GROUNDWATER QUALITY INFLUENCING THE POTATO TUBER YIELD IN DOABA REGION OF PUNJAB, INDIA

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ABSTRACT: Groundwater is extensively used for irrigation in the Doaba region of Punjab, where it supports the cultivation of various crops, including potatoes. This region relies heavily on chemical fertilizers and pesticides for growing different crops, which pose a dual threat by potentially degrading groundwater quality and depleting its reserves. To address these concerns, a survey-based investigation was conducted to evaluate the quality of irrigation water and assess potato tuber yields. It was observed that farmers are drawing groundwater from borewells with an average depth of 254.0 feet, and the water is delivered from a depth of 145.67 feet. The analytical results showed that all the groundwater samples tested were suitable for irrigation. Additionally, a significant positive correlation was found between potato tuber yield and the nitrate content of the groundwater. Consequently, it is essential to factor in the nitrate contribution from groundwater when making recommendations for nitrogen usage in the region.

KEYWORDS: Groundwater, Nitrate, Physico-chemical, Potato and Tuber yield

INTRODUCTION

In the post-Green Revolution era, characterized by high cropping intensity and increasing human population, anthropogenic activities, inappropriate use of fertilizers, overexploitation, quality deterioration, and groundwater depletion have emerged as major challenges for humanity (Kumar *et al.*, 2007a; Srivastava *et al.*, 2017; Sekhon *et al.*, 2019a; Kumar *et al.*, 2021). In India, groundwater is used for more than 90% of irrigation (Jain *et al.*, 2019a), making it a vital and critical input for achieving sustainable crop yields. As global demand for potatoes continues to rise (Danielescu *et al.*, 2022; Stark *et al.*, 2020), so too will the water requirements for crop production, raising concerns about irrigation water resources and water quality (Haverkort and Struik, 2015a; Levy *et al.*, 2013).

In an era marked by escalating environmental challenges and population growth, sustainable agriculture has become a paramount concern (Foley et al., 2011). It is within this context that the significance of groundwater quality comes to the fore. Groundwater, often relied upon for irrigation, not only provides the essential moisture required for plant growth but also carries with it a suite of chemical and physical attributes that can profoundly impact crop health and yield (Boithias et al., 2016).

Potatoes (*Solanum tuberosum*) are a staple crop of paramount importance, particularly in regions like the Doaba region of Punjab, India, where agriculture plays a vital role in sustaining livelihoods and ensuring food security (Singh et al., 2019). The yield and quality of potato tubers are influenced by a multitude of factors, ranging from

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climatic conditions to agricultural practices and irrigation methods. In this context, groundwater quality has emerged as a critical determinant in the pursuit of optimal potato production within the Doaba region. This region is characterized by its intense agricultural activity, primarily relies on groundwater for irrigation purposes (Jain et al., 2019b). However, the quality of this groundwater is subject to a host of variables, including natural geochemical processes and anthropogenic activities such as fertilization and industrial discharge (Kumar et al., 2021). These factors can introduce a wide range of contaminants and variations in groundwater parameters, potentially impacting potato crops at various stages of their growth cycle.

This introductory exploration aims to investigate the intricate relationship between groundwater quality and potato tuber yield in the specific context of the Doaba region of Punjab, India. It delves into the diverse parameters and contaminants that can infiltrate the groundwater in this region, examining their potential effects on potato plants throughout their growth cycle (Sekhon et al., 2019b). Furthermore, it considers the implications of groundwater quality on agricultural practices and food security within this agriculturally significant region (Kumar et al., 2007). Through this investigation, we endeavor to shed light on the importance of proactively addressing groundwater quality issues to ensure sustained and robust potato production in the Doaba region, ultimately contributing to the region's agricultural prosperity.

