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Efficiency Assessment of Rainwater Harvesting Systems for Water Supply in Livestock and Poultry Units: A Case Study of Golestan Province, Iran

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ABSTRACT

Aims: Excessive water extraction, inefficient management, climate change, and population growth have created significant global water supply challenges, particularly in arid and semi-arid regions like Iran. Rainwater Harvesting Systems (RWHS) have emerged as an effective water management strategy. This study investigates the role of rainwater harvesting in fulfilling the water needs of dairy cattle and broiler chicken units in Gorgan County, Golestan Province.
Materials & Methods: In this study, data were collected on annual rainfall, the number and capacity of dairy cattle and broiler chicken units, roof surface areas, and their water requirements. Subsequently, the contribution of rainwater to meeting these units' water needs was calculated considering rainfall amounts, roof material types, and water consumption rates of dairy cattle and broiler chickens. Furthermore, rainwater sampling was conducted, and its physical, chemical, and microbiological parameters were evaluated according to the standards of the German Federal Ministry of Food and Agriculture (BMEL).
Findings: Rainwater harvesting can meet 87.07% of annual water requirements in broiler chicken facilities, equivalent to 214,711 $m^3 \cdot y^{-1}$, demonstrating significant potential to reduce dependency on alternative sources. In contrast, this percentage is only 1.05% for dairy cattle units, equivalent to 13,432 $m^3 \cdot y^{-1}$, due to their higher water consumption. The analysis of rainwater quality shows compliance with BMEL standards, indicating favorable water quality.
Conclusion: Rainwater harvesting effectively manages water resources in livestock and poultry farming, particularly in the poultry sector. These findings inform sustainable solutions for water scarcity challenges and highlight the potential of alternative water collection methods to alleviate resource pressures, especially in environmentally and agriculturally constrained regions. The study provides valuable insights for strategic water planning and sustainable agricultural development, emphasizing the varying efficiencies across farming sectors.

Keywords: Broiler Production Units; Dairy Cattle; Sustainable Water Management; Water Consumption Per Capita.

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Introduction

Water extraction has raised critical concerns regarding water resource sustainability and management globally. According to projections, population growth through increasing water demand, coupled with climate change through disrupting precipitation patterns, intensifying droughts, increasing evaporation rates, and so on, will substantially exacerbate water scarcity for significant portions of the world's population [1]. Due to climate change's impact on water resource demands, optimizing water accessibility and utilization should be prioritized as a critical determinant of agricultural and livestock production [2]. Sustainability in livestock production is directly related to water resource management [3]. Also, broiler farms' high feed-to-protein conversion ratio and substantial water consumption necessitate identifying and implementing water optimization methods. These interventions can enhance sustainable water resource management and mitigate environmental, economic, and social challenges [2]. Identifying and implementing novel water harvesting and management approaches can enhance water resource conservation and operational efficiency in the agricultural and livestock sectors. Iran, one of the world's arid and semi-arid regions, confronts substantial water scarcity challenges. Climate change impacts and suboptimal water resource management have made water supply a critical nationwide concern. Furthermore, demographic expansion has intensified water resource demands, placing unprecedented pressure on water supply infrastructure [4]. Increasing pressure on water resources makes meeting the needs of livestock and poultry more challenging and highlights the necessity for efficient water use and the search for alternative sources [3]. In this context, Rainwater Harvesting Systems (RWHS) have emerged as an effective solution for water resource management, capable of alleviating pressure on existing water resources. Assessment and analysis of these systems' performance are pivotal in promoting their adoption and implementation among potential users [5]. Existing research demonstrates the technical viability and efficacy of rainwater harvesting systems across residential and industrial sectors, particularly in livestock and poultry operations. Implementing these systems can mitigate pressure on renewable water resources while optimizing water utilization efficiency in these sectors. Research by Rashidi Mehrabadi et al. demonstrates that conventional buildings can meet up to 75% of non-potable water requirements through rainwater harvesting systems when 70% of precipitation is efficiently captured [6]. Their findings highlight these systems' significant potential for reducing dependence on conventional water sources while enhancing water efficiency. Subsequently, Edge et al. examined water accessibility for poultry production and rainwater harvesting's role in minimizing reliance on low-yield water sources. They developed a Rainwater Harvesting (RWH) model to estimate daily water consumption patterns for poultry operations, evaluating its performance over 25 years at a northern Alabama facility. Their model achieved approximately 87.3% accuracy in estimating total water consumption [7]. Furthermore, Amos et al. assessed rooftop rainwater harvesting potential for urban agriculture, encompassing system design, modeling, and economic analyses. Their comparative analysis of developed and developing nations revealed limited rainwater utilization initiatives in urban agriculture while indicating that purpose-designed rainwater harvesting systems could effectively support urban farming operations [8]. Eratalar and Kaveci investigated rainwater utilization in broiler production, establishing no adverse effects on performance metrics, including feed consumption, water intake, live weight, feed conversion ratio, meat quality, and pH levels. Their research confirms rainwater as a viable alternative to healthy water in broiler operations without compromising production parameters or meat quality [9]. Hoss et al. investigated the implementation of rainwater harvesting systems in industrial livestock facilities. They demonstrated that these systems can fulfill up to 100% of water requirements in poultry farms and between 32.7% and 68.3% in swine production facilities. Furthermore, the water conservation potential in this region was estimated at 5.2 million cubic meters annually. These findings indicate the significant potential of such systems in mitigating drought impacts and managing local water resources [3]. Yaylı et al. examined the potential of rainwater harvesting from livestock facility rooftops. They demonstrated that the highest water collection occurs in December, while the lowest occurs in August. The research findings indicated that this system can fulfill up to 90.4% of water requirements in sheep farms and 57.4% in cattle farms. Additionally, these systems were shown to be capable of recovering their costs within 7 years [10]. Muhirirwe et al. designed and evaluated water treatment systems in a rainwater harvesting and purification study for dairy cattle. The results demonstrated that these filters effectively reduced bacteriological contamination and heavy metals in drinking water for dairy cattle. Furthermore, their economic analyses revealed that implementing rainwater harvesting systems, with their short payback period and high reliability, presents an economically viable solution for livestock farmers in low-income regions [11]. Napierała et al. investigated rainwater harvesting from livestock facilities in Poland and its potential for meeting animal water requirements. Their findings demonstrated that Polish farms could store more than 41 million cubic meters of rainwater annually, meeting only 15 percent of livestock water demands. Furthermore, the economic efficiency of these systems across different regions of the country was influenced by municipal water prices [12].

