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Comparative Assessment of Groundwater Quality and Its Implications for Poultry Farming in Hisar and Jind Districts of Haryana, India

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Abstract
Ground water is considered to be the major source of drinking water in commercial poultry farms in Haryana and its physico-chemical and microbiological characteristics has a direct impact on the health of the birds, efficiency of feeds and productivity of poultry farms. In the present paper, the data pertaining to physico-chemical, microbiological and heavy metal of water samples obtained from the water sources of poultry farms in Hisar (16 samples) and Jind (17 samples) districts of Haryana has been used for comparative analysis of the quality of drinking water to assess its possible effect on poultry farming. The following twelve parameters were studied: pH, total dissolved solids (TDS), total hardness, calcium carbonate ($CaCO_3$), nitrate, nitrite, chloride, fluoride, total coliform count, total viable count (TVC), sulphate and lead. The results show that the water is slightly alkaline to alkaline in both districts with mean pH of 7.5 and 7.6 respectively in Hisar and Jind which is above the permissible limit of BIS, while the water quality is high to medium mineralised with mean TDS of 1046.5 and 1271.2 mg/L in Hisar and Jind respectively. Microbiological parameters indicated that the total coliform and total viable counts were also higher for larger percentage of the samples in both districts, suggesting poor protection of groundwater sources and possible increasing of the biofilm in the farm water distribution systems. High mean values of total hardness, $CaCO_3$, sulphate and lead and wide ranges of fluoride from 0.5 to 3.3 mg/L in the samples from the two districts indicated microbiological protection problems and potential biofilm formation in the farm water-distribution systems. The results suggest that water from both districts can be considered generally acceptable for use for domestic purposes, however, the relatively high mineral content and the moderate microbial contamination, in particular, are problematic for the palatability, digestion, immunity and productivity of poultry. Based on the above findings, the paper recommends regular monitoring of water quality, treatment (softening, filtering, disinfection) and management strategies to ensure the health of the poultry and sustainable production of poultry in the Hisar-Jind belt, Haryana.

Keywords: Groundwater quality; Poultry drinking water; Hisar; Jind; Haryana; Total dissolved solids; Coliform contamination; Heavy metals; Water quality standards; Sustainable poultry farming.

1. Introduction

Water is also known as a "forgotten nutrient" in poultry production but it is involved in nearly all of the physiological processes of the bird such as digestion, nutrient absorption, thermoregulation and removal of metabolic wastes. Drinking water is often obtained from borewells or tube wells without treatment and its quality is not routinely monitored, unlike that of feed which is formulated on most commercial farms and is carefully monitored. It is very significant in semi-arid agriculture states like Haryana where water from aquifers is the almost ubiquitous source of water for farming operations [1]. The nature of the groundwater in Haryana is known to be naturally mineralised due to its geology, its concentration by evaporation in the semi-arid climate and intensive agriculture based on irrigation that has been practiced for decades in a few districts giving rise to high salinity, hardness and nitrate level in the groundwater [11]. In addition to this natural mineralisation, there is an increasing load of agro-chemicals, uncontrolled release of animal wastes and municipal sewerage as well as industrial effluents in some pockets of the state which can further compromise the water quality of the groundwater. Poults that are raised on a poultry farm located in such areas are fed from these aquifers and, hence, the water quality of the aquifers filters straight through to the birds on the poultry farm. Hisar and Jind are some of the districts in Haryana where the commercial poultry farms are located in high density and these districts are also heavily dependent on groundwater for human drinking water supply as well as stocking of water for livestock and poultry [1,4]. The semi-arid climate, hard rock, alluvial aquifer systems and the recognized groundwater mineral and fluoride enrichment in the district of Hisar in particular [9] make it important to make a specific comparison of water quality between the two adjacent but hydrogeologically distinct districts for use by agricultural managers, veterinarians and policy makers in the region.

Image 1: *Groundwater Sampling at Poultry Farms*

Poultry birds require about double the amount of water that they eat per unit of weight and even slight changes in water quality can significantly affect feed and water consumption, growth rate, feed conversion ratio and mortality [22,24]. The palatability of water is affected by physico-chemical properties like pH, TDS and hardness; birds consuming poorly palatable water will decrease their water consumption and lower feed intake and growth rates [23]. Surplus dissolved minerals and salts impose an extra osmotic load on the gastrointestinal tract, disrupt electrolyte balance and are linked to wet litter, increased ammonia release and increased footpad dermatitis [18,21]. In addition to the physico-chemical aspect, microbiological quality of drinking water is also important. The presence of coliform bacteria and high levels of total viable count (TVC) are a sign of faecal pollution or inadequate water system hygiene and are known to be a source of enteric pathogens in a flock [16,19]. Heavy metals, even at low concentrations, can impact growth, immune competence and reproductive performance and can also result in residues in food (meat and eggs) that may be transferred to the human food chain, and may also accumulate in soft tissue and bones during the productive life of the bird [16,17]. All these factors make routine, parameter-wise water-quality assessment a necessary, not optional, management part of poultry farms.

Hisar district of semi-arid area of western Haryana is a part of the areas where several investigations have been conducted for groundwater quality; which indicated high level of TDS, hardness and in parts of the district fluoride in the groundwater samples that are greater than the desirable limit for drinking water [5,9]. The Jind district in the central plains of the state of Haryana is also almost fully dependent on groundwater resources for its domestic, agricultural and livestock needs and has been reported to have a significant variation in mineral content between villages related to local hydrogeology and irrigation return flow [4,8]. Both the districts are in the over-exploited aquifer zone of Haryana, and the Central Ground Water Board has charted a long-term decrease in ground level water levels, that could lead to accumulation of dissolved salts and increase the eventual risk of nitrate and fluoride contamination. Since both districts are dependent on the same type of aquifer systems for the production of poultry and for rural population drinking-water, a comparison of water quality at the district level is essential to be able to pinpoint district specific risks instead of relying on state averages.

Image 2: *Poultry Drinking-Water Supply System*

2. Research Gap and Objectives

Groundwate quality in Haryana has received considerable attention for general drinking-water and irrigation-suitability considerations, but few published studies have investigated the quality of water consumed in poultry farms and its potential impact on bird health and production, at a district level, like Hisar and Jind. A large share of the poultry-waters literary works comes from outside of India [15] and lacks district specific, India based information that can be directly used by farm managers and poultry extension workers in Haryana. The present paper attempts to bridge this gap by analyzing physico-chemical, microbiological and heavy metal data of poultry farms collected specifically in Hisar and Jind districts. The objectives of the study are: (i) Characterization and statistical summarization of 12 water quality parameters of the drinking water supplied to poultry farms of Hisar and Jind; (ii) comparing two districts and comparing both with the water quality parameters of WHO and BIS for drinking water; (iii) discussing the possible implications of the observed water quality on poultry health, welfare and production performance; and (iv) suggesting appropriate management and mitigation measures [2].

