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# Assessment of Water Quality in Indo-Gangetic Plain of South-Eastern Asia under Organic vs. Conventional Rice Farming

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Received: 1 March 2020; Accepted: 24 March 2020; Published: 28 March 2020

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**Abstract:** Water contamination is often reported in agriculturally intensive areas such as the Indo-Gangetic Plain (IGP) in south-eastern Asia. We evaluated the impact of the organic and conventional farming of basmati rice on water quality during the rainy season (July to October) of 2011 and 2016 at Kaithal, Haryana, India. The study area comprised seven organic and seven conventional fields where organic farming has been practiced for more than two decades. Water quality parameters used for drinking (nitrate, $NO_3$; total dissolved solids (TDS); electrical conductivity (EC) pH) and irrigation (sodium adsorption ratio (SAR) and residual sodium carbonate (RSC)) purposes were below permissible limits for all samples collected from organic fields and those from conventional fields over the long-term (~15 and ~20 years). Importantly, the magnitude of water $NO_3$ contamination in conventional fields was approximately double that of organic fields, which is quite alarming and needs attention in future for farming practices in the IGP in south-eastern Asia.

**Keywords:** water quality; conventional farming; organic farming; nitrate; residual sodium carbonate; sodium adsorption ratio; total dissolved solids

## 1. Introduction

The enormous rate of agricultural production required to feed the burgeoning population in India (and other parts of south-eastern Asia) needs a constant supply of irrigation water. One such reliable source of irrigation is well water (~borewell water) in the Indo-Gangetic Plain (IGP), India, where deep wells extract water from the underlying aquifer [1]. The global importance of well water for both irrigation and drinking purposes in south-eastern Asia is obvious, but its deteriorating quality has become a serious decadal concern in IGP for intensive agriculture operations [2,3]. Basmati rice is an important commodity for the Indian economy related to the export business, and reports are limited to the effects of basmati rice cultivation on groundwater quality.

Nitrate ($NO_3$) concentrations exceeding the permissible limits in well water due to agricultural management practices (e.g., fertilizer/manure application, irrigation etc.) have been reported throughout the world including the United States [4], Europe [5], Australia [6], China [7], Germany [8] and France [9]. Other than well water nitrates, pH, electrical conductivity (EC), and total dissolved solids (TDS) (i.e., factors directly related to dissolved mineral matter) are other useful indicators of well water quality for drinking purposes due to their close association with human health problems [1]. The assessment of well water quality for irrigation purposes is usually achieved by using indices including the sodium adsorption ratio (SAR) and residual sodium carbonate (RSC), which are calculated using the concentrations of various nutrients such as carbonate ($CO_3^{2-}$), bicarbonate ($HCO_3^-$), calcium ($Ca^{2+}$), magnesium ($Mg^{2+}$), and sodium ($Na^+$) in well water [1].

The simultaneous evaluation of the long-term (~15–20 years) effects of farming practices (organic vs. conventional) on well water quality parameters has still seldom been practiced. To that end, we focused on assessing water quality parameters, for both drinking ($NO_3^-$, pH, EC, TDS) and irrigation (SAR, RSC) purposes, under long-term organic vs. conventional practices of basmati rice in the Indo-Gangetic Plain (IGP)—the bread basket of south-eastern Asia. We have assessed these well water quality parameters with the hypothesis that well water pollution will be higher in conventional farming systems than in organic farming systems under long-term (~15 and ~20 years) cultivation practices.

## 2. Materials and Methods

### 2.1. Site Description and Well Water Samples Collection

The study area is situated in Kaithal, Haryana, India (Table S1 and Figure S1). Seven farmers' fields, from both organic and conventional basmati rice systems, were chosen for comparative analysis with farmers' participation during the Kharif (or rainy) season (July to October) of 2011 [10,11] and 2016 (unpublished data) (see Appendix A for details). The well water samples were collected at the end of the growing season after 15 (2011) and 20 (2016) years of rice cultivation in both systems (see Appendix B for details). All samples were collected and preserved following the operating procedure for well water sampling [12]. Well water samples were collected at each site from the wells or bore well (or tube wells) with depths ranging from approximately 28.7 to 89.3 m. Details of study sites, farming practices and sample collection are described in the Appendix section (as Supplementary Materials).