A literature review indicates that studies on rainwater harvesting in livestock and poultry operations are limited and insufficiently addressed globally and in Iran. However, given the increasing water demand in agriculture, rainwater harvesting from these operations could be a viable strategy to alleviate pressure on conventional water resources [11,12].

Therefore, this study investigates the potential of rainwater harvesting as a supplementary water source for dairy cattle and broiler chicken units in Gorgan County, Golestan Province, Iran. The study area was selected due to its strategic importance in Iran's national production of dairy products, red meat, and white meat [13]. Golestan Province, particularly Gorgan County, maintains a notable position in the country's production of these agricultural commodities, warranting a comprehensive investigation of water management strategies in this region. The region hosts many broiler farms, integral to Iran's food security and placing considerable demand on water resources. This unique context warrants a comprehensive investigation of sustainable water management strategies tailored to the needs of this high-density agricultural area.

The primary objective of this research is to assess rainwater harvesting as a sustainable water resource management approach for partially fulfilling the annual water requirements of livestock and poultry facili-

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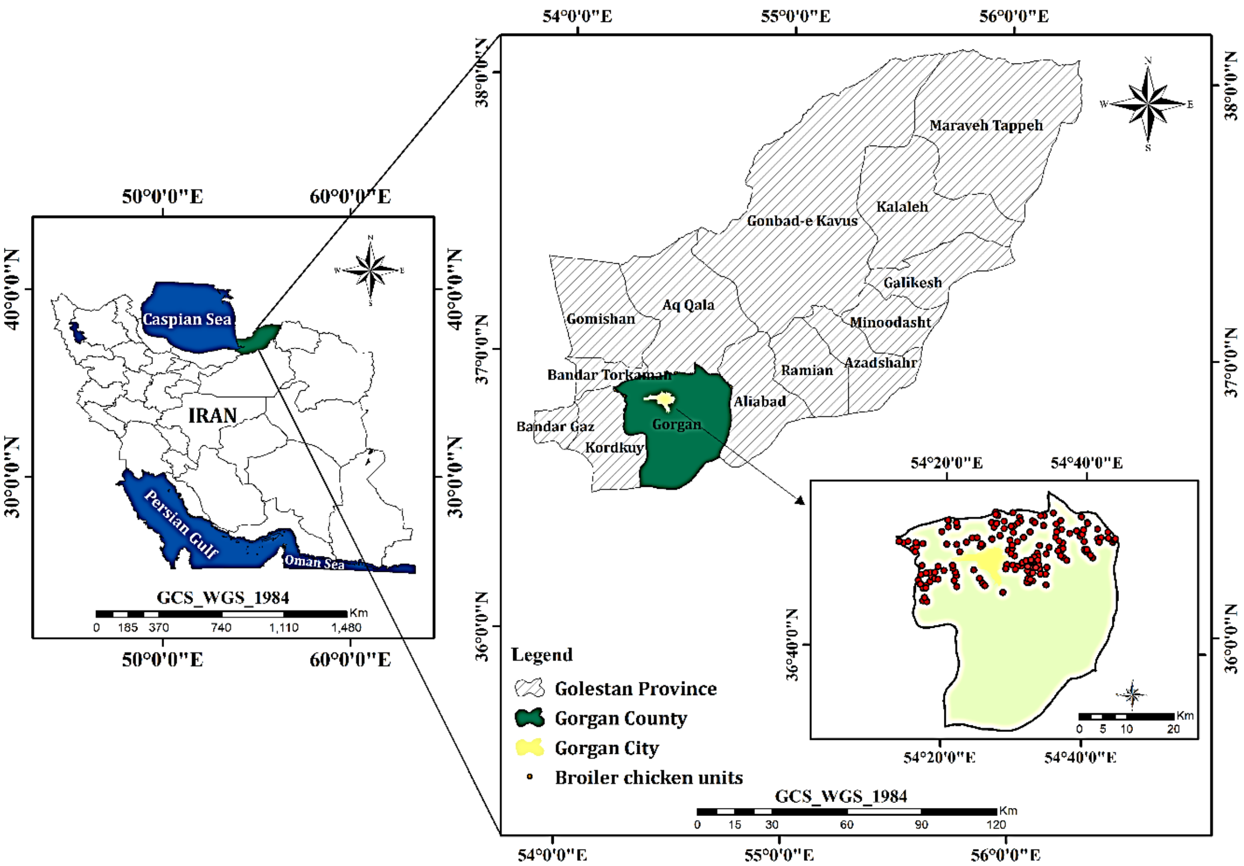

Figure 1) Geographic location of livestock and poultry farming units. (Red dots are the studied sites).

ties. This study represents a significant step toward developing efficient and sustainable management solutions to minimize water waste and mitigate the region's water scarcity crisis. The research's novelty lies in examining the relationship between rainwater harvesting and water consumption patterns in livestock and poultry operations, which remains largely unexplored in current literature. The findings are expected to inform evidence-based management policies addressing water scarcity challenges.

Materials & Methods

Study Area