3. Materials and Methods

The data reported in this paper relate to the poultry farms in Hisar and Jind districts of Haryana, India where the hot summer, limited and irregular rainfall and heavy dependence on groundwater for domestic, agricultural and livestock uses makes it a semi-arid to sub-humid agro-climatic zone [4]. A total of 33 water samples were selected for present comparative analysis: 16 samples from hisar district and 17 samples from Jind district and each sample is selected from different blocks in both district to represent the local hydrogeological variation. Samples of water were collected in sterile, 1 litre glass containers which were autoclaved at 121°C for 15 minutes before sampling. This continued at each farm with the source water permitted to flow for about 5 minutes from which a sample was then taken aseptically to get water that had been flowing through the system, and not stagnant in the pipeline. In all cases samples were marked with the district, farm code and date and time of the sampling, to allow complete traceability for further laboratory processing [1]. Samples were collected and transferred to a laboratory for analysis within 24 hours in insulated cool boxes with ice packs held at around 4 to 8°c. Physico-chemical parameters which are sensitive to storage time were analysed as early as possible and microbiological analysis was also given priority to prevent artificial variations in bacterial counts before analysis [1].

Each sample was tested for pH using a calibrated digital pH meter calibrated with buffer solutions of known pH. Total dissolved solids were measured by digital TDS meter and the total hardness of the water sample was measured by EDTA titrimetric method, and the concentration of calcium carbonate was measured by standard kit based titration (expressed as $CaCO_3$ equivalent). Nitrate and nitrite were determined colorimetrically, chloride argentometrically, fluoride by visual colour comparison with the certified standards and sulphate spectrophotometrically or nephelometrically, according to the standard method of determination of drinking water components [3]. The microbiological quality was evaluated by the total coliform count calculated by Most Probable Number (MPN) method using three tube fermentation method and the total viable count (TVC) calculated by pour plate method after

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serial dilution and incubation at 37ºC. Lead contamination was screened for using Potassium iodide (KI) qualitative colorimetric method, where a yellow colour would show the presence of lead in the sample [16]. The minimum, maximum and mean values were calculated for each district for each parameter, separately for Hisar and Jind and are summarized in tabular and graphical form in Section 3 of this paper. All the values are compared with World Health Organization and BIS (IS 10500:2012) drinking water quality standards to check the values of the parameters and samples exceeding permissible limit [3]. As in the parent study from which this district-level comparison is drawn [1] we will use descriptive statistics as the basis for the comparative discussion in Section 4.

Sampling Design

Water samples were taken from the commercial poultry farms in Hisar and Jind districts of Haryana, India using standardized procedure for physico-chemical and microbiological water quality assessment for the accuracy and reproducibility of the results.

Table 1: *Sampling Design*

Sampling Parameter	**Description**
Study districts	Hisar and Jind, Haryana, India
Number of poultry farms sampled	33 farms (Hisar: 16; Jind: 17)
Sample type	Drinking water supplied to poultry farms (groundwater / borewell source)
Sample container	Sterilised 1-litre glass containers, autoclaved at 121°C for 15 minutes (or boiled 30 minutes)
Sampling protocol	Source allowed to flow for 5 minutes before aseptic collection
Sample labelling	District name, farm code, date and time of collection
Preservation and transport	Insulated cool boxes with ice packs, maintained at 4–8°C
Time to analysis	Within 24 hours of collection
Reference standards used	WHO Guidelines for Drinking-water Quality (4th ed., 2017); BIS IS 10500:2012
Statistical analysis	Descriptive statistics (minimum, maximum, mean) computed district-wise; significance set at $p < 0.05$

Twelve water-quality parameters, spanning physical, physico-chemical, microbiological and heavy-metal categories, were analysed using standard analytical techniques as summarised below.

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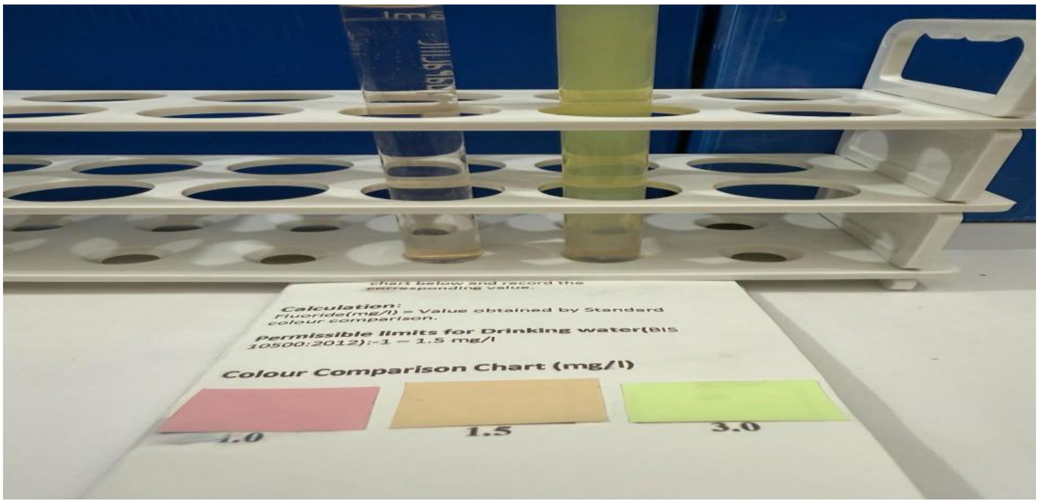
Table 2: *Analytical Parameters, Methods and Instruments*

Category	Parameter	Unit	Method / Technique	Instrument / Reagent Used
Physical	pH	–	Electrometric method	Calibrated digital pH meter, standardised with buffer solutions
Physical	Total Dissolved Solids (TDS)	mg/L	Electrometric (conductivity-based) method	Digital TDS meter
Physico-chemical	Total Hardness	mg/L	EDTA titrimetric method	EDTA titrant, Eriochrome Black-T indicator / HiMedia hardness test kit
Physico-chemical	Calcium Carbonate ($CaCO_3$)	mg/L	Titrimetric method (buffering capacity)	Standard titration kit / reagents
Physico-chemical	Nitrate (NO_3^-)	mg/L	Colorimetric method	Colorimeter / commercial nitrate test kit
Physico-chemical	Nitrite (NO_2^-)	mg/L	Colorimetric method	Colorimeter / commercial nitrite test kit
Physico-chemical	Chloride (Cl^-)	mg/L	Argentometric (Mohr's) titration	Silver nitrate titrant / HiMedia aqua-check chloride kit
Physico-chemical	Fluoride (F^-)	mg/L	Visual colour comparison against certified standards	Merck Fluoride Test kit, SPADNS reagent
Physico-chemical	Sulphate (SO_4^{2-})	mg/L	Spectrophotometric / nephelometric method	Spectrophotometer or nephelometer
Microbiological	Total Coliform Count	MPN/100 mL	Most Probable Number (MPN) technique, three-tube fermentation	MacConkey broth / lactose broth, incubator
Microbiological	Total Viable Count (TVC)	CFU/mL	Pour-plate method after serial dilution	Nutrient agar plates, incubator (37°C mesophilic; 20–22°C psychrophilic)