### 2.2. Analysis of Well Water Samples

Well water quality parameters for drinking purposes were measured following the standard methods used by the American Public Health Association and American Water Works Association [13]. Well water pH and EC were measured using a pH and EC meter following the standard method of water sample analysis [14]. TDS was measured following the procedure in [15]. Nitrate was measured using salicylic acid nitration methods [16]. RSC and SAR were calculated following the method described in [14].

### 2.3. Statistical Analysis

The effects of farming practices on well water quality parameters were determined based on the completely randomized design using an analysis of variance (ANOVA) in JMP Pro 14.0 [17]. The year was treated as a random factor. Tukey's test was used to perform post-hoc multiple comparisons. All statistical analyses were conducted at a 5% level of significance.

## 3. Results and Discussion

### *3.1. Evaluation of Well Water Quality Parameters for Drinking Purposes*

We evaluated the influence of farming practices on well water quality parameters after ~15 (2011) and ~20 (2016) years of the onset of organic farming practices. In general, the farming practice significantly affected all well water quality parameters (Figure 1, Figure 2 and Table 1). In the biplot, two groups of well water samples collected from organic vs. conventional fields could be easily identified, and the first two principal components explained 95.2% of the total variance (Figure 2A,B). Similar results were obtained from the cluster analysis (Figure S2). The dendrogram consisted of two distinct clusters, where the first cluster included well water samples collected from the organic fields and the second cluster included well water samples collected solely from conventional farming systems. All well water quality indices were better in the organic farming system than in the conventional farming system, indicating the potential reduction of well water pollution risks from organic farming systems [14]. For instance, the values of all the parameters, such as well water pH, EC, TDS, $NO_3$, RSC, and SAR, were lower in organic fields than conventional fields for both years, where the corresponding values fall within the standard range [3] (Figure 1).