The study area, Gorgan County, is geographically positioned within the coordinates of 36°30' to 36°58' North latitude and 54°13' to 54°44' East longitude. This region encompasses portions of three significant watershed basins: Gorganrud, Nekarud, and Qarasu. Meteorological data indicate that while Golestan Province experiences a mean annual precipitation of 200 to 1000 mm [14], Gorgan County exhibits an approximate precipitation rate of 500 mm per annum. The mean yearly temperature in Gorgan County is approximately 18°C [15]. The research investigation encompasses 21 dairy cattle operations and 150 broiler poultry production facilities distributed throughout the study area. Figure 1 illustrates the spatial distribution of these Farms within the geographical context of the county.

Required Statistics and Data

Comprehensive statistical data were systematically collected through the Agricultural and Natural Resources Engineering Organization of Gorgan County in 2024 to support the established research objectives. The ag-

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gregated data, which form the foundational basis for this investigation, are systematically presented in Table 1.

Table 1) Required data and statistics for evaluating rainwater harvesting potential in livestock and poultry units in Gorgan county: annual precipitation, farm characteristics, and roof areas of dairy and broiler farms.

Annual precipitation in Gorgan	500 mm
Number of dairy farms	21 units
Number of broiler farms	150 units
Total capacity of dairy farms	30,450 head
Roof area of dairy farms	29,849 m^2
Total capacity of broiler farms	5,503,860 birds
Roof area of broiler farms	477,137 m^2

Table 1 shows the capacity of dairy and broiler chicken farms (considering the number of production cycles), the rainfall data for Gorgan County, and the roof surface area of dairy cattle and broiler chicken farming units, which were used to achieve the study objectives.

Water Requirements of Dairy Cattle and Broiler Chickens

The water requirements of dairy cattle exhibit significant correlations with multiple variables, including milk production efficiency, feed moisture content, and environmental parameters such as ambient temperature and relative humidity. Peak water consumption patterns in bovine species are predominantly observed during feeding intervals [16,17]. Water intake requirements for dairy cattle are systematically categorized according to two primary determinants: growth trajectory and milk production capacity. These consumption patterns have been extensively documented in the literature [16,17]. Table 2 presents a comprehensive analysis of dairy cattle water requirements, stratified by growth parameters and milk production metrics.