Heavy Metal	Lead (Pb)	mg/L	Qualitative colorimetric method	Potassium iodide reagent (yellow colouration indicates presence)

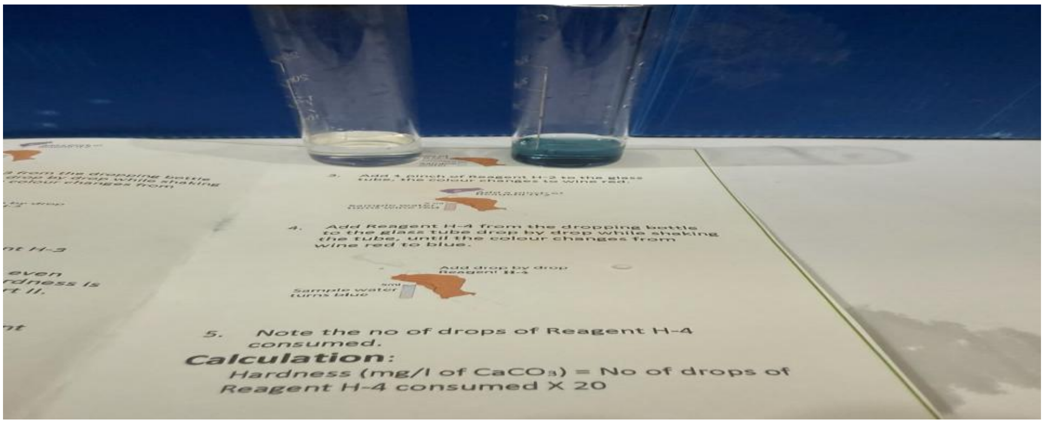
Source: Methodology compiled from Poonia, A. Assessment of Water Quality and Their Potential Impact on Poultry Farming in Haryana, India. PhD Thesis, Om Sterling Global University, Hisar, 2026.

Image 1: Determination of Fluoride Concentration in Drinking Water by Standard Colour Comparison Method



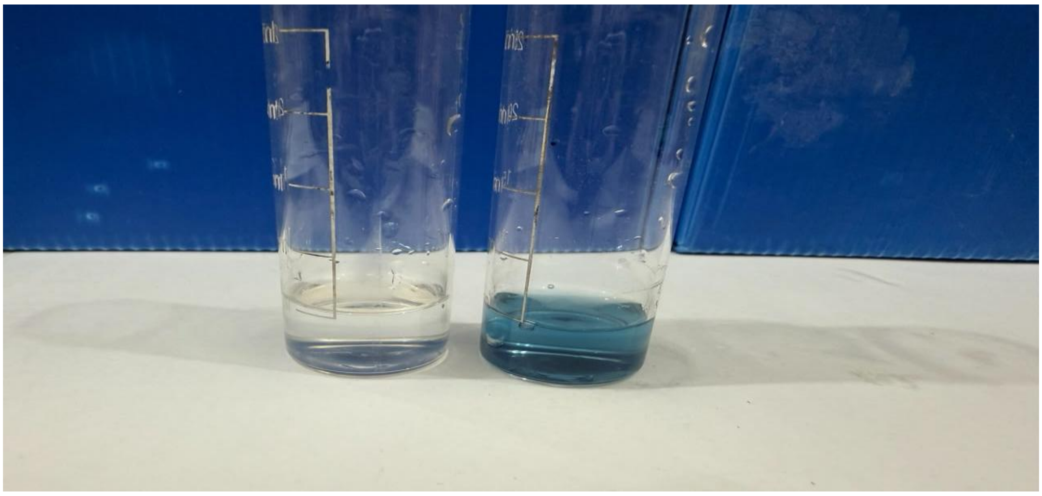
This image shows the use of a standard colour comparison method for measuring the concentration of fluoride in a drinking-water sample. The required reagent is added to the water sample to give a colour that depends on the concentration of fluoride in the sample. The developed colour is then visually compared to a standard colour chart that relates to known concentrations of fluoride, such as 1.0, 1.5, and 3.0 mg/L. The colour of the sample is compared to the closest standard colour and the estimated level of fluoride in the sample is determined. This method offers a simple and quick way of estimating fluoride level in drinking water and to determine if the fluoride level is within the allowable concentration for safe drinking water.

Image 2: Determination of Total Hardness of Water by Drop Titration Method



This is a set-up for the drop titration method to determine the total hardness of a water sample. The sample is then treated with the appropriate reagents until the reaction changes color to signal the reaction has reached the end point. The amount of titrating reagent used is recorded and then used to determine the amount of hardness in the water, usually in mg/L of $CaCO_3$. The calculation in the procedure above is using the number of drops of Reagent H-4 times the conversion factor. It is a simple and convenient way to calculate the concentration of calcium and magnesium ions that cause water hardness.

Image 3: *Colour Change Observed during Total Hardness Determination of Water*



This picture shows the visible colour change that takes place when determining the total hardness for a water sample. As the titration progresses, there is a distinct colour change when the hardness-testing reagent is added, which shows how the reaction is going and towards the endpoint. The almost colourless sample is compared to the blue-coloured sample to determine the completion of the titration. This colour change is a useful visual indicator for the concentration of hardness causing ions, primarily calcium and magnesium, in the water sample.

Image 4: Measurement of Water Quality Parameters Using a Digital Multiparameter Meter

An image of the measurement of important water quality parameters with a digital multiparameter meter. The sensor probe is placed directly in the water sample, so that physicochemical parameters (such as pH, temperature, and electrical conductivity) can be measured rapidly and simultaneously. The values measured are shown on a digital display which aids in making more accurate and consistent laboratory observations. Multiparameter

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meters can also be helpful for routine water-quality assessment since they yield results in a timely fashion, and they do not require separate meters for each water-quality parameter.

