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Water quality effects on germination of okra seed (*Abelmoschus esculentus* L.)

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Water quality effects on germination of okra seed (*Abelmoschus esculentus* **L.**)

Abstract: This study, conducted at Bakrajo Technical Institute in 2023, assessed the water quality of 24 resources using the Irrigation Water Quality Index (IWQI). Results revealed two categories: "Excellent" (19 resources, IWQI 91.4-96.5) and "Good" (5 resources, IWQI 70-90). Water in the "Excellent" category was highly suitable for irrigation, while the "Good" category was of lower quality but still acceptable. Electrical conductivity (EC) was identified as a key factor influencing the IWQI, with higher EC correlating with lower water quality. Principal Component Analysis (PCA) and Agglomerative Hierarchical Clustering (AHC) were used to classify resources based on cation, anion, and heavy metal content. A negative correlation between EC and IWQI emphasized the importance of monitoring EC for irrigation purposes. The study also found weak, non-significant correlations between pH, EC, and germination ratio, but noted that higher IWQI values and lower EC levels generally promoted better seed germination. The findings highlight the value of advanced models in water quality classification, offering essential insights for agricultural water management.

Key words: water quality, germination ratio, okra, irrigation water, pH, EC

Kakovost vode vpliva na kalitev semen jedilnega osleza (*Abelmoschus esculentus* **L.**)

Izvleček: V raziskavi, izvedeni na Bakrajo Technical Institute, v letu 2023 je bila ocenjena kakovost 24 vodnih virov z indeksom kakovosti vode (IWQI). Rezultati so odkrili dve kategoriji, "odlična" (19 virov, IWQI 91.4-96.5) in "dobra" (5 virov, IWQI 70-90). Voda iz virov "odlična" je bila zelo primerna za namakanje, med tem, ko je bila voda iz kategorije "dobra" slabše kakovosti vendar še sprejemljiva. Električna prevodnost (EC) je bila prepoznana kot ključni dejavnik, ki vpliva na indeks kakovosti vode (IWQI), pri čemer so večje vrednosti EC korelirale s slabšo kakovostjo vode. Analiza glavnih komponent (PCA) in hierarhično aglomerativno grozdenje (AHC) sta bila uporabljena za klasifikacijo vodnih virov glede na vsebnost kationov, anionov in težkih kovin. Ugotovljena je bila negativna korelacija med EC in IWQI, kar poudarja pomen monitoringa EC za namene namakanja. Raziskava je tudi odkrila šibko, neznačilno povezavo med pH, EC in deležem kalitve, pri čemer so večje vrednosti IWQI in manjše vrednosti EC navadno pospeševale boljšo kalitev. Ta odkritja pojasnjujejo vrednost naprednejših modelov pri klasifikaciji kakovosti vod in ponujajo bistven vpogled v kmetijsko upravljanje z vodo.

Ključne besede: kakovost vode, kalitev, jedilni oslez, voda za namakanje, pH, EC

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1 INTRODUCTION

Water quality plays a crucial role in determining both agricultural productivity and the overall health of ecosystems. It directly impacts plant growth, germination, and the subsequent development of crops, influencing both yield and quality (Yuan et al., 2024: Wakchaure et al., 2023). The importance of water in agriculture is underscored by its effect on various physiological processes within plants, such as nutrient uptake, photosynthesis, and transpiration. For crops like okra (*Abelmoschus esculentus* L.), which is widely cultivated in tropical regions, water quality can significantly alter germination rates and early vegetative growth, ultimately affecting overall crop performance. Okra is a staple vegetable in many countries, with a global cultivation area of approximately 2.5 million hectares, yielding 10.5 million tons annually (Ibrahim, 2024): Food and Agriculture Organization of the United Nations, 2018).

Seed priming, a pre-sowing treatment of seeds using water or other solutions, is an important technique to enhance germination and improve early seedling growth. When combined with high-quality irrigation water, seed priming has been shown to accelerate seedling emergence, leading to more robust and healthy plants. Water quality, defined by parameters such as salinity, pH, dissolved oxygen, and presence of contaminants, directly affects seed priming outcomes. Numerous studies have demonstrated that water with high salinity or other undesirable characteristics can hinder seedling emergence and reduce crop yields. Okra is not only valuable for its role in agriculture but also an important source of nutrition, providing essential vitamins, minerals, and dietary fiber. Given the crop's significance, understanding how different water qualities impact okra germination and seedling development is vital for optimizing agricultural practices, particularly in regions where water resources may be limited or of varying quality. Previous studies have highlighted the influence of water quality on seed germination and vegetative growth across different regions (Rima, 2021).

The aim of the present research is to assess the water quality from 25 different water resources, classifying the irrigation water based on the Sulaimani Irrigation Water Quality Index (SIWI) proposed by Marif and Esmael (2023), as well as the classification system by Todd (1966). Additionally, this study utilizes advanced statistical techniques such as Principal Component Analysis (PCA) and Cluster Analysis to classify the water resources further and investigate their impact on okra seed germination. This research will provide a comprehensive understanding of how various water qualities influence the early