Table 2) Daily water consumption of a dairy cow based on key growth and milk production stages(average requirements during different lactation phases and growth periods)[16–19].

Dairy Cattle Breeds	Level of Milk Production ($kg.d^{-1}$)	Water Requirement Range ($l.d^{-1}$)	Average Typical Water Use ($l.d^{-1}$)
Dairy calves (1–4 months)	-	4.9-13.2	9
Dairy heifers (5–24 months)	-	14.4-36.3	25
Milking cows	13.6	68-83	115
	22.7	87-102	
	36.3	114-136	
	45.5	132-155	
Dry cows	-	34-49	41

Table 3) Daily water requirements of broilers based on age groups, environmental temperature, and seasonal variations [16,17].

Broiler Chicken Age (weeks)	Water Requirement ($l.d^{-1}$)			
	21°C	32°C	Winter, fall, and spring	Summer
1-4	0.05 – 0.26	0.05 – 0.415	0.28	0.45
5-8	0.345 – 0.47	0.55 – 0.77		

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This study estimated that the average daily water consumption of dairy cattle in Iran, considering the type of dairy cattle, is 115 liters.

Water consumption patterns in poultry demonstrate significant associations with feed intake parameters and ambient thermal conditions. Notably, more than 50% of poultry hydration is derived from dietary sources, while thermal stress, particularly when ambient temperatures exceed 30°C, precipitates a 50% elevation in water consumption rates [16,17]. Table 3 presents a comprehensive analysis of water consumption metrics in broiler species, delineated by age-specific cohorts, thermal gradients, and seasonal variations.

Also presented is the daily water consumption of broiler chickens as a function of their age in the form of Eq. (1)[20]:

$$DFWI = -2.78 + 4.70D + 0.128D^2 - 0.00217D^3 \quad \text{Eq. (1)}$$

where DFWI represents daily water consumption (L per 1,000 birds), and D denotes age in days.

Considering the broiler chicken rearing period in Iran and based on Table 3 and Eq. (1), broiler chickens' average daily water consumption from day 1 to day 56 was estimated at 0.2 liters daily.

Rainwater Harvesting Volume

In the present investigation, the quantitative assessment of harvested precipitation from poultry and dairy facility roofing systems was calculated through the application of Eq. (2) [21,22]:

$$I_t = R_t.A.\phi \quad \text{Eq. (2)}$$

Where I_t denotes the potential volume of harvested precipitation from the rooftop surface (m^3), ϕ represents the rooftop runoff coefficient, R_t signifies the daily precipitation magnitude measured in mm (The amount of rainfall is converted from mm to m), and A indicates the catchment surface area quantified in m^2 [23]. The runoff coefficient parameter ranges from 0 to 1.

The quantitative and qualitative characteristics of the harvested precipitation are influenced by multiple parameters, with roof surface materiality and spatial dimensions being the primary determinants [24,25]. Among various roofing materials, galvanized sheets and polymeric surfaces, owing to their enhanced surface smoothness and impermeability characteristics, constitute optimal solutions for precipitation collection systems. Concurrently, planar concrete roofing structures exhibit satisfactory performance metrics [21].

The runoff coefficient (RC) parameter, defined as the volumetric ratio between collected precipitation and total rainfall, quantitatively assesses the collection efficiency of varied surface typologies. Table 4 presents a comprehensive analysis of RC values for diverse roofing materials.

Table 4) Runoff coefficient according to roof type [21].

Type	Runoff coefficient
Galvanized iron sheets	>0.9
Tiles (glazed)	0.6-0.9
Aluminum sheets	0.8-0.9
Flat cement roof	0.6-0.7
Organic (e.g., thatched)	0.2

In this study, considering that the roofs of most broiler chicken and dairy cattle farming units are made of galvanized material, the runoff coefficient for these roofs was supposed to be 0.9, according to Table 4.

Permissible Water Quality Limits

Table 5 presents the permissible water quality limits for livestock and poultry consumption according to the German Federal Ministry of Food, Agriculture, and Consumer Protection (BMEL) recommendations.

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Table 5) Standard physical, chemical, and microbiological parameters and acceptable limits for livestock and poultry drinking water quality assessment [26].