Image 5: *Measurement of pH, Temperature and Electrical Conductivity of Water Using a Digital Multiparameter Meter*

Shows how pH, temperature and electrical conductivity are measured at the same time in a water sample with a digital multiparameter meter. The probe is dipped into the sample and the readings on the instrument are displayed on a digital screen. The parameters are useful indicators of water quality because pH is a measure of the acidity or alkalinity of water, electrical conductivity can affect chemical and biological reactions, and water temperature can be a measure of the presence of dissolved ionic substances or chemicals. A multiparameter meter can be used to measure these important physicochemical parameters rapidly, easily and accurately.

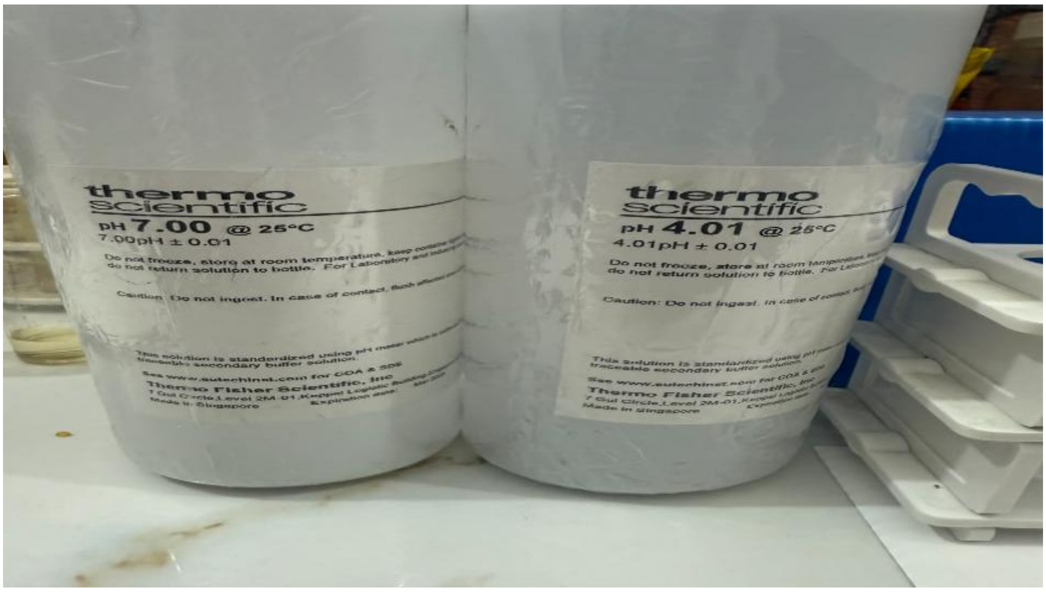
Image 6: Visual Colour Comparison of Water Samples after Chemical Reagent Treatment

This is a picture of a visual comparison of the treated water, using a chemical reagent, with the untreated water. The sample gets a distinct reddish-brown colour while the other sample remains almost clear, suggesting difference in the chemical response of the samples. Such colour changes are commonly used as a qualitative or semi-quantitative indicator during water-quality analysis. The strength and type of the color produced can be used to determine if the desired chemical component is present in the water sample and how much of it is present.

Image 7: Chloride Estimation in Water Using Chloride Test Reagent

This is an image of using a chloride test reagent to estimate the amount of chloride in a water sample. Water sample is treated with the specific reagent which will give a colour reaction during the test. The colour change is used to show if there are chloride ions in the sample and approximately how much. This technique is a simple, quick, practical way to routinely assess chloride concentrations in drinking water and determine the suitability of the water for poultry and drinking use.

Image 8: Standard Buffer Solutions of pH 4.01 and pH 7.00 Used for pH Meter Calibration



These are the standard buffer solutions of pH 4.01 and pH 7.00 used for calibration of digital pH meter. These are certified buffer solutions with known and stable pH values which can be used to calibrate the instrument before it is used to measure an unknown water sample. Using acidic and neutral calibration buffers helps to assure the accuracy and reliability of pH measurements. Calibration is an important part of water-quality analysis as it helps reduce instrumental error and will help to increase the repeatability of results recorded.

4. Results

The following table shows the comparison of various parameters of drinking-water quality at poultry farms of Hisar (n = 16) and Jind (n = 17) districts as per twelve physico-chemical, microbiological and heavy-metal parameters as described in Section 2. The minimum, maximum and mean values for both districts are summarized in Table 1 and the mean value comparison for both districts are provided in the accompanying figures (1, 2, 3, and 4). The pH of the drinking water for poultry in Hisar was 6.8 to 8.6 with an average of 7.5 and in Jind, the pH was 6.4 to 8.2 with an average of 7.6. The mean value of both districts is within the range acceptable by WHO/BIS (6.5-8.5) but maximum value recorded in Hisar (8.6) is just above the upper limit and minimum value recorded in Jind (6.4) is just below the lower limit of the desirable range, suggesting that individual farms in both districts have water outside the recommended pH band [1,2,3]. The differences between the two districts were greater and more significant for the TDS data. The mean TDS in Hisar is 1046.5 mg/L, maximum TDS is 3015 mg/L and in Jind, 1271.2 mg/L and 2527 mg/L respectively, while BIS recommended limit for the same is 500 mg/L, which implies that a significant proportion of poultry farms in Hisar and more significantly in Jind use highly mineralised groundwater [1,3,5]. The pattern of total hardness was similar to that of TDS. The hardness values ranged from 142 to 2450 mg/L with the mean value of 601.8 mg/L in case of Hisar and 239 to 2200 mg/L with the mean value of 670.3 mg/L in case of Jind, both of which falls in the "very hard" category as per the standard hardness classification and both are above the BIS recommended limit of 600 mg/L with Jind being marginally higher than Hisar [1,3].

Table 3. *Comparative summary of drinking-water quality parameters, poultry farms of Hisar and Jind districts, Haryana*

Parameter	**Unit**	**Hisar (n = 16)**			**Jind (n = 17)**		
		Min	**Max**	**Mean**	**Min**	**Max**	**Mean**
pH	–	6.8	8.6	7.5	6.4	8.2	7.6
Total Dissolved Solids	mg/L	308	3015	1046.5	420	2527	1271.2
Total Hardness	mg/L	142	2450	601.8	239	2200	670.3
Calcium Carbonate ($CaCO_3$)	mg/L	30	662	194.6	55	2070	395.1
Nitrate (NO_3^-)	mg/L	2	84	42.1	9.8	82	36.1
Nitrite (NO_2^-)	mg/L	1.3	6	2.1	1.3	3.5	1.9

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Chloride (Cl^-)	mg/L	80	1498	323.8	30	602.7	249.3
Fluoride (F^-)	mg/L	0.2	3.3	1.3	0.2	2.5	1
Total Coliform Count	MPN/100 mL	0	33	11.4	1	117	13.9
Total Viable Count	CFU/mL	7	420	55.4	7	370	52.4
Sulphate (SO_4^{2-})	mg/L	17	235	111.1	15	703	231.5
Lead (Pb)	mg/L	ND	0.07	0.021	ND	0.32	0.077

Note: ND = not detectable. Values compiled from physico-chemical, microbiological and heavy-metal analysis of poultry farm water samples (Hisar n = 16, Jind n = 17). Data source: Poonia, A. (2026) [1].