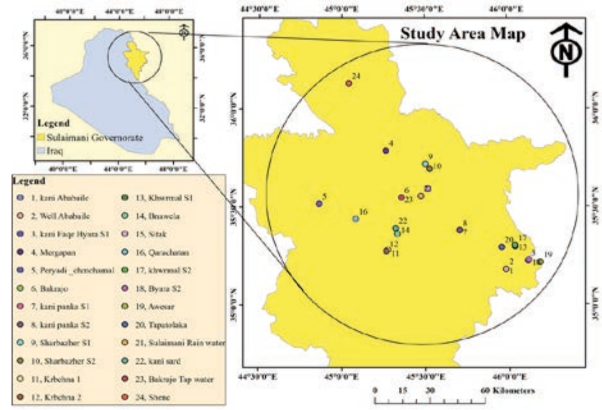

Figure 1: Study Area Map

Tabel 1: Study area description and GPS Coordination's

No.	Location	GPS Coordinate		Altitude
1	Kani Ababaile	35.18235	45.98377	915
2	Well Ababaile	35.18235	45.98377	910
3	Kani Faqe Byara S1	35.2250909	46.11599645	1087
4	Mergapan	35.78892	45.26581	1226.85
5	Peryadi _chmchamal	35.51728	44.86407	697.58
6	Bakrajo	35.550052	45.358326	743.36
7	Kani panka S1	35.3816374	45.7082884	549
8	Kani panka S2	35.3816374	45.7082884	549
9	Sharbazher S1	35.720167	45.502614	827.28
10	Sharbazher S2	35.695679	45.528932	846.55
11	Krbchna 1	35.283103	45.276888	989
12	Krbchna 2	35.27582	45.26 786	933
13	Khwrmal S1	35.2971744	46.03963419	567
14	Bnawela	35.3647.1	453351.2	1130
15	Sitak	35.593677	45.517543	1126
16	Qarachatan	354410.3	450842.2	807
17	Khwrmal S2	35.30378	46.03852	567
18	Byara S2	35.23021	46.1212	1117
19	Awesar	35.21647	46.18916	1671
20	Tapatolaka	35.29402	45.95852	508
21	Sulaimani Rain water	35.557215	45.47464	1002
22	Kani sard	35.3932.4	453229	896
23	Bakrajo Tap water	35.550052	45.358326	743.36
24	Shene	36.1327	450425	570

stages of okra cultivation and offer insights into improving irrigation practices for better crop performance.

2 MATERIALS AND METHODS

2.1 STUDY AREA

The research was conducted at the Bakrajo Technical Institute Field, located in the Sulaimani Governorate of the Kurdistan Region, Iraq. This field site is situated in Sulaimani City, which lies at an elevation of 888 meters above sea level. The geographical coordinates of the location are approximately 35.39705° N latitude and 45.28260° E longitude, as shown in Figure 1 and detailed in Table 1. The specific location's altitude and geographic position are important factors in determining the climate, soil conditions, and overall environmental characteristics of the study area, all of which play significant roles in influencing the results and interpretation of the research. Sulaimani's climate is influenced by its semi-

Table 2: Water cations and anions analysis

No.	Location	PH	EC dS m^{-1}	TDS mS.cm^{-1}	Na %	Ca^{2+} mg l^{-1}	Mg^{2+}	Na^{+}	K^{+}	CO_3^{-}	HCO_3^{-}	SO_4^{--}	Cl^{-}	NO_3^{-}
1	Kani Ababaile	7.3	0.58	368.36	8.0	1.14	1.083	0.172	0.021	0	1.967	0.219	0.014	0.013
2	Well, ababaile	7.1	0.57	362.83	9.1	1.28	1.156	0.234	0.010	0	1.901	0.474	0.199	0.018
3	Kani Faqe Byara S1	7.1	0.54	346.58	8.8	1.17	1.142	0.179	0.044	0	1.820	0.215	0.243	0.075
4	Mergapan	7.1	1.01	645.67	9.1	2.20	1.190	0.335	0.006	0	1.059	1.310	1.029	0.171
5	Shwan _chmchamal	7.2	0.83	533.85	14.5	1.48	1.124	0.397	0.044	0	1.803	0.077	1.086	0.065
6	Bakrajo	7.3	1.02	649.64	12.8	1.20	1.125	0.190	0.151	0	1.984	0.216	0.329	0.021
7	Kani panka S1	7.4	0.54	344.13	3.5	1.65	1.250	0.101	0.005	0	1.984	0.500	0.429	0.013
8	Kani panka S2	7.3	0.60	386.82	4.5	1.30	1.100	0.108	0.006	0	1.746	0.328	0.191	0.013
9	Shakhasur	7.1	0.45	288.45	6.5	1.24	1.138	0.158	0.008	0	1.910	0.191	0.286	0.022
10	Sharbazher tagaran	7.2	0.44	284.50	6.6	1.30	1.243	0.165	0.014	0	1.929	0.654	0.029	0.032
11	Krbchna 1	7.3	1.48	946.58	16.7	1.95	1.821	0.219	0.536	0	1.115	1.890	1.186	0.129
12	Krbchna 2	7.2	0.70	450.67	3.5	1.35	1.123	0.087	0.003	0	1.931	0.431	0.091	0.023
13	Khwrmal S1	7.1	1.99	1273.61	6.8	2.10	2.103	0.248	0.059	0	1.459	1.550	1.229	0.177
14	Bnawela	7.2	0.69	443.46	5.8	1.30	1.271	0.148	0.010	0	1.820	0.595	0.029	0.022
15	Sitak	7.1	0.74	475.24	8.9	1.12	1.283	0.220	0.015	0	1.900	0.088	0.629	0.013
16	Qarachatan	7.3	0.43	275.03	4.0	1.31	1.212	0.078	0.026	0	1.787	0.398	0.243	0.083
17	Khwrmal S2	7.2	0.50	318.08	19.0	1.81	1.159	0.626	0.070	0	1.838	0.763	0.571	0.099
18	Byara S2	7.1	0.52	329.94	4.7	1.23	1.010	0.104	0.006	0	1.484	0.475	0.243	0.025
19	Awsar	7.1	0.37	237.74	8.1	1.05	0.890	0.143	0.028	0	1.203	0.805	0.029	0.043
20	Tapatolaka	7.2	0.58	372.74	8.8	1.393	0.910	0.200	0.023	0	1.216	0.683	0.322	0.324
21	Rain water	7.1	0.34	218.88	2.2	1.1	0.920	0.030	0.014	0	1.323	0.353	0.280	0.028
22	Kani sard	7.2	0.32	204.80	6.0	0.7	0.430	0.059	0.013	0	0.436	0.446	0.186	0.048
23	Bakrajo Tap water	7.3	0.25	162.56	10.3	0.411	0.410	0.082	0.012	0	0.492	0.165	0.169	0.063
24	Shene	7.1	0.321	205.44	8.5	0.332	0.367	0.054	0.011	0	0.321	0.210	0.154	0.043

