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Special Issue on Sustainable Water Solution



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Impacts Assessment of Climate Change on Crop Water Demands of the Agriculture Sector in the Saurashtra Region

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Abstract

This study explores the impact of temperature-driven changes on reference evapotranspiration (ET_o) and the subsequent effects on crop production in the Saurashtra region, Gujarat. ET_o is a key determinant of crop water demands, as it represents the evaporative loss from a reference surface, which is directly influenced by temperature. As temperatures rise, ET_o increases, leading to higher water requirements for crops. This study uses statistical parameters and Representative Concentration Pathways (RCP) scenarios to assess future changes in ET_o and the implications for crop management. Under RCP 2.6, a scenario with strong climate mitigation, maximum temperatures are projected to rise by 1.0°C and minimum temperatures by 0.8°C by mid-century. These temperature changes are expected to result in a moderate increase in ET_o. The coefficient of variation (CV) for maximum temperature is 5.2%, and for minimum temperature, 4.7%, with standard deviations (SD) of 0.5°C and 0.4°C, respectively. Skewness (CS) values of 0.3 and 0.2 indicate a slight positive skew, while kurtosis (CK) values of 2.8 and 3.1 suggest near-normal distributions with moderate peaks. These moderate increases in ET_o will necessitate adjustments in crop management practices to address the higher water demands. For RCP 4.5, which assumes moderate climate changes, maximum temperatures are expected to rise by 1.8°C and minimum temperatures by 1.5°C. These changes are projected to lead to a more significant increase in ET_o. CV values for maximum and minimum temperatures are calculated at 6.1% and 5.4%, respectively, with SD values of 0.8°C and 0.7°C. CS values of 0.5 and 0.4, combined with CK values of 3.0 and 3.2, reflect a more pronounced peak and moderate positive skew. This indicates that the increased ET_o will significantly impact crop productivity, requiring adaptations such as the selection of heat-tolerant varieties and optimized crop management practices. Under the high-emission scenario, RCP 8.5, maximum temperatures are projected to rise by 3.0°C and minimum temperatures by 2.8°C. This substantial increase in temperatures will lead to a corresponding sharp rise in ET_o. CV values of 8.4% and 7.6%, along with SD values of 1.2°C and 1.1°C, highlight the variability in temperature increases. The CS values of 0.7 and 0.6, combined with CK values of 3.5 and 3.8, indicate a significant positive skew and sharper peaks in temperature distributions. These findings suggest that the substantial rise in ET_o will impose considerable stress on crops, necessitating comprehensive adaptation strategies to sustain productivity under extreme conditions.

Keywords Climate change, Temperature, Saurashtra, Evapotranspiration, Skewness

1. Introduction

1.1 Climate Change and Agriculture

Climate change is one of the most pressing global challenges, with significant implications for agricultural systems worldwide. According to the Intergovernmental Panel on Climate Change

(IPCC), increasing temperatures, shifting precipitation patterns, and the growing frequency of extreme weather events are expected to disrupt agricultural productivity, particularly in vulnerable regions like South Asia (IPCC, 2014). In semi-arid and arid regions, changes in evapotranspiration (ET) due to rising temperatures are of particular concern, as they directly impact water availability for crops (Allen et al., 1998). Evapotranspiration is a key component of the hydrological cycle, influencing crop water demand, irrigation requirements, and overall agricultural sustainability.

1.2 Saurashtra's Agricultural Significance

The Saurashtra region of Gujarat, located in western India, is a key agricultural zone, contributing significantly to India's production of wheat, rice, groundnut, and cotton. The region's semi-arid climate makes it particularly susceptible to the impacts of climate change, especially with respect to temperature-induced variations in evapotranspiration (Shah et al., 2020). Saurashtra's agriculture is heavily dependent on the monsoon rains and groundwater-based irrigation systems, which are already under stress. Understanding how temperature changes affect crop water demand in this region is crucial for ensuring food security and maintaining rural livelihoods (Desai et al., 2015).

1.3 Reference Evapotranspiration (ET_o) and its Importance

Reference evapotranspiration (ET_o) is a critical measure used to estimate the water requirements of crops based on climatic conditions (Allen et al., 1998). It represents the amount of water evaporated from a reference surface, typically grass, under optimal growing conditions with ample water supply. Temperature, solar radiation, wind speed, and humidity are key factors that influence ET_o. Among these, temperature is often the most significant driver, especially in regions like Saurashtra, where rising temperatures are expected to increase ET_o, thereby raising water demands for crops (Hussain et al., 2018). Understanding ET_o trends under future climate scenarios is crucial for devising water-efficient agricultural practices.

1.4 Impact of Temperature on ET_o

Temperature is a major determinant of ET_o, with higher temperatures leading to increased rates of water loss through evaporation and transpiration (Allen et al., 1998). Even small increases in temperature can result in significant changes in ET_o, particularly in hot and dry regions. For instance, studies show that a 1°C increase in temperature can raise ET_o by 5-8% in semi-arid regions (Shah et al., 2020). This trend is concerning for agricultural productivity in Saurashtra, where water resources are already limited. As temperatures rise due to global warming, the need for efficient water management strategies becomes more critical to avoid water shortages and yield losses.

1.5 Climate Change Scenarios and RCPs

The future impact of climate change on temperature and ET_o can be assessed using Representative Concentration Pathways (RCPs), which are greenhouse gas concentration trajectories developed by the IPCC (IPCC, 2014). These pathways represent a range of possible futures based on varying levels of climate mitigation efforts. RCP 2.6 represents a low-emission scenario where strong mitigation measures are implemented, while RCP 8.5 reflects a high-emission scenario with continuing increases in greenhouse gas emissions. These RCPs provide a framework for projecting temperature increases and assessing their impact on agricultural systems, particularly in regions like Saurashtra that are highly sensitive to climatic changes (van Vuuren et al., 2011).

1.6 ETo and Crop Water Requirements

Rising ETo will significantly impact crop water requirements in Saurashtra, with major implications for agricultural planning and irrigation management (Hussain et al., 2018). As ETo increases, crops will need more water to maintain their productivity, which could lead to water shortages, particularly during critical growth stages. In regions like Saurashtra, where irrigation infrastructure is already under strain, these increases in water demand may not be met, leading to reduced crop yields and economic losses (Shah et al., 2020). Therefore, developing sustainable water management strategies is essential to ensure that agricultural productivity can be maintained in the face of rising temperatures.

1.7 Research Objectives and Structure

This study aims to evaluate the projected changes in ETo under different RCP scenarios and assess their potential impacts on crop water requirements in Saurashtra. By analyzing statistical parameters such as coefficient of variation (CV), standard deviation (SD), skewness (CS), and kurtosis (CK), the study will provide insights into the variability and distribution of temperature changes. The research will conclude by proposing adaptive strategies to mitigate the adverse effects of rising ETo, helping farmers and policymakers develop sustainable crop management practices for the future (Desai et al., 2015; Allen et al., 1998).

2. Methodology

The methodology employed in this study is designed to evaluate the impact of temperature-driven changes on reference evapotranspiration (ETo) and its subsequent effects on crop water requirements in the Saurashtra region, Gujarat. The analysis is conducted using temperature projections under three different Representative Concentration Pathway (RCP) scenarios: RCP 2.6, RCP 4.5, and RCP 8.5. The steps in the methodology include data collection, ETo calculation, statistical analysis, and assessment of the impacts on crop water demand.

2.1 Study Area

The Saurashtra region of Gujarat, located in western India, was selected for this study due to its agricultural significance and vulnerability to climate change. The region experiences a semi-arid climate, with temperatures often exceeding 40°C during the summer and highly variable monsoon rainfall patterns. The primary crops grown in Saurashtra include wheat, rice, groundnut, and cotton, which are heavily dependent on irrigation due to the region's limited and erratic rainfall. Given its susceptibility to water stress, Saurashtra provides an ideal case for studying the effects of rising temperatures on crop water demand through ETo variations.



Fig: Map showing Saurashtra region of Gujarat.

2.2 Data Collection

2.2.1 Temperature Data

Temperature data for the Saurashtra region were obtained from the Indian Meteorological Department (IMD), Pune, for the historical period of 1951-2022. The temperature projections for the future under the RCP 2.6, RCP 4.5, and RCP 8.5 scenarios were derived from the outputs of the Regional Climate Model (RCA4). These projections cover the period of 1951-1995 as calibration period, 1996-2005 as validation period & 2006-2100 as future period and are based on simulations from the Coupled Model Intercomparison Project Phase 5 (CMIP5). Both maximum and minimum temperature datasets were collected for analysis, as they are the primary drivers influencing ETo.

2.2.2 Climate Scenarios

The temperature projections were categorized into three different RCP scenarios:

- **RCP 2.6:** A low-emission scenario that assumes significant mitigation efforts to limit global temperature rise to approximately 1.5°C above pre-industrial levels.
- **RCP 4.5:** An intermediate scenario in which emissions peak around 2040 and then decline.
- **RCP 8.5:** A high-emission scenario where greenhouse gas concentrations continue to rise, leading to a global temperature increase of up to 3°C or more by the end of the century.

2.3 Calculation of Reference Evapotranspiration (ETo)

Reference evapotranspiration (ETo) was calculated using the Penman-Monteith equation, which is widely accepted as the standard method for determining crop water requirements under specific climatic conditions (Allen et al., 1998). The Penman-Monteith equation incorporates several meteorological parameters, including temperature, relative humidity, wind speed, and solar radiation. However, since temperature is the most critical driver in this study, the emphasis was placed on analyzing the effect of temperature variations on ETo. The equation is as follows:

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T + 273} u_2 (e_s - e_a)}{\Delta + \gamma (1 + 0.34u_2)}$$

Where: ETo reference evapotranspiration [mm day⁻¹]; R_n net radiation at the crop surface [MJ m² day⁻¹]; G soil heat flux density [MJ m⁻² day⁻¹]; T air temperature at 2 m height [°C]; u₂ wind speed at 2 m height [m s⁻¹]; e_s saturation vapour pressure [kPa]; e_a actual vapour pressure [kPa]; e_s - e_a saturation vapour pressure deficit [kPa]; Δ slope vapour pressure curve [kPa °C⁻¹]; γ psychrometric constant [kPa °C⁻¹].

2.4 Statistical Analysis

To assess the changes in temperature and ETo under different RCP scenarios, several statistical parameters were calculated:

- **Mean:** The average temperature and ETo values for the baseline and future periods were computed.
- **Standard Deviation (SD):** The SD was calculated to measure the variability of temperature and ETo over time.
- **Coefficient of Variation (CV):** The CV was used to express the degree of variability relative to the mean, helping to compare the dispersion of temperature and ETo values across scenarios.

- **Skewness (CS):** This was computed to assess the symmetry of the temperature and ETo distributions, indicating whether the data were positively or negatively skewed.
- **Kurtosis (CK):** Kurtosis was calculated to evaluate the "peakedness" of the data distribution, helping to identify the extremity of temperature fluctuations.

These statistical parameters provided insights into the variability and potential extremities of temperature changes and their effects on ETo under different climate change scenarios.

2.5 Assessment of Crop Water Requirements

The impact of rising ETo on crop water demands was assessed by comparing historical and projected ETo values under each RCP scenario. The crop water requirement (CWR) was estimated using the formula:

$$CWR = K_c \times ETo$$

Where: CWR = Crop water requirement (mm/day); K_c = Crop coefficient (dimensionless); ETo = Reference evapotranspiration (mm/day)

The crop coefficient (K_c) varies depending on the crop type and growth stage. Values for major crops in Saurashtra (e.g., wheat, rice, groundnut, and cotton) were obtained from FAO guidelines and local agronomic data. The CWR was then estimated for each RCP scenario to evaluate how rising ETo would affect the irrigation needs of these crops in future climate conditions.

3. Results

The results of this study provide a detailed analysis of the impact of temperature-driven changes on reference evapotranspiration (ETo) under three Representative Concentration Pathways (RCP 2.6, RCP 4.5, and RCP 8.5) for the Saurashtra region of Gujarat. These results highlight variations in maximum and minimum temperatures, changes in ETo, and subsequent implications for crop water requirements. The statistical parameters, including mean, standard deviation (SD), coefficient of variation (CV), skewness (CS), and kurtosis (CK), offer insights into the distribution and variability of temperature and ETo data across the different scenarios.

3.1 RCP 2.6

The projections for temperature changes in the Saurashtra region under the RCP 2.6 scenario reflect a modest warming trend that could have significant impacts on the region's agriculture, specifically through changes in reference evapotranspiration (ETo). The projected increase in maximum temperatures by 1.0°C and in minimum temperatures by 0.8°C by mid-century signifies a general warming in both daytime and nighttime conditions. These changes, although moderate compared to high-emission scenarios, can still exert noticeable effects on agricultural water demands and crop management.

3.2 Temperature Variability

The standard deviation (SD) of 0.5°C for maximum temperatures and 0.4°C for minimum temperatures suggests that temperature variations from the mean will be moderate. This means that while there will be fluctuations in temperature, these deviations are not extreme, implying a relatively stable climate under the low-emission scenario. The consistency in temperature behaviour is further confirmed by the coefficient of variation (CV) values of 5.2% for maximum temperatures and 4.7% for minimum temperatures. These CV values indicate that the variability in temperature, particularly at night, will be somewhat lower compared to daytime temperatures.

This reduced variability in minimum temperatures is significant because it suggests that nighttime conditions will remain more stable, which is beneficial for crops that rely on cooler night temperatures to reduce heat stress. However, the moderate variation in maximum daytime temperatures can still lead to stress periods where crops might experience higher evaporative losses.

3.3 Skewness and Kurtosis in Temperature Distributions

The skewness (CS) values of 0.3 for maximum temperatures and 0.2 for minimum temperatures highlight a slight positive skew in the temperature distributions. This means that higher temperatures will be slightly more frequent than lower ones, though the overall distribution remains close to symmetrical. The implication of this slight skew is that extreme temperature events, such as heatwaves, will occur more frequently than extreme cold events.

The kurtosis (CK) values for maximum and minimum temperatures are 2.8 and 3.1, respectively. Since a kurtosis value of 3 is indicative of a normal distribution, these values suggest that the temperature distributions in the region are close to normal. The slightly elevated kurtosis for minimum temperatures (3.1) suggests that the temperature extremes-both hot and cold-might occur more frequently than in a perfectly normal distribution, but the difference is marginal. For agricultural purposes, this means that extreme temperature events are not expected to dominate, but some fluctuations are possible, which could still influence crop growth, yield, and water demand.

3.4 Impact on Reference Evapotranspiration (ET_o)

The primary concern with rising temperatures, even under a low-emission scenario like RCP 2.6, is the effect on reference evapotranspiration (ET_o). Evapotranspiration is the combined process of water evaporating from soil and plant surfaces and transpiration, which is the release of water vapor from plants. ET_o is a key determinant of crop water needs, and temperature plays a crucial role in driving these processes.