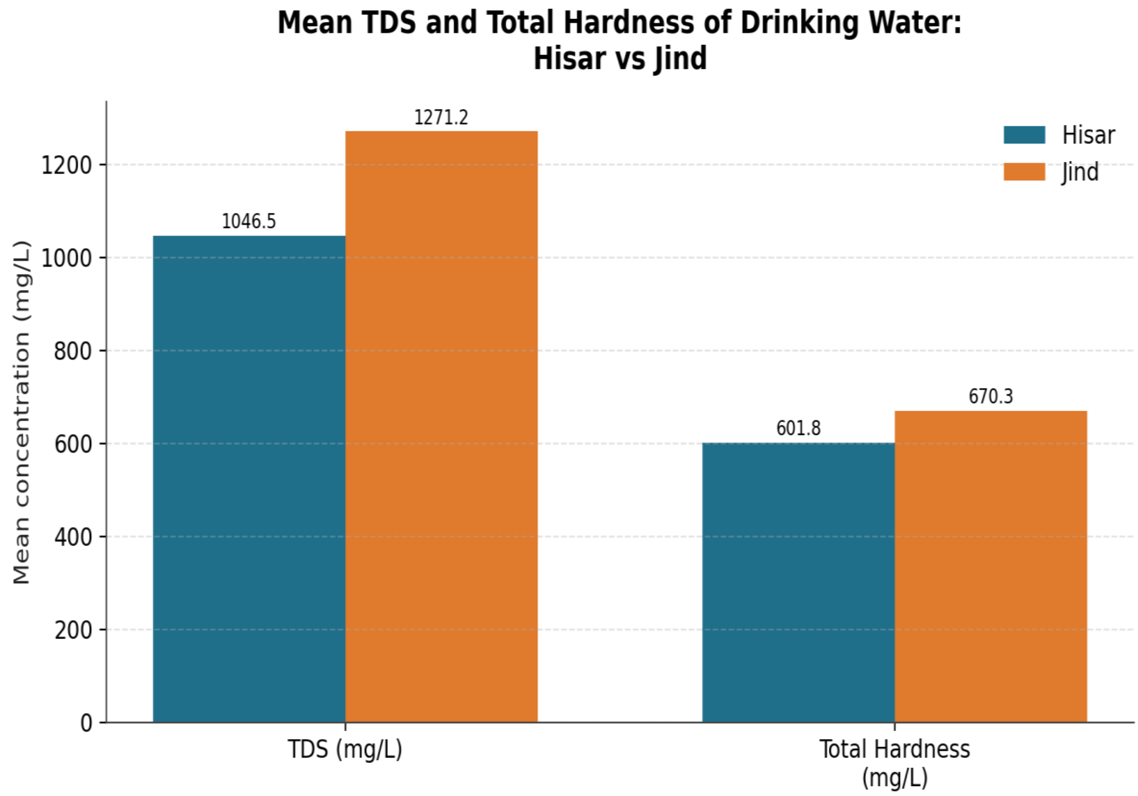

Figure 1. Mean TDS and total hardness of poultry farm drinking water in Hisar and Jind (mg/L).

Concentration of calcium carbonate was significantly higher in Jind than Hisar. The range of values of Jind (55 to 2070) is comparable to the parent dataset while the range of values of Hisar (30 to 662) is lower and its mean value is around half of that of Jind (194.6 mg/L) in the same parent dataset (395.1 mg/L) of Haryana recorded in the highest district with respect to this parameter [1]. The large difference between these two values indicates that the calcareous nature of the aquifer underlying Jind district is far more evident than that of the Hisar farms sampled. The nitrate concentration was found to be greater in the Hisar area than in Jind area.

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The nitrate concentrations in both districts were very high (mean nitrate of 42.1 mg/L in Hisar and 36.1 mg/L in Jind), the latter is the highest mean nitrate concentration recorded by any district in the parent study and the high mean nitrate concentration in both districts is approached or exceeded by individual samples indicating significant farm-to-farm variation in exposure to agricultural nitrate sources [1,2,11]. There were comparatively narrow and similar concentrations of nitrite in both the districts with the mean concentration in Hisar being 2.1mg/L ranging from 1.3 to 6.0mg/L and in Jind, the mean concentration was 1.9mg/L ranging from 1.3 to 3.5mg/L. Typical level of nitrite is similar in the two districts, but the upper end of the variability is somewhat more in the district of Hisar as compared to other district of 8 districts of the parent study [1] as the highest value recorded in the district is 6.0 mg/L of nitrite.

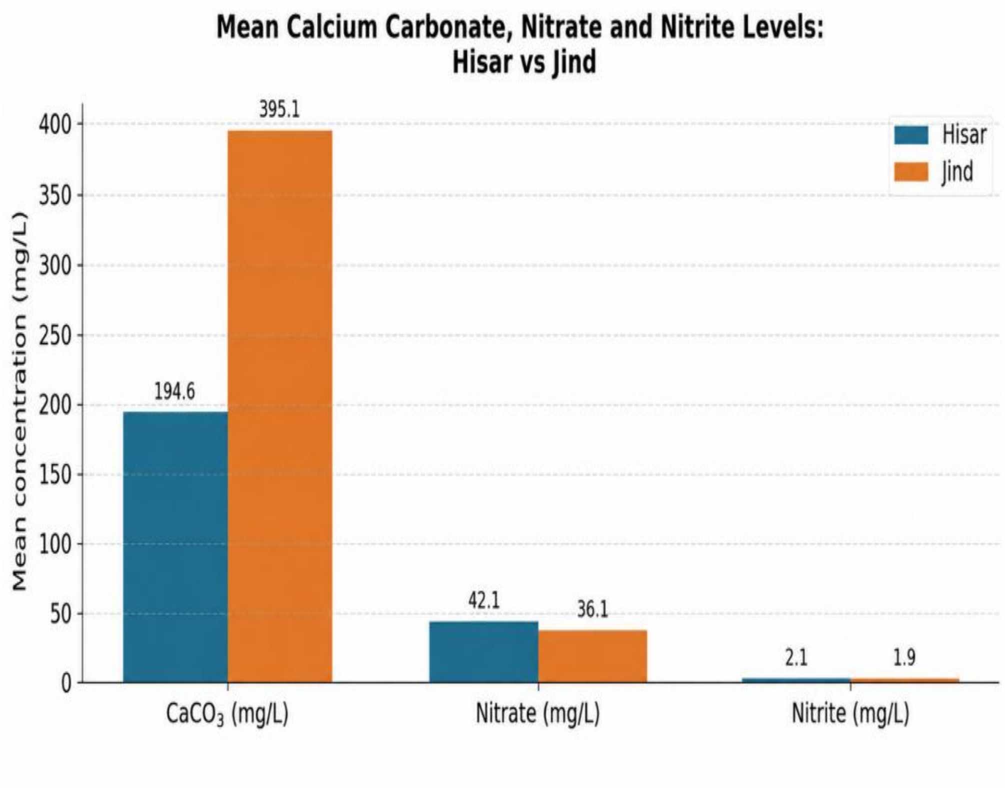

Figure 2. Mean calcium carbonate, nitrate and nitrite levels of poultry farm drinking water in Hisar and Jind (mg/L).