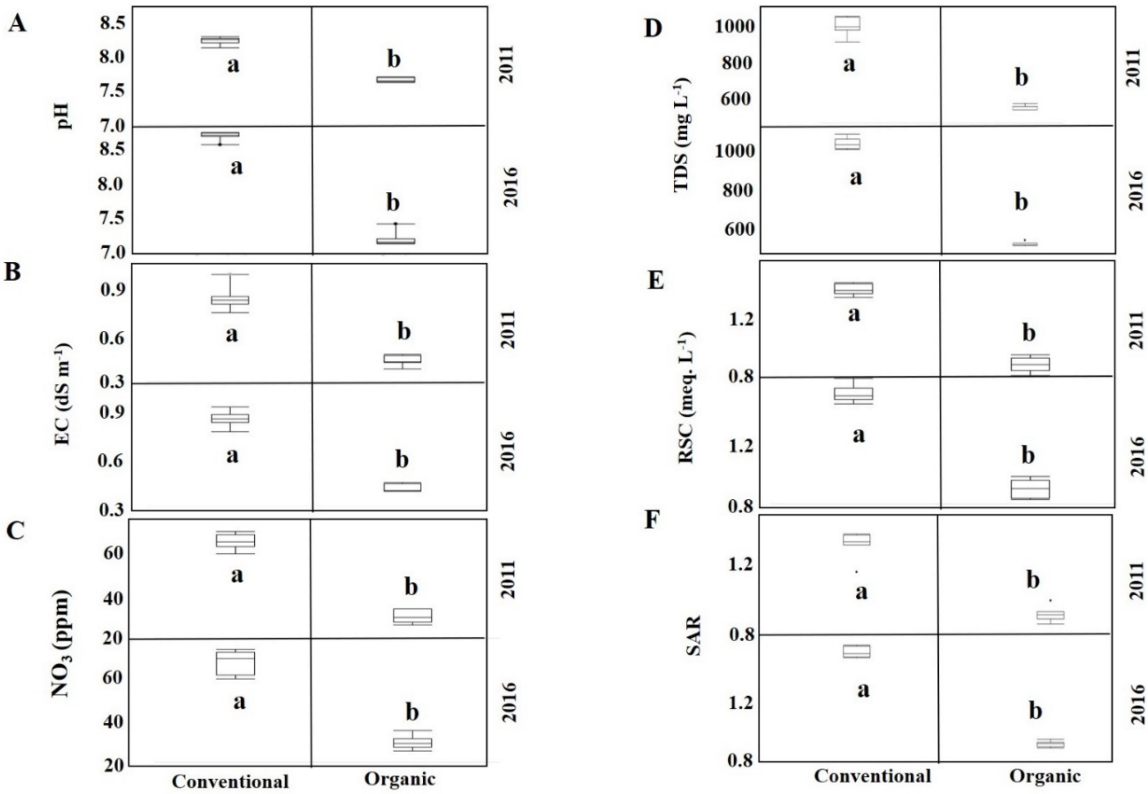


**Figure 1.** Comparison between the environmental impacts of organic vs. conventional rice cultivation on groundwater quality parameters ((**A**). pH, (**B**). electrical conductivity (EC), (**C**). $NO_3$, (**D**). total dissolved solids (TDS), (**E**). residual sodium carbonate (RSC), and (**F**). sodium absorption ratio (SAR)) (n = 21 for each year) in Kaithal, Haryana, India. Different letters indicate significant difference at a 5% level of significance.

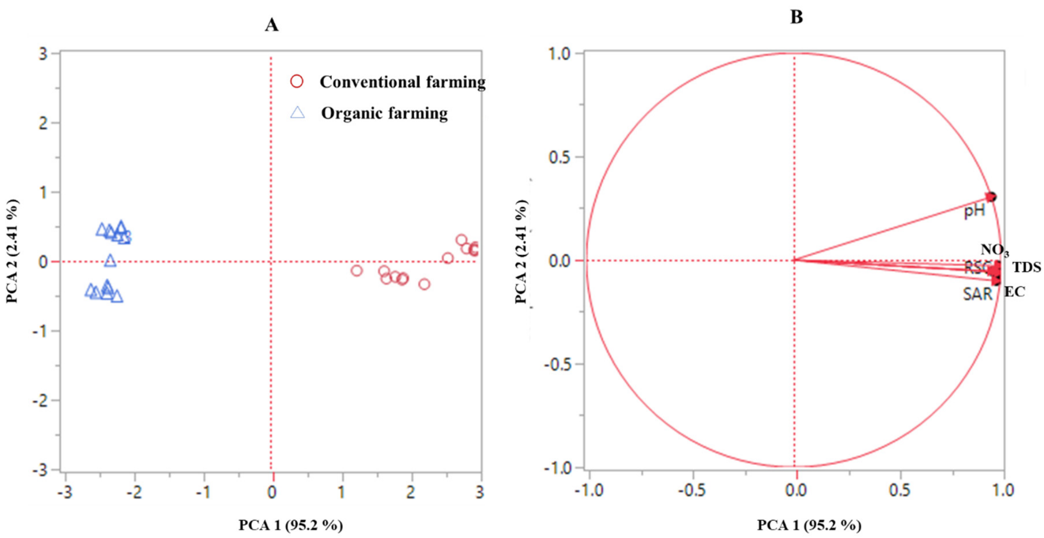


**Figure 2.** Biplot (**A**) and loading plot (**B**) from the principal component analysis of groundwater quality parameters under organic and conventional rice cultivation systems (n = 42 by combining both years) in Kaithal, Haryana, India.