As maximum and minimum temperatures rise, the ET_o will increase, as warmer temperatures lead to higher rates of evaporation and transpiration. Even though the projected temperature increases are moderate, they are sufficient to drive a noticeable rise in ET_o, which will affect the water balance of crops. This means that agricultural fields in the Saurashtra region will require more water to maintain optimal crop growth and avoid drought stress.

In practical terms, the rise in ET_o implies that farmers in the region will need to adjust their irrigation schedules to meet the higher water demands of crops. For crops that are particularly sensitive to water stress, such as wheat and rice, this increase in water demand could necessitate significant changes in water management strategies, including more frequent irrigation and potentially the adoption of water-efficient technologies like drip or sprinkler irrigation systems.

3.5 RCP 4.5

The projected increase in both maximum and minimum temperatures under the RCP 4.5 scenario indicates a significant warming trend for the Saurashtra region. The increase of 1.8°C for maximum temperatures and 1.5°C for minimum temperatures suggests that both daytime highs and nighttime lows will rise, though daytime temperatures are expected to increase more than nighttime ones. This differential rise between daytime and nighttime temperatures can influence several key climate processes that are crucial to agriculture, infrastructure, and human health.

3.6 Temperature Variability and Spread

The coefficient of variation (CV) is used to understand the variability in projected temperature changes. For maximum temperatures, the CV is 6.1%, indicating moderate variability around the projected increase. This means that although the overall trend points to a temperature rise of 1.8°C, the actual increase could vary somewhat across different years or seasons. For minimum temperatures, the CV is 5.4%, showing slightly less variability, meaning that nighttime temperatures are expected to be more stable in comparison to daytime highs. The overall variability in temperature changes could lead to certain years or periods experiencing higher or lower temperature increases than the average.

The standard deviation (SD) of 0.8°C for maximum temperatures and 0.7°C for minimum temperatures further supports the finding of moderate variability. These SD values suggest that while the mean temperature increase is projected to be 1.8°C for daytime highs and 1.5°C for nighttime lows, there is a noticeable range of variation around these averages. This variability can cause intermittent extreme temperature events, especially during the warmest months, potentially leading to heat stress on crops, increased evapotranspiration (ET_o), and water stress.

3.7 Skewness and Kurtosis: Temperature Distribution

The skewness of temperature distribution provides insight into the symmetry of the temperature changes. For maximum temperatures, the skewness is 0.5, and for minimum temperatures, it is 0.4, both of which indicate a positive skew or rightward skew. This means that higher-than-average temperature increases will occur more frequently than lower-than-average increases. In practical terms, the region is likely to experience more frequent hot spells, which could have significant implications for agriculture, water management, and energy demands.

The kurtosis of 3.0 for maximum temperatures and 3.2 for minimum temperatures indicates that the temperature distribution is close to normal but with slightly heavier tails, especially for nighttime lows. A kurtosis value of 3 reflects a normal distribution, but the value of 3.2 for minimum temperatures suggests that there may be a higher probability of extreme temperature events. However, these extremes are not expected to be overly severe, meaning that while occasional temperature spikes (both hot and cold) may occur, they are unlikely to dominate the climate dynamics of the region.

3.8 Impacts on Agriculture and ET_o

One of the most critical impacts of the projected temperature increase is on reference evapotranspiration (ET_o), which directly affects crop water demand. The rise in maximum and minimum temperatures under the RCP 4.5 scenario leads to a substantial increase in ET_o. This means that crops will require more water to meet their physiological needs as higher temperatures accelerate the processes of evaporation from the soil and transpiration from plant surfaces.

The rise in ET_o is particularly concerning for the Saurashtra region, where water availability is already a challenge due to irregular rainfall patterns and limited freshwater resources. Crops such as wheat and rice, which are sensitive to both temperature and water availability, will experience increased water stress. This necessitates more efficient irrigation strategies and possibly a shift towards more drought-resistant crop varieties.

Increased temperatures and higher ET_o will also shorten the growing season for some crops. For example, crops that rely on cooler temperatures during the vegetative or reproductive phases

(such as wheat) may mature more quickly under elevated temperatures, reducing the time available for biomass accumulation and grain filling. This can lead to lower yields unless adaptive agricultural practices are implemented. Such practices could include altering sowing dates to avoid peak heat periods, using heat-tolerant crop varieties, or adopting climate-smart irrigation techniques like drip irrigation.

3.9 RCP 8.5

The RCP 8.5 scenario represents a high-emission pathway that projects significantly greater increases in both maximum and minimum temperatures compared to the RCP 4.5 scenario. Under this pathway, maximum temperatures are expected to rise by 3.0°C and minimum temperatures by 2.8°C in the Saurashtra region. This sharp rise in temperatures has wide-ranging implications for agriculture, water resources, ecological systems, and human health in the region. The results indicate that Saurashtra is likely to experience more intense warming, potentially affecting the frequency and severity of heatwaves, seasonal cycles, and overall climatic stability.

3.10 Temperature Variability and Spread

The coefficient of variation (CV) is an essential indicator of the variability in projected temperature changes. For maximum temperatures, the CV is 8.4%, and for minimum temperatures, it is 7.6%. These values are higher than those projected under the RCP 4.5 scenario, indicating a greater degree of variability in the RCP 8.5 projections. This means that while the overall trend shows a significant increase in temperatures, there is a broader range of potential outcomes, with temperatures potentially fluctuating more than expected. The higher variability introduces a greater degree of uncertainty, making it difficult to predict the exact magnitude of temperature changes in specific years or seasons.

In practical terms, the increased variability could result in years of extreme heat interspersed with periods of milder warming. The consequences of this variability are critical for agriculture, as crops may experience unpredictable growing conditions, making it challenging for farmers to plan planting schedules, water management strategies, and harvesting times.

The standard deviation (SD) further supports the notion of heightened variability under RCP 8.5. The SD for maximum temperatures is 1.2°C, and for minimum temperatures, it is 1.1°C. These values are considerably higher than those observed under the RCP 4.5 scenario, indicating that temperature projections deviate more widely from the mean. This greater variability introduces the risk of more frequent temperature extremes, where certain years may experience far greater temperature increases than the average projections suggest.

3.11 Skewness and Kurtosis: Greater Likelihood of Extreme Events

Skewness provides insight into the asymmetry of the temperature distribution. The skewness for maximum temperatures is 0.7, and for minimum temperatures, it is 0.6, both of which indicate a rightward skew (positive skewness). This means that the temperature distribution under the RCP 8.5 scenario is shifted towards higher values, suggesting that the region will likely experience more frequent extreme heat events than cold events. These skewed distributions imply a tendency for higher-than-average temperatures, which could exacerbate the impacts of heatwaves, especially during critical agricultural seasons such as the summer crop cycle.

The kurtosis for maximum temperatures is 3.5, and for minimum temperatures, it is 3.8, both indicating a leptokurtic distribution (kurtosis values greater than 3). A leptokurtic distribution

is characterized by heavier tails, meaning that the probability of encountering extreme temperature increases is higher than under a normal distribution. This suggests that under the RCP 8.5 scenario, extreme temperature events are not only more likely but may also be more intense. In agricultural terms, this could result in more frequent occurrences of severe heat stress, which can devastate crop yields, particularly for temperature-sensitive crops like wheat and rice.

3.12 Impacts on Evapotranspiration (ET_o) and Agriculture

One of the most significant consequences of the projected temperature increases under RCP 8.5 is the impact on evapotranspiration (ET_o), which measures the combined loss of water through evaporation and plant transpiration. The sharp increase in both maximum and minimum temperatures will lead to a substantial rise in ET_o, causing the water requirements for crops to increase significantly.

As temperatures rise, more water is lost from the soil and through plant surfaces, forcing farmers to apply additional irrigation to meet the crops' growing demands. This increased water demand presents a major challenge in a region like Saurashtra, where water resources are already limited, and rainfall patterns can be unpredictable. Irrigation efficiency and water management strategies will need to be optimized to minimize water loss and ensure that crops receive the necessary moisture to thrive under hotter conditions.

Crops such as wheat, rice, and cotton, which are staples in the Saurashtra region, are particularly vulnerable to increased evapotranspiration. Wheat, for instance, is highly sensitive to temperature increases during its reproductive phase, and a sharp rise in ET_o could lead to premature senescence, reduced grain filling, and ultimately lower yields. Similarly, rice cultivation, which requires a large amount of water, will be further strained by the higher water demand resulting from increased ET_o, forcing farmers to adopt water-saving techniques or shift to drought-resistant varieties.

3.13 Policies Recommendation for farmers

3.13.1. Promotion of Heat-Tolerant Crop Varieties

- **Context:** Saurashtra experiences high temperatures and erratic rainfall patterns, making it crucial to use crops that can tolerate these stresses.
- **Actions:**
 - **Research and Development:** Invest in research to develop heat-tolerant varieties of key crops like wheat, cotton, and groundnut, which are vital to the region's agriculture.
 - **Extension Services:** Strengthen agricultural extension services to disseminate information about these varieties. Demonstration plots and field days can help showcase the benefits of heat-tolerant crops.
 - **Support Programs:** Provide subsidies or incentives for farmers to purchase seeds of these improved varieties.

3.13.2. Enhanced Irrigation Infrastructure

- **Context:** With limited and irregular rainfall, efficient water management is essential for crop survival and productivity in Saurashtra.
- **Actions:**
 - **Infrastructure Investment:** Invest in modern irrigation systems such as drip and sprinkler irrigation. These systems can significantly reduce water wastage and improve crop yields.

- o **Subsidies and Incentives:** Offer financial support or subsidies for the installation of these systems to make them more affordable for smallholder farmers.
- o **Maintenance and Training:** Provide training on the maintenance and effective use of advanced irrigation systems to ensure their long-term success.

3.13.3. Water-Saving Practices

- **Context:** Water conservation is critical in Saurashtra due to its semi-arid climate and water scarcity issues.
- **Actions:**
 - o **Mulching and Soil Moisture Conservation:** Promote the use of organic or synthetic mulches to reduce soil evaporation and retain moisture.
 - o **Training Programs:** Organize workshops and training sessions for farmers on water-saving techniques and the benefits of soil moisture conservation practices.
 - o **Incentives:** Provide financial incentives or technical support to encourage the adoption of these water-saving practices.

3.13.4. Adaptive Crop Management Strategies

- **Context:** Changes in evapotranspiration (ETo) due to climate change necessitate adjustments in crop management practices.
- **Actions:**
 - o **Sowing and Harvesting:** Develop guidelines for optimal sowing and harvesting times based on projected ETo data to maximize yield and minimize losses.
 - o **Nutrient Management:** Adjust nutrient management practices to align with changing climatic conditions and improve crop resilience.
 - o **Support Programs:** Create advisory services to assist farmers in adapting their crop management strategies in response to changing climate conditions.

3.13.5. Climate Resilience Planning

- **Context:** Climate variability and change pose significant risks to agriculture in Saurashtra.
- **Actions:**
 - o **Risk Management:** Develop comprehensive risk management strategies that include crop insurance and emergency support for farmers facing climate-related challenges.
 - o **Financial Assistance:** Provide financial aid or low-interest loans for farmers to invest in adaptive measures and infrastructure improvements.
 - o **Climate Data and Forecasting:** Facilitate access to accurate climate data and forecasting tools to help farmers make informed decisions and plan for climate extremes.

4. Conclusion

This study provides a detailed assessment of how temperature-driven changes affect reference evapotranspiration (ETo) in the Saurashtra region of Gujarat under three Representative Concentration Pathways (RCP 2.6, RCP 4.5, and RCP 8.5). The results demonstrate that even moderate increases in temperatures, as projected under RCP 2.6, will lead to higher ETo, requiring

adjustments in irrigation practices to address increased water demands. The study shows that while temperature variability remains relatively stable under this scenario, the rise in ETo will necessitate more frequent irrigation and the adoption of water-efficient technologies to maintain optimal crop growth.

Under the RCP 4.5 scenario, the projected rise in both maximum and minimum temperatures is more pronounced, leading to a substantial increase in ETo. This scenario highlights a need for enhanced water management strategies and potentially the use of drought-resistant crop varieties to cope with higher water stress. The increased temperature variability under this scenario suggests that farmers will face more frequent and intense temperature extremes, which could impact crop yields and necessitate adaptive agricultural practices.

The RCP 8.5 scenario, representing a high-emission pathway, forecasts the most significant increases in temperatures and ETo, posing substantial risks to agriculture in Saurashtra. The study indicates that the high variability and frequency of extreme temperature events under this scenario will exacerbate water demand and strain already limited resources. Farmers will need to address these challenges through improved irrigation infrastructure, more efficient water conservation techniques, and the development of heat-tolerant crop varieties to manage the increased water requirements and mitigate the effects of extreme heat.

This study underscores the urgent need for proactive measures to adapt to the changing climate in the Saurashtra region. Implementing the recommended policies and practices-such as upgrading irrigation systems, adopting water-saving techniques, and investing in heat-tolerant crops-will be essential for enhancing agricultural resilience. By taking these steps, farmers can better manage the impacts of rising temperatures and ETo, ensuring sustainable agricultural practices and improved climate adaptation in the face of increasing climate challenges.

References

- Allen, R. G., Pereira, L. S., Raes, D., & Smith, M. (1998). Crop evapotranspiration: Guidelines for computing crop water requirements (FAO Irrigation and Drainage Paper No. 56). Food and Agriculture Organization of the United Nations (FAO).
- Desai, D. N., Patel, R. C., & Rana, R. S. (2015). Assessment of climate change impact on reference evapotranspiration in semi-arid regions of India. *International Journal of Climatology*, 35(12).
- Hussain, M. S., Verma, N. K., & Kumar, R. (2018). Impact of climate change on reference evapotranspiration across India. *Theoretical and Applied Climatology*, 134(3), 1025-1037.
- IPCC. (2014). *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II, and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* (Core Writing Team, R. K. Pachauri & L. A. Meyer, Eds.). IPCC.
- Shah, K., Patel, J., & Desai, R. (2020). Estimating the impacts of climate change on evapotranspiration and crop water demands in the Gujarat region. *Journal of Water and Climate Change*, 11(1), 234-245.
- vanVuuren, D. P., Edmonds, J., Kainuma, M., Riahi, K., Thomson, A., Hibbard, K., ... & Rose, S. K. (2011). The representative concentration pathways: An overview. *Climatic Change*, 109(1), 5-31.

Innovative Facilities and Smart Approaches for Sustainable Wastewater Resource Recovery

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Abstract

The conference paper displays the innovative facilities and smart approaches for sustainable wastewater resource recovery. This paper discusses the different types of sustainable and valuable approaches to recycling wastewater. In this paper, including the four different innovative technologies explained in detail. This technology reduces water scarcity. By developing a sustainable infrastructure, we are minimizing wastewater and pollution. This approach helps protect the environment and public health. Also, reduce the scarcity of clean water resources. For growing industries and urbanization, we need to develop sustainable wastewater management plants. In India, dumping waste is rapidly increasing with the growing population. This waste generates electricity from the Waste to Energy concept. By promoting this sustainable approach, we reduce our dependency on conventional energy sources like coal, petroleum, nuclear energy, or natural gas. This paper presents a sustainable and efficient method for converting wastewater into a valuable resource.

