

Hydro-chemical Evolution and Groundwater Quality Dynamics under the Influence of Narmada Canal Irrigation in the Sanchoe Region of Jalore District, Rajasthan, India

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Abstract

Groundwater is the main and last source of water for residential and agricultural use. The present paper deals with the influence of Narmada Canal irrigation system in the dry zone of low rainfall regions of the western Rajasthan namely the Sanchoe area of Jalore district on ground water recharge, agricultural development and chemical features of the water. The present study deals with the assessment of hydro-chemical composition and groundwater quality in the command area of canal irrigation. Groundwater samples were collected from selected villages and analyzed for key physicochemical parameters like pH, Electrical Conductivity (EC), Total Dissolved Solids (TDS), Total Hardness (TH), Calcium, Magnesium, Bicarbonate, Chloride, Sulfate, Nitrate and Fluoride using standard analytical methods. The results showed that the Groundwater is generally neutral to slightly alkaline and the dissolved ion concentrations showed significant regional variation due to water-rock interactions, mineral dissolution, evaporation, canal seepage, irrigation return flow and agricultural activities. The results of the study show that the hydro-chemical character of groundwater in the area is controlled by natural geochemical processes and anthropogenic activities. The present study will be helpful in analyzing the groundwater quality, sustainable irrigation, water resource planning and long-term groundwater management in the Narmada Canal command region of western Rajasthan.

Keywords:

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Introduction

Water is one of the most important natural resources for sustaining life, ecosystems, agriculture and socio-economic development. Groundwater is the most dependable supply of fresh water, particularly in arid and semi-arid areas where surface water is scarce and rainfall is highly erratic. Groundwater is the main supply of water for drinking, agriculture, livestock and industrial operations in western Rajasthan. The growing population, agricultural intensification, industrial expansion, excessive groundwater abstraction and climate variability have put a great burden on groundwater resources resulting in both quantitative depletion and qualitative deterioration. Sustainable water resource management has resulted in the need of groundwater quality assessment.[1] The groundwater chemistry is influenced by natural hydro geochemical processes and by human activities. The ionic composition of groundwater is controlled by natural factors like mineral dissolution, weathering, interaction between groundwater and rocks, evaporation and aquifer properties, while its chemical characteristics are also altered by anthropogenic activities like intensive irrigation, fertilizer application, irrigation return flow, landuse changes and overexploitation. Hydro-chemical investigations

are therefore important to discover the controlling processes of the groundwater evolution and its suitability for drinking and irrigation purposes.[2] Sanchoe region of Jalore District of south-western Rajasthan is a typical dry environment where traditionally groundwater has been the main source of water. The Narmada Canal irrigation system has brought about a drastic change in the hydrological and agricultural circumstances of the area. It has improved the irrigation facilities, increased the groundwater recharge, increased the cropping intensity and improved the agricultural yield. However, the changing groundwater recharge patterns and hydrochemical properties due to canal seepage, irrigation return flow, and intensive agricultural methods make continual groundwater quality monitoring an indispensable tool for sustainable management of aquifer systems.[3]

The present study was carried out in 10 sample villages of Narmada Canal Command Area, viz., Sanchoe, Dabhal, Agar, Paharpura, Partappura, Barsam, Jajusan, Hadetar, Phalna and Lachadi. Groundwater samples were collected from representative locations and their geographical coordinates were recorded with the Global Positioning System (GPS) for GIS-based spatial analysis. The collected samples were analyzed

for their major physicochemical parameters such as pH, Electrical Conductivity (EC), Total Dissolved Solids (TDS), Total Hardness (TH), Calcium (Ca^{2+}), Magnesium (Mg^{2+}), Chloride (Cl^-), Bicarbonate (HCO_3^-), Sulfate (SO_4^{2-}), Nitrate (NO_3^-) and Fluoride (F^-) by using standard analytical procedures.[4]

The objectives of the present study are to evaluate the hydro-chemical characteristics of groundwater, identify the natural and anthropogenic factors controlling groundwater chemistry, assess the influence of Narmada Canal irrigation on groundwater quality and to determine its suitability for drinking and irrigation uses.[5] The results are intended to give useful scientific information for groundwater quality monitoring, hydro-chemical interpretation, sustainable groundwater management, agricultural planning and long term water resource conservation in the Narmada Canal Command Area of western Rajasthan.