Table 3: Water heavy metals analysis

		Fe	Mn	Cu	Co	Ni	Zn	Cd	Cr
No	Location	mg l-1							
1	Kani Ababaile	0.011	0.036	0.02383	0.00150	0.007	0.016	0.00090	0.00156
2	Well ababaile	0.014	0.020	0.01257	0.00105	0.004	0.012	0.00326	0.00152
3	Kani Faqe Byara S1	0.019	0.033	0.02368	0.00201	0.005	0.002	0.00427	0.00300
4	Mergapan	0.031	0.046	0.02214	0.00213	0.005	0.012	0.00105	0.00190
5	Shwan _chmchamal	0.022	0.029	0.02334	0.00195	0.006	0.003	0.00166	0.00115
6	Bakrajo	0.025	0.004	0.03474	0.00184	0.007	0.006	0.00179	0.00210
7	Kani panka S1	0.057	0.014	0.01360	0.00415	0.001	0.046	0.00215	0.00331
8	Kani panka S2	0.016	0.032	0.02377	0.00120	0.004	0.001	0.00158	0.00393
9	Shakhasur	0.017	0.026	0.02286	0.00117	0.004	0.001	0.00275	0.00104
10	Sharbazher tagaran	0.014	0.026	0.01256	0.00111	0.004	0.03110	0.00569	0.00211
11	Krbchna 1	0.045	0.037	0.02890	0.00166	0.001	0.00164	0.00244	0.00664
12	Krbchna 2	0.023	0.016	0.03490	0.00156	0.005	0.00532	0.00530	0.00332
13	Khwrmal S1	0.033	0.039	0.02225	0.00174	0.003	0.00131	0.00353	0.00091
14	Bnawela	0.002	0.023	0.01124	0.00190	0.002	0.00210	0.00231	0.00100
15	Sitak	0.013	0.039	0.01560	0.00138	0.037	0.00313	0.00174	0.00125
16	Qarachatan	0.010	0.014	0.01856	0.00112	0.001	0.00210	0.00171	0.00210
17	Khwrmal S2	0.013	0.038	0.01530	0.00110	0.001	0.00132	0.00217	0.00132
18	Byara S2	0.007	0.002	0.01260	0.00200	0.002	0.00142	0.00132	0.00142
19	Awsar	0.024	0.023	0.01220	0.00416	0.004	0.00673	0.00388	0.00273
20	Tapatolaka	0.029	0.034	0.01490	0.00125	0.006	0.00598	0.00129	0.00218
21	Rain water	0.022	0.033	0.02230	0.00118	0.003	0.00031	0.00140	0.00031
22	Kani sard	0.019	0.035	0.01410	0.00108	0.003	0.00104	0.00138	0.00144
23	Bakrajo Tap water	0.003	0.039	0.01530	0.00196	0.002	0.00091	0.00126	0.00091
24	Shene	0.016	0.034	0.01250	0.00110	0.002	0.00560	0.00135	0.05600

arid conditions, with distinct seasonal variations that can impact agricultural practices and ecological studies. These geographic and climatic features, combined with the region's unique environmental factors, provide valuable insights into the scope of the research, highlighting the importance of this field site in understanding local agricultural systems, climate adaptation, and ecological sustainability in the context of the Kurdistan Region.

2.2 WATER SAMPLING COLLECTING

The water sampling process for evaluating the water quality index in this research followed these steps:

First step: Water samples were collected from 24 different locations or wells (labeled 1 to 24) in the study area. These samples were analyzed and compared based on their electrical conductivity (EC) and pH values.

Second step: A total of 24 water samples were selected for the study.

Third step: The water from the 24 selected wells or water resources was tested for physicochemical properties and some heavy metals. Additionally, 24 of these samples were used for germination experiment with okra seeds. The samples were classified according to various methods outlined in Tables 2 and 3. Each water sample was collected in a 1.5-liter container for physicochemical analysis and was also used for germinating okra seeds in the laboratory at Bakrajo Technical Institute, maintained at a temperature of 25 °C.

2.3 WATER ANALYSIS AND COMPUTING THE IRRIGATION WATER QUALITY INDEX (IWQI).

The water analysis was conducted as follows:

2.3.1 pH and electrical conductivity (EC) measurement

A portable pH meter (Hanna pH H 98107) was used to measure the pH of the water sample, and an EC meter (HI981311) was employed to determine the electrical conductivity, following the standard methods described in the APHA (1998) guidelines for water quality analysis.

2.3.2 Cation and anion analysis

The concentrations of various cations calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^{+}), and sodium (Na^{+})) and anions carbonate (CO_3^{2-}, bicarbonate (HCO_3^{-}), sulfate (SO_4^{2-}), nitrate (NO_3^{-}), and chloride (Cl^{-})) were measured to assess the chemical composition of the water.

2.3.3 Heavy metal concentration analysis

The concentrations of heavy metals, including cobalt (Co^{2+}), copper (Cu^{2+}), iron (Fe^{2+}), manganese (Mn^{2+}), zinc (Zn^{2+}), chromium (Cr^{2+}), cadmium (Cd^{2+}), and nickel (Ni^{2+}), were determined using a Shimadzu ICP-9820 inductively coupled plasma atomic emission spectrometer (ICP-AES), made in Japan, which is capable of detecting trace amounts of these metals in the water. The results from these analyses are summarized in Table 3.