It was observed that there was more chloride in Hisar than in Jind. The range of 80 – 1498 mg/L was recorded in Hisar with a mean chloride level of 323.8 mg/L, while Jind recorded a lower range of 30 – 602.7 mg/L with a mean chloride level of 249.3 mg/L, and the minimum chloride level recorded in all eight of the study districts was Jind (30 mg/L) [1]. The average of both district samples is below the BIS permissible limit of 1000 mg/L, while individual Hisar samples were close to the BIS limit. The fluoride concentration in the water samples collected from Hisar varied from 0.2 to 3.3 mg/L with a mean value of 1.3 mg/L, where the minimum and maximum fluoride concentrations were 0.2 mg/L (also found in Jind) and 3.3 mg/L respectively and also included all the minimum and maximum fluoride concentration of all 8 districts studied. Jind had a relatively small range of 0.2 to 2.5 mg/L with an average of 1.0 mg/L. The mean fluoride concentrations in the Hisar district (1.0 mg/L) and Jind district (1.19

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mg/L) are higher than the recommended limit of 1.0 mg/L recommended by BIS and the maximum concentrations in both districts are higher than the recommended limit of 1.5 mg/L. This is consistent with the report of fluoride enrichment in the groundwater of Hisar district earlier [1,9]. The most significant differences between the two districts were in the sulphate content. The highest district mean sulphate concentration recorded across Haryana in the parent study is found in Jind with a range of 15-703 mg/L and a mean of 231.5 mg/L while the comparatively low range of 17-235 mg/L and mean of 111.1 mg/L are recorded in Hisar, approximately half the mean of Jind [1]. There were detectable levels of lead in both districts, although at generally low concentrations: In the Jind district, the mean concentration of lead was 0.077 mg/L, as compared to 0.021 mg/L in the Hisar district, with the highest concentration in Jind being 0.320 mg/L, compared to 0.070 mg/L in Hisar, the latter having the highest recorded concentration in the parent study.

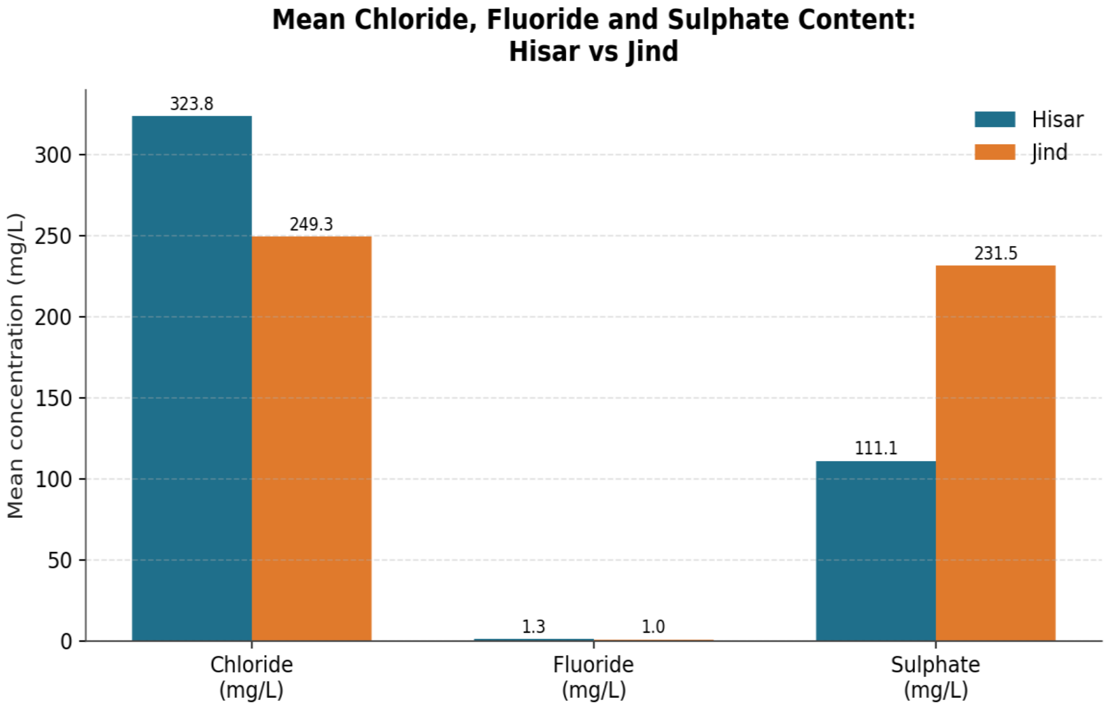

Figure 3. Mean chloride, fluoride and sulphate content of poultry farm drinking water in Hisar and Jind (mg/L).

The total coliform counts were slightly higher in Jind than in Hisar. In the case of Hisar it was 0-33 MPN/100 mL with a mean of 11.4 MPN/100 mL; and in the case of Jind it was 1-117 MPN/100 mL with a mean of 13.9 MPN/100 mL; that is, some of the samples contained no detectable coliforms, while at least one sample was heavily contaminated in Jind [1]. In both districts, the number of FIO in other water sources of poultry farms was lower than the maximum recorded in other districts in Haryana, but still suggested that FIO are present in poultry farms water sources in both districts, which requires further attention [1,16,19]. The total viable counts for the two districts were generally similar with Hisar 7-420 CFU/mL (mean 55.4) and Jind 7-370CFUmL (mean 52.4). The similarity of these means despite the many differences that were observed in the mineral parameters, indicates that the general bacterial load, in farm water-distribution systems, is controlled more by sanitation and maintenance procedures common to both districts, than by the geochemistry of the underlying aquifer [1,16].