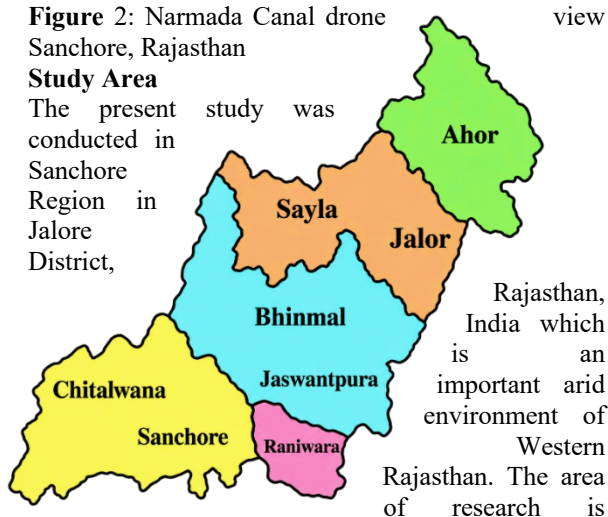
Study Area

Figure 1: Jalore District

Figure 2: Narmada Canal drone view
Sanchore, Rajasthan

Study Area

The present study was conducted in Sanchore Region in Jalore District,



situated within the influence zone of Narmada canal Command Area and has typical dry to semi arid climatic characteristics. The area is characterized by low and irregular rainfall, high temperatures, intense sun radiation and high rates of evaporation which significantly affect the availability and quality of water resources.

The restricted quantity of surface water and severe climatic circumstances have traditionally made groundwater the principal source of water for home consumption, agriculture, cattle and other socio-economic activities. Dependence on groundwater resources has increased with increasing population pressure and development of agricultural methods. Hence, hydro-chemical assessment is crucial for sustainable water management.

The advent of the Narmada Canal irrigation system has brought about drastic changes in the hydrological and

socio-economic conditions of the region. The irrigation through canals has boosted the productivity of agriculture, area under cultivation and intense cultivation. Groundwater systems are also affected by canal seepage, irrigation return flow and changing recharge methods that influence groundwater levels and chemical properties. Therefore, the research of ground water chemistry of the canal command area is vital for understanding the interplay between surface irrigation systems and aquifer activities.

Geographical and Physiographic Characteristics

The research region is a transition zone between desert and semi-arid environment of western Rajasthan. The scenery is mostly flat to gradually rolling terrain, alluvial plains, cultivated farms and scattered sandy areas. The area is located in the Thar Desert environment, characterized by restricted surface drainage due to the arid climate.

The geological setting is characterized by unconsolidated alluvial deposits of sand, silt, clay and gravel. These deposits are the principal groundwater carrying formations and govern the occurrence and transport of groundwater. The main contributors to the groundwater recharge are rainfall infiltration, canal seepage and irrigation return flow. The regional disparities of the groundwater quality are due to the lithology variations and the groundwater movement.[12]

Climate and Hydro-chemical Importance

Climate in Sanchore region is hot and arid with very high summer temperatures and large evaporation losses. Rainfall is quite erratic, insufficient for natural groundwater recharging and is largely confined to the southwest monsoon. High rates of evaporation concentrate dissolved minerals, altering the chemistry of groundwater.[9]

Natural processes such as mineral dissolution, weathering, interaction between groundwater and rocks, evaporation and anthropogenic activities such as fertilizer application, irrigation techniques and groundwater exploitation affect groundwater quality. Hence, hydro-chemical analysis gives vital information on groundwater evolution and appropriateness for drinking and irrigation reasons.[10,11]

In the present study, ten locations for groundwater sampling were selected from different villages in Narmada Canal Command Area. The selected places exhibit a variety of hydro geological conditions, agricultural methods, and influence of canals. GPS based coordinates of each sampling location were acquired for spatial analysis and GIS based groundwater quality mapping.