2.4 GERMINATION RATIO CALCULATIONS

A germination assessment is often the most reliable method to evaluate whether a seed is ready for planting. For this particular test, local varieties of okra seeds were used. Germination in these seeds typically begins after approximately 4 days, provided that the seeds are kept under optimal temperature and humidity conditions. The germination rate can be calculated using a specific equation, which helps to quantify the proportion of seeds that successfully sprout. The data collected during this experiment is summarized in Table 4, where the calculated germination ratio is recorded for each observation. This test is essential for determining the viability of the seeds before planting.

$$Germination\ ratio\% = \frac{Number\ of\ germination\ seeds}{Number\ of\ all\ seeds} \times 100 \quad \text{.............................. (1)}$$

2.5 IRRIGATION WATER QUALITY CALCULATION

2.5.1 Irrigation water quality calculation according to modified SIWi 2023 (Marif and Esmael, 2023)

The irrigation water quality calculation, according to the modified SIWi 2023 as modified by (Marif and Esmael, 2023), involves a detailed analysis of several water quality parameters, including salinity, pH, sodium, chloride, and other essential factors that affect crop growth and soil health. This method incorporates updated thresholds and classifications to assess the suitability of water for irrigation, ensuring its compatibility with specific soil types and crop needs. In this context, the quality of irrigation water is categorized based on these criteria, which are then cross-referenced with the standards listed in Table 5 of the modified SIWi 2023. This table provides a classification system that ranks water quality into different categories, helping to determine whether the water is suitable for different agricultural purposes, these calculations and classifications are critical for managing

Table 4: Germination ratio of the study area

No	Location	Germination Ratio %
1	Kani Ababaile	88.3
2	Well ababaile	90
3	Kani Faqe Byara S1	86.5
4	Mergapan	87.0
5	Shwan _chmchamal	85
6	Bakrajo	88
7	Kani panka S1	81.7
8	Kani panka S2	80
9	Shakhasur	83.0
10	Sharbazher tagaran	85.0
11	Krbchna 1	86.67
12	Krbchna 2	88.3
13	Khwrmal S1	81.0
14	Bnawela	82.0
15	Sitak	80.0
16	Qarachatan	83.3
17	Khwrmal S2	79
18	Byara S2	83.0
19	Awesar	91.7
20	Tapatolaka	88.3
21	Rain water	92
22	Kani sard	83.3
23	Bakrajo Tap water	88.3
24	Shene	87.0

Table 5 Irrigation water quality calculation according to modified SIWi 2023(Marif and Esmael, 2023)

No	Location	IWQI	Classes
1	kani Ababaile	92.1	Excellent
2	Well Ababaile	93.8	Excellent
3	kani Faqe Byara S1	93.1	Excellent
4	Mergapan	90.9	Good
5	Shwan _chmchamal	91.4	Excellent
6	Bakrajo	89.7	Good
7	kani panka S1	84.4	Good
8	kani panka S2	92.4	Excellent
9	Shakhasur	94.0	Excellent
10	sharbazher tagaran	93.3	Excellent
11	Krbchna 1	86.4	Good
12	Krbchna 2	91.5	Excellent
13	Khwrmal S1	85.5	Good
14	Bnawela	93.8	Excellent
15	Sitak	92.3	Excellent
16	Qarachatan	94.7	Excellent
17	khwrmal S2	92.5	Excellent
18	Byara S2	96.0	Excellent
19	Awesar	94.9	Excellent
20	Tapatolaka	92.5	Excellent
21	Rain water	95.0	Excellent
22	kani sard	96.5	Excellent
23	Bakrajo Tap water	96.3	Excellent
24	Shene	91.4	Excellent

Table 6: Irrigation water quality classification according (Todd,1966)

No	Location	Classes
1	kani ababaile	Suitable for Irrigation
2	well ababaile	Suitable for Irrigation
3	kani faqe byara s1	Suitable for Irrigation
4	Mergapan	Suitable for Irrigation
5	shwan _chmchamal	Suitable for Irrigation
6	Bakrajo	Suitable for Irrigation
7	kani panka s1	Suitable for Irrigation
8	kani panka s2	Suitable for Irrigation
9	Shakhasur	Suitable for Irrigation
10	sharbazher tagaran	Suitable for Irrigation
11	krbchna 1	Suitable for Irrigation
12	krbchna 2	Suitable for Irrigation
13	khwrmal s1	Suitable for Irrigation
14	Bnawela	Suitable for Irrigation
15	Sitak	Suitable for Irrigation
16	Qarachatan	Suitable for Irrigation
17	khwrmal s2	Suitable for Irrigation
18	byara s2	Suitable for Irrigation
19	Awesar	Suitable for Irrigation
20	Tapatolaka	Suitable for Irrigation
21	rain water	Suitable for Irrigation
22	kani sard	Suitable for Irrigation
23	bakrajo tap water	Suitable for Irrigation
24	Shene	Suitable for Irrigation

irrigation practices, preventing soil degradation, and maximizing crop yield.

2.6 DATA ANALYSIS

The data were analyzed using XLSTAT 2019.2.2.59614, a comprehensive statistical software tool. Principal Component Analysis (PCA) was applied to reduce the dimensionality of the data while retaining its most significant features, helping to uncover patterns and structure in complex datasets. Agglomerative Hierarchical Clustering (AHC) was also utilized to group similar data points based on their characteristics, allowing for the identification of distinct clusters or patterns within the data. Additionally, correlation analysis was performed to examine the relationships between various variables, helping to understand the strength and direction of their associations. Together, these analytical methods provided a thorough exploration of the data, generating valuable insights for further interpretation and decision-making.