Keywords Water monitoring System, Recycle, Wastewater treatment, Waste to Energy, Clean Water

1. Introduction

This Conference Paper has been prepared for the purpose of identifying the Innovative Facilities and Smart Approaches for Sustainable Wastewater Resource Recovery. Water is the primary requirement for human being and many other living things. In India 40% of people are facing a water crisis. The growing population is causing climate change due to pollution and unpredictable rainfall cycles. As per the Water Resources Division (WRD), given the Data of water resources, Gujarat is 89%, Saurashtra is 9% and Kutch Region has only 2% of surface water resources available. In a summer situation, a water crisis increases when it is difficult to access safe drinking water due to a water shortage. In the summer season underground water levels decrease. Around 80% of surface water in Gujarat is used for agriculture sector. To avoid water crisis in future on permanent basis, The state must be adopting some technologies according to this conference paper.

2. Innovative Water Reuse Strategies

The clean water shortage is a growing global crisis. The global demand for freshwater is increasing day by day. These innovative water reuse strategies offer the Safe, efficient, and produce low-carbon emission by its construction.

This technology reuses wastewater by recycling process to produce freshwater. This water is reused for agriculture Irrigation process, factory uses, car washing, filling water ponds, including vegetable gardens, toilet cleaning and washing clothes. and thermal power plants.

Human societies are struggling with the fundamental requirement for safe and clean water

for consumption for agriculture and sanitation and many uses for day-to-day life. Human Bing after a longtime realizing the importance of wastewater management for improving public health and environmental Wellbeing.

2.1. Aqua Sense Water Monitoring System

Introducing Aqua Sense, the revolutionary water monitoring system designed to revolutionize your household's water conservation efforts. The aqua sense water monitoring system offers a solution to reduce water consumption. By implementing this technology in Rajkot, an estimated 37.5 crore litres of water can be saved daily across the 5 lakh households.

While the average daily water usage per person for showering is 30 litres, some individuals consume more, reaching up to 50 litres. This excess water is often wasted. Aqua Sense helps conserve water by providing real-time monitoring and allowing users to identify and reduce wasteful habits.

Moreover, by reducing water consumption, Aqua Sense helps conserve energy. The pumping of water by municipalities and households using submersible pumps requires significant electricity. By saving water, there is a corresponding reduction in consumption of energy.

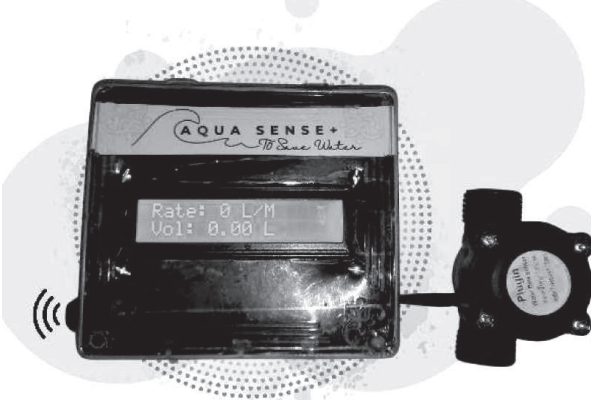


Fig. 1. Aqua Sense Water Monitoring System



Fig. 2. Visual Representation of Aqua Sense

2.1.1. Working

Aqua Sense is an advanced water monitoring system designed to revolutionize household water conservation. It provides precise measurements of water usage, offering a clear understanding of consumption patterns. The device is equipped with advanced sensors that accurately track water flow, enabling users to identify and volume of excessive water consumption. Its user-friendly interface displays real-time data and gives alerts for excessive water consumption by buzzer and LED light. This device is used to plug and play and is compatible with a USB cable or charger and battery supply. making it easy to monitor water usage and implement water-saving strategies. Aqua Sense also features a durable construction and long-lasting performance, ensuring reliable operation over time. It is used to monitor the flow of water quantities in measures in Litres (Ltr) with flow rate in Litres per minute (L/M).

2.1.1.1. Equation of Hall effect sensor

From This Equation,

$$Q = F \div P \quad (1)$$

Where, Q = Flow Rate (Litres/Minute); F = Hall Sensor's Pulses; P = single pulse Value is 7.5

For example,

- (1) if the Hall effect Sensor produces 105 pulses, it means the flow rate is 14 Liters/Minute.
- (2) if the Hall Sensor produces 210 pulses, it means the flow rate is 28 Liters/Minute.

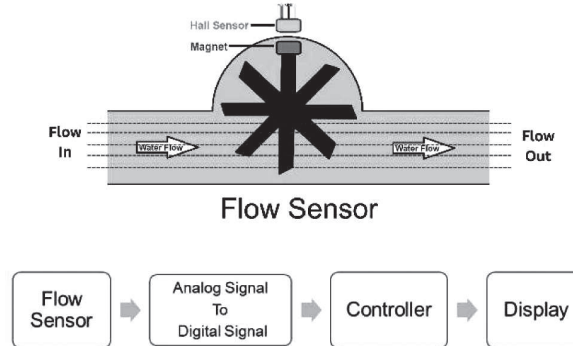


Fig. 3. Block Diagram of Water monitoring System

2.1.2. Aqua Sense Solution For Water And Energy Conservation

The device is used for the water monitoring system in household bathrooms and commercial facilities.

Aqua Sense delivers precise measurements of your water usage, offering a clear understanding of your consumption patterns. Aqua Sense is a powerful tool for energy conservation. The pumping of water, whether by municipal utilities or households using submersible pumps, is a significant consumer of electricity. By reducing water consumption, Aqua Sense directly contributes to energy savings. Its user-friendly design and simple installation process make it accessible to everyone.

2.2. Sustainable Reuse of R.O Filter Water

This Type of solution is no requirement on any equipment. According to the World Economic Forum an average R.O Filter wastes approximately 30 liters of water for every 10 Litre of drinkable water. that means only 25% of the total amount of water is filtered by 75% of water. Normally 75% of waste from the R.O filter is discharged in the sewage. But this water is reusable directly for some applications like: car washing, toilet cleaning, cloth laundering, dish washing, housecleaning, washing machine, agriculture irrigation and etc..

As per The U.S. National Academies of Sciences, average 3.7 liters of drink water a day for men. The Rajkot District data population review As of 2024, the population of Rajkot is 30,34,722. The daily consumption of drinking water is 1.13 crore litres in Rajkot. And wastage water by R.O filter 22.5 crore litres in 5 lacs houses.

This water is reused as model Shown in Fig. 4. to save the huge wastewater.



Fig. 4. Reuse of R.O Filter Water

2.3. Factory wastewater treatment Cycle

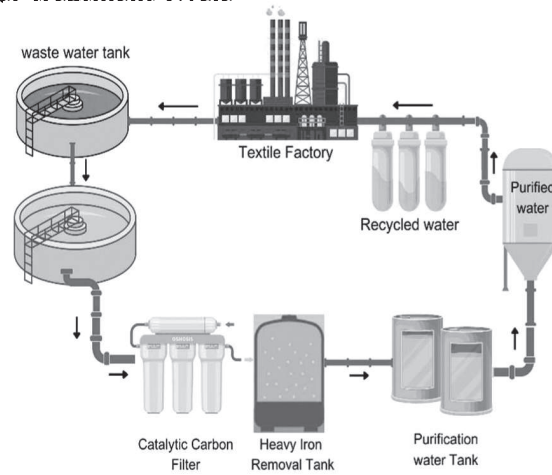


Fig. 5. Factory wastewater treatment Cycle

Factories are producing huge amounts of wastewater. Most of Factory's discharge in sewage. It's very harmful to the environment. In wastewater harmful mixtures of carbons, chemicals, and solid waste materials.

This treatment process is affordable for every industry. By using wastewater reusing by step-by-step cycle Followed factories reuse the wastewater into clean water Shown in Fig. 5.

2.3.1. Factory wastewater treatment Cycle

Fig. 5 shows the factory wastewater treatment cycle. It rotates in the anticlockwise direction, the first cycle is clean primary wastewater, and after this water is transferred to the secondary wastewater tank. This water cleans 30%. The next treatment is a catalytic carbon filter, after this water is passing through a heavy iron removal tank. Therefore, this water is passing through three different types of filters tanks. For this Factory wastewater treatment Cycle recovered 80% of usable clean water.

2.4. Sustainable Electricity Generation By Disposing of Solid Waste Materials

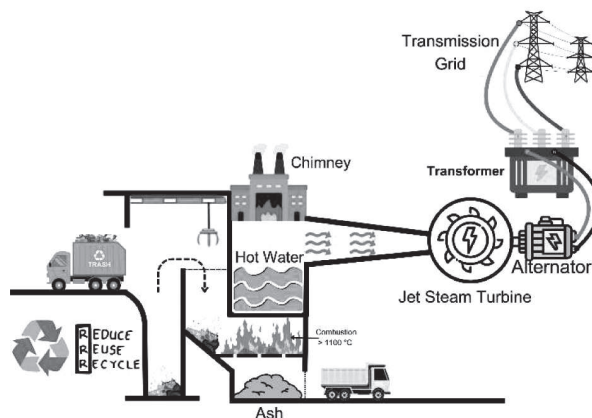


Fig. 6 Electricity generation From Solid waste Materials

This technology is based on the Waste to Energy concept, in this power plant similar as a thermal power plant. But in the plant primary fuel is waste material. This technology also called as a WtE technology.

The main purpose of this technology is to reduce solid waste like plastics, paper textile materials, sanitary waste food, and medical waste. As shown Fig. 6. All waste materials are burning as fuel of plant to produce electricity. And the ash is used in road construction works.

2.4.1 process of (Waste to energy) WtE Power plant

The waste is dumping in the storage area. The crane is picking up the waste and combustion at >1100 o C. at a time boiler is boiling the water at the highest temperature to get high pressure steam.

This steam runs the jet steam turbine this turbine is mechanically connected to the alternator. This turbine is rotating the alternator produces 11kV power supply. This supply is step-up by 11kV/220kV transformer and fed to the grid.

3. Conclusion

This conference paper is designed for the provide Innovative Facilities and valuable approaches for Sustainable Wastewater Resource Recovery. by adopting this framework, we can make revolutionary change in recycling processes of the wastewater into valuable water resources. These technologies we can adopted to create the potential of reducing environmental impact and public health. This approach minimizes waste materials and creates new economic opportunities. By this technology is to reduce solid waste like paper, textile materials, sanitary waste food, plastics, and medical waste. The R.O filter water Reuse is shown in Fig. 4 to save 22.5 crore liters of water wastage in 5 lakh households at Rajkot through this technology. And for the industries are recovered 80% of usable clean water by wastewater treatment cycle. and The aqua sense water monitoring system offers a solution to reduce water consumption. By implementing this technology in Rajkot, an estimated 37.5 crore litres of water can be saved daily across the 5 lakh households. with reducing water consumption, Aqua Sense helps conserve energy. The pumping of water by municipalities and households using submersible pumps requires significant electricity. By saving water, there is a corresponding reduction in consumption of energy.

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References

- [1] Beth A. Covitt, Tania T. Hinojosa, Jose Marcos-Iga, Earth's freshwater by national geographic. National Geographic Education Programs 1145 17th Street NW Washington, DC 20036 natgeoed.org
- [2] Jyotsana Maura, SuchitaAtreya, AnfalArshi, The Treatment of Wastewater, Recycling and Reuse. (IJSR) ISSN: 2319-7064 SJIF (2022): 7.942.
- [3] Water Resources Division, Narmada, Water Resources, Water Supply and Kalpsar Department, source of water for Gujarat.
- [4] Gujarat Samachar, Water-crisis looms for Saurashtra-Kutch as reservoirs hit half capacity.
- [5] Amitava Bhattacharyya, Drinking Water Security in Gujarat: The Current Scenario, The energy and resources institute (TERI).

- [6] U.S. Commercial service in India, India solid waste management, international trade administration.
- [7] Sahana J, Anvith V Badikana, Akshay M, Muhammad Shunaif, generation of electricity using solid waste. Reference No.: 45S_ BE_1864.
- [8] Hshit Sharma, Aditya Jain, Dr. Sanjiv Kumar Jain, Electricity Generation from Waste Materials, 2023 IJRTI | Volume 8, Issue 5 | ISSN: 2456-3315.
- [9] Waste2fresh project,the textile manufacturing industry to reduce water contamination and scarcity. Nov 2023.

Potential of IoT based Micro Irrigation Systems for Sustainable Agriculture in Saurashtra and Kutch Region

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Abstract

Water scarcity is a critical issue in arid and semi-arid regions like Saurashtra and Kutch, where traditional irrigation methods lead to significant water losses. With India facing severe water stress, there is an urgent need for more sustainable water management practices in agriculture. This article examines the integration of micro irrigation systems with Internet of Things (IoT) technology as a solution to this challenge. Micro irrigation, including drip and micro-sprinkler systems, delivers water directly to plant root zones, improving efficiency and reducing wastage compared to conventional methods. By incorporating IoT technology, such as soil moisture sensors, weather stations, automated controllers, and cloud-based analytics, these systems can further optimize water use, enhance crop productivity, and support environmental conservation. The article reviews the current implementation of micro irrigation systems in Gujarat, highlighting the distribution of these systems across various crops and districts. It also explores the benefits of IoT-based systems, including optimized water usage, improved crop yields, cost efficiency, and environmental sustainability. Despite the potential advantages, challenges such as high initial costs, technical expertise, and infrastructure limitations need to be addressed. The article underscores the role of IoT in advancing sustainable agriculture and the importance of continued support and innovation in this field.

Introduction

Water scarcity is one of the most pressing challenges facing in arid and semi-arid regions like Saurashtra and Kutch especially in agriculture. Traditional irrigation methods such as flood, basin, border and furrow irrigation leading to significant water losses due to percolation, evaporation, runoff which is inefficient utilization of water resources (Walker, 1983; Sarker et al., 2019). India accounts for about 17% of the world's population but only 4% of the world fresh water resources (Dhawan, 2017). Agriculture consumes of 70 freshwater resources globally, however in India, this figure stand 90 % (Dhawan, 2017). There is a critical need for more sustainable water management practices. The integration of micro irrigation systems with Internet of Things (IoT) technology represents a promising solution to this challenge. This article explores the potential of IoT-based micro irrigation systems in advancing sustainable agriculture by optimizing water use, improving crop productivity, and promoting environmental conservation.

Understanding Micro Irrigation Systems

Micro irrigation includes drip irrigation and micro-sprinkler systems, delivers water directly to the root zones of plants at low pressure. Unlike conventional irrigation methods, which irrigate large areas uniformly. Micro irrigation applies water precisely where it is needed, that minimizing waste and maximizing efficiency. This technique is particularly effective in regions where water is scarce region like Saurashtra and Kutch. It Improves water use efficiency and reducing evaporation,

runoff, and deep percolation losses (Sarker et al., 2019). The key benefits of micro irrigation to water conservation up to 50-70 % as compared to traditional irrigation methods by delivering water directly to plant roots. It enhanced crop yield and better quality produce. Micro irrigation helps prevent soil erosion and keeps nutrients in the root zone by minimizing surface water flow. It is efficient energy management system by require less energy for water pumping due to lower water volumes and pressure needs. Micro irrigation is a more efficient alternative to traditional irrigation methods. However, its effectiveness can be further enhanced by integrating IoT technology.