Value	Drinking water For livestock and poultry consumption
pH	5-9
Conductivity	< 3,000 µS.cm^{-1}
Ammonium (NH_4^+)	< 3 mg.l^{-1}
Chloride (Cl^-)	< 500 mg.l^{-1}
Iron (Fe)	< 3 mg.l^{-1}
Manganese (Mn)	< 4 mg.l^{-1}
Nitrate (NO_3^-)	< 200 mg.l^{-1}
Nitrite (NO_2^-)	< 30 mg.l^{-1}
Sulfate (SO_4^-)	< 500 mg.l^{-1}
CFU at 20°C	≤ 10,000 in 1 ml
CFU at 36°C	≤ 1,000 in 1 ml
Escherichia coli	≤ 10 in 10 ml

In this research study, three samples were analyzed using laboratory conditions at Gorgan University of Agricultural Sciences and Natural Resources to evaluate rainwater quality regarding physical, chemical, and microbiological parameters. The samples were collected from existing storage tanks at this university, serving as representative specimens of rainwater harvesting systems from buildings with galvanized roofing in Gorgan County. Following collection, the samples were transported to the laboratory under completely sterile conditions, and analyses were conducted in duplicate according to the laboratory facilities and BMEL protocol parameters. Subsequently, the mean values of the results were reported.

The rainwater harvesting system implemented at this university represents the most basic system, operating without filters or treatment facilities. The collected water is utilized for irrigation of the university's green spaces. Therefore, this investigation demonstrates our hypothesis regarding the quality status of harvested water in storage tanks without treatment operations.

Research Methodology

To investigate the role of rainwater harvesting, the roofed area of livestock and poultry production units was initially obtained through the Agricultural and Natural Resources Engineering Organization of Gorgan County. Subsequently, the annual runoff volume from these units' rooftops was determined by establishing the runoff coefficient and yearly average precipitation relative to the geographical location of the livestock and poultry production facilities. Following this, considering the annual water consumption per capita for different types of livestock and poultry units (dairy cattle and broiler chickens), along with their capacity and production cycles in Iran, the volume of harvested water was calculated and presented in terms of its compensation for the total water consumption across all livestock and poultry units. Finally, to ensure greater confidence in the potential utilization of rainwater for meeting livestock and poultry consumption needs, rainwater samples were collected, analyzed for quality parameters, and compared against existing standards (Figure 2).

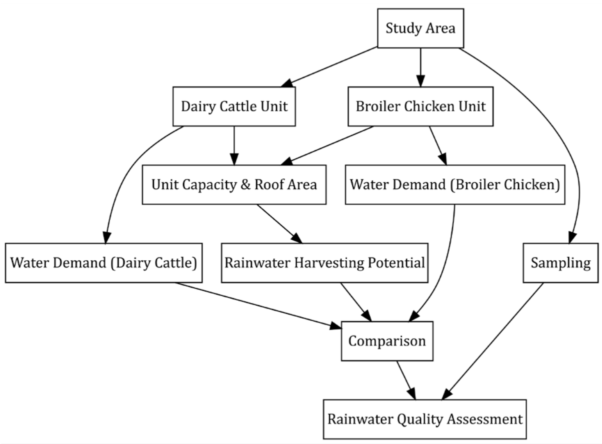

Figure 2) Flowchart of research methodology for evaluating rainwater harvesting potential in livestock and poultry facilities of Gorgan County.

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Findings

Assessment of Rainwater Harvesting Potential in Livestock and Poultry Production Facilities

The quantitative analysis in Table 6 demonstrates that the potential volumetric rainwater harvesting capacity is 214,711 $m^3.y^{-1}$ from broiler production facilities and 13,432 $m^3.y^{-1}$ from dairy cattle operations. Table 6 comprehensively delineates rainwater harvesting potential across livestock and poultry production facilities, stratified by facility type and harvesting capacity.

The Role of Rainwater Harvesting in Meeting the Per Capita Water Consumption Needs of Livestock and Poultry Farming Units

Quantitative analyses presented in Table 7 demonstrate that broiler production facilities, operating on four 56-day growth cycles annually with a mean daily water consumption rate of 0.2 liters per unit, exhibit an annual water demand of 246,572 m^3 per cycle. Furthermore, data analysis from Table 8 reveals that dairy cattle operations maintain a yearly water consumption of 1,278,138 m^3. When analyzing the contribution of harvested rainwater to total water requirements, the data indicate that rainwater harvesting systems could potentially satisfy 87.07% and 1.05% of the total annual water demand for broiler and dairy cattle facilities, respectively—tables 7 and 8 present comprehensive volumetric analyses of annual water requirements stratified by facility type.