3 RESULTS AND DISCUSSIONS

3.1 CLASSIFICATION OF WATER RESOURCES ACCORDING TO MODIFIED SIWI (MARIF & ESMAEL, 2023)

The study results classify the water resources into two distinct quality categories based on the Irrigation Water Quality Index (IWQI). Nineteen of the resources were categorized as "Excellent" for irrigation, demonstrating IWQI values above 90, with individual values ranging from 91.4 to 96.5, indicating that these water sources are highly suitable for agricultural use. These resources, spread across various locations (1, 2, 3, 5, 8, 9, 10, 12, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, and 24), exhibit optimal quality for irrigation, as reflected in their consistently high IWQI scores. In contrast, five water sources (locations 4, 6, 7, 11, and 13) were classified as "Good," with IWQI values between 70 and 90, indicating that they are still suitable for irrigation but with slightly lower quality compared to the "Excellent" category. These lower IWQI scores correspond to higher electrical conductivity (EC) values, as seen in the data, with EC emerging as a key factor influencing water quality. Specifically, the study found that water resources with lower EC values tended to have higher IWQI scores, while those with higher EC values showed lower IWQI values. This pattern is consistent with findings from Dhaoui et al. (2023) and Benaafi et al. (2024), which also identified a strong correlation between EC levels and IWQI, underlining the critical role of EC in evaluating the suitability of water for irrigation purposes. This classification provides valuable insights into the variability of water quality across different locations and highlights the importance of monitoring EC as a predictor of irrigation water suitability.

3.2 CLASSIFICATION OF WATER RESOURCES ACCORDING TO ACCORDING (TODD,1966)

Water classification results indicated that all water resources (1, 2, 3, 4, ... to 24) were initially considered suitable for irrigation, with no variation observed across the resources. However, upon comparing the findings to the classification framework proposed by Todd (1966), it was evident that recent studies have led to significant changes in water classification due to the inclusion of additional parameters and updated models for calculating the Irrigation Water Quality Index (IWQI). These changes in classification can be attributed to the introduction of more comprehensive criteria for assessing water quality, which in turn influenced the classification of water resources. The results presented in Table 6 align with recent research conducted by Mahammad and Islam (2024), as well as Laaraj et al. (2024), which highlights the evolving nature of water classification models as they adapt to new data and methodologies. This shift underscores the importance of using more advanced and detailed models to accurately reflect the quality and suitability of water resources for irrigation purposes, as these models provide a more nuanced understanding of water quality and its potential impact on agricultural practices.

3.3 CLASSIFICATION OF WATER RESOURCES ACCORDING TO CATIONS AND ANIONS USING PRINCIPAL'S COMPONENT ANALYSIS PCA

The classification of 24 water resources based on their cation and anion content using Principal Component Analysis (PCA) reveals significant insights into water quality variations across different locations. As shown in Figure 2, the water resources are divided into seven distinct classes, each represented by a unique shape. Class 1, depicted by a left arrow shape, corresponds to water resource number 13. Class 2, represented by a north arrow shape, includes water resource number 11. Class 3, with a circle shape, includes water resources 4 and 17. Class 4, represented by a pentagon shape, is assigned to water resource number 20. Class 5, with a cylinder shape, corresponds to water location number 19. Class 6, represented by a triangle shape, groups water resources 22, 23, and 24. Finally, Class 7, depicted by a square shape, includes a broad range of water locations, including 1, 2, 3, 5, 6, 7, 8, 9, 10, 12, 14, 15, 16, 18, and 21. PCA analysis indicates that Factor 1 (F1) accounts for 48.17 % of the variation in water classification, while Factor 2 (F2) explains 14.53 %, together making up 62.70 % of the total variance. These findings are consistent with recent studies by Hammoumi et al. (2024), Arıman et al. (2024), and Ali et al. (2024), which similarly applied PCA to classify water resources, highlighting the effectiveness of this statistical approach in understanding water quality and variability across different regions. This analysis emphasizes the substantial influence of the first factor (F1), suggesting that cation-anion concentrations are the primary determinants in classifying water resources.

3.4 CLASSIFICATION OF WATER RESOURCES ACCORDING TO CATIONS AND ANIONS USING AGGLOMERATIVE HIERARCHICAL CLUSTERING (AHC)

The classification of water resources according to their cation and anion concentrations using Agglomerative Hierarchical Clustering (AHC) provides a structured approach to grouping water samples based on their chemical composition. As shown in Table 7 and Figure 3, the AHC analysis divided the water resources into five distinct classes. Class 1, which includes 16 water resources (locations 1, 2, 3, 7, 8, 9, 10, 16, 17, 18, 19, 20, 21, 22,

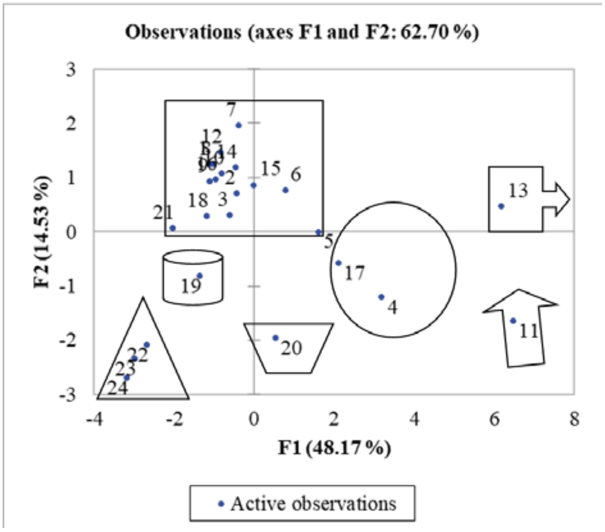

Figure 2: Classification of water resources according to cations and anions using principal's component analysis PCA

