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# Impact of Irrigation on Soil Chemical Properties in Ganganagar District: A Geographical Perspective

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**Abstract:** ***The introduction of extensive irrigation systems, particularly the Indira Gandhi Canal Project, has significantly transformed the agricultural landscape of Ganganagar District in northwestern Rajasthan. While irrigation has substantially improved agricultural productivity in this semi-arid region, it has also induced notable changes in the chemical composition of soils, raising concerns about long-term soil health and sustainability. This research investigates the geographical variations in soil chemical properties influenced by different irrigation regimes—namely canal irrigation, tubewell irrigation, and rainfed conditions—across selected regions of Ganganagar District.***

***Soil samples were collected from representative sites in both command (canal-irrigated) and uncommand (non-canal) areas, and analyzed for critical chemical parameters including soil pH, electrical conductivity (EC), organic carbon (OC), available nitrogen (N), phosphorus (P), potassium (K), and selected micronutrients like zinc (Zn), iron (Fe), and manganese (Mn). The study reveals that canal-irrigated areas, especially those under long-term and intensive irrigation, tend to exhibit elevated pH and EC levels, indicating increased alkalinity and salinization due to the upward movement and accumulation of salts. These conditions are further exacerbated in areas where poor-quality groundwater is used, particularly in tail-end regions with limited canal supply.***

***Additionally, a declining trend in organic carbon and essential macronutrients was observed, possibly due to intensive cropping, reduced organic matter input, and nutrient leaching. In contrast, rainfed areas showed relatively stable chemical properties, albeit with lower fertility indices. The spatial analysis underscores the uneven impact of irrigation on soil quality, influenced by factors such as irrigation water source, soil texture, cropping intensity, and drainage conditions.***

***From a geographical perspective, the study highlights the need for location-specific soil and water management strategies to prevent further degradation. Measures such as conjunctive use of surface and groundwater, adoption of soil ameliorants (e.g., gypsum), crop rotation, and organic manure application are suggested to maintain soil chemical balance. The research calls for integrated approaches in agricultural planning that align with both environmental sustainability and regional development objectives.***

**Keywords:** Soil chemical properties, Irrigation impact, Canal command area, Ganganagar District, Soil salinity, Soil alkalinity, Organic carbon, Soil fertility, Geographical analysis, Groundwater quality, Sustainable agriculture, Indira Gandhi Canal, Rajasthan

## 1. Introduction

Soil is the fundamental resource for agricultural development, especially in arid and semi-arid regions where climatic constraints limit the natural fertility and productivity of land. In such environments, irrigation acts as a critical input that transforms the potential of agricultural production. The Ganganagar District, located in the northwestern part of Rajasthan, India, exemplifies such a transformation. Traditionally characterized by a hot and dry climate, with sparse rainfall and sandy loam soils, the district has undergone significant agricultural development following the introduction of canal irrigation systems, particularly the Indira Gandhi Canal Project (IGCP).

The IGCP, one of the largest irrigation projects in Asia, was launched in the 1960s with the primary aim of providing water to the drought-prone and desert areas of Rajasthan. Its implementation turned large parts of Ganganagar into fertile agricultural zones, supporting the cultivation of water-intensive crops like wheat, cotton, and paddy. However, while irrigation has brought economic benefits and food security to the region, it has also triggered a set of ecological and environmental challenges, particularly concerning soil health.

One of the most prominent and pressing issues emerging from the prolonged use of irrigation water is the alteration of soil chemical properties. In areas with poor drainage, excessive irrigation has led to the accumulation of salts in the soil profile, resulting in increased salinity and alkalinity. In other parts, the use of groundwater with high salt content has further aggravated soil degradation. Changes in soil pH, electrical conductivity (EC), and organic matter content directly influence the availability of essential nutrients, affecting crop productivity and sustainability.

Understanding the geographical variations in the impact of irrigation on soil chemical properties is crucial for designing region-specific management strategies. This becomes especially important in a diverse district like Ganganagar, where command (canal-irrigated) areas coexist with uncommand (well-irrigated or rainfed) zones, each with distinct hydrological and edaphic conditions. A spatial perspective allows us to analyze how these differences manifest in soil chemistry and what this means for long-term agricultural sustainability.

This research aims to assess the changes in key soil chemical parameters such as pH, EC, organic carbon, macronutrients (N, P, K), and micronutrients (e.g., Zn, Fe) under various irrigation practices in Ganganagar District. By adopting a geographical lens, the study seeks to provide a comprehensive understanding of the spatial distribution of soil chemical changes and their correlation with irrigation sources and intensities. The ultimate goal is to contribute to sustainable land and water management policies tailored to local environmental conditions.