Area under MIS in Gujarat (GGRC 2024)

The Gujarat green revolution company was started in May, 2005 by the joint venture of Gujarat State Fertilizer Corporation (GSFC), Gujarat Narmada valley Fertilizer Corporation and Gujarat Agro Industrial Corporation (GAIC). The company implements micro irrigation scheme on behalf of Government of India and Government of Gujarat in Gujarat State through reputed authorized micro irrigation system suppliers, who supplies and installs the micro irrigation system and also provides agro services pertaining to micro irrigation system. The total no. of beneficiaries farmers and area under MIS recorded as 14, 84, 058 and 23, 13, 998 ha since 2005 to March 2024 as depicted in fig.1.

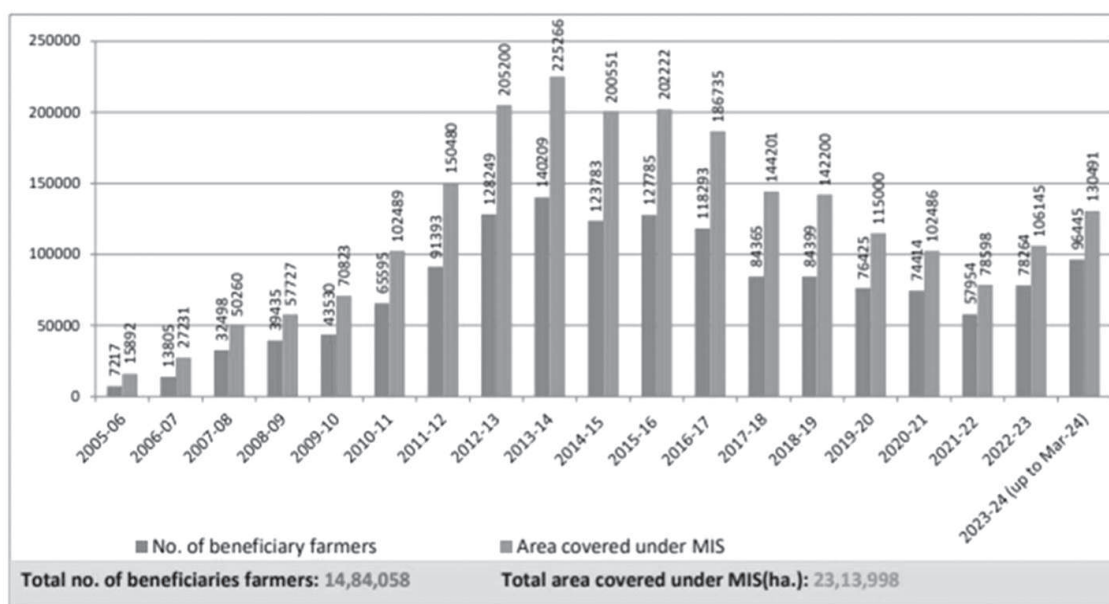


Fig 1: Cumulative no. of beneficiariesfarmers and area under MIS (GGRC 2024)

Among the total area, area covered in horticulture crop is 3, 97, 514 ha for various horticultural crop as shown in Fig. 2. However the area under micro irrigation system other than horticulture crop remained 19, 16,485 which are 4.82 times higher than area under horticulture crop. The majority area under MIS is groundnut where mostly sprinkler irrigation system is practiced. The most grown crop under drip irrigation system is cotton followed by banana, mango, papaya, sugarcane, castor, lemon and sapota. There are vegetables crop are under MIS where figure stood 71, 567 ha as depicted in Fig. 3.

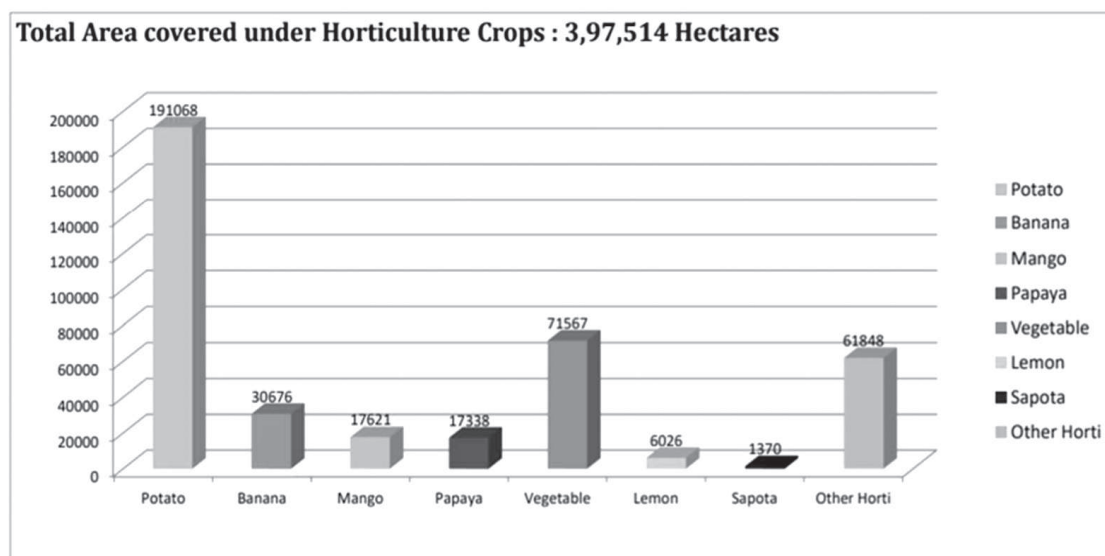


Fig. 2: Area Covered under MIS for Horticulture crop in Gujarat since March 2024 (GGRC 2024)

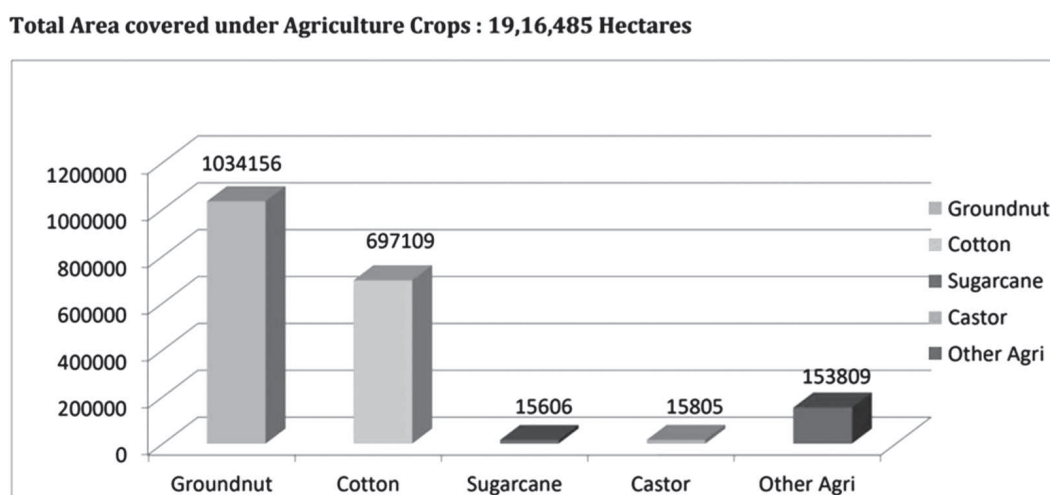


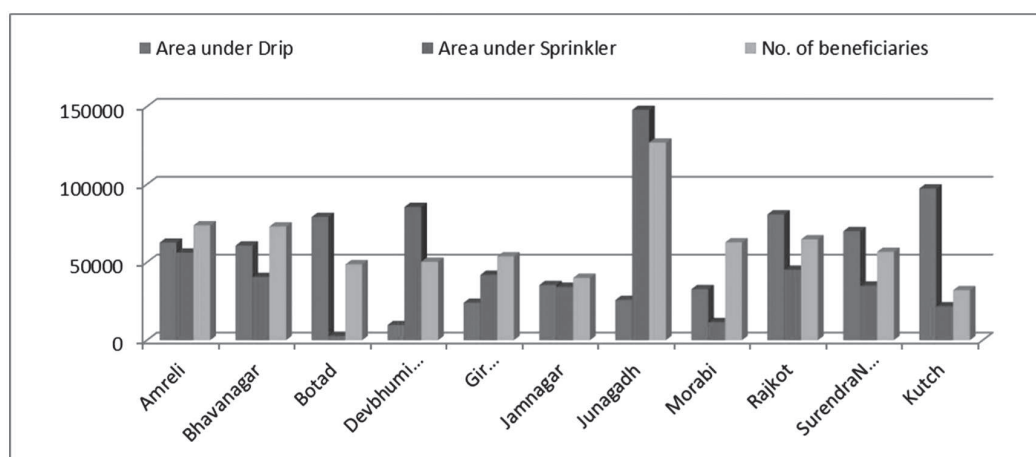
Fig. 3: Area Covered under MIS for Agriculture crop in Gujarat since March 2024 (GGRC 2024)

Area under MIS in Saurashtra and Kutch (GGRC 2024)

There are 10 district like Amreli, Bhavanagar, Botad, DevbhumiDwarika, GirSomanath, Jamanagar, Junagadh, Morabi, Rajkot and Surendranagar are fall in Surasthtra where kutch itself as district. The highest area under drip irrigation was observed kutch followed by Rajkot and Botad in Surashtra and Kutch region as shown Table 1. However the highest area under sprinkler irrigation system is observed in Junagah district with highest beneficiaries followed by DevbhumiDwarika.

Table 1: Area under Drip and Sprinkler irrigation system with beneficiaries for Saurashtra and Kutch region

Sr.	District	Area under Drip, ha	Area under Sprinkler, ha	No. of beneficiaries
1	Amreli	62595	56217	73697
2	Bhavanagar	60745	40573	72995
3	Botad	79080	2728	48690
4	DevbhumiDwarika	9708	85458	50336
5	GirSomanath	23993	41942	53801
6	Jamnagar	35414	34198	40014
7	Junagadh	25825	147794	126834
8	Morabi	32748	11547	62829
9	Rajkot	80715	45204	64746
10	SurendraNagar	70004	34951	56704
11	Kutch	97329	21745	32123
Total		578156	522357	682769



The Role of IoT in Micro Irrigation

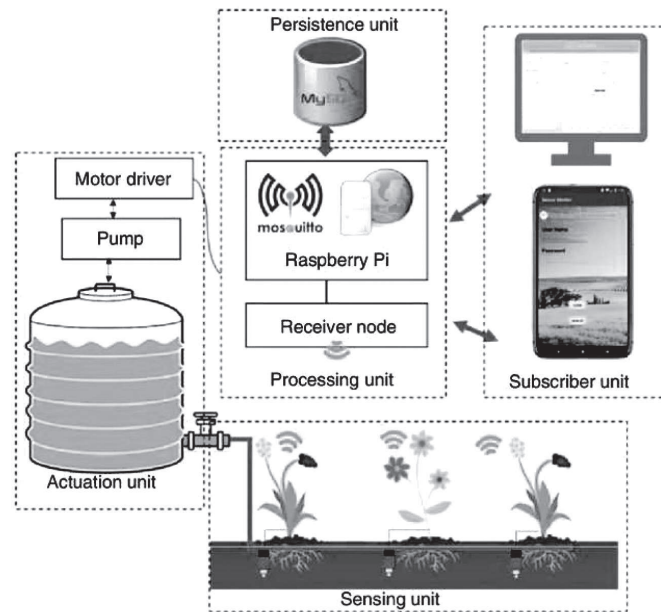
IoT technology enables real-time monitoring, automation, and data-driven decision-making in irrigation systems. By integrating IoT devices such as sensors, controllers, and data analytics platforms into micro irrigation systems, farmers can optimize water usage, respond to environmental conditions dynamically, and improve the overall efficiency of their irrigation practices.

Key Components of IoT-Based Micro Irrigation Systems

Soil Moisture Sensors: These sensors measure the moisture content of the soil at various depths, providing real-time data on soil conditions. This allows the system to adjust irrigation schedules automatically based on actual plant water needs, reducing the risk of over- or under-watering. It measure the moisture level in the soil to determine when and how much water is needed by the plants.

Weather Stations and Forecasting: IoT-based weather stations collect data on temperature, humidity, wind speed, and rainfall. By using weather forecasts, the system can predict irrigation

needs and adjust water delivery accordingly. For example, the system can delay irrigation if rain is expected or increase watering during hot or dry periods.



Automated Irrigation Controllers: These controllers receive data from soil and weather sensors and adjust water delivery in real-time. They enable precise control over the timing, frequency, and amount of water delivered to each section of the field, ensuring optimal irrigation.

IoT-Based Smart Irrigation System Diagram (Khrijiet al., 2021)

Cloud-Based Analytics Platforms: Data collected from sensors and controllers is transmitted to cloud-based platforms, where it is analyzed to provide insights into irrigation performance, crop health, and water usage patterns. Farmers can access this data remotely via mobile apps or web interfaces, enabling them to monitor and manage their irrigation systems from anywhere.

Potential Benefits of IoT-Based Micro Irrigation Systems for Sustainable Agriculture

1. Optimized Water Usage

One of the most significant advantages of IoT-based micro irrigation systems is their ability to optimize water use by applying the exact amount of water needed by crops at any given time. By continuously monitoring soil moisture levels and adjusting irrigation schedules in real-time, these systems ensure that water is applied precisely where and when it is needed, minimizing wastage. Studies have shown that IoT-enabled micro irrigation systems can reduce water usage by 30-50% compared to traditional methods, making them ideal for water-scarce regions.

2. Improved Crop Yields and Quality

Precision irrigation through IoT-based systems leads to better water management, which directly impacts crop health and yields. By ensuring that crops receive the right amount of water at the right time, IoT-enabled micro irrigation systems reduce plant stress and improve overall growth conditions. This can result in higher yields, better-quality produce, and increased profitability for farmers. Additionally, healthier plants are more resilient to diseases and pests, reducing the need for chemical inputs such as pesticides and fertilizers.

3. Energy and Cost Efficiency

IoT-based micro irrigation systems help farmers reduce energy consumption and operational costs by automating irrigation processes. Automated systems reduce the need for manual intervention, saving time and labor. Additionally, by delivering water more efficiently, these systems require less energy for pumping and distribution, further reducing operational costs. In the long term, the water and energy savings achieved through IoT-enabled irrigation can offset the initial investment in technology, making these systems cost-effective for farmers.

4. Data-Driven Decision Making

IoT-based systems generate a wealth of data that can be used to make informed decisions about irrigation practices, crop management, and resource allocation. For example, farmers can use data from soil moisture sensors to determine which parts of their fields require more or less water, allowing them to adjust irrigation accordingly. Data analytics can also help farmers identify trends and patterns in water usage, enabling them to optimize their water management strategies over time. This data-driven approach not only improves irrigation efficiency but also helps farmers make better decisions about crop rotation, planting schedules, and nutrient management.