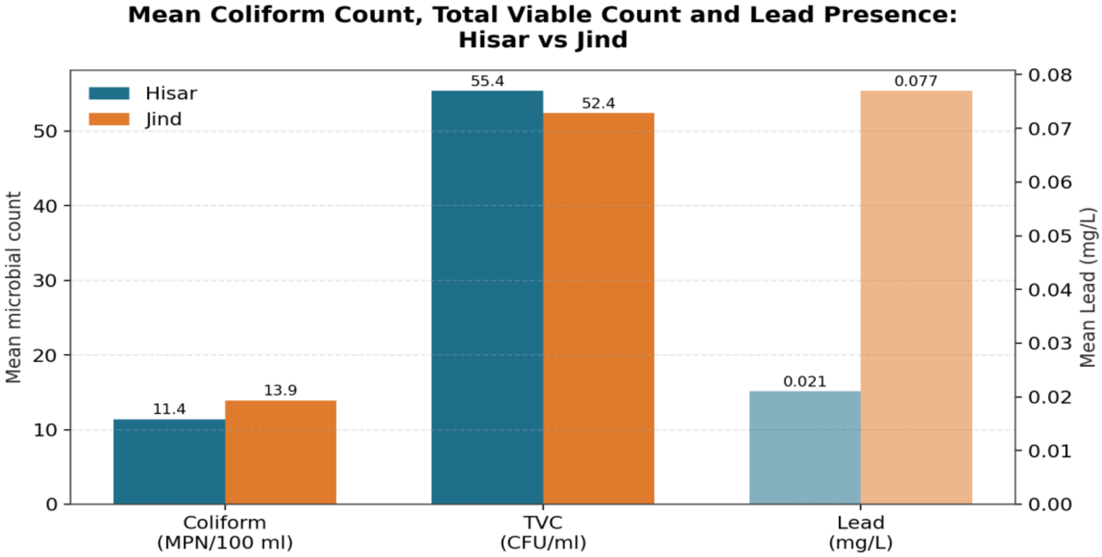

Figure 4. Mean coliform count, total viable count and lead presence in poultry farm drinking water in Hisar and Jind.

5. Discussion

The results of the two districts, Hisar and Jind, taken together, show that they have different groundwater-quality profile, both are physically adjacent and they are both in the same agro-climatic belt of Haryana, and are significant for the management of poultry farms. The aquifers of Jind consistently showed higher mean values for TDS, TH, calcium carbonate, sulphate, and lead concentrations while the ranges of these parameters on these parameters, even the highest single value recorded in Jind, were lower than those in Hisar, indicating a more strongly mineralised and, on some parameters, more polluted aquifer.

These differences are similar to those reported in previous groundwater quality studies for the state of Haryana and are attributed to the differences in local geology, depth to the water table, extent of irrigation return flow and to the location of industries and human habitation. The relative fluoride load in Hisar, as observed in the study is consistent with the earlier hydro-chemical survey that had identified fluoride enriched areas in Hisar district that need defluoridation intervention, whereas the higher level of hardness, $CaCO_3$ and sulphate in Jind suggests a calcareous and sulphate rich aquifer matrix in that district. The higher TDS, hardness and $CaCO_3$ level, particularly in Jind in both districts is probably due to natural geogenic mineralisation as well as decades of high intensity irrigation, which results in the concentration of salts and progressive salinisation of shallow aquifers, a process well established in the alluvial plains of Haryana.

The relatively high nitrate concentrations in Hisar are in line with agricultural intensification such as the significant use of nitrogenous fertilisers in the area and livestock wastes, which have been known to enrich nitrate in the groundwater in intensively farmed areas. The proportion of samples containing coliforms in both stations and especially the high single sample count at station Jind suggests that sanitary protection of borewells is insufficient, that waste material has been seeping into the drinking water source, or that there has been accumulation of biofilm in the drinking water storage tanks in the farm or in the delivery pipelines, which are all known sites where coliforms can contaminate poultry drinking water. The higher mean concentration of lead recorded in Jind could be attributed to the localised anthropogenic inputs, including agrochemical residues, industrial discharge or corrosion of old pipes and fittings, which have been observed in other areas with measurable lead contamination of groundwater for livestock use.

The high TDS and hardness recorded in both the districts, particularly in the Jind district are of great concern for poultry performance. Increased dissolved-solid levels in drinking water have been found to correlate with decreased palatability, altered digestive tract osmotic balance and hence decreased feed consumption in broilers fed for long periods. In addition to this risk, high hardness compounds the issue because of its ability to lower phosphorus availability, disrupt mineral balance, and increase the risk of scale in drinkers and pipelines that can reduce flow and lead to biofilm growth in pipelines. This is particularly noteworthy in the case of elevated nitrate levels in Hisar, because nitrate is transformed to nitrite in the birds' digestive system, resulting in methaemoglobinisation of haemoglobin and reduced O_2-carrying capacity of the blood; young birds are especially sensitive to the effects of nitrite, as their ability to convert nitrite back to haemoglobin is comparatively low, and this will lead to poorer growth rate, feed efficiency and increased susceptibility to secondary problems, such as respiratory infections. The mean concentrations of sulphates and lead found in Jind were also of biological interest, as elevated levels of sulphates are associated with osmotic diarrhoea, wet litter and decreased feed conversion efficiency, and low chronic exposure to lead may lead to reduced growth, immune competence and reproductive performance over the productive life of the flock as well as food-safety concerns due to potential residues in meat and eggs.

In both districts, coliform bacteria and significant total viable counts (TVC) were found in the water, meaning there is a potential risk of enteric pathogens via the waterborne pathway being present and causing digestive upset, loss of feed efficiency and potentially higher flock mortality rates in more severe cases. These results indicate that the water quality of both districts is not so severe that it would not be suitable for raising poultry, but that continued use of untreated water from either source is a measurable cumulative risk to the welfare of poultry which should be considered a management concern for farm managers in Hisar and somewhat more in Jind.

A baseline management practice is recommended for both districts, namely, a regular testing program for water for the minimum number of chemical parameters, such as pH, TDS, hardness, nitrate, coliform, and lead, as the water quality has been found to vary from farm to farm within each district. If levels of TDS and hardness are detected to be above the permissible limit as observed in majority of the samples from Jind, the farm managers should consider softening the water or blending with lesser mineral water sources, or reverse osmosis treatment for high yielding or breeder stock etc.

With elevated nitrate levels recorded in Hisar, it is recommended that more attention be paid to managing animal-waste disposal and fertiliser application near recharge areas of water sources, and that denitrification treatment or mixing with less nitrate water be considered for

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the affected farms. The findings common to both districts for coliform and total viable counts would mean that regular chlorination or UV disinfection of the storage tanks and delivery lines, along with regular cleaning to prevent the buildup of biofilm would significantly lower the likelihood of microbial risk to the flock. Because the higher level of lead and sulphate noted in Jind, regular heavy metal monitoring and treatment, if necessary, using activated-carbon or ion exchange, should be emphasized on farms in that district.