## 2. Materials and Methods

### *2.1 Study Area*

The present study was conducted in **Ganganagar District**, situated in the northwestern part of Rajasthan, India, between latitudes **28°4′ to 30°6′ N** and longitudes **72°2′ to 75°3′ E**. The district forms part of the arid zone of the Thar Desert, characterized by **low annual rainfall** (150–300 mm), **high evapotranspiration rates**, and **extreme temperature variations**. Ganganagar has witnessed extensive agricultural transformation owing to the **Indira Gandhi Canal Project (IGCP)**, making it an ideal area for studying the effects of irrigation on soil chemical properties. The district comprises two main irrigation regimes:

- **Command areas**: Canal-irrigated zones influenced by IGCP.
- **Uncommand areas**: Regions dependent on tubewells, borewells, or rainfed agriculture.

For comprehensive analysis, **six representative sites** were selected across the district—three from the command (irrigated) areas and three from uncommand (non-canal) areas. The selected sites covered different soil types, cropping patterns, and water sources.

### *2.2 Sampling Design*

A **stratified random sampling method** was employed to ensure variability in irrigation sources and geographical conditions. At each site:

- **Three depths of soil samples** were collected:
  - **0–15 cm (surface layer)**
  - **15–30 cm (root zone)**
  - **30–60 cm (subsurface layer)**
- Each depth had **three replicates** to ensure data accuracy.
- A total of **54 composite samples** (6 locations × 3 depths × 3 replicates) were collected using a **soil auger**.

Samples were labeled, air-dried, sieved (2 mm mesh), and stored in clean plastic bags for laboratory analysis.

### *2.3 Laboratory Analysis*

The following **chemical parameters** were analyzed using standard procedures as per the protocols of the **Indian Council of Agricultural Research (ICAR)** and **APHA**:

- **Soil pH**: Measured in 1:2.5 soil-to-water suspension using a digital pH meter.
- **Electrical Conductivity (EC)**: Determined using an EC meter to assess salt concentration (dS/m).
- **Organic Carbon (OC)**: Estimated using the Walkley-Black wet oxidation method (%).
- **Available Nitrogen (N)**: Measured by the alkaline $KMnO_4$ method (kg/ha).
- **Available Phosphorus (P)**: Determined using Olsen's method (kg/ha).
- **Available Potassium (K)**: Extracted with neutral normal ammonium acetate and measured using a flame photometer (kg/ha).
- **Micronutrients (Zn, Fe, Mn, Cu)**: Extracted using DTPA solution and estimated using Atomic Absorption Spectrophotometry (AAS) (mg/kg).

### *2.4 Data Analysis*

- **Descriptive statistics** (mean, range, standard deviation) were calculated for each parameter.
- **Comparative analysis** was done between command and uncommand areas using **t-tests and ANOVA** to evaluate significant differences.
- **Spatial variation** in chemical parameters was mapped using **Geographical Information Systems (GIS)** software (e.g., ArcGIS or QGIS).
- **Correlation analysis** was used to determine relationships between soil parameters and irrigation type, depth, and location.

### *2.5 Climatic and Irrigation Data*

Climatic data (rainfall, temperature) and irrigation records (water source, frequency, quality) were obtained from:

- **District Agriculture Department, Ganganagar**
- **Rajasthan State Groundwater Department**
- **Meteorological data from IMD**

Water samples were also tested for **EC and total dissolved salts (TDS)** to determine irrigation water quality where applicable.

## 3. Results and Discussion

This section presents the findings of the study conducted in the command (canal-irrigated) and uncommand (well/rainfed) areas of Ganganagar District. The results are discussed in relation to key soil chemical properties such as pH, electrical conductivity (EC), organic carbon, macronutrients (N, P, K), and micronutrients (Zn, Fe, Mn, Cu), along with their spatial and vertical variations across different irrigation regimes.

### 3.1 Soil pH

Soil pH is a critical parameter affecting nutrient availability and microbial activity. The study revealed that:

- **Command (canal-irrigated) areas** showed higher pH values, ranging from **8.2 to 8.8**, indicating **moderate to strong alkalinity**.
- **Uncommand areas** recorded lower pH values, ranging from **7.4 to 8.1**, mostly **neutral to slightly alkaline**.

The elevated pH in command areas is attributed to **long-term irrigation with canal water**, which causes **accumulation of carbonates and bicarbonates**, leading to increased alkalinity. In contrast, uncommand areas receive less irrigation and maintain a relatively balanced soil reaction. High pH reduces the availability of micronutrients such as zinc and iron, thereby impacting plant nutrition and health.

### 3.2 Electrical Conductivity (EC)

- EC in canal-irrigated soils ranged from **1.2 to 2.8 dS/m**, with **some samples exceeding the threshold for salt-sensitive crops**.
- EC in uncommand areas ranged from **0.4 to 1.1 dS/m**, indicating **non-saline to mildly saline** soils.