These findings have significant implications for agricultural water management strategies. For broiler facilities, the high percentage (87.07%) suggests that rainwater harvesting could serve as a primary water source, substantially reducing reliance on conventional water supplies and potentially leading to significant cost savings. However, for dairy cattle operations, the notably lower percentage (1.05%) indicates that while rainwater harvesting could supplement existing water sources, additional water supply strategies would be necessary to meet the bulk of water demands. This stark contrast in potential coverage highlights the importance of facility-specific water management approaches. The economic viability of rainwater harvesting systems may vary significantly based on the type of agricultural operation.

Figure 3 presents a detailed comparative assessment of water consumption patterns between broiler production and dairy cattle facilities, juxtaposed with their respective potential for rainwater harvesting within their operational parameters.

Rainwater Quality Status

Table 9 presents the results of rainwater quality analysis regarding select physical, chemical, and microbiological parameters. According to this table, the rainwater quality status meets the acceptable livestock and poultry consumption standards based on the German Federal Ministry of Food, Agriculture, and Consumer Protection recommendations.

Table 6) Annual harvestable rainwater volume from roof surfaces in livestock and poultry production units of Gorgan County.

Annual precipitation (mm)	Runoff Coefficient	Roof Area of Livestock and Poultry Units (m^2)		Harvestable Rainwater Volume ($m^3.y^{-1}$)	
		Broiler chicken Units	Dairy Cattle Units	Broiler Chicken Units	Dairy Cattle Units
500	0.9*	477137	29849	214711	13432

The roofs of most dairy and poultry farms in the studied area are made of galvanized iron sheets.

Table 7) Annual water replacement requirements for broiler chicken units.

Type of Production Unit	Production Capacity	Per Capita Water Consumption ($l.d^{-1}$)	Number of Production Cycles (56 days)	Annual Water Requirement ($m^3.cycle^{-1}$)	Harvestable Rainwater Volume ($m^3.y^{-1}$)	Annual Demand Replacement (%)
Broiler Farm	5,503,860 birds	0.2*	4	246572	214711	87.07
Broiler Farm	5,503,860 birds	0.2*	3	184929	214711	116.10

* This water requirement is considered an average for a 56-day production cycle.

Table 8) Annual water replacement requirements for dairy cattle units.

Type of Production Unit	Production Capacity	Per Capita Water Consumption ($l.d^{-1}$)	Annual Water Requirement ($m^3.y^{-1}$)	Harvestable Rainwater Volume ($m^3.y^{-1}$)	Annual Demand Replacement (%)
Dairy Farm	30,450 head	115	1278138	13432	1.05

Table 9) Rainwater quality analysis results.

Value	Average of samples	Permissible Water Quality Limits
pH	6.96	5-9
TDS	192	< 300
TSS	3.096	-
Mv	-70	-
Conductivity	384	< 3,000 $\mu S.cm^{-1}$
Ammonium (NH_4^+)	0.01	< 3 $mg.l^{-1}$
Chloride (Cl^-)	0.609	< 500 $mg.l^{-1}$
Iron (Fe)	0.016	< 3 $mg.l^{-1}$
Manganese (Mn)	0.39	< 4 $mg.l^{-1}$
Nitrate (NO_3^-)	0.05	< 200 $mg.l^{-1}$
Nitrite (NO_2^-)	0.08	< 30 $mg.l^{-1}$
Sulfate (SO_4^-)	19	< 500 $mg.l^{-1}$
CFU at 20°C	800	≤ 10,000 in 1 mL
CFU at 36°C	9000	≤ 1,000 in 1 mL
N.T.U	3.4	1-5

However, it is essential to note that the microbiological parameter of CFU (Colony Forming Units) in the rainwater sample, measured at 36°C, exceeds the permissible limit. The standard for CFU at 36°C is ≤ 1,000 CFU per milliliter, while the measured value in the sample is 9,000 $CFU.ml^{-1}$. This indicates a higher level of microbial contamination, which could pose health risks if the rainwater were used for livestock or poultry consumption without appropriate treatment. This is primarily due to the type of sampling tanks used, which are simple reservoirs without filtration and treatment facilities and are mainly intended for irrigation purposes in the university's green spaces.

Discussion

Extensive research findings in rainwater harvesting in broiler poultry farms indicate the significant potential of this method. Our research results demonstrate that in broiler farms with four breeding cycles, rainwater harvesting can supply 87.07 percent of the annual water demand, indicating this method's remarkable efficiency in reducing dependency on other water resources. These findings align with numerous international studies. For instance, Chung et al. confirmed in their research that rainwater harvesting effectively reduces poultry farms' dependence on conventional water resources [27]. In our study, the obtained percentage in compensating for water requirements could

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substantiate this reasoning. Furthermore, the findings of Hoss et al. demonstrate even more promising results, emphasizing that rainwater harvesting systems can meet 100 percent of poultry farms' water requirements [3].