**Table 1.** Effect of farming practice on groundwater quality parameters under organic and conventional rice cultivation systems (n = 42 by combining both years) in Kaithal, Haryana, India.

| Parameters | Farming Practices | |
|---|---|---|
| | F Ratio | *p*-Value |
| Groundwater pH | 623 | <0.0001 * |
| Groundwater EC | 204 | <0.0001 * |
| Groundwater total dissolved solids (TDS) | 619 | <0.0001 * |
| Groundwater nitrate ($NO_3$) | 529 | <0.0001 * |
| Residual sodium carbonate (RSC) | 633 | <0.0001 * |
| Sodium adsorption ratio (SAR) | 156 | <0.0001 * |

* The level of significance for each parameter was determined at $p < 0.05$.

Over the longer term, the well water pH was 0.54 (for 2011) and 1.41 (for 2016) units higher in conventional farming systems than in the organic farming system. Well water pH values from both farming systems fell within the safe limit (6.5 to 8.5) as per the drinking water guidelines [18] for 2011, but not for 2016, when the well water pH values were approximately 0.1 unit higher than the threshold value (see corresponding values for samples collected before transplanting in Figure 1A). The pH of well water depends on the acidity or basicity of the leachate from the soil accessing and/or recharging water table; the high pH leachate is possibly responsible for raising the well water pH in conventional fields. Thus, the basic nature of chemical fertilizers applied to the conventional fields resulted in leachate with a high pH. Conversely, the application of organic manures in organic fields conceivably enhanced the formation of acids, leading to a decrease in the pH of the leachate as well as well water pH.

Soil EC—similar to soil pH—can also control the EC of the leachate reaching the well water. Thus, higher values of EC in the well water of conventional fields (see corresponding values for samples collected before transplanting Figure 1B) may be attributed to the higher amounts of dissolved ions in soil solution leaching down due to the excess of the available form of nutrients (i.e., surplus amount) from applied fertilizers. The EC in well water usually depends on the presence of dissolved mineral matter (solid content; TDS). The TDS values of well water samples collected from conventional fields were 1.97 (for 2011) and 2.09 (for 2016) times higher than those collected from organic fields (see corresponding values for samples collected before transplanting in Figure 1D). Moreover, the TDS values of well water samples from our conventional fields were always above the drinking water threshold limit of 500 mg $L^{-1}$; however, corresponding values from organic fields indicated that water samples from organic fields may be suitable for drinking purposes [18].

Similar to TDS, the well water $NO_3$ levels in conventional fields were also beyond threshold level for drinking water (50 mg $L^{-1}$), as specified in [19], and may pose a health risk to humans or other animals. The lower $NO_3$ content in well water under organic cultivation (see corresponding values for samples collected before transplanting in Figure 1C) may be due to the N mineralization rate, which matches with the plant uptake and a reduced risk for N leaching and well water pollution. In contrast, the residual $NO_3$ accumulated from the excessive application of inorganic fertilizers in conventional farming [20] is subject to leaching and becomes part of the sub-surface or well water [7] and continuously moves downward even after the season of application, particularly in semi-arid regions [21]. It has been further reported that $NO_3$ leaching could be 50% greater in conventionally managed fields compared to organically managed fields [22].

### *3.2. Evaluation of Well Water Quality Parameters for Irrigation Purposes*

The well water quality indices used for irrigation purposes (RSC and SAR) also showed a similar trend to that of well water quality parameters used for drinking purposes (see Figure 1E,F). Higher RSC and SAR values in conventional farming indicated an appreciable hazard in soils in the long-term since the corresponding values passed the safe limits for irrigation water (1.24 and 1.0 for RSC and SAR, respectively), but the water could be used for irrigation purposes after proper management (e.g., gypsum application). On the contrary, both RSC and SAR values in the organic farming system were within safe limits and would not pose any hazard when applied for irrigation purposes (see Table S2 and standard permissible limits [1]). The higher organic matter applications in organic fields may have helped to ameliorate the soil and water sodicity by mobilizing Ca (and Mg) from soil minerals [23].