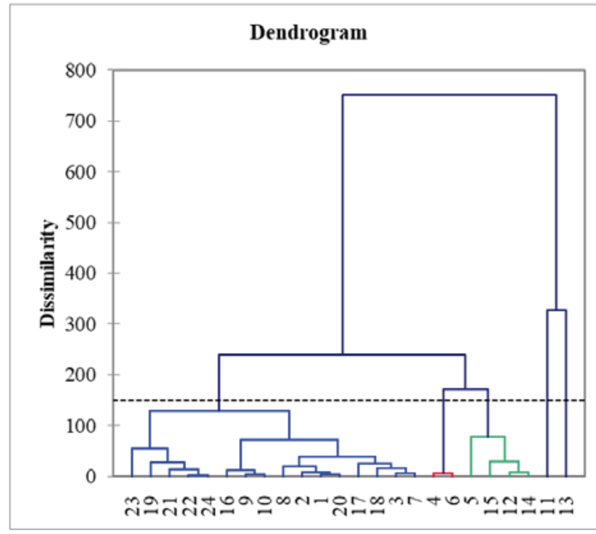

Figure 3: Classification of water resources according to cations and anions using agglomerative hierarchical clustering (AHC)

23, and 24), exhibited relatively low variation in terms of ion concentration. In contrast, Classes 2 and 3 each included fewer resources, with Class 2 comprising only locations 4 and 6, and Class 3 encompassing resources 5, 12, 14, and 15. Both Class 4 and Class 5 contained only one water resource each, located at positions 11 and 13, respectively. The lower variation observed in Classes 1 and 3 suggests a more homogeneous ionic composition, whereas the higher variation in Classes 4 and 5 can be attributed to the greater influence of electrical conductivity (EC), which likely caused more significant differentiation in the clustering. The impact of EC on water classification is well-documented in previous studies (Marif and Esmail, 2023; Mishra et al., 2023; Djaafri et al., 2024), supporting the findings of this research. This clustering technique thus underscores the complex interplay of cations, anions, and EC in determining the quality and characteristics of water resources.

Table 7: Classification of water resources according to cations and anions using agglomerative hierarchical clustering (AHC)

Classes	Class 1	Class 2	Class 3	Class 4	Class 5
Number of classes	16	2	4	1	1
Water Resources or Locations	1, 2, 3, 7, 8, 9, 10, 16, 17, 18, 19, 20, 21, 22, 23 and 24	4 and 6	5, 12, 14, and 15	11	13

3.5 CLASSIFICATION OF WATER RESOURCES ACCORDING TO HEAVY METAL CONTENTS USING PRINCIPAL'S COMPONENT ANALYSIS PCA

The classification of water resources based on heavy metal content using Principal Component Analysis (PCA) offers a comprehensive approach to understanding the variability and quality of water bodies in relation to pollutants. In this study, 24 water resources were categorized into six distinct classes according to their heavy metal profiles, as demonstrated in Figure 4. These classes are represented by different geometric shapes, each corresponding to specific water resource locations. Class 1, marked by a circle, includes water resources at locations 6 and 12, while Class 2, represented by a north arrow, encompasses resources at locations 5, 3, 8, 9, 11, 13, 16, and 21. Class 3, shown with a rectangular shape, includes resources at locations 1, 2, 4, 14, 15, 17, 18, 20, 22, and 23. Class 4, marked by a pentagon, represents locations 10 and 19, while Class 5, identified by a triangle, corresponds to location 7. Finally, Class 6, represented by a cylinder shape, is composed of resource 24. The PCA results, as depicted in Figure 2, show that the first factor (F1) accounts for 26.68% of the total variability affecting water classification, while the second factor (F2) contributes 16.59%. Together, these factors explain 43.28 % of the variance in the water classification, highlighting the significant influence of heavy metal content on water quality. These findings align with previous research by Hammoumi et al. (2024) and Arıman et al. (2024), validating the effectiveness of PCA in classifying water

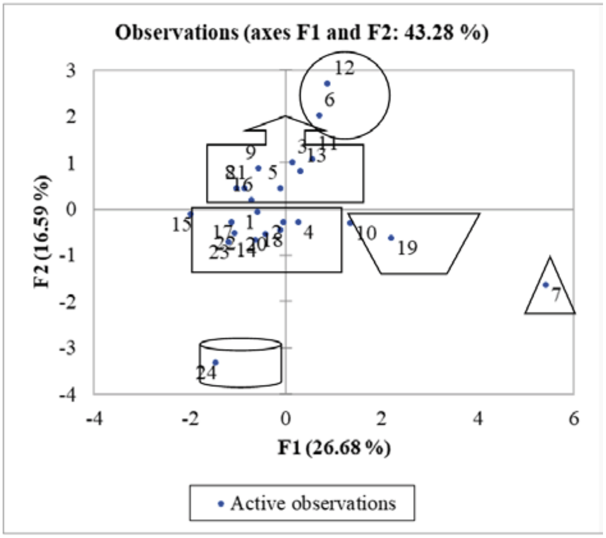

Figure 4: Classification of water resources according to heavy metal contents using principal's component analysis PCA

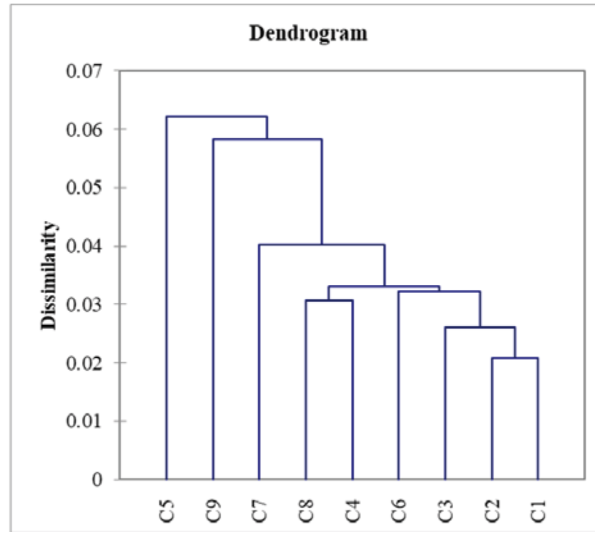

Figure 5: Classification of water resources according to heavy metal contents using agglomerative hierarchical clustering (AHC)

resources based on their contamination levels. This analysis underscores the importance of understanding the principal factors contributing to water quality variations and their implications for environmental monitoring and management.