MATERIALS AND METHODS

Description of the study area

The present investigation was carried out in the year 2019-20 in three districts of the Doaba region of Punjab, namely Jalandhar, Hoshiarpur, and Kapurthala (Figure 1). Potato is a major cash crop in the Doaba region, typically following rice as preceding and wheat/maize as succeeding crop, playing a vital role in meeting the country's seed potato requirements. The climate in this study area varies from sub-humid to semi-arid and is generally dry, except during the monsoon season (Anonymous, 2013). The soil in the study area is characterized by light texture, with significant variations in organic carbon content (ranging from 0.17% to 0.77%), soil pH (ranging from 6.5 to 8.4), and low levels of available nitrogen (ranging from 131.7 to 211.0 kg/ha). In contrast, there are high levels of available phosphorus (ranging from 25.3 to 30.3 kg/ha) and medium levels of available potassium (ranging from 223.9 to 259.9 kg/ha) (Kumar *et al.*, 2021).

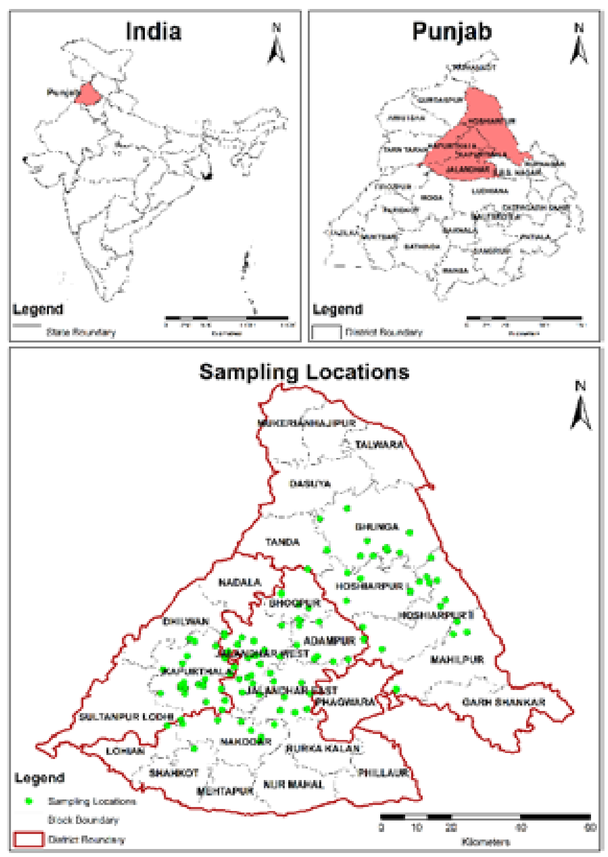


Fig. 1. Study area and ground truth points.

Selection of farmers

The study was conducted in the Doaba region of Punjab, specifically focusing on three districts: Jalandhar, Hoshiarpur, and Kapurthala. These districts were deliberately selected due to their significant contributions to seed potato production in the country and their dedicated focus on potato cultivation in the state of Punjab (Ministry of Agriculture and Farmers' Welfare, 2018). An extensive survey was undertaken to collect and authenticate the necessary information using structured questionnaires administered through interviews. A total of 100 farmers were contacted, each having a minimum of 10 years or more of experience in potato cultivation within the region (Figure 1). All required information was systematically gathered from the respondents, including data related to the application of various inputs such as fertilizers (NPK), the source of irrigation, and the depth of groundwater delivery. Additionally, information on tuber yield of single year harvested during 2020 for each farm was recorded, along with Global Positioning System (GPS) coordinates using GPS essential mobile application.

Water samples collection and analysis

Groundwater samples were systematically collected from 100 locations, specifically from selected farmers' tubewells using Global Positioning System (GPS) coordinates during the months of March to June in 2019. The sampling procedure involved collecting the samples after 15 minutes of pumping and storing them in high-quality 250 ml polythene bottles. These bottles had been pre-soaked in a 10% nitric acid solution for 24 hours and rinsed with deionized water to ensure their cleanliness. All the collected samples were stored at 4°C until they were used for further analysis.

The chemical analysis of the groundwater samples was conducted in triplicate. Bicarbonate and chloride contents were determined by titration method and sulphate content by turbidimetric method (Tondon, 2001). Nitrate (NO_3^-) concentration was determined using a UV-visible spectrophotometer at wavelengths of 220 nm and 275nm. Concentrations of Iron (Fe), Zinc (Zn) , Manganese (Mn), Copper (Cu), calcium (ca) and Magnesium (Mg) were determined using a Flame Atomic Absorption Spectrophotometer (FAAS). Sodium (Na) and Potassium (K) were determined by flame photometer method. Double distilled water was used to prepare reagents and solutions for the analysis (Tandon, 2001).