## 4. Conclusions

Long-term organic rice farming practices are characterized by favorable pH, EC, TDS, $NO_3$, RSC, and SAR values of water compared to the conventional systems. Our findings indicated that well water $NO_3$ may lead to the water having poor drinking quality when adjacent to an agricultural field with conventional cultivation practices. The novelty of this study is its characterization and comparison of water quality indices under long-term organic vs. conventional systems and the sustainability of farming practices. To the best of our knowledge, our approach has resulted in some unique findings as we evaluated the long-term (~15 and ~20 years) effects of farming practices on water quality parameters in the Indo-Gangetic Plain of south-eastern Asia for the very first time. Additionally, we have documented the comparison of water quality parameters conducted with farmers' participation in certified organic and conventional fields. This finding will be useful for decision-makers to identify farming practices that enhance well water qualities in agriculture-intensive areas such as the IGP, south-eastern Asia. However, a long-term research approach involving both the economic and environmental implications of well water and associated farming practices would provide insights into the subject matter in a broader context.

**Supplementary Materials:** The following are available online at http://www.mdpi.com/2073-4441/12/4/960/s1, Table S1: An overview of the study area and fertilizer application under organic and conventional "Taraori Basmati" rice cultivation systems in Kaithal, Haryana, India, Table S2: Permissible limits (or threshold values) of groundwater quality parameters for drinking and irrigation purposes, Figure S1: Study locations in Kaithal district of Haryana, India, and geographical positions of the organic and conventional fields used for groundwater sample collection, Figure S2: Dendrogram of the clusters identified from the analysis of answers related to the groundwater quality parameters of the samples collected from organic and conventional "Taraori Basmati" rice cultivation systems in Kaithal, Haryana, India. Cluster I and II explain the groundwater samples collected from organic and conventional fields, respectively. EC; electrical conductivity, EC; electrical conductivity, TDS; total dissolved solids, $NO_3$; nitrate, RSC; residual sodium carbonate, SAR; sodium adsorption ratio.

**Author Contributions:** The contributions of individual authors are as follows: Conceptualization, D.S. and B.D.; methodology, D.S., D.K.S., H.P., O.P.S., L.N.; software, B.D., Z.Y.; validation, D.S., B.D., Z.Y., D.K.S.; formal analysis, D.S., B.D., Z.Y., H.P.; investigation, D.S., D.K.S, O.P.S.; resources, D.K.S., H.P., O.P.S., L.N.; data curation, D.S.;

writing—original draft preparation, D.S., B.D., Z.Y.; writing—review and editing, D.S., B.D., Z.Y., D.K.S., H.P., O.P.S., L.N.; visualization, D.S., B.D., Z.Y., supervision, D.K.S, H.P.; project administration, D.K.S., H.P., funding acquisition, D.S., D.K.S. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research received no external funding.

**Acknowledgments:** The author wish to thank the Junior Research Fellowship (JRF) program of the Indian Council of Agricultural Research (ICAR) and Sushmita Munda, Totan Adak, and all fourteen farmers for the support of this study.

**Conflicts of Interest:** The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

## Appendix A

**Site Description and Details of Organic Farming Practices and Related Management Practices**

Organic farming practices have been conducted in partnership with Agrocel Pvt. Ltd., a private company certified by SKAL (also known as the Control Union certification, which is accredited to APEDA, Agricultural and Processed Food Products Export Development Authority) since late 1990's in Kaithal (Haryana, India). This company is the second largest organic rice exporter of India and mainly focused on Taraori Basmati Rice (i.e., CSR-30 or Yamini). The certified farming practices under contract organic farming have been conducted since last 15 years with the same partnership in Kaithal area and was recognized by FLO and Fair-Trade in 2007. Originally, the activities were developed in parallel strategies with IFOAM (International Federation of Organic Agriculture Movements) under farmers' participatory mode. Currently, 5750 ha land has been included in this contract organic farming with a public-private partnership.