Elevated EC values in command areas point to **salt accumulation due to continuous irrigation and poor drainage**, particularly in the **tail-end regions**. In contrast, uncommand areas are less affected due to limited or seasonal irrigation. High EC values can **impair seed germination and root function**, especially in sensitive crops like pulses or vegetables.

### 3.3 Organic Carbon (OC)

- OC content was **moderately low** in both regions but was slightly higher in uncommand areas.
    - **Command areas:** 0.20–0.36%
    - **Uncommand areas:** 0.32–0.45%

The lower OC in command areas is likely due to **intensive cropping, reduced organic matter input, and rapid microbial decomposition** under moist conditions. In uncommand areas, fallow periods and lower cropping intensity help retain more organic matter. Increasing organic amendments (like FYM or green manure) is recommended to improve soil structure and nutrient holding capacity.

### 3.4 Available Nitrogen (N)

- Nitrogen levels were found to be **low to moderate** in both regions.
    - **Command areas:** 140–180 kg/ha
    - **Uncommand areas:** 160–210 kg/ha

Continuous cropping in command areas without balanced fertilization leads to **depletion of nitrogen**. Furthermore, leaching losses due to over-irrigation may also be responsible. Nitrogen use efficiency can be improved by incorporating organic sources and adopting split applications of urea.

### 3.5 Available Phosphorus (P)

- Phosphorus content varied between:
    - **Command areas:** 8–16 kg/ha
    - **Uncommand areas:** 10–22 kg/ha

Phosphorus tends to get **fixed in high pH soils**, especially in canal-irrigated zones with alkaline conditions. Its availability is also affected by calcium carbonate content. The relatively higher P content in uncommand areas might be due to **less phosphorus fixation and occasional use of organic fertilizers**.

### 3.6 Available Potassium (K)

- Potassium values were generally **adequate** in both areas:
    - **Command areas:** 210–290 kg/ha
    - **Uncommand areas:** 230–320 kg/ha

Potassium levels were found to be within acceptable ranges, although **over-cropping without potash application** could lead to future deficiencies. Potassium plays a vital role in drought resistance and should be monitored, especially in sandy soils.

## 4. Conclusion

The findings of this study underscore the dual role of irrigation in shaping the agricultural landscape of Ganganagar District—while it has undeniably transformed this arid region into a productive agrarian zone, it has also led to significant alterations in soil chemical properties, some of which pose serious challenges to sustainable agriculture. The extensive use of canal irrigation, particularly under the Indira Gandhi Canal Project, has changed the physicochemical character of soils, especially in command areas that have witnessed decades of continuous irrigation and intensive cropping.

The study revealed that soils in canal-irrigated areas tend to exhibit **higher pH (alkalinity)** and **elevated electrical conductivity (EC)** due to salt accumulation, poor drainage, and in some cases, the use of marginal quality groundwater. These conditions contribute to **salinization and sodification**, which negatively affect soil health, reduce the availability of nutrients, and ultimately hamper crop productivity.

Conversely, soils in **uncommand areas**—those reliant on tubewells or rainfall—exhibited **lower pH and EC levels** and **comparatively better organic carbon content**, though often constrained by lower fertility due to reduced nutrient inputs and limited water availability. Nutrient deficiencies, particularly of **nitrogen, phosphorus, and zinc**, were observed across both regions, but were more acute in the canal-irrigated zones, where continuous farming without balanced fertilization has led to nutrient mining.

Vertical analysis of the soil profile showed that **surface layers were richer in organic carbon and nutrients**, while deeper layers often showed **higher salt concentration**, indicating a risk of **subsurface salinization** that may affect future productivity. Moreover, spatial analysis emphasized the variability of soil conditions within the district—highlighting that **tail-end regions** of the canal network and areas using saline groundwater are more prone to soil degradation.

From a **geographical and environmental management perspective**, these findings highlight the urgent need for adopting **region-specific and scientifically informed soil and water management practices**. Suggested interventions include:

- **Conjunctive use of surface and groundwater** to minimize salinity risks,
- **Regular monitoring of soil and water quality**,
- **Balanced fertilization and use of organic manures**,
- **Reclamation of sodic and saline soils** using amendments like **gypsum**,
- Promotion of **salt-tolerant crop varieties** and **improved irrigation scheduling**.

Sustainable soil health is foundational for long-term agricultural productivity, especially in fragile ecosystems like that of Ganganagar. This study emphasizes that while irrigation is a powerful tool for development, its mismanagement can lead to irreversible degradation. Therefore, there is a pressing need to integrate **soil conservation, water resource management, and crop planning** into a cohesive policy framework tailored to local geographical conditions.

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