5. Environmental Sustainability

The efficient use of water in IoT-based micro irrigation systems contributes to environmental sustainability by conserving precious water resources and reducing the environmental impact of agriculture. By minimizing water wastage and runoff, these systems help prevent water pollution and reduce the strain on local water supplies. Additionally, by promoting healthier crop growth and reducing the need for chemical inputs, IoT-based micro irrigation systems can help reduce the environmental footprint of agriculture.

Challenges and Considerations

Despite the many benefits of IoT-based micro irrigation systems, there are several challenges that need to be addressed to ensure their widespread adoption:

Initial Investment Costs: The upfront cost of installing IoT-enabled micro irrigation systems can be high, particularly for small-scale farmers. However, government subsidies, financial incentives, and support programs can help offset these costs, making the technology more accessible.

Technical Expertise: Farmers need to be trained in the use of IoT technology and data interpretation to fully realize the benefits of these systems. Providing education and training programs for farmers is essential for successful implementation.

Infrastructure and Connectivity: IoT systems rely on reliable internet connectivity and power supply to function effectively. In remote or underdeveloped areas, infrastructure limitations may pose a barrier to adoption. However, advancements in low-power wide-area networks (LPWAN) and solar-powered IoT devices can help overcome these challenges.

In India, where water scarcity is a significant issue, several states have implemented IoT-based micro irrigation systems to improve water efficiency in agriculture. In Gujarat and Maharashtra, for example, farmers using IoT-enabled systems have reported up to 40% reductions in water usage, along with improved crop yields and lower operational costs. Government support and collaboration with technology providers have played a key role in the success of these initiatives.

Conclusion

The potential of IoT-based micro irrigation systems to revolutionize sustainable agriculture is immense. The Saurashtra region has 64 lac ha out of them 42 lac ha are arable which shows the tremendous potential for adoption of micro irrigation system. The Saurashtra and kutch region has only 20% of the total water resources for the 53% of the total geographical area of Gujarat. By optimizing water usage, improving crop yields, and reducing energy consumption, these systems offer a powerful solution to the growing challenges of water scarcity region like the Saurashtra and kutch. As technology continues to evolve and become more accessible, IoT-based micro irrigation systems are poised to become a cornerstone of modern, sustainable farming practices around the world. Investing in these technologies and supporting farmers in their adoption is critical to ensuring the long-term sustainability of agriculture, particularly in water-stressed regions like Saurashtra and Kutch. By harnessing the power of IoT, farmers can cultivate more with less, contributing to global food security while preserving vital natural resources for future generations.

References

Dhawan, V. 2017. Water and agriculture in India. In Background paper for the South Asia expert panel during the Global Forum for Food and Agriculture, 28:80-85.

GGRC 2024 Achievements

Download and retrieved from <https://ggrc.co.in/documents/Achievements.pdf> on August 22, 2024.

Khrijji, S., El Houssaini, D., Kammoun, I., & Kanoun, O. (2021). Precision irrigation: an IoT-enabled wireless sensor network for smart irrigation systems. *Women in Precision Agriculture: Technological Breakthroughs, Challenges and Aspirations for a Prosperous and Sustainable Future*, 107-129.

Sarker, K.K., Hossain, A., Murad, K.F.I., Biswas, S.K., Akter, F., Rannu, R.P., Moniruzzaman, M., Karim, N.N. and Timsina, J. 2019. Development and Evaluation of an Emitter with a Low-Pressure Drip-Irrigation System for Sustainable Eggplant Production. *AgriEngineering*, 1:376-390.

Walker, W.R. 1983. *Irrigation Engineering-Sprinkler, Trickle, Surface Irrigation Principles, Design and Agricultural Practices*: A. Benami and A. Ofen. IESP, Haifa, in Cooperation with the International Irrigation In. *Agric. Water Manag.* 9: 263-264.

Assessment of Runoff Potential across Gujarat: A Study Using Region-Specific Weighted Curve Numbers and the SCS CN Method

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Abstract

Runoff is the most basic and important data needed when planning water control strategies/ practices, such as, waterways, storage facilities or erosion control structures. This study, the runoff potential across the 33 districts of Gujarat was assessed using the Soil Conservation Service Curve Number (SCS CN) method, which was enhanced by incorporating region-specific weighted Curve Numbers (CN). This method, widely used for estimating runoff, was adapted to reflect the unique hydrological and land use conditions of each district. The weighted CN values were determined based on a combination of factors including land use, hydrologic soil groups, and antecedent moisture conditions specific to each district. For instance, districts characterized by extensive agricultural lands were assigned lower CN values, around 65, while urban districts with significant impervious surfaces received higher CN values, up to 80. The application of these weighted CN values resulted in a mean runoff depth of 45 mm across the study area. The standard deviation of 12 mm indicated notable variability in runoff depths from district to district, reflecting the diverse land use and hydrological characteristics across Gujarat. The coefficient of variation, calculated at 26.7%, demonstrated the relative dispersion of runoff depths, providing insight into how runoff varies across different regions. The range of estimated runoff depths was quite broad, spanning from a minimum of 20 mm in less affected areas to a maximum of 80 mm in heavily urbanized regions, highlighting the wide disparity in runoff potential across the state. The high correlation coefficient of 0.85 underscored a strong linear relationship between the observed rainfall and the estimated runoff, confirming that the model's predictions closely followed the observed data trends. This approach supports more precise water resource management and flood risk assessment by reflecting the regional Evaluation of Runoff Potential in Gujarat: Applying Weighted Curve Numbers and the SCS CN Method".

Keywords Runoff estimation, Curve number, Remote Sensing, GIS

1. Introduction

Rainfall-runoff relationship is very complex, influenced by various storm and drainage characteristics. There are several approaches to estimate the runoff. The Soil Conservation Service-Curve Number (SCS-CN) method developed by National Resources Conservation Service (NRSC), United States Department of Agriculture (USDA), is simple, predictable and stable conceptual method for estimation of direct runoff depth based on storm rainfall depth.

In the present study, SCS-CN method was used for estimating the runoff depth in the Gujarat State. The Gujarat State is 1, 96.0094 Sq.Km. The LULC, Soil map were taken from BISAG ghandhinagar and rain gauge stations wise rainfall data from 1981 to 2020 have been used. The objective of this study is to assess the quantity of surface runoff from the study area using GIS based ArcGIS software and to compare the runoff volume estimated. The SCS-CN model is then applied to estimate the monthly runoff from the watershed for monsoon (S-W) of 40 years (1981-2020).Climate

2. Material and methods

2.1. Geographical area

Gujarat lies between latitude 20°07' and 24°43' N and longitude 68°10' and 74°29' E. Gujarat has 1600 km long coast line forming the western and south-western boundary and located on the country's western coast on the Arabian Sea. The state has an area of 1, 96,024 km². This is the seventh largest state in terms of area in India. The state has mainly three geographical regions - the mainland, the peninsular region of Saurashtra and the Kutch region. The mainland has black and fertile soil and alluvial soil. It has a large area of desert land known as Rann of Kutch. The State is divided administratively in to 33 districts. The State of Gujarat can be divided in to five major parts as-Central Gujarat, South Gujarat, Saurashtra, Kutch and North Gujarat.

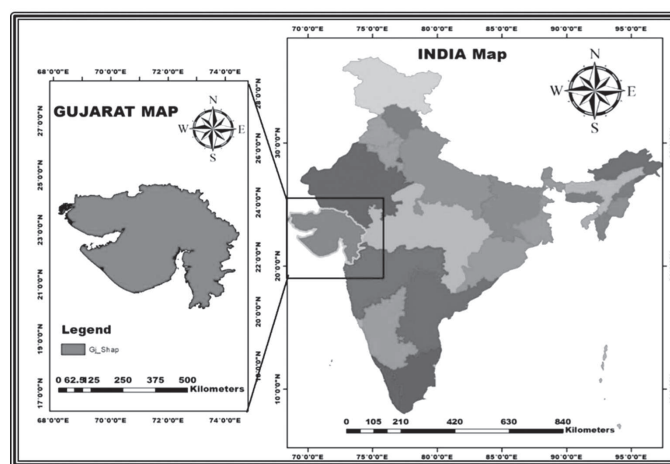


Fig.2.1: Location of Gujarat State

The main source of water for Gujarat is surface water. The State has 185 river basins and the available quota of water in the State is 55608 million cubic meters, out of which, 38100 million cubic meters is surface water, which is only 2% of the entire quota of surface water of the country. Moreover, the available quota of surface water is also not distributed properly. Gujarat, Saurashtra and Kutch have water resources of 89%, 9% and 2% respectively, against this, the total geographical area of these regions is 45%, 31% and 24% respectively. The underground water resources of State are 17508 million cubic meters.

2.2 Data Collection and Analysis

Daily Precipitation data the past 42 years (1980-2020) for different stations were obtained from the State water data centre, Gandhinagar and Gujarat State Disaster Management Authority. The open-source digital data of SRTM DEM and Sentinel 2 satellite images for the construction of the thematic layers such as land use/land cover was obtained from the USGS Earth Explorer database. The soil map developed by the National Bureau of Soil Survey (NBSS) was collected from the BISAG, Gandhinagar.

2.3 CN Map Preparation

The rainfall distribution by Thiessen polygon method was adopted. The monthly wise rainfall data has been converted as raster data set using conversion toolbox in ArcGIS. The Curve Number has been assigned for the Gujarat State considering combination of soil data and land use/land cover. The average CN value (AMC II) has been slope adjusted and converted to CN I, dry condition

(AMC-I) based on Antecedent Moisture Condition (AMC) of the study area. Map algebra-raster calculator of ArcGIS was used for maximum potential retention (S), initial abstraction (Ia) and excess runoff depth (Q). The surface runoff depth of 1981-2020 were estimated and established the rainfall-runoff relationship for the study area.

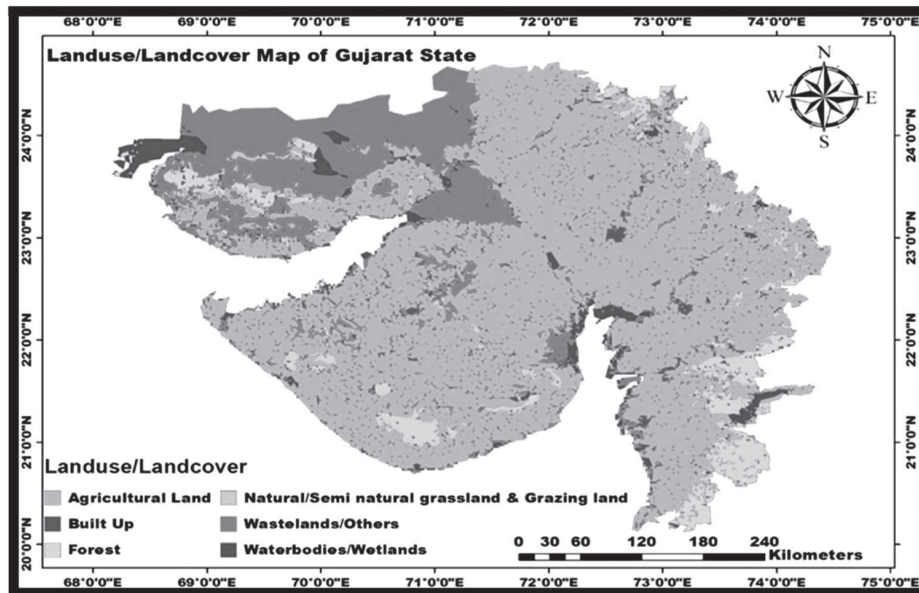


Fig. 2.3: Land use/Land cover map of Gujarat State

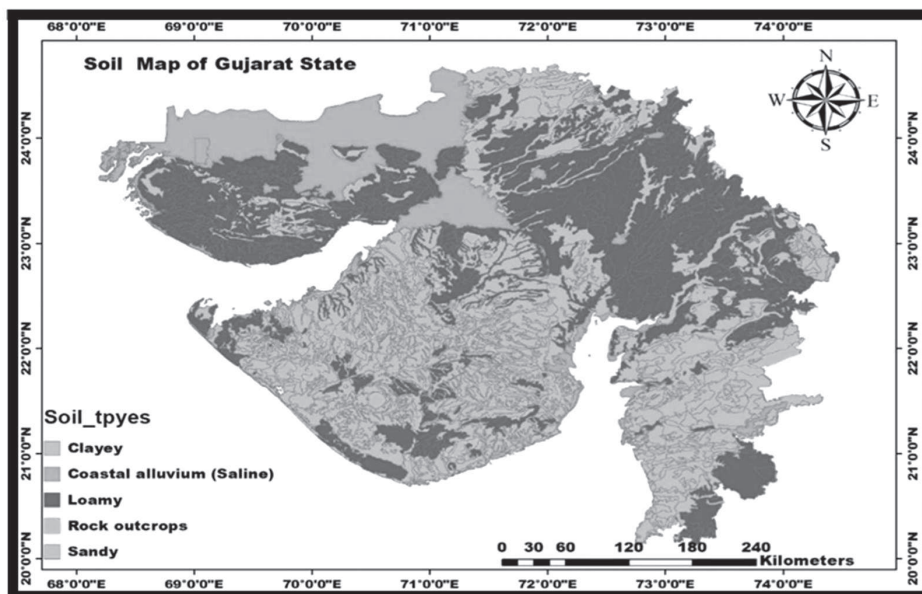


Fig. 2.4: Soil Map of Gujarat State

2.4 SCS-CN Method for Calculation of Potential Runoff

The SCS-CN method (SCS, 1972) also known as hydrologic soil group method is a versatile and popular approach for quick runoff estimation and is relatively easy to use with minimum data and to get adequate results. It is widely and efficiently used for planning the structures aimed at water storage and erosion and flood control.

A curve number (CN), an index developed by the Soil Conservation Service (SCS) now called the Natural Resource Conservation Service (NRCS) is used to estimate the amount of rainfall that infiltrates into the soil and the amount of surface runoff. SCS developed a methodology for adjusting CN with AMC conditions based on accumulated rainfall in five days preceding a rainy storm. There are in total three levels of AMC conditions used in the CN method:

AMC I. This includes the lowest runoff potential of the soil that is dry enough for satisfactory cultivation to take place (Dry condition).

AMC II. The average condition regarding runoff potential (Normal condition).

AMC III. Highest runoff potential of the soil (Wet condition).