A tropical steppe, semi-arid and hot climate usually prevails in the Kaithal district in Haryana, India (study area). The average annual precipitation and temperature of the region are 568 mm and 24.6 °C, respectively. The soils of study region can generally be categorized as sandy to sandy loam, marginally fertile, and named as Sierozem soil (under major zonal soil classification system in India). The lands were prepared by plowing the plots using a tractor draw mold board plow followed by cross-disking and leveling and pressing with a tractor drawn leveler. In organic fields, recommended dose of certified organic fertilizers in terms of farm yard manure i.e., FYM (0.5% N, 0.2% $P_2O_5$ and 0.5% $K_2O$) and decorticated neem cake (a bio-fertilizer-cum-organic soil amendment made of neem [*Azadirachta indica* L.] seed kernels after removing the husk, 2.0 to 5.0% N, 0.5 to 1% P and 1.0 to 2.0% K) were applied @ 5 t $ha^{-1}$ and 125 kg $ha^{-1}$, respectively. In conventional fields, the inorganic fertilizers in terms of urea, diammonium phosphate (DAP) or single super phosphate (SSP), and muriate of potash (MOP) were applied as recommended doses (150 kg N $ha^{-1}$, 40 kg $P_2O_5$ $ha^{-1}$, and 40 kg $K_2O$ $ha^{-1}$, respectively). A recommended practices i.e., wet method of nursery raising was followed to raise the nursery of rice followed by transplanting using 30 d old seedlings @2–3 seedlings per hill in rows and 20 cm apart. A 2–3 cm water level was maintained during the initial stage followed by 4–5 cm to maintain a standard water level in the rice field up to milk or dough stage. No synthetic chemical or plant growth regulator has been applied in organic fields. The hexaconazole @300 mL $ha^{-1}$, tricyclazole @120 g $ha^{-1}$, carbendazim @1.35 kg ai $ha^{-1}$ were applied for controlling bacterial leaf blight (BLB), sheath blight, stem borer and leaf folder diseases, respectively in the conventional fields. The harvesting was performed with sickle at 110 d after transplanting when about 90% of the grains in panicle had ripened.

## Appendix B

**Well Water Sample Collection**

The depth of water table in the entire study area ranged between 31 to 37 m below ground level, which closely matches with that a standard method used in the area [24]. The information on the water table depth was collected from individual farmers who estimated the depth while digging the tube wells in <2 years before our first field campaign. Thus, we carefully chose farmers' fields such that there was potentially negligible gravity-driven lateral flow of groundwater as adjacent fields which were of the similar hydraulic head (or, groundwater table depth) [2]. Additionally, a considerable distance (a minimum of 10 km radius) was always maintained between an organic and an adjacent conventional field used in this study to avoid any contamination between these two farming systems. Given the geology of the region (unconsolidated alluvial deposits of Quaternary age) [25], climate (hot semi-arid climate as per Köppen-Geiger climate classification system; Geiger 1954), and soil type (sandy loam) [11] are similar in both conventional and organic fields, the management practices associated with the type of fertilizers/manures played an instrumental role in controlling the groundwater quality parameters.

## Appendix C

**Collection of Groundwater Samples**

Field campaigns were conducted before transplanting and after harvest of the growing basmati rice crop in both the systems. All samples were collected and preserved following the operating procedure for groundwater sampling [12]. Three field replicates of groundwater samples were collected at each site from the boreholes (or tube wells) with depth ranging from approximately 120 to 180 feet (~37–55 m). Thus, the number of our collected samples equate to a total of twenty-one samples (3 field replicates × 7 farmer's field) from both organic and conventional farming systems. We used boreholes (or tube wells) because of its increased use in extracting groundwater for both drinking and irrigation water purposes in the Indian subcontinent [24]. All samples were poured in high-density polyethylene (HDPE) round plastic bottles with a threaded cap. After collection, all samples were transported to the laboratory facility of the Division of Environmental Sciences, Indian Agricultural Research Institute (IARI) and stored at 4 °C until processed.