Table 1: Details of Groundwater Sampling Villages, Sample ID and Geographical Location

Sr. No.	Village Name	Sample	Latitude	Longitude
1	Sanchore	GWS-01	24.75658 2° N	71.75537 4° E
2	Dabhal	GWS-02	24.76148 3° N	71.71520 2° E
3	Agar	GWS-03	24.74389 4° N	71.72352 6° E
4	Paharpura	GWS-04	24.72119 7° N	71.74428 1° E
5	Partappura	GWS-05	24.70889 1° N	71.78837 7° E
6	Barsam	GWS-06	24.72195 1° N	71.80196 7° E
7	Jajusan	GWS-07	24.74472 7° N	71.81719 5° E
8	Hadetar	GWS-08	24.76311 2° N	71.83280 6° E
9	Phalna	GWS-09	24.76843 9° N	71.81632 9° E
10	Lachadi	GWS-10	24.77127 1° N	71.80856 2° E

Significance of the Study Area

The Sanchore Region is very significant for groundwater studies as it is an arid region, where the groundwater supplies are affected by natural processes and big scale irrigation projects. The interplay of canal water, agricultural activities and the ground water systems provides a chance to examine the hydrochemical changes occurring in the canal command regions.

The present work is focused to investigate the hydrochemical evolution and groundwater quality assessment under the influence of Narmada Canal irrigation in Sanchore Region of Jalore District, Rajasthan, India. The results of this study will contribute to the understanding on groundwater behavior, geographical variation in groundwater quality and long term implications of canal based irrigation development in dry parts of western Rajasthan.

Hydro-chemical Analysis

Hydro-chemical analysis is an important instrument for comprehending the chemical features, origin, evolution and quality status of groundwater resources.

The chemical composition of groundwater is affected by several natural and manmade variables, such as geological formations, mineral dissolution, groundwater-rock interaction, evaporation processes, recharge conditions, agricultural activities and irrigation methods. In arid and semi-arid countries, where groundwater is the most vital source of water supply, hydro-chemical analysis plays a crucial role in assessing the groundwater suitability for household, agricultural and other applications.[6,7]

The present study was carried out in the Narmada canal command area of Sanchore region, Jalore District, Rajasthan, India, where the canal irrigation has profoundly affected the circumstances of groundwater recharge and agricultural methods. The interplay of canal water, irrigation return flow, and aquifer minerals can affect groundwater chemistry and generate geographical differences in groundwater quality.[8]

Groundwater samples from 10 selected villages in the research region were collected for the present experiment and tested for critical physicochemical parameters. The analysis includes pH, Electrical Conductivity (EC), Total Dissolved Solids (TDS), Total Hardness (TH), Calcium (Ca²⁺), Magnesium (Mg²⁺), Chloride (Cl⁻), Bicarbonate (HCO₃⁻), Sulfate (SO₄²⁻), Nitrate (NO₃⁻) and Fluoride (F⁻). These characteristics provide information on groundwater mineralization, salinity, hardness, alkalinity, and potential sources impacting groundwater quality.

Table 2: Physico-Chemical Characteristics of Groundwater Samples Collected from the Narmada Canal Command Area of Sanchore Region, Rajasthan

Sample No.	pH	TDS (mg/L)	EC (µS/cm)	TH (mg/L)	Ca ²⁺ (mg/L)	Mg ²⁺ (mg/L)	Cl ⁻ (mg/L)	HCO ₃ ⁻ (mg/L)	SO ₄ ²⁻ (mg/L)	NO ₃ ⁻ (mg/L)	F ⁻ (mg/L)
GWS-01	7.40	1540	2406	380	84	42	250	464	102	12	0.9
GWS-02	7.51	913	1423	180	40	20	272	220	107	15	1.2