Determination of groundwater quality for irrigation

The crucial criteria for classifying the quality of groundwater for use in irrigation are Sodium Absorption Ratio (SAR), Magnesium Ratio (MR) and Corrosivity Ratio (CR) (Tripathi *et al.*, 2012). The SAR value of each samples of groundwater was calculated by using,

$$SAR = \frac{Na^{+}}{\sqrt{(Ca^{2+} + Mg^{2+})/2}}$$

The MR value of each samples of groundwater was calculated by

$$MR = \frac{Mg^{2+}}{(Ca^{2+} + Mg^{2+})} \times 100$$

and CR value of each samples of groundwater was by using following relation as,

$$CR = \frac{\frac{Cl^{-}}{35.5} + \frac{2(SO_4^{2-})}{96}}{\frac{2(HCO_3^{2-} + CO_3^{2-})}{100}}$$

Statistical analysis

All the responses obtained from farmers and the water quality data were meticulously organized using the MS-Excel program (MS office version 2014) to prepare them for further statistical analysis. Descriptive statistics were also derived for the physicochemical parameters of the groundwater samples. Correlation and regression analyses were performed to examine the relationships between tuber yield and various elements. Statistical analysis was carried out using R software version 2.15.1, while QGIS version 3.22.16 was employed for creating spatial distribution maps.

RESULTS AND DISCUSSION

The physico-chemical parameters of groundwater samples

The data presented in Table 1 shown that out of a total of 100 observations, the mean tuber yield in the Doaba region of Punjab was recorded at 23.06 t/ha. The borewell depth and groundwater delivery depth for the region averaged 254.00 feet and 145.67 feet, respectively. Additionally, the mean values for pH (7.98) and EC (0.60 ds/m) were observed.

Table 1. Descriptive statistics of the physico-chemical parameters of groundwater samples (N=100).

Parameters	Unit	Mean	SD	Min.	Max.	CV (%)
pH		7.98	0.22	7.40	8.40	2.77
EC	ds/m	0.60	0.15	0.35	0.96	24.88
Nitrate (NO_3^-)	ppm	34.97	28.40	1.90	130.10	81.22
Chloride (Cl^-)	me/L	3.07	0.66	2.00	5.00	21.34
Carbonate (CO_3^{2-})	me/L	0.40	0.00	0.40	0.40	0.00
Bicarbonate (HCO_3^-)	me/L	0.53	0.19	0.20	1.10	36.82
Sulphate (SO_4^{2-})	ppm	8.98	5.89	0.39	23.70	65.62
Sodium (Na^+)	ppm	55.56	23.36	15.00	131.30	42.05
Calcium (Ca^{2+})	ppm	119.09	74.21	20.41	422.51	62.31
Magnesium (Mg^{2+})	ppm	30.57	6.67	16.45	46.55	21.82
Zinc (Zn^{2+})	ppm	0.05	0.07	0.00	0.58	148.28
Iron (Fe^{2+})	ppm	0.05	0.04	0.00	0.21	65.37
Copper (Cu^{2+})	ppm	0.19	0.38	0.00	3.39	202.28
Manganese (Mn^{2+})	ppm	0.07	0.07	0.00	0.22	94.20
SAR		2.43	1.14	0.51	6.41	1.31
MR		23.99	10.83	0.30	54.70	117.30
CR		0.31	0.23	0.05	1.41	0.05

Note: SD=Standard deviation; SAR=Sodium Absorption Ratio; MR=Magnesium Ratio; CR=Corrosivity Ratio