The curve number (CN) is dependent on the land use pattern and soil conditions. In other words, it is a function of land use/land cover and hydrologic group. The range of the CN values lies between 0 and 100, with 100 associated with higher runoff potential and 0 representing the least or no possibility of the runoff potential. The SCS-CN method assumes that before starting of runoff generation through the area initial losses must be satisfied. The SCS method of the curve number for the determination of the runoff potential from the watershed is based on the water balance equation and two basic assumptions expressed as:

1. The ratio of the actual direct runoff to the potential runoff is equal to the ratio of the actual infiltration to the potential infiltration.
2. The amount of initial abstraction is a fraction of the potential infiltration. (Handbook of Hydrology, 1972)

$$\frac{(P - Ia)}{S} = \frac{Q}{Q_p} \quad (1) \quad Q = (P - Ia) \frac{Q_p}{S}$$

$$F = (P - Ia) - Q \quad (2)$$

Where, F = the cumulative infiltration excluding Ia; Q = actual runoff (mm), P = rainfall (mm); Ia = initial abstraction, which represents all the losses before the runoff begins and is given by the empirical equation; Ia = 0.2S (Handbook of Hydrology, 1972)

$$Q = ((P - Ia) - 0.2S)^2 / (S - 0.2S) \quad (3)$$

For P > Ia, S = the potential infiltration after the runoff begins given by the following equation (mm) (4) $S = 25400 / CN - 254$

The curve number of the region was estimated by analysis the results obtained in the GIS analysis on the thematic layer of Land use/ Land cover and soil map (Hydrologic soil group). Land use-Land cover and HSG was added in the Attribute table using union tool in Arc GIS 10.4.1 environment. The result acquired from the union attribute was used to calculate the weighted area curve number of the Gujarat state.

The equation for the computation of Weighted CN is given below

$$CN_w = \frac{\sum(CN_i \cdot A_i)}{\sum A_i} \quad (5)$$

Where, CN_w = Weighted curve number; CN_i = curve number from 1 to 100; A_i = area with curve number CN_i

The runoff was estimated on daily basis for the monsoon period (June-October) for the year from (1980-2020). The daily runoff was summed up to get the monsoon runoff. The area-weighted runoff was obtained for the Gujarat state using the equation. $Q_b = \sum Q_i \cdot A_i / \sum A_i$ (6)

Q^b = Average runoff depth for the Gujarat State in mm; Q_i = Average runoff depth from the polygon in mm A_i = Area of a polygon in KM2 i = an index for the polygon, $i = 1$ to n

CN Map Preparation of Gujarat State

Preparation of CN (Curve Number) map for Gujarat state was used land use and soil maps in ArcGIS. The primary datasets were required the land use map, soil map, and the boundary map of Gujarat. Both the land use and soil maps were properly geo-referenced and use the same coordinate system to avoid projection issues during analysis.

Union operation was proceed with the Union tool, which is located under Analysis Tools > Overlay > Union. This tool combines the attributes of the land use and soil maps into a single layer, allowing for integrated analysis. The resulting layer was have polygons that represent unique combinations of land use and soil types.

After performing the union, the attribute table of the new layer was opened and add a new field to store the Curve Number (CN) values. The CN value is crucial for hydrological modelling as it reflects the potential runoff from different land and soil combinations. Using a reference standard CN table was used for curve number, according to the specific soil types and LuLc types. New field was Populate by assigning CN values based on the land use and soil type combinations present in attribute table.

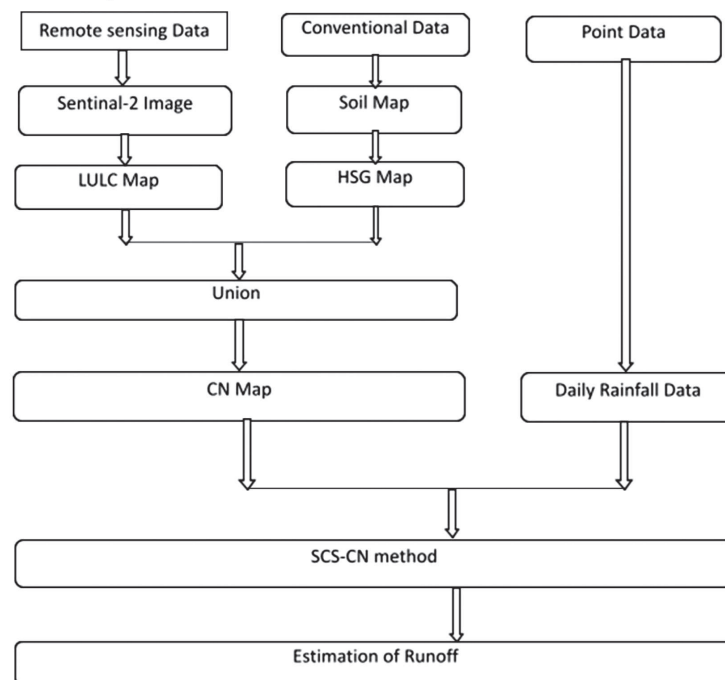


Fig.2.5:Flow chart for runoff estimatione

3. Results and Discussion

3.1 CN Map Preparation of Gujarat State

Preparation of CN (Curve Number) map for Gujarat state was used land use and soil maps in ArcGIS. The primary datasets were required the land use map, soil map, and the boundary map of Gujarat. Both the land use and soil maps were properly geo-referenced and use the same coordinate system to avoid projection issues during analysis.

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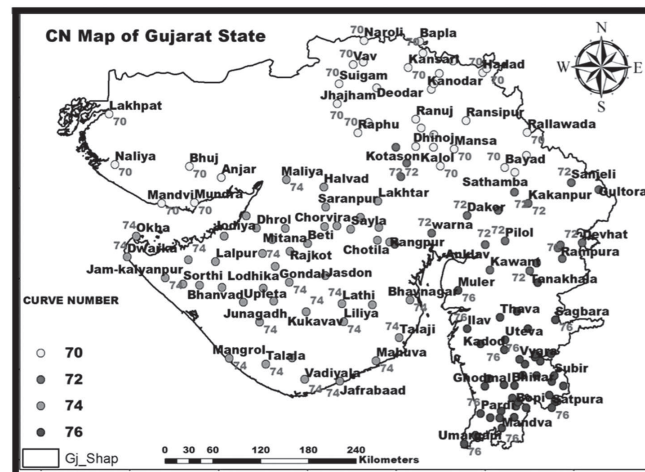


Fig. 2.6: CN Map Station-wise of Gujarat

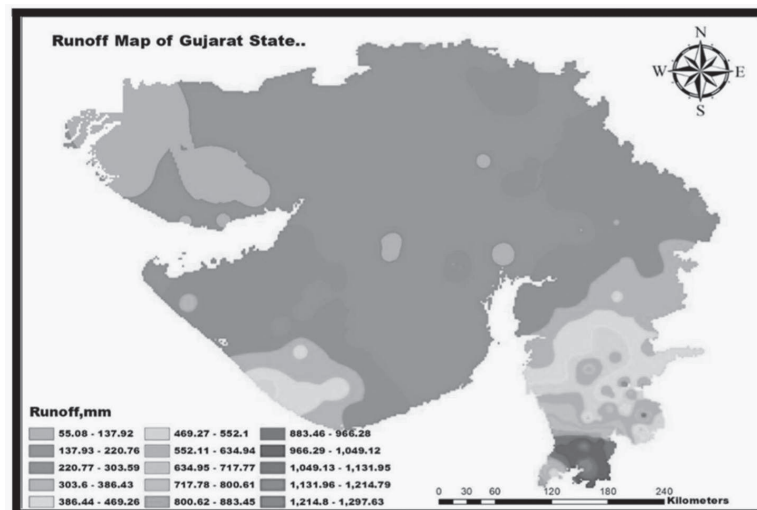


Fig. 2.7: Runoff Map se of Gujarat

The CN value of each polygon was used to calculate maximum potential retention S for each polygon thus has been estimated with the help of Equation (5). The runoff of each polygon thus has been estimated with the help of Equation (6). The runoff depth has been estimated for years 1981-2020. The average runoff volume of Modikuntavagu watershed was worked out from 2006-2016 and found as 83.66MCM. The rainfall-runoff depth relationship has been established for forty years 1981-2020) and found that the statistically positive correlation n ($R^2=0.82$) between rainfall and runoff depth. In (Figure: 2.7).

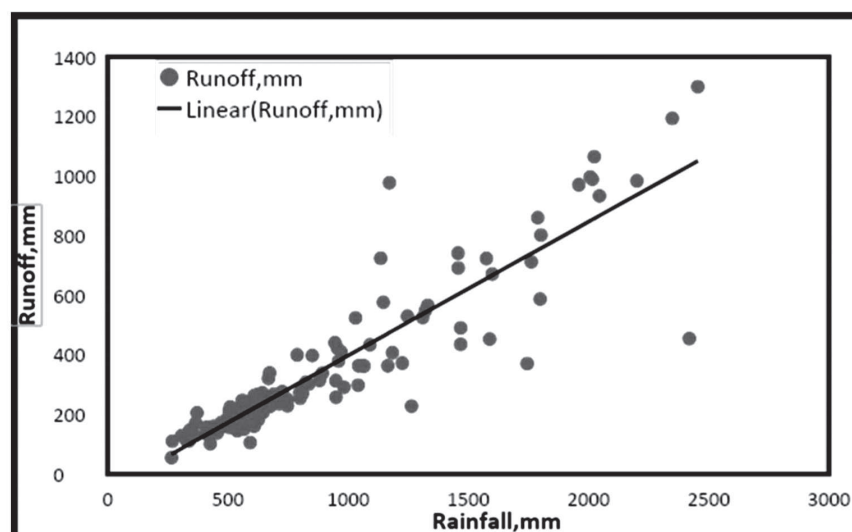


Fig.2.8: Rainfall-Runoff relationship for 1981-2020

4. Conclusion

Curve number estimation was performed using extracted geomorphological data including thematic layers of such as land use, soil type, drainage order, etc under the environment of RS and GIS. In the study it was found that integration of SCS CN method with environment RS and GIS can enhance model performance significantly. It was also found that GIS is the most effective and efficient tool for thematic map preparation as an input for SCS-curve number method. Finally it was concluded in this study that curve number method in integration with environment of RS and GIS techniques is very effective and efficient method for simulating rainfall-runoff and to determine total surface runoff. Total runoff volume was estimated 3901874 MCM for Gujarat state. The high correlation coefficient R^2 of 0.82 underscored a strong linear relationship between the observed rainfall and the estimated runoff.

References

- Adam, E. O., Abdelbasit, M. A., Solomon, T. and Ahmed, F. (2017). Integration of satellite rainfall data and curve number method for runoff estimation under semi-arid wadi system. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, 42: 1-7.
- Ahmed, I. D. and Fattah Sheikh Suleimany, J. M. (2023). Preparation of Curve Number Grid Map of Rawanduz River Basin in KRI Using GIS Techniques. *Polytechnic Journal*, 12(2): 14.
- Bhuktar, V. S. and Regulwar, D. G. (2015). Computation of runoff by SCS-CN Method and GIS. *International Journal of Engineering Studies and Technical Approach*, 1(6):63-70.
- Chavda, D. B., Makwana, J. J., Parmar, H. V., Kunapara, A. N. and Prajapati, G. V. (2016). Estimation of runoff for Ozat catchment using RS and GIS based SCS-CN method. *Forest*, 225(15.99):15-99.
- Dalavi, P., Bhakar, S. R., Bhange, H. N., and Gavit, B. K. (2018). Assessment of empirical methods for runoff estimation in Chaskaman catchment of Western Maharashtra, India. *International Journal of Current Microbiology and Applied Sciences*, 7(5):1511-1515.
- Dhawale, A. W. (2013). Runoff estimation for Darewadi watershed using RS and GIS. *International Journal of Recent Technology and Engineering*, 1(6): 46-50.

Trivedi, A., and Awasthi, M. K. (2021). Runoff estimation by integration of GIS and SCS-CN method for Kanari River Watershed. *Indian Journal of Ecology*, 48(6): 1635-1640.

Young RA, Onstad CA, Bosch DD and Anderson WP. 1989. AGNPS: A nonpoint-source pollution model for evaluating agricultural watersheds. *Journal Soil Water Conservation*, 44(2): 168-173.

ZangGP, and Savenije HG. 2005. Rainfall-runoff modelling in catchment with complex groundwater: application of representative elementary watershed (REW) approach. *Hydrology and Earth Science*, 9:243-261.

Delineation of potential groundwater recharge zones of the Aji River Basin in Saurashtra region of Gujarat state using remote sensing, GIS, and AHP approaches

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Abstract

Groundwater is a critical natural resource, especially in regions with prevalent agricultural and industrial activities. However, overexploitation due to these activities has led to significant depletion of groundwater reserves. To address this issue, it is essential to implement sustainable water management practices aimed at enhancing groundwater recharge. This study focuses on the Aji River Basin in the Saurashtra region of Gujarat, India, utilizing advanced geospatial technologies to identify potential groundwater recharge zones. The primary goal of the study was to enhance groundwater recharge in the Aji River Basin. Several factors influencing groundwater availability were analyzed, including lineament, geology, soil density, slope, rainfall, land use/land cover, geomorphology, and drainage density. An integrated approach combining Remote Sensing (RS), Geographic Information System (GIS), and Multi-Criteria Decision Analysis (MCDA) was used to achieve this objective. The Satty's Analytic Hierarchy Process (AHP) method was applied to determine the influence of each factor, and sub-parameters were ranked based on the AHP scale. A weighted overlay analysis tool in ArcGIS software was then utilized to map the potential groundwater recharge zones within the basin. The resulting map classified the basin into five distinct zones based on their potential for groundwater recharge: 'Excellent' (50.50 km², 2.36%), 'Good' (1376.78 km², 64.56%), 'Moderate' (599.14 km², 28.09%), 'Poor' (90.67 km², 4.25%), and 'Very Poor' (15.32 km², 0.718%). Additionally, the SCS-Curve Number method was employed to assess the potential for rainfall-induced runoff. The study found that the Aji River Basin had a weighted mean rainfall of 622.68 mm and a weighted mean runoff of 241.07 mm. The total estimated weighted runoff for the basin was 514.07 million cubic meters (MCM), with a 75% exceedance probability indicating a runoff of 152.97 MCM.

Keywords Potential groundwater recharge zones, Groundwater recharge, Analytical hierarchy process, Geographical information system, Remote sensing, Ajiriver basin

1. Introduction

Global climate change has significantly increased the likelihood of extreme weather events, leading to various abiotic stresses such as drought, salinity, floods, and heat waves, along with biotic stresses like pest and disease infestations, all of which severely impact crop production. Compounding this challenge is the rapidly growing human population, which is expected to surpass 9.7 billion by 2050. Urbanization further exacerbates the situation by reducing the availability of agricultural land, making it increasingly difficult to meet the food demands of a larger population with shrinking land resources[1]. Moreover, urbanization seriously threatens available agricultural

land, indicating that feeding a population with limited land is a herculean task. Projected global food production of primary staple crop production and productivity has declined worldwide. It affects biodiversity and ecosystem services of the agricultural production system. The adverse impact of climate change would be more significant in traditional semi-arid or arid rainfed zones, including India [2]. Arid and semi-arid zones in India are approximately 15.8 % and 37 %, respectively, nearly half of the total geographical areas. Hot arid regions falling states are Rajasthan (61 %), Gujrat (19.6 %), Haryana and Panjab (9 %), Andra Pradesh (7 %), Karnataka (3 %) and Maharashtra (0.4 %). This rainfed agriculture production system accounts for 40 % of the food grains and sustains 2/3rd of the livestock population [3].