G W S- 03	6 . 8	1 1 0 5	1 7 2 7	5 2 0	1 1 5	5 7	2 5 5	6 3 4	1 0 1	9	0 . 7
G W S- 04	7 . 7	1 5 5 5	2 4 3 0	3 6 0	7 9	3 9	2 3 5	4 3 9	9 5	1 9	1
G W S- 05	7 . 6	2 0 8 3	3 2 5 5	3 7 2	8 2	4 1	2 4 5	4 5 4	9 9	2 9	0 . 8
G W S- 06	7 . 7	1 1 7 8	1 8 4 1	1 5 0	3 3	1 6	2 6 8	1 8 3	1 0 6	1 0	1 . 4
G W S- 07	7 . 3	2 7 6 7	4 3 2 3	4 1 8	9 2	4 6	2 8 5	5 1 0	1 1 2	1 8	1 . 1
G W S- 08	7 . 1	2 7 7 0	4 3 2 8	2 1 0	4 6	2 3	3 0 0	2 5 6	1 1 8	2 1	0 . 9
G W S- 09	7	2 0 8 0	3 2 5 0	3 9 5	8 7	4 3	2 6 5	4 8 2	1 0 5	3 3	1 . 5
G W S- 10	7 . 6	2 7 8 0	4 3 4 4	2 5 0	5 5	2 7	2 9 0	3 0 5	1 1 4	4	1 . 2

Potential of Hydrogen

pH is an important parameter for the determination of the acid or basicity of groundwater which influence the solubility and mobility of dissolved constituents. The pH values of the groundwater samples ranged from 6.8 to 7.7, which is slightly acidic to slightly alkaline. The almost neutral to alkaline pH shows that carbonate and bicarbonate are the major buffering agents. The alkalinity could be due to breakdown of carbonate minerals and extended interaction with groundwater constituents. Canal seepage and irrigation drainage can potentially alter the quality of groundwater.

Electrical Conductivity (EC) and Mineralization Status

The electrical conductivity is a measure of how mineralized the ground water is. The degree of mineralization is the concentration of dissolved ionic elements in groundwater. The EC readings ranged from 1423 to 4344 $\mu\text{S}/\text{cm}$. The lowest value was seen at GWS-02 (Dabhal) while highest was recorded at GWS-10 (Lachadi).

Higher values of EC are associated with high concentration of dissolved salts due to evaporation, mineral dissolution, longer residence time of ground water and salt accumulation in aquifer system. In arid regions like western Rajasthan, the major cause for groundwater salinity is the high rate of evaporation. The recharging mechanism is responsible for the variations in the EC distribution in the Narmada Canal system. Dilution effects may be produced by canal seepage although dissolved ion levels may be increased by irrigation return flow.

Total Dissolved Solids (TDS)

Total Dissolved Solids (TDS) is the total concentration of inorganic and organic substances in solution in groundwater. The content of total dissolved solids ranged from 911 to 2780 mg/L. The lowest value was found in GWS-02 and highest value was recorded in GWS-10.

Changes in the replenishment of groundwater, evaporation rates, mineral solubility and the transportation of groundwater can all cause TDS levels to vary. In some regions there are high TDS levels due to salt buildup in dry conditions and widespread irrigation.

Hardness and Major Cations

Total Hardness is governed mainly by calcium and magnesium ions and reflects the suitability of ground water for home and agricultural purposes. TH values were from 150 to 520 mg/L.

Calcium concentrations ranged from 33 to 115 mg/L and magnesium values ranged from 16 to 57 mg/L. Calcium and magnesium are present mainly because of carbonate mineral dissolution and groundwater-aquifer material interaction. The spatial variation in hardness is a reflection of varied lithological conditions, groundwater circulation and residence time.

Major Anion Chemistry

Bicarbonate (HCO_3^-) :

One of the most prominent sources of alkalinity in ground water is bicarbonate. Concentration ranged from 183 to 634 mg/L. High bicarbonate values show active carbonate dissolution and interaction activities between groundwater and rocks.