This conclusion aligns with Barker's study, which emphasizes the significance of rainwater harvesting in cost reduction and improved water resource management [28]. This scientific evidence demonstrates that rainwater harvesting systems efficiently meet water demands and play a vital role in sustainable water resource management by optimizing rainwater collection and reducing dependence on other water sources. This approach can serve as an effective model for the conservation and sustainable utilization of water resources across various poultry industry sectors. Shokati et al. concluded that rainwater harvesting systems reduce pressure on renewable water resources [5].

However, a significant difference was observed in meeting water requirements in dairy farms compared to poultry farms. Our research analysis indicates that rainwater only supplies 1.05 percent of the annual water demand, which appears negligible considering the high volume of water consumption in dairy farms. These findings are inconsistent with numerous international studies. For instance, Napierała et al. confirm that rainwater harvesting from livestock farms as an innovative solution can meet 15 percent of livestock water requirements [12], and Hoss et al. demonstrate that rainwater harvesting systems can supply between 32.7 to 68.3 percent of livestock farms' water demands [3].

Numerous studies support the potential of rainwater harvesting as a supplementary water source in dairy farms. For instance, Muhirirwe et al. stated in their research that rainwater harvesting for dairy cattle consumption can be an economical solution with a short payback period, particularly beneficial for farmers in low-income regions [29]. Furthermore, from an economic perspective, the study by Kılıç et al. demonstrated that harvesting rainwater from stable roofs can meet a significant portion of water requirements and is also financially viable, with initial costs recoverable within 7 years [10]. This scientific evidence indicates that despite the relatively small contribution of rainwater to meeting dairy farms' water needs, implementing rainwater harvesting systems as a supplementary source can play a significant role in their water resource sustainability and prove particularly effective during drought conditions.

Given that the qualitative challenges of rainwater must be addressed, the quality analysis results of collected samples in this study indicate that rainwater from tanks without filtration and treatment processes meets acceptable standards by the recommendations of the German Federal Ministry of Food, Agriculture and Consumer Protection [26]. These findings align with Eratalar & Kaveci's Research, which demonstrated that rainwater usage has no adverse effects on broiler chicken performance and can serve as a suitable alternative to plunging, healthy water, thus assuring its implementation in poultry facilities. However, numerous sources suggest that harvested rainwater requires treatment, which may be attributed to regional conditions, the type of rainwater harvesting system, and the collection environment conditions [9]. For example, Tobin Is somewhat acidic, necessitating treatment before use [30].

Rahman et al. The quality of rainwater was examined and found satisfactory according to Bangladesh standards [31]. Similarly, Kasmin et al. Stated that rainwater harvesting can be used as drinking water [32]. However, the conflicting results in studies on rainwater quality highlight the need for more com-

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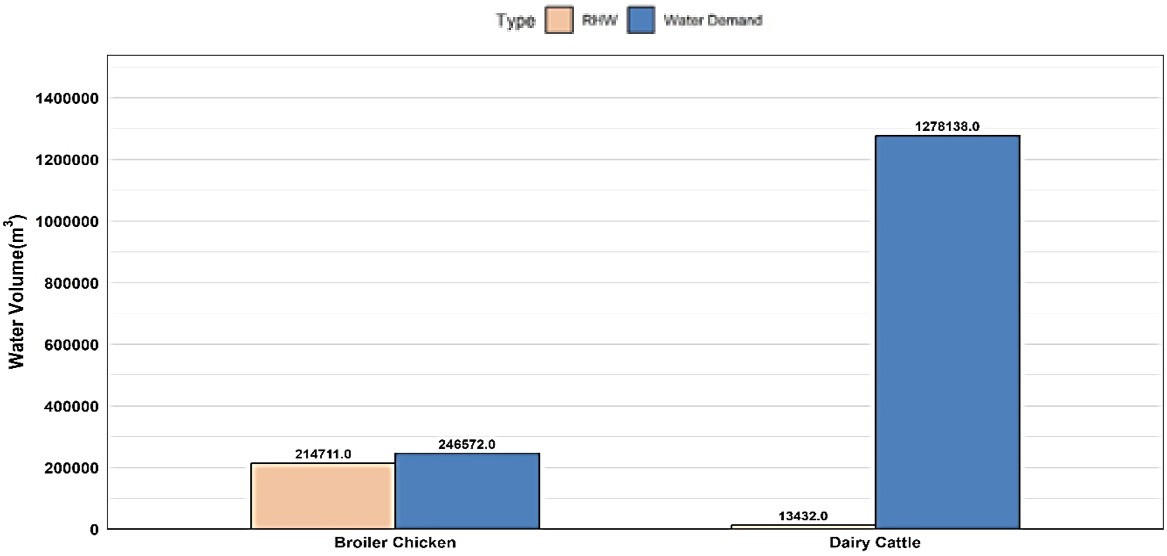

