et al., 2010).

Interestingly, water has to be managed properly via conducting some regular and periodic examinations to ensure proper water quality, changing water filters and maintaining them regularly, flushing water lines with regular intervals, and the use of some elements that might improve water quality and enhance their consumption by broiler chickens (Mohamed et al., 2020). According to Almond and Monahan (2011), the effectiveness of water treatment can be impacted by issues related to poor water quality. When inorganic ferrous iron-using bacteria develop reddish slime in water filters on commercial farms, it might eventually get into drinkers and obstruct water flow. They also noted that hard water locations' mineralization of pipes and users, rust from galvanized pipes, and the buildup of other solids from contaminated water could reduce water flow, which can impact drug efficacy. According to Forrest et al. (2011), low water quality causes unsteady drug products, which result in low bioavailability, inability to optimize active ingredients (affecting both efficacy and safety), failure to respond proportionately to the dose, and ultimately result in sub-optimal dosing and unfavorable post-medication effects. Additionally, it advised against using apramycin in water with a lot of iron since it can create chelates that would reduce its therapeutic potency.

Remarkably, a water pH between 5.5 and 7 maintains minerals soluble in the solution and improves the efficiency of antimicrobials (Berghaus and Stewart-Brown, 2013). According to Van Heugten (2000) and Scandurra (2013), a low water pH may lead to the deposition of certain antibacterial drugs provided through drinking wa-

ter, whereas a high-water pH results in worse chlorination efficiency. Sulfonamides have also been observed to lose their solubility at acidic pH levels. Additionally, he stated that the presence of iron in water could promote the development of specific bacteria, which could lead to the deposition of derivatives of iron. In addition, he mentioned that iron levels of 2–3 ppm do not affect animal health. Still, it was recorded to block drinking nozzles, and oxytetracycline and its derivatives form chelates with iron at 5 ppm or more concentrations, preventing its absorption. However, animals will switch off the water if the iron level exceeds 10 ppm. To reduce the likelihood of bacterial minimum inhibitory concentrations (MICs) being exceeded by tetracycline, Mason et al. (2012) looked at the factors that led to the most precise prediction of observed plasma therapeutic doses of tetracycline in swine. They discovered that factors like pig age or weight gain, temperature, tetracycline content in water, and water use per unit of time were essential.

Oxytetracycline and tylosin, two common veterinary medications used in animals' drinking water, were tested for their dissolving kinetics, and the effects of various drinking water characteristics on therapeutic effects were examined (Scandurra, 2013). Along with one sample of distilled water and another sample made by combining distilled water in a 1:1 ratio with water gathered from the Bologna aqueduct, nine drinking water samples were collected from various breeding farms (swine, rabbit, and poultry farms) in Italy. It was noted that the solubility tended to decline between 0 h and 24 h for all oxytetracycline-based compounds considered. The results for the tylosin-based products were diverse, with some exhibiting a rise in solubility between the 0- and 24-hour results. All tylosin-based products showed active component levels between 80% and 164% at 24 hours (relative to those found at 0 hours). Therefore, the inherent properties of the water, such as its pH, conductivity, hardness, and calcium content, may impact how well medications tested in water dissolve (Scandurra, 2013). Despite being classified as good water and not harming poultry, hardness levels greater than 100 ppm impair the efficiency of various water-administered drugs, soap, and many disinfectants (ROSS, 2018).

Conclusion

Water has a crucial role in poultry production, and it is a need for various processes in poultry metabolism, including digestion, reproduction, and feed absorption. The present literature demonstrated how the quality of water supply is crucial for broiler performance and poultry production. Besides, different water sources impact the broiler chicks' water intake and weight growth. Water pollution is an undesirable change in water's physical and chemical properties that creates health issues for plants, animals, and humans. Numerous factors, including hardness, pH, and total dissolved solids, affect water consumption in chicken farms. Minerals and salts at high concentrations in animal drinking water produce physi-

ological abnormalities in broilers, resulting in loss of the broilers' health, growth, feed intake, and immune status. As a result, using various sustainable ways to improve its quality to regulate its effects on chicks and boost immune function is necessary. Vaccines and antibiotics are among the most recommended and effective applications to improve water quality, mitigate the adverse effects of pollutants and affect the feed-to-gain ratio, blood biochemical behavior, the broiler chickens' performance, and poultry production.

Conflicts of interest

All authors declare that they have no conflicts of interest that could inappropriately influence this manuscript.

Author contribution

All authors contributed equally to writing this review article. All authors read and approved the final version of this manuscript.

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