Chloride (Cl^-) :

Chloride acts as a conservative ion and indicates evaporation effects, agricultural influence, and

external contamination sources. The chloride concentration ranged from 235 to 300 mg/L. Variations may be related to irrigation return flow, evaporation concentration, and dissolution of chloride-bearing minerals.

Sulphate (SO_4^{2-}):

Sulphate concentration varied between 95 and 118 mg/L. Its occurrence is mainly controlled by dissolution of sulphate minerals and agricultural inputs.

Nitrate (NO_3^-):

Nitrate concentration ranged from 4 to 33 mg/L. Higher nitrate values indicate the possible influence of fertilizer application, irrigation return flow, and agricultural activities within the canal command area.

Fluoride (F^-):

Fluoride concentration varied from 0.7 to 1.5 mg/L. The variation is mainly controlled by geological conditions, fluoride-bearing minerals, and groundwater-rock interaction.

Results and Discussion

The present study aims to assess the groundwater quality and hydrochemical parameters of Narmada Canal Command Area in Sanchore region. Analysis of ten groundwater samples indicates significant geographical heterogeneity in groundwater chemistry. Groundwater samples are mostly neutral to slightly alkaline suggesting carbonate and bicarbonate reactions dominate. The variability of EC and TDS reveals the changes in salinity and mineralization of groundwater. These changes are influenced by evaporation, mineral solubility, aquifer properties, replenishment mechanisms, and irrigation methods.

The effect of Narmada Canal has changed the groundwater state by providing additional source of recharge through seepage and irrigation return flow. High evaporation and return flow may lead to increased salinity in evaporation and return flow zones, while canal recharge areas may be subjected to dilution effects.

Calcium, magnesium, bicarbonate, chloride, sulfate, nitrate, and fluoride concentrations are a product of both natural geological processes and human activity. The principal natural regulation processes are mineral dissolution and the interaction between groundwater and rock, while agricultural activities cause nitrate enrichment and changes in ionic composition. The hydrochemical analysis results show that the groundwater quality in the study area is controlled by complex interrelationships between climate, geology, irrigation practices and groundwater flow regimes.

Recommendations

- Regular Groundwater Monitoring: Establish a systematic monitoring program to evaluate seasonal and long-term changes in groundwater quality.

- Efficient Irrigation Practices: Promotion of drip and sprinkler irrigation systems should be pushed to decrease excessive water use and limit salt accumulation.

- Integrated Canal and Groundwater Management: The balanced use of canal water and groundwater should be practiced to preserve sustainability of the aquifer.

- Control of Agricultural Pollution: To limit nitrate pollution, excessive application of fertilizer and pesticides should be minimized.

- Artificial Recharge Measures: Rain water collection, recharge ponds and other artificial recharge measures should be established.

- GIS-Based Groundwater Management: Application of GIS and remote sensing techniques for mapping of groundwater quality and identification of sensitive zones.

- Community Participation: Organize public awareness campaigns on conservation of groundwater and sustainable agriculture methods.

Conclusion

The study was carried out to evaluate the groundwater chemistry and quality of Narmada Canal command area in Sanchore, Jalore District, Rajasthan, an arid to semi-arid region where groundwater is the lifeline for domestic, agricultural and livestock needs. Canal irrigation has led to higher agricultural yield and changed recharge conditions. Groundwater chemistry has been altered by seepage, irrigation return flow, evaporation and intensive farming. The analysis of 10 samples revealed considerable regional variability. Groundwater was generally neutral to slightly alkaline with buffering effect of carbonate and bicarbonate. Differences in electrical conductivity and total dissolved solids represented differences in mineralization and salinity influenced by evaporation, residence time, mineral dissolution and recharge. The major-ion composition was influenced by both natural processes of weathering and water-rock interaction and human actions of fertilizer application and irrigation return flow. The results emphasize the need for regular monitoring and integrated approach for groundwater management. Protecting water quality, enhancing long-term water security and supporting sustainable agricultural growth in western Rajasthan can be achieved through efficient irrigation, pollution management, artificial recharge, GIS-based assessment and community participation.

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