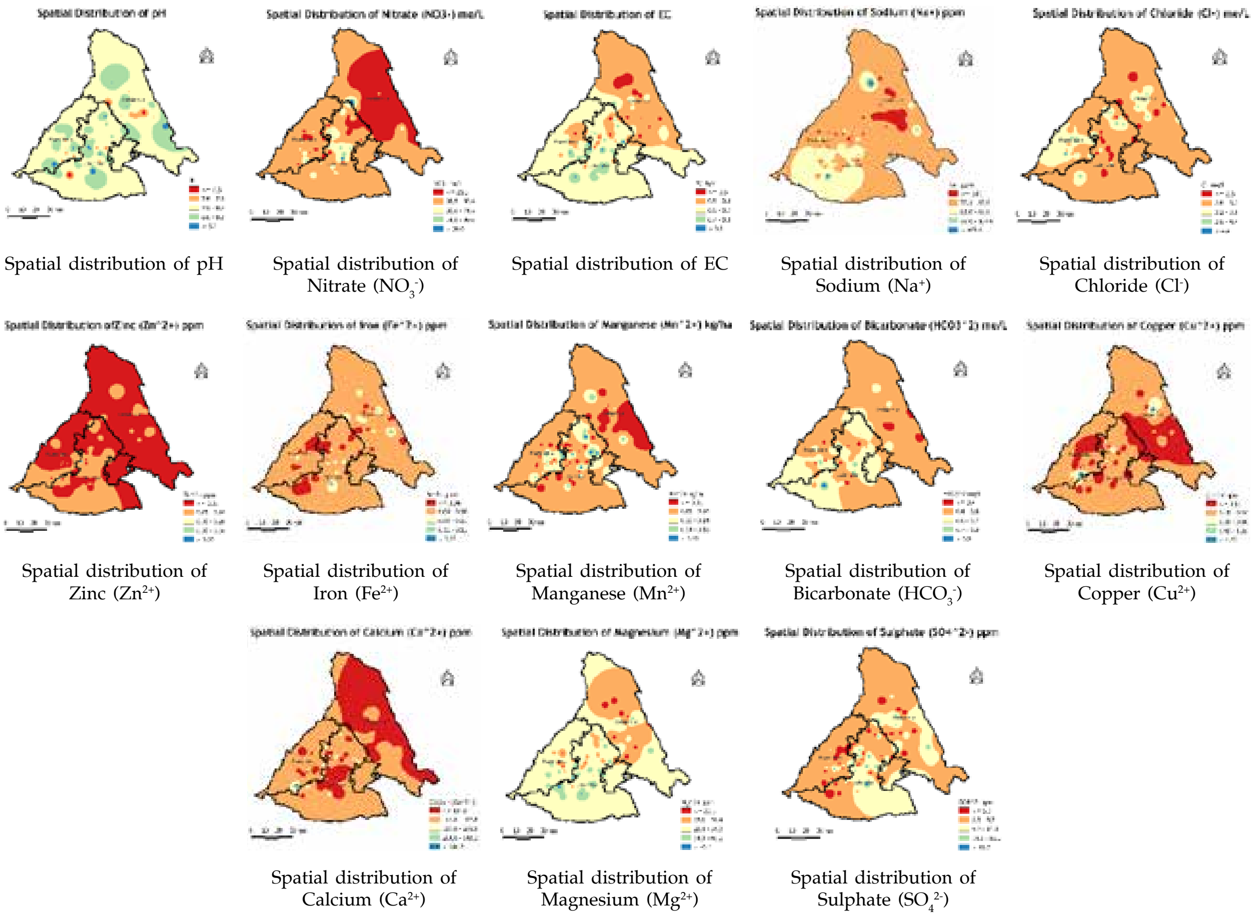
The mean concentrations of major anions were as follows: NO_3^- (34.97 ppm), Cl^- (3.07 me/L), CO_3^{2-} (0.40 me/L), HCO_3^- (0.53 me/L), and SO_4^{2-} (8.59 ppm). For cations, the mean concentrations were Na^+ (55.56 ppm), Ca^{2+} (119.09 ppm), Mg^{2+} (30.57 ppm), Zn^{2+} (0.05 ppm), Fe^{2+} (0.05 ppm), Cu^{2+} (0.19 ppm), and Mn^{2+} (0.07 ppm). Key ratios were calculated as follows: Sodium Absorption Ratio (SAR) at 2.43, Magnesium Ratio (MR) at 23.99, and Corrosivity Ratio (CR) at 0.31. The mean application rates for $N:P_2O_5:K_2O$ nutrients were 198.61:160.64:92.72 kg/ha.