3.6 CLASSIFICATION OF WATER RESOURCES ACCORDING TO HEAVY METAL CONTENTS USING AGGLOMERATIVE HIERARCHICAL CLUSTERING (AHC)

The classification of water resources based on heavy metal contents, utilizing Agglomerative Hierarchical Clustering (AHC), groups the water sources into nine distinct classes, as shown in Table 8 and Figure 5. Class 1, which includes water sources 1, 3, 5, 8, 9, 17, 21, 22, and 23, represents the largest cluster with nine water resources. Class 2, containing four locations (2, 14, 16, and 19), and Class 3, which includes locations 4, 11, 13, and 20, each contain four water resources. Class 4, consisting of only two locations (6 and 12), demonstrates a more limited variation in heavy metal content. In contrast, Classes 5, 6, 7, 8, and 9 are more distinct, each containing a single water resource—specifically, water sources 7, 10, 15, 18, and 24, respectively. The classification shows low variability in heavy metal concentrations for Class 1 and Class 3, which are likely influenced by similar environmental or anthropogenic factors, while a greater degree of variability is observed in Classes 5 through 9. This greater variation can be attributed to factors such as electrical conductivity (EC), which significantly impacts water quality classification by affecting the solubility and mobility of heavy metals in aquatic environments. These findings align with previous studies by Marif and Esmail (2023) and Mohsine et al. (2023), confirming that clustering based on heavy metal content provides a reliable method for assessing water quality, revealing both regional differences and the influence of chemical processes on water resources.

3.7 CORRELATION COEFFICIENT BETWEEN PH, EC, IWQI AND GERMINATION RATIO

The correlation analysis presented in Tables 4 and 9 reveals intriguing insights into the relationships between

Table 8: Classification of water resources according to cluster analysis of heavy metal contents

Classes	Class 1	Class 2	Class 3	Class 4	Class 5	Class 6	Class 7	Class 8	Class 9
Number of classes	9	4	4	2	1	1	1	1	1
Water resources or Locations	1, 3, 5, 8, 9, 17, 21, 22, and 23	2, 14, 16, and 19	4, 11, 13, and 20	6 and 12	7	10	15	18	24

pH, electrical conductivity (EC), irrigation water quality index (IWQI), and germination ratio. Notably, the study found a positive but non-significant relationship between the germination ratio and IWQI, with a correlation coefficient (r) of 0.218, suggesting that although IWQI may have some influence on germination, its effect is weak and not statistically meaningful (Lal et al., 2024). Additionally, a similarly weak but negative correlation between pH and the germination ratio (-0.157), and EC and the germination ratio (-0.196), indicates that as pH and EC increase, there is a slight decrease in the germination ratio. However, these correlations are also non-significant, implying that other factors may be influencing the germination rate more strongly. A more robust and significant negative correlation was observed between EC and IWQI, with an r value of -0.727, which implies a strong inverse relationship. This suggests that as EC (a measure of salinity) increases, the overall quality of irrigation water as indicated by the IWQI declines. This negative significant relationship is critical because high EC typically denotes saline water, which can have detrimental effects on plant growth and germination. In summary, while the correlations between pH, EC, and germination ratio are weak and non-significant, the strong negative relationship between EC and IWQI underscores the importance of monitoring EC levels in maintaining irrigation water quality and optimizing germination success.

3.8 EFFECTS OF WATER QUALITY ON GERMINATION RATIO

The data presented in Tables 10 and 4 provides valuable insights into the relationship between water quality and the germination ratio of okra seeds. The maximum germination ratio recorded was 92 %, observed under excellent water quality conditions with an electrical conductivity (EC) of 0.34 dS m^{-1} and a standard deviation of 3.72. In contrast, the minimum germination ratio of 79 % was observed at a slightly higher EC of 0.5 dS m^{-1}, accompanied by the same standard deviation, indicating that even small variations in EC can influence seed germination. This decline in germination is likely due to the combined effects of EC and pH on water quality, which have been shown to impact the osmotic potential and the uptake of water by seeds, ultimately affecting their ability to sprout. Higher EC levels can cause osmotic stress, making it more difficult for the seed to absorb sufficient water, which is crucial for the germination process. This aligns with the findings of Seymen et al. (2023), Singh et al. (2023), and Nautiyal et al. (2023), who demonstrated that water quality parameters such as EC and pH are critical factors in seed viability and germination. In this study, the mean values for pH, EC, and IWQI (Irrigation Water Quality Index) were 7.19, 0.66 dS m^{-1}, and 92.28, respectively, indicating that maintaining water quality within optimal ranges is essential for maximizing germination rates and ensuring successful crop establishment.