**Analysis of Groundwater Samples**

Groundwater quality parameters were measured following the standard protocol for water quality parameters analysis [13]. To measure total dissolved solids (TDS), the water samples were filtered with glass microfiber filter, and then 50 mL of filtrate was added to a pre-weighed ceramic dish and placed in a drying oven to evaporate at 105 °C. Quantification of TDS was done by subtracting the initial weight of the empty ceramic dish from the weight of the ceramic dish with the dried residue. Carbonate ($CO_3^-$) and bicarbonate ($HCO_3^-$) in groundwater sample were determined by titrating 25 mL of water sample against standardized 0.1 N $H_2SO_4$ using phenolphthalein and methyl red as indicators, respectively. The concentration of calcium ($Ca^{++}$) and magnesium ($Mg^{++}$) was determined by versenate titration method by titrating against 0.01 (N) EDTA-disodium salt solution using Erichrome black T dye as an indicator and ammonium chloride-ammonium hydroxide buffer. Sodium ($Na^+$) concentration was measured using a flame photometer. The pH of groundwater samples was measured by shaking 50 mL of water sample in a 100-mL beaker using a glass electrode in a pH meter. The electrical conductivity (EC) (dS $m^{-1}$ at 25 °C) was measured in 50 mL of the water sample using conductivity meter [14].

The $NO_3^-$ concentration in groundwater was derived on the basis of nitration of salicylic acid [16]. One mL standard or sample was transferred into a 50 mL Erlenmeyer flask and 0.5 mL TRI solution (1 g sodium salicylate + 0.2 g NaCl + 0.1 g $NH_4SO_3NH_2$) and swirled thoroughly. Evaporated to dryness for 5 min at 100–120 °C) and cooled thereafter. The residue was wetted with 1 mL concentration $H_2SO_4$, swirled, and allowed to stand for 5 min. Then, 5 mL MilliQ water and 5 mL 40 percent NaOH were also added down the flask wall and swirled and cooled. The absorbance of the yellow color was measured at 410 nm immediately after the solution solutions were cooled.

**Indices of Groundwater Quality Parameters for Irrigation Purposes**

**Residual Sodium Carbonate (RSC)**

The RSC exists when the content of the ($CO_3^-$ and $HCO_3^-$) exceeds the ($Ca^{++}$ and $Mg^{++}$) content of the irrigation water. RSC was defined as follows [14] (Equation (A1)).

$$RSC = (CO_3^- + HCO_3^-) - (Ca^{++} + Mg^{++}) \quad (A1)$$

The safe limit of RSC for irrigation purpose is <1.24 meq. $L^{-1}$ (Table S2). Irrigation water having RSC values higher than safe limits pose hazards to the crop development (or growth) and leads to accumulation of Na in the soils. It also exerts higher EC and excess salinity in soils.

**Sodium Adsorption Ratio (SAR)**

The SAR is the relative concentration of Na to the combined concentration of ($Ca^{++}$ and $Mg^{++}$). Usually, it is used to predict the hazards of $Na^{+}$ in soils. As such, it is a measure of the sodicity/alkaline hazard of irrigation water [14], calculated (Equation (A2)) using the concentration of ions in millimol (+)/1.

$$\mathrm{SAR} = \frac{\mathrm{Na}^{+}}{\sqrt{\frac{\mathrm{Ca}^{++}+\mathrm{Mg}^{++}}{2}}} \tag{A2}$$

Irrigation water is considered to be hazardous with a SAR value >1.0 [14].

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