Relationship between tuber yield and various elements

The results of the correlation study reveal the relationships between variables in this investigation, we have documented the relationship between tuber yield and various elements. The correlation matrix of 14 variables, as shown in Figure 3, highlights a strong, positive, and highly significant correlation between EC-SO_4^{2-} (r=0.62), EC-Na^+ (r=0.58), and EC-Mg^{2+} (r=0.77). This indicates that the presence of sulfate, sodium, and magnesium in groundwater has a significant impact on electrical conductivity (EC). Notably, pH did not exhibit any significant correlation with any parameter.

Furthermore, we found a significant positive correlation between EC-NO_3^- (r=0.34) and EC-Zn^{2+} (r=0.32). These results align with the findings of Kaur et al., 2016. Nitrate displayed a highly significant positive correlation with sulfate (r=0.26) but had a negative correlation with chloride (r=-0.24). A strong, positive, and highly significant correlation was observed between Ca^{2+} and Mn^{2+} (r=0.58). Tuber yield exhibited a significantly positive correlation with nitrate (r=0.20) but showed a negative correlation with magnesium (r=-0.21) only.

Potato crops are known to be highly responsive to nitrogen, which significantly



Spatial distribution of pH

Spatial distribution of Nitrate (NO_3^-)

Spatial distribution of EC

Spatial distribution of Sodium (Na^+)

Spatial distribution of Chloride (Cl^-)

Spatial distribution of Zinc (Zn^{2+})

Spatial distribution of Iron (Fe^{2+})

Spatial distribution of Manganese (Mn^{2+})

Spatial distribution of Bicarbonate (HCO_3^-)

Spatial distribution of Copper (Cu^{2+})

Spatial distribution of Calcium (Ca^{2+})

Spatial distribution of Magnesium (Mg^{2+})

Spatial distribution of Sulphate (SO_4^{2-})

Fig.2. Spatial distribution of the chemical parameters of groundwater.

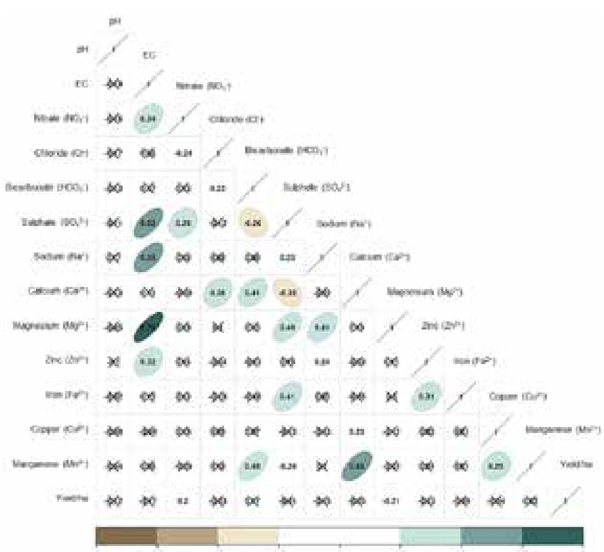


Fig.3. Correlation matrix of tuber yield and groundwater elements.

contributes to increased tuber yields. Considering an average irrigation supply of 430 mm for potato crops (Anonymous, 1990), groundwater contributes nitrate-nitrogen in the range of 1.84 to 125.87 Kg/ha, with an average of 33.65 Kg per ha. This average nitrogen contribution is equivalent to about 19.22 percent for seed crops (175 kg per ha) and 14.02 percent for ware crops. Since plants primarily take up nitrogen in the form of nitrate, it is crucial to consider the nitrate content in groundwater when recommending nitrogen application. In addition, this groundwater is also contributing appreciable level of calcium, magnesium and sulphate-sulphur in the range of 87.76 to 1816.79 kg/ha, 70.74 to 200.17 kg/ha and 0.50 to 30.57

kg/ha with mean level of 512.19, 130.93 and 11.51 kg/ha, respectively.