Appendix: Sample-wise Raw Water Quality Data (Hisar and Jind)

The table below presents the individual farm-level sample readings of all water sources under Hisar and Jind district (16 and 17 respectively) which are summarized in Table 1 and Figures 1-4 respectively. Units follow those given in Table 1; TDS, hardness, $CaCO_3$, chloride and sulphate are in mg/L, nitrate and nitrite in mg/L, fluoride in mg/L, coliform count in MPN/100 mL, total viable count in CFU/mL and lead in mg/L (ND = not detectable) [1].

Table 4. Sample-wise Raw Water Quality Data — Poultry Farm Drinking-Water Sources of Hisar and Jind Districts, Haryana

S.No	District	pH	TDS	Hardness	CaCO3	Nitrate	Nitrite	Chloride	Fluoride	Coliform	TVC	Sulphate	Lead
1	Jind	6.8	2527	2200	1910	30	1.9	230	0.2	32	95	21	0.3
2	Jind	6.4	2259	2100	2070	20	2.3	130	0.8	1	40	230	0.3
3	Hisar	6.8	1263	759	662	70	6	190	1.2	23	420	90	0.012
4	Jind	7.8	1196	455	249	82	3.5	270	1.3	3	10	60	0.001
5	Jind	8	849	525	492	26	1.7	250	0.6	3	50	15	0.02
6	Jind	7.5	1257	350	311	47	1.5	155	1.2	16	7	102	0.002
7	Hisar	8.6	560	210	194	48	1.6	187	1.3	7	11	110	ND
8	Jind	7.8	626	425	185	71	2	205	2.5	6	8	172	ND
9	Hisar	7.9	643	425	100	49	1.5	110	1.7	24	53	110	ND
10	Jind	8.1	640	290	55	47	2.2	30	0.8	11	21	62	ND

11	Hisar	7.4	1265	1140	600	40	1.7	350	0.5	15	27	173	0.014
12	Hisar	7.8	308	302	85	10	3.8	80	2.2	24	35	50	ND
13	Hisar	7.6	350	142	30	2	2	91	3.3	0	11	17	ND
14	Hisar	7.2	850	301	58	84	1.5	306	0.8	12	26	70	ND
15	Hisar	7.3	857	312	35	66	2.2	282	0.9	9	7	60	ND
16	Hisar	7.6	923	286	60	78	1.4	280	1	6	16	90	ND
17	Hisar	7.8	860	305	33	71	1.4	279	0.9	7	13	88	0.001
18	Jind	7.7	1417	601	140	67	2.1	332	1.2	6	80	175	0.001
19	Hisar	7	550	247	75	11.9	1.3	178	0.8	4	48	155	ND
20	Hisar	7.3	1350	890	360	6	1.3	420	0.7	33	84	125	0.015
21	Hisar	7.8	1470	878	320	45	1.8	366	1.8	2	46	235	0.018
22	Hisar	7.1	3015	2450	281	45	2.2	1498	1.6	3	21	150	0.07
23	Jind	7.7	1450	480	151	40	1.4	380.9	1	3	ND	120	0.025
24	Jind	7.6	1410	440	125	34	1.9	360	0.9	3	ND	106	0.023
25	Jind	7.7	1591	678	182	13.1	1.3	602.7	1	10	16	115	0.003
26	Hisar	7.3	940	430	59	35	2.2	210	0.2	3	ND	145	ND
27	Hisar	7.1	1540	552	161	12.3	1.6	354.5	2.1	11	13	110	0.02
28	Jind	7.2	1040	600	103	10.1	1.6	319	0.6	3	ND	365	0.001

29	Jind	8	1050	239	63	9.8	2	160	0.7	5	8	650	0.001
30	Jind	7.5	500	460	175	12.3	1.7	71	0.6	5	8	380	ND
31	Jind	7.2	420	398	164	11.9	1.5	63	0.7	7	10	300	ND
32	Jind	7.2	1280	879	282	14.1	2.2	319	0.7	6	11	360	0.004
33	Jind	8.2	2099	275	60	78	1.4	360	1.9	117	370	703	0.32

6. Conclusion and Recommendations

The present paper has made comparison of the qualitative parameters for the drinking water used in poultry farms in Hisar and Jind districts of Haryana on the basis of 12 physico-chemical, microbiological and heavy metal parameters. The groundwater was found to be moderately to highly mineralised and there is a moderately high concentration of alkaline, hard water in both districts on several parameters that have exceeded WHO and BIS drinking-water limits. Higher mean values of total dissolved solids, hardness, calcium carbonate, sulphate, lead were consistently shown by Jind, whereas a higher mean value of nitrate concentration was shown by Hisar and the widest range of fluoride concentration was recorded within the underlying dataset. There was coliform contamination and high TVC levels found in both districts, suggesting that improvement of microbiological protection at the farm is needed regardless of district. The results are in full agreement that water quality is not homogenous throughout the poultry belt of Haryana and even in the neighbouring districts there is meaningful difference in the water quality which has significant implications for palatability, digestibility, immune responses and consequently production performance and farm profitability of poultry. It is recommended that: (i) the poultry farms in both the districts should test their drinking water at regular intervals (at least once in every quarter) for the above mentioned physico-chemical and microbiological parameters for comparative purposes; (ii) the poultry farms of Jind district should desalinate the drinking water containing high concentrations of hardness, sulphate and lead using appropriate softening, filtering or ion exchange treatment; (iii) the poultry farms of Hisar district should regularly monitor the drinking water for nitrate and fluoride and if required, should take the necessary steps to remove nitrate and fluoride from the drinking water; and (iv) all the poultry farms in both the districts should ensure that the storage tanks and delivery pipelines are mechanically cleaned and disinfected regularly (atleast once in every quarter) to reduce the coliform and total viable bacterial counts of the drinking water. District animal husbandry authorities and extension services should make district-specific water-quality advisories (such as the types shown in this comparison) part of routine poultry extension programming, as these will help identify specific risks which may be significant locally, while state-level averages may not. This comparison has been done on a cross sectional basis on 16 samples of water collected from the Hisar and 17 from Jind and hence does not show the range of water quality in the two areas which is known to vary with season and water-table depth and should be taken into account for future work. Lead was only qualitatively evaluated in the underlying dataset and quantitative heavy-metal panels including other elements like arsenic and cadmium could be useful in future studies. Lastly, it would be useful to correlate these water-quality parameters with production parameters at the farm-level (growth rate, feed conversion, mortality and egg output) for Hisar and Jind specifically to provide stronger evidence to support the farm-level management recommendations suggested here.

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