Groundwater is essential for drinking, irrigation, and domestic and industrial use in these hot-arid areas. As Groundwater in this area is limited, quantity and quality are a severe concern in these areas [3]. Additionally, excessive groundwater extraction and insufficient recharge processes contribute to the depletion of water resources within aquifers. Previous studies showed groundwater recharge is most sensitive, where potential evapotranspiration exceeds precipitation. It showed that the recharge potential of the semi-arid and arid zones would be mostly negatively affected by climate change [4]. Recharging the groundwater is essential for sustainable human and water resource development. Future climate will mainly affect recharge through precipitation changes, amplifying groundwater recharge more than anticipated. Sensitivity to aridity, underestimated by global models, may significantly impact groundwater sustainability, surpassing prior forecasts [5]. Therefore, groundwater recharge potential study through remote sensing (RS) and geographic information systems (GIS) provides assessment, monitoring, and conservation of groundwater resources. Remote sensing imagery is applied to extract key features such as base map, geomorphology, rainfall, slope, drainage density, soil type, land cover, land use, lineament density, and geology [6]. The study involves the development of remote sensing algorithms for feature extraction (base map, geomorphology, etc.), integrate them in ArcGIS software using Satty's analytic hierarchy process (AHP) and Multi-Criteria Decision Analysis (MCDA) for weighted analysis, estimating rainfall-runoff potential with SCS-CN approach, and validating the results via ground truthing data [6-9]. Furthermore, water harvesting structures (RWH) are predicted based on slope, land use, soil, rainfall, and stream order to assess sub-surface storage capacity and surplus water availability and develop RWH structures [10-11]. A GIS database is accessible for assessing water harvesting potential within semi-arid and arid agro-ecological regions. It details engineering methodologies and the hydrological model's implications concerning future climate change scenarios.

Artificial groundwater recharge is pivotal, particularly considering that over 45% of the nation's irrigation relies on groundwater. With growing demands from agriculture, households, and industries, the daily draft on groundwater continues to rise. Therefore, in the present study, we explored the integration of remote sensing (RS) and Geographic Information Systems (GIS) to create a composite picture of the Aji River basin's characteristics, analyse rainfall-runoff potential, and identify potential groundwater recharge zones.

2. Methodology

2.1 Study area overview

The Aji River, the most significant river in Saurashtra, flows through the city of Rajkot and is positioned between latitudes 21° 25'N to 22° 10'N and longitudes 70°45'E to 71° 20'E. With a length of 164 km and a catchment area of 2132.41 km² (Fig. 1). It plays a crucial role in the region's geography. Major tributaries contribute to its flow, including the Nyari, Lalapari,

Khokaldadi, Bhankudi, and Dondi. The river originates from the hills of Sardar near Atkot and flows to its mouth at the Gulf of Kutch in Ranjit Para of Jamnagar district [12]. Four dams are constructed along the Aji River: Aji-I, Aji-II, Aji River-I II, and Aji River-IV dams. These dams serve various purposes, such as water storage, irrigation, and flood control, contributing to the region's agricultural and environmental needs [13].

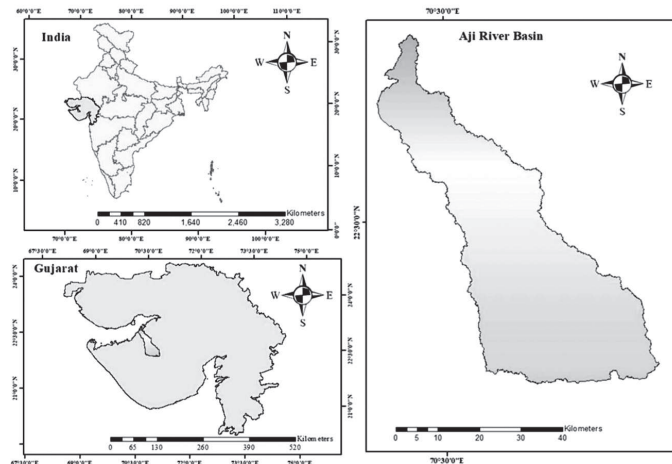


Fig.1. Study area map of Aji River Basin generated through ArcGIS 10.4.1

2.2 Data acquisition

Data on precipitation covering the past 40 years (1981-2020) were obtained from different stations and sourced through the State Data Centre in Gandhinagar and the Gujarat State Disaster Management Authority. Thematic layers, including slope and drainage density, were generated using open-source digital data from the SRTM DEM obtained from the Earth Explorer-USGS database. Geological and geomorphological maps were acquired from the Bhukosh Geological Survey of India database. The soil map, developed by the National Bureau of Soil Survey & Land Use Planning (NBSS&LUP), was obtained from BISAG in Gandhinagar (Table 1).

Table 1. Different input parameters are used to analyse the potential groundwater zones for the Aji River basin.

Data	Description	Source
Rainfall data	Annual average Rainfall	Gujarat State Disaster Management Authority. (http://www.gsdma.org/). State Water Data Centre, Gandhinagar.
Remote Sensing Data	LULC SRTM DEM	Bhaskaracharya Institute for Space Application and Geo-informatics (BISAG), Gandhinagar. Earth Explorer-USGS (https://earthexplorer.usgs.gov)
	Soil map	Bhaskaracharya Institute for Space Application and Geo-informatics (BISAG), Gandhinagar.
Conventional data	Geomorphology Geology	Bhukosh - Geological Survey of India. (http://bhukosh.gsi.gov.in/Bhukosh/Public)
	Lineament	Bhuvan Indian Geo platform of ISRO https://bhuvan.nrsc.gov.in/home/index.php

2.3 Estimation of runoff potential in the Aji River Basin

The daily flow of water in the Aji River Basin was calculated from 1981 to 2020 using the SCS Curve Number technique. This method involves assessing the potential maximum retention capacity of the watershed, influenced by its wetness, by referring to its physical characteristics and prior moisture conditions. The curve number (CN) depends on the land use pattern and soil conditions. In other words, it is a function of land use/ land cover and soil hydrologic group. The range of the CN values lies between 0 and 100, with 100 associated with higher runoff potential and 0 representing the least or no possibility of the runoff potential. The SCS method of the curve number for determining the runoff potential in the watershed is based on the water balance equation and two basic assumptions given in [23].

2.4 Demarcation of potential groundwater recharge zones

The various thematic maps were processed to delineate the potential groundwater zones.

2.4.1 Base Map

The base map is the foundational representation, delineating the boundary of the Aji River Basin watershed - the primary region of interest. It functions as the fundamental reference map for all subsequent thematic maps. The base map was created with 30 m spatial resolution using SRTM DEM data viz., SRTM1N22E071V3, SRTM1N22E069V3, SRTM1N23E070V3, and SRTM1N22E070V3. The mosaic tool was used to merge them. The Fill and Sink tools were used to remove defects in the DEM. Flow Direction, Flow Accumulation, and streams were generated. A suitable outlet for the Aji River was selected, and the watershed was delineated.

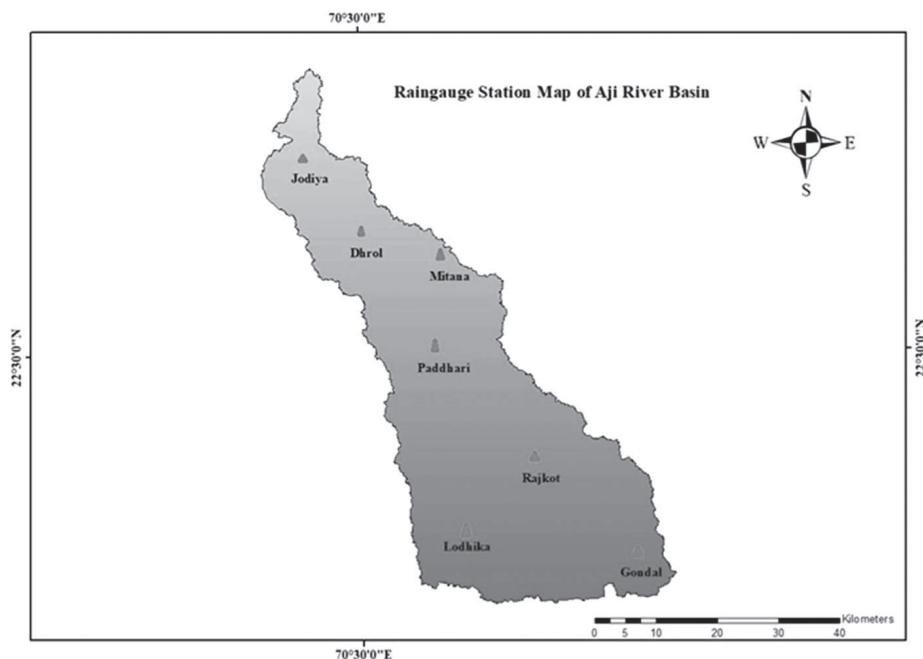


Fig. 2. Map of Rain-gauge Station of Aji River basin generated through ArcGIS 10.4.1

2.4.2 Geomorphology

Geomorphology, depicting diverse landforms and topographic features, is crucial in delineating zones with groundwater potential. It details the dispersion of different landform characteristics and phenomena, such as temperature fluctuations, geochemical reactions, water

movement, and freezing and thawing cycles [14]. In the present study, the digital data for the Geomorphology of Gujarat State, India, was obtained from open-source data of the Bhukosh-Geological Survey of India, and the raster file of the Geomorphology Map of the Aji River Basin has developed in ArcGIS 10.4.1 software. The reclassification was done to make the obtained data compatible and clear for further analysis. The "classify tool" under the spatial analyst tool in ArcGIS 10.4.1 was used to reclassify the obtained data.

2.4.3 Rainfall

Rainfall plays a crucial role in the hydrological cycle, significantly affecting groundwater recharge. The infiltration rate depends on rainfall intensity and duration; high-intensity, short-duration rainfall tends to increase runoff, while low-intensity, long-duration rainfall enhances infiltration and reduces runoff. In this study, average precipitation was calculated using daily rainfall data from the past 40 years (1981-2020) collected from seven stations: Gondal, Lodhika, Paddhari, Rajkot, Mitana, Dhrol, and Jodia. The annual weighted precipitation for the study area was determined using the Thiessen polygon method, dividing the region into seven polygons, each associated with one station. A rainfall map of the Aji River Basin was then generated using the Inverse Distance Weighted (IDW) Interpolation approach, which assigns weights to sampling points based on their distance, with influence decreasing as distance increases.

2.4.4 Slope

The slope is a crucial topographical feature, indicating the degree of incline on the Earth's surface. It provides valuable insights into the geological and geodynamic processes at a broader geographical level. The steepness of the terrain directly affects surface runoff and the rate at which water infiltrates the ground [14]. The DEM data was used to construct the slope map. The slope map raster file was created in percentages, and the Arc map software utilized the slope tool.

2.4.5 Drainage Density

The drainage network relies on the lithological characteristics of the area and serves as a crucial indicator of infiltration rates. The drainage density is inversely proportional to permeability or infiltration [14]. Drainage density is determined by dividing the total length of all rivers within a drainage basin by the total area of that specific basin [15].

2.4.6 Soil

The soil's capacity for retention or texture significantly influences the groundwater presence. Soil composition, particularly the proportions of silt, clay, and sand, establishes its texture. The clay soil has smaller pores, leading to increased runoff and reduced infiltration, while sandy soil facilitates higher infiltration with larger pores, thus replenishing groundwater [14].

2.4.7 Lineament Density

Lineaments are direct features observed on Earth's surface, indicating zones of structural movement or weakness in the Earth's crust. Lineament density was calculated using the mathematical formula [16].

2.4.8 Geology

The geological composition plays a significant role in determining the occurrence and groundwater flow within a particular area. The particular rock types in a specific area significantly influence the accessibility and replenishment of groundwater reserves. In this study, the resource

map was scanned, rectified, and georeferenced using the Arc GIS 10.4.1 software, and the map of Geology for the Aji River Basin was constructed.

2.4.9 Land Use Land Cover (LULC)

Land use involves various human activities and intentions on a specific land. In contrast, land cover encompasses vegetation, water bodies, rocks/soil, artificial structures, and other features arising from land modifications[8].

2.5 Saaty's Analytical Hierarchy Process

In the Analytical Hierarchy Process (AHP), decision-makers assign individual weights to evaluation criteria through pairwise comparisons, indicating their relative importance. Subsequently, for a specific criterion, each option is given ratings based on the decision maker's comparisons in a pairwise manner. The AHP consolidates these weights assigned to criteria and the scores allocated to options to calculate an overall score for each option, establishing a ranking. The global score is calculated as a weighted sum across all criteria. Notably, 9 signifies higher importance, 1/9 denotes the least, and 1 signifies equal weight for a parameter or category. Using these weighted criteria, each parameter in the study was categorized accordingly[17] (**Table 4**).

2.6 Integration of various thematic maps to demarcate potential groundwater recharge zones (PGWRZ)

Several thematic maps covering diverse groups and their standardized weights were integrated into the ArcGIS 10.4.1 framework. The Potential Groundwater Recharge Zone Index (PGWRZI) computation included integrating all thematic maps into the GIS environment using the equation specified by[18].

$$\text{GWRPZI} = \sum_i^n (X_A * Y_B)$$

Where, PGWZI = Potential Groundwater Zones Index; X_A - Denotes the weightage of the thematic layers, where $A = 1, 2, 3, \dots$; Y_B - Signifies the rank of the thematic layers' subclass, where $B = 1, 2, 3, \dots, Y$

2.7 Probability analysis of rainfall-runoff data

Rainfall information spanning forty years (1981-2020) was analysed to calculate the runoff and assess its probability, which was accomplished by applying Weibull's method. Utilizing this method, the calculation of the total runoff produced in the basin area at a 75% confidence level, as outlined by [19], was performed.

3. RESULTS AND DISCUSSION

3.1 Study area

The Aji basin is situated within the latitudinal range of $21^{\circ} 25'N$ to $22^{\circ} 10'N$ and the longitudinal range of $70^{\circ} 45'E$ to $71^{\circ} 20'E$. It spans an area of 2132.41 km², and the Aji River measures 164 km in length.