Table 9: Correlation between pH, EC, IWQI and germination ratio

Variables	pH	EC dS m^{-1}	IWQI	Germination Ratio
pH	1			
EC dS m^{-1}	-0.012	1		
IWQI	-0.322	-0.727	1	
Germination Ratio	-0.157	-0.196	0.218	1

Table 10: Summary of water quality effect on germination ratio

Variable	Observations	Minimum	Maximum	Mean	Std. deviation
PH	24	7.1	7.4	7.19	0.01
EC	24	0.26	1.2	0.66	0.40
IWQI	24	84.43	96.55	92.28	3.18
Germination Ratio	24	79	92	85.36	3.72

3.9 RELATION BETWEEN GERMINATION RATIO AND EC DS M^{-1}

Figure 6 illustrates the inverse relationship between the germination ratio and electrical conductivity (EC, measured in dS m^{-1}), showing a significant negative correlation. As EC increases, the germination ratio decreases dramatically, which can be attributed to the detrimental effects of high salinity on seed germination. Electrical conductivity in soil is a direct measure of its salinity, and when the EC is high, it indicates that the soil solution has a higher concentration of dissolved salts. These salts can create an osmotic pressure that reduces the availability of water to seeds, impairing their ability to absorb water and thus hindering the germination process. This negative relationship is supported by the correlation coefficient (r = -0.07), which highlights the weak yet consistent inverse trend between EC and germination. These findings align with those of Hossain et al. (2023) and Naher et al. (2024), who also observed similar impacts of salinity on seed germination. High salinity can induce

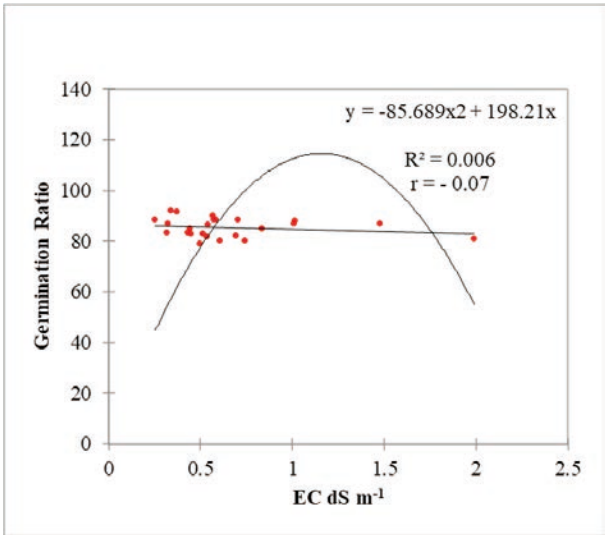

Figure 6: Relation between germination ratio and EC dS m^{-1}

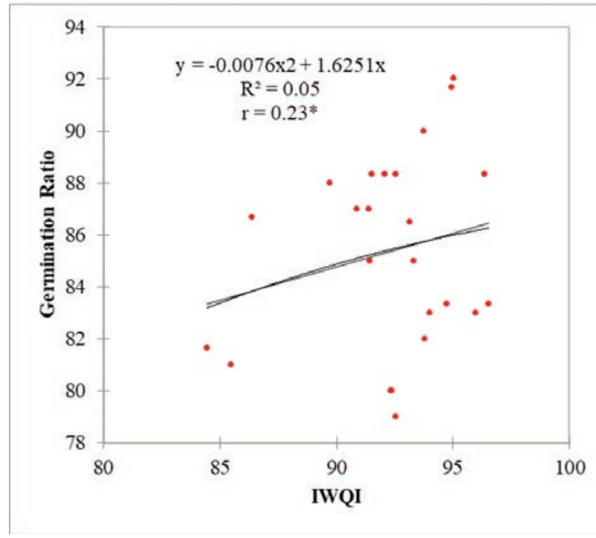

Figure 7: Relation between germination ratio and IWQI

physiological stress in seeds, affecting enzyme activity, cell membrane integrity, and nutrient uptake, all of which are essential for successful germination and early seedling development.

3.10 RELATION BETWEEN GERMINATION RATIO AND IRRIGATION WATER QUALITY INDEX (IWQI)

Figure 7 illustrates a positive correlation between germination ratio and the Irrigation Water Quality Index (IWQI), demonstrating that as the germination ratio increases, so does the IWQI, indicating better water quality. This relationship suggests that higher IWQI values, which reflect cleaner, more suitable water for irrigation, promote better seed germination and overall plant growth. Conversely, a decrease in IWQI corresponds to lower germination ratios, highlighting the detrimental effects of poor water quality on seedling establishment. This finding is consistent with previous studies, such as those by Marif and Esmail (2023) and Mezlini et al. (2024), which emphasize the significant role of water quality in agricultural productivity. Poor-quality irrigation water, characterized by high salinity, contamination, or imbalanced nutrient content, can impede seedling growth by creating osmotic stress, altering nutrient availability, or introducing toxic compounds, all of which negatively affect germination. Thus, maintaining a high IWQI is critical for ensuring successful crop establishment and maximizing agricultural yields.

4 CONCLUSIONS

The study of irrigation water quality (IWQ) from various locations or water sources reveals significant variations in water quality parameters, with conductivity being one of the most influential factors. Electrical conductivity (EC) serves as an indicator of the ion concentration in water, reflecting the level of dissolved salts or minerals. In agricultural practices, water with high EC values can lead to salinity stress, which adversely affects plant growth and seed germination. Conversely, water with lower EC values, indicating fewer dissolved salts, tends to be more favorable for seedling establishment and plant growth. The observed variations in water quality across different sources can thus be attributed to the local environmental conditions, such as soil composition and water sources, which influence the ion concentrations and overall quality of irrigation water.

Furthermore, the study demonstrates a positive correlation between irrigation water quality and the germination rate of okra seeds. As the IWQ index increases, particularly in relation to lower EC values, the germination ratio of okra seeds also increases. This suggests that water with lower salt concentrations provides a more conducive environment for seed sprouting, likely due to reduced osmotic stress and enhanced water uptake. High-quality irrigation water, characterized by low EC values, ensures that seeds receive the optimal conditions necessary for proper germination, leading to higher success rates in seedling emergence. This finding underscores the importance of maintaining high-quality water for irrigation to promote healthy crop development and improve agricultural productivity. Therefore, the results highlight that managing water salinity, by monitoring and controlling EC levels, is crucial for optimizing crop germination and growth.

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