Figure 3) Diagram of the role of rainwater harvesting in compensating for the water demand of broiler chicken and dairy cattle units.

prehensive research into rainwater quality and its effects on growth processes. Nevertheless, Despins et al. This indicates that selecting appropriate materials for storage and collection and utilizing treatment methods can maintain high water quality in rainwater harvesting systems [33]. Additionally, Mohajan Emphasized that untreated rainwater is generally unsuitable for drinking and may be contaminated [34]. Abuelfutouh et al. Evaluated rainwater parameters and concluded that the water quality is within acceptable ranges but still unsuitable for direct consumption without further treatment [35]. This study aligns with our findings regarding rainwater quality assessment. Nonetheless, considering the ongoing water crisis, even with treatment costs, harvested rainwater can be more economically viable than piped water. However, according to studies, Various factors can influence the acceptance of rainwater harvesting systems [36-39].

Limitations of this study include the lack of assessment of the economic aspects of implementing rainwater harvesting systems and the absence of long-term evaluations of their impacts on the performance of livestock and poultry units. Future studies are recommended to conduct a comprehensive cost-benefit analysis of implementing these systems and investigate the effects of different seasons and climate variations on the volume of harvested rainwater and the quality of rainwater in livestock production.

Overall, this study's results demonstrate that rainwater harvesting can effectively manage water resources in livestock and poultry farming units, particularly in the poultry sector. These findings can inform policy-making on water resource management in livestock and poultry operations and help design sustainable solutions to the water scarcity crisis.

Conclusion

This investigation examined the efficacy of rainwater harvesting systems in addressing water requirements within dairy cattle and broiler chicken facilities in Gorgan County. The empirical findings demonstrate significant heterogeneity in harvesting effectiveness across different agricultural production units. The methodology exhibits a substantial capacity for meeting annual water demands in broiler chicken facilities, indicating considerable

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potential for reducing dependency on conventional water resources. This observation represents a potentially transformative development in water resource management protocols within the poultry sector. Conversely, analysis of dairy operations reveals that rainwater harvesting systems contribute minimally to annual water requirements, suggesting their optimal utilization as supplementary water sources within a comprehensive resource management framework. This marked disparity can be attributed to dairy operations' substantially higher volumetric water consumption patterns. The research findings collectively demonstrate that rainwater harvesting systems represent a viable, sustainable water resource management strategy, particularly within poultry production facilities.

These findings could provide a foundation for developing management policies and practical strategies to reduce reliance on conventional water sources and address the water scarcity crisis. Policymakers can create the use of rainwater harvesting systems in industrial and agricultural units by establishing technical standards and guidelines for the use, design, and installation of these systems, as well as providing incentive and educational programs. This can reduce the dependence on conventional water resources and contribute to agriculture's sustainability. Additionally, it is recommended that the operators of industrial and agricultural units consider rainwater harvesting systems as a recognized and reliable solution, given the country's water crisis. However, it is recommended that future studies explore the qualitative aspects of rainwater harvesting, the economic implications of implementing these systems, and the impact of seasons, months, and climatic changes on the potential for rainwater harvesting.

Authors Contributions

Seyed Pedram Nainiva: Idea generation, defining concepts, Article writing, performing calculations, and revising content. **Marym Mohammadrezaei:** Article writing (Introduction and Discussion), reviewing references, and revising content. **Kosar Ghezelsefli**: data collection and correspondence with the Agricultural and Natural Resources Engineering Organization. **Mostafa Hosseinabadi:** Scientific supervision, **Taghi Ghoorchi:** Scientific supervision

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Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

Data and information supporting this study's findings are available from the corresponding author upon reasonable request. Upon submission of such a request, the concerned person/ people will be provided with all relevant data and spatial layers utilized in this article.

Use of Generative AI and AI-assisted Technologies

No generative AI or AI-assisted technologies were employed in preparing this manuscript; the authors used only Grammarly Premium software to improve the translation from Persian to English.

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