Given the substantial variability in nitrate content, it is essential to adjust nitrogen fertilizer doses accordingly to avoid excessive use. Excessive nitrogen not only leads to pollution but also contributes to carbon footprints (Kumar et al., 2021). Regression analysis was conducted to identify which groundwater quality parameters significantly influence tuber production. The results indicated that EC, nitrate, and sulfate content in groundwater have a positive and significant contribution to tuber yield (Table 3), with an R^2 value of 0.248.

Groundwater assessment for irrigation quality

The groundwater quality parameters are categorized in Table 4. Electrical conductivity (EC) serves as an indicator of the salinity hazards to crops, reflecting the Total Dissolved Solids (TDS) value of groundwater. According to Wilcox's classification (1955), 83 percent of the samples were categorized as "good," while 17 percent fell into the "permissible" class. None of the samples were classified as "excellent," "doubtful," or "unsuitable."

Table 3. Groundwater chemical constituents influencing tuber yield.

Variable	Estimate	S.E.	t-value	p-value
Intercept	32.22**	8.24	3.91	0.00
pH	-0.90	0.98	-0.92	0.36
EC	-6.78*	3.12	-2.17	0.03
NO_3^-	0.02**	0.01	2.55	0.01
Cl^-	0.06	0.33	0.18	0.85
HCO_3^-	2.88*	1.34	2.15	0.03
SO_4^{2-}	0.15**	0.06	2.51	0.01
Na^+	0.00	0.01	0.30	0.76
Ca^{2+}	0.00	0.00	0.53	0.59
Mg^{2+}	-0.05	0.05	-1.07	0.28
Zn^{2+}	-0.29	3.07	-0.10	0.92
Fe^{2+}	-8.64	6.47	-1.34	0.18
Cu^{2+}	-0.75	0.56	-1.35	0.18
Mn^{2+}	0.86	4.13	0.21	0.83
		Model accuracy		
	R^2	Residual Std. error		
	0.248	1.888		

*Significant at 0.05 level; **Significant at 0.01 level

Table 4. Classification of groundwater samples quality for irrigation.

Attribute	Range	Classification	No. of samples
Salinity hazard (EC) (μs/cm)	<250	Excellent	-
	250-750	Good	83
	750-2000	Permissible	17
	2000-3000	Doubtful	-
	>3000	Unsuitable	-
Alkalinity hazard (SAR) (Richards, 1954)	<10	Excellent	100
	10-18	Good	-
	18-26	Doubtful	-
	>26	Unsuitable	-
Magnesium ratio (MR) (Palliwal, 1972)	<50%	Suitable	99
	>50%	Unsuitable	1
Corrosivity ratio (CR) (Raman, 1985)	<1	Safe	99
	>1	Unsafe	1

Additionally, the Sodium Absorption Ratio (SAR) characterizes the sodium or alkali hazards to crops. In the present study, all the collected groundwater samples were rated as "excellent" for irrigation, indicating no alkali hazards for crops being cultivated in the region. Furthermore, the current investigation revealed that 99 percent of the samples were deemed suitable and safe in terms of magnesium ratio and corrosivity ratio.

In conclusion, this study underscores the pivotal role of nitrogen in potato cultivation and stresses the need to consider nitrate content in groundwater when recommending nitrogen application. Groundwater quality parameters indicate that salinity and alkali hazards to crops are negligible, ensuring favorable conditions for cultivation. Moreover, specific parameters such as electrical conductivity, nitrate, and sulfate content are found to significantly and positively impact tuber yield, offering insights for optimizing potato production. The majority of groundwater samples are deemed suitable for irrigation according to Wilcox's classification. Additionally, the study highlights the safety of groundwater in terms of magnesium and corrosivity ratios, reducing the risk of adverse effects on crop growth. These findings can be used to devise strategies to enhance potato crop yields while minimizing environmental concerns in the region. Consequently, it is imperative for farmers to continually test their irrigation water when making decisions regarding nutrient application by considering the nutrient contribution through irrigation. This approach ensures the optimal and sustainable management of resources for improved potato cultivation practices.

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CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

ETHICAL STATEMENT

This article does not contain any studies with human participants or animal performed by any of the authors.

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