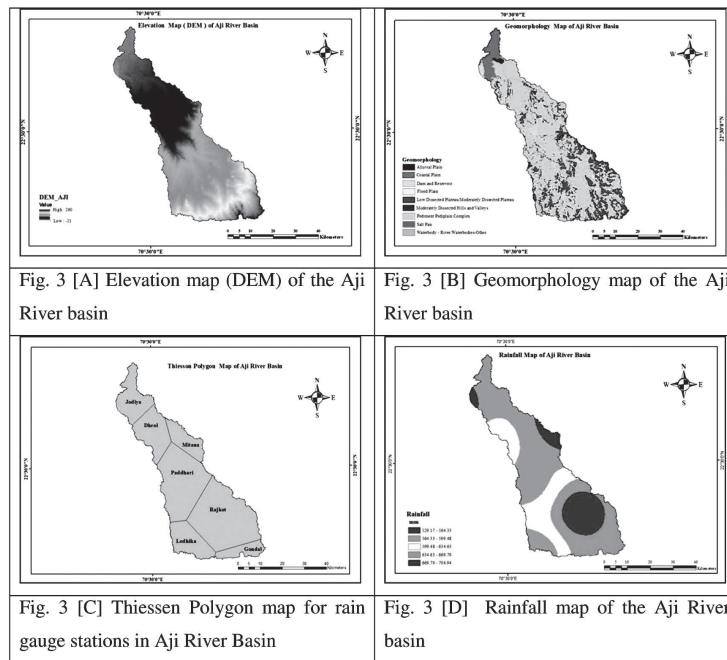


Fig. 3. [A] Elevation map, [B] geomorphology map, [C] Thiessen polygon map, and [D] Rainfall map of Aji river basin generated using ArcGIS 10.4.1

The AHP pair-wise matrix was created by assigning scale weights to themes and features, considering their impact on groundwater occurrence. This involved synthesizing insights from literature reviews and expert opinions. A pair-wise comparison matrix, established in an 8 x 8 format using Saaty's analytical hierarchy process, determined influenced weights for each theme based on a rating scale. The consistency ratio of the assigned weights falls within the predefined range of $(0.084 < 0.10)$; it can be concluded that the matrix is consistent, and the allocated weights are deemed acceptable (Table 3).

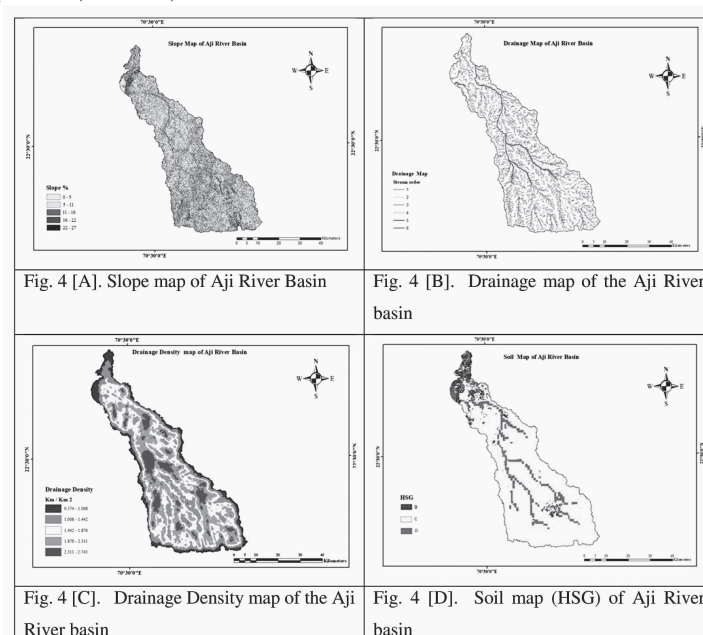


Fig. 4 [A] Slope map, [B] Drainage map, [C] Drainage density map, and [D] Soil map of the Aji river basin generated through ArcGIS 10.4.1

The smaller the consistency index, the higher the consistency of the matrix. In the ideal case, $CI = 0$. The ideally consistent matrix is a rare case, even if the transitivity of its elements has been checked. The consistency degree of matrix P may be determined quantitatively by comparing the calculated consistency index of the matrix with a randomly generated consistency index (based on the scale 1-3-5-7-9) of the inverse symmetrical matrix of the same order (Table 4).

The normalized matrix is derived from a pair-wise comparison matrix by adding the entries in each column of the comparison matrix and dividing each entry a_{jk} by the sum of the entries in the corresponding column $\sum a_{jk}$ of the comparison matrix. The sum of normalized entries in each column will equal one (Table 5).

The Elevation map DEM prepared for the Aji River basin (Fig. 3[A]) shows the highest elevation of 260 m and the lowest Elevation of 21 m. The pediment pediplain complex covers the highest vast area of 1,431.55 km², constituting 67.13% of the total region, while the salt pan covers 1.01 km², 0.05 of the basin area (Fig. 3[B]) and (Table 6). The range of rainfall classes, the highest precipitation, measuring 704.94 mm, was recorded in the Rajkot station, which covers an area of 664.97 km², calculating 15.76% of the total area. In contrast, the lowest rainfall, at 516.42 mm, is observed in Mitana, which spreads over 150.89 km² (Fig. 3[C-D]) and (Table 2). In the analysis of slope percentages, the range of 0-5% encompasses the highest area, covering 2,095.4 km², which accounts for a substantial 98.26% of the total area, while the range of 22-27% represents the lowest area, with only 0.01 km² (Fig. 4[A]) and (Table 7). The drainage density, range of (1.008 - 1.442) km/km² represents the highest area, covering 1181.45 km², which accounts for a significant 55.40% of the total area, while the range of (2.311 - 2.745) km/km² signifies the lowest area, with just 12.84 km² (0.60%) of the total area (Fig. 4[B-C] and (Table 6).

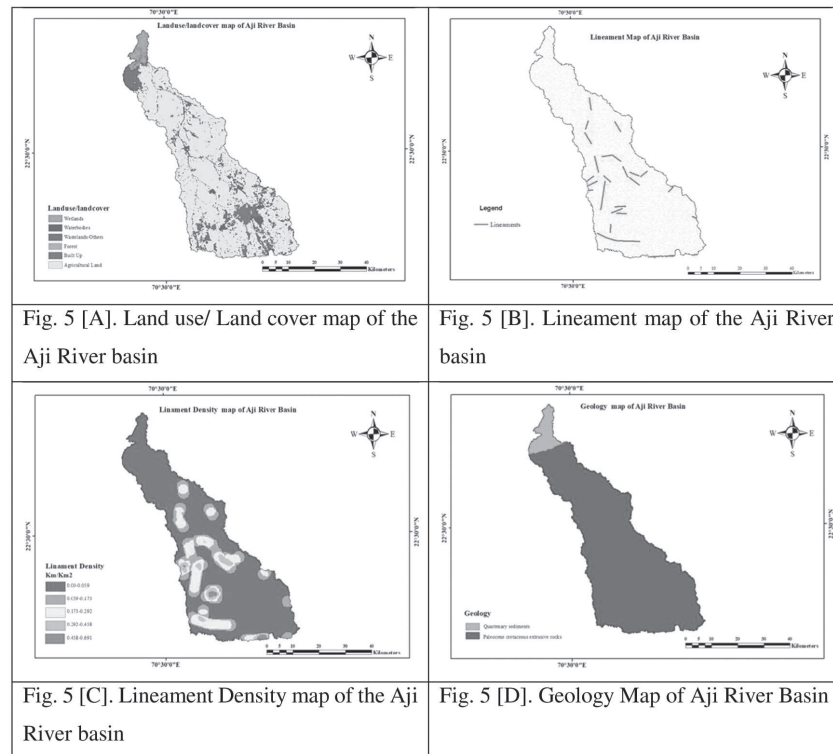


Fig. 5. [A] Land cover map, [B] Lineament map, [C] Lineament density map, and [D] Geology map of the Aji river basin generated through ArcGIS 10.4.1

Group C has the highest area among the hydrologic soil groups, covering 1,802.41 km², representing 84.52% of the total area. In contrast, Group B, with an area of 110.16 km², constitutes a smaller portion, accounting for 5.16% of the total area (Fig. 4[D]) and (Table 7). In the Land Use Land Cover (LULC) categories, agricultural land is the most extensive, covering 1,642.84 km², constituting 77.04% of the total area. Conversely, forest, with an area of only 2.53 km², represents the smallest category, making up just 0.12% of the total area (Fig. 5[A]) and (Table 7). The lineament density km/km² covers a substantial area of 1,561.38 km², accounting for 73.22% of the total. In contrast, the 0.458 to 0.691 km/km² range represents a much smaller area, comprising only 13.62 km² or 0.63% of the total area (Fig. 5[B-C]) and (Table 7). In geology features, paleocenecretaceous extrusive rocks dominate with the highest area covering 2019.20 km², representing 94.69% of the total area. On the other hand, quaternary sediments cover the least area, measuring 113.21 km², representing 5.30% of the entire area (Fig. 5[D]) and (Table 6). The lowest area in runoff potential class ranges is covered by the 188.55 - 204.54 mm range, spanning 105 km² (4.9%). In contrast, the highest area is attributed to the 236.52 - 252.51 mm range, encompassing 786 km², representing 36.86% of the total area (Fig. 6) and (Table 9).

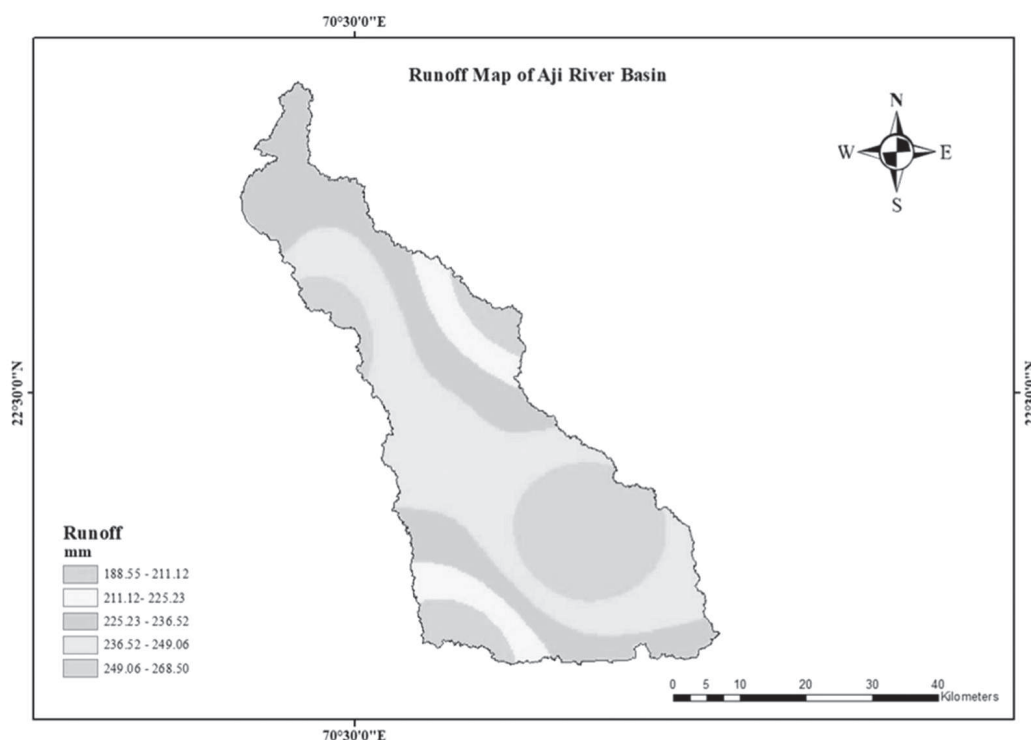


Fig. 6. Runoff Potential Map of Aji River Basin generated through ArcGIS 10.4.1

3.3 DEMARCATION OF POTENTIAL GROUNDWATER RECHARGE ZONES

Following the assignment of different weights to the thematic layers and their respective attributes, the next step involved the integration of all these thematic maps within the ArcGIS platform. The integration was accomplished by applying the "weighted overlay" spatial analyst tool. The potential groundwater recharge zone index was employed to pinpoint and characterize potential groundwater recharge zones. The outcome of the overlay analysis has been categorized into five zones based on their suitability for groundwater recharge. These five categories include Very Poor, Poor, Moderate, Good, and Excellent (Fig. [7]), and (Table 8) illustrates the ultimate potential groundwater recharge zones in the Aji River basin.

Table 2. Rainfall-runoff of various zones in the Aji River basin (Fig. 2,3[D], and 6)

Sr. No.	Zone	Rainfall (mm)	Runoff (mm)	Area(m ²)
1	Rajkot	704.96	268.51	664967000
2	Gondal	675.22	227.12	104929000
3	Dhrol	643.24	272.61	244785000
4	Paddhari	584.32	240.21	527841000
5	Lodhika	570.98	192.86	213670000
6	Jodia	543.17	220.80	225328000
7	Mitana	516.425	180.27	150887000
	Weighted Average	622.68	241.07	

Table 3. A pair-wise matrix calculation determines the weight assigned to the thematic layers.

Layers	SL	GEO M	SO	GEO	LULC	DD	R	LD
GEO M	3	1	6	7	5	5	3	4
R	5	0.33	6	9	7	5	1	8
SL	1	0.33	3	7	5	2	0.20	6
DD	0.50	0.20	2	6	3	1	0.20	5
SO	0.33	0.16	1	5	2	0.5	0.16	3
LULC	0.20	0.20	0.5	3	1	0.33	0.14	2
LD	0.16	0.25	0.33	3	0.5	0.2	0.11	1
GEO	0.14	0.14	0.20	1	0.33	0.16	0.11	0.33
TOTAL	10.34	2.62	19.03	41	23.83	14.20	4.93	29.33

Where, SL = Slope; GEOM = Geomorphology; SO = Soil; GEO= Geology; LU-LC = Land use / land cover; DD = Drainage Density; R = Rainfall; LD = Lineament Density

Table 4. Parameters of AHP to check the consistency of weights assigned to thematic layers.

Parameter	Formula	Value
Consistency measures	(A column of comparison Matrix) x (Eigen Vector) (Corresponding Eigen Vector of the row)	70.66
	$\lambda_{max} = \frac{70.63}{8} = 8.83$	
Principal Eigen Value		8.83
Consistency Index (CI)	$\frac{(\lambda_{max} - n)}{(n-1)} = \frac{(8.83-8)}{(8-1)} = 0.119$	0.119
Consistency Ratio (CR)	$\frac{CI}{RCI} = \frac{0.119}{1.41} = 0.084$	0.084

After interpretation, it was observed that more than half of the designated area falls within the combined categories of good and moderate zones. This suggests sufficient potential for capturing and replenishing the groundwater table in the river basin. Specifically, the area with excellent groundwater recharge potential comprises 50.50 km² (2.36%), and the zone with good potential covers 1376.78 km² (64.56%). An additional 599.14 km² (28.09%) falls within the moderate zone. The cumulative area categorized as Poor and Very Poor amounts to approximately 105.99 km² (4.97%). Table 8 illustrates the spatial distribution of the various zones within the potential groundwater recharge zone in the Aji River basin.

Table 5: Normalized Weights for thematic layer

Sr. No.	Parameters	Value	Eigen Value	Normalized Weightage %
1	Geomorphology	High	0.307	30.7
2	Rainfall		0.283	28.3
3	Slope		0.143	14.3
4	Drainage density		0.097	9.7
5	Soil		0.065	6.5
6	Land use/landcover		0.044	4.4
7	Lineament Density		0.036	3.6
8	Geology	Low	0.020	2
Total				100

Table 6. Weightage allocation to various subclasses of the thematic layers

Parameter	Parameter weight (%)	Sub-class Groundwater Recharge	Potential scale	Saaty's weight	Relative
Drainage Density (km/km ²)	9.7	0.574 - 1.008	Very high	9	36
		1.008 - 1.442	High	7	28
		1.442 - 1.846	Moderate	5	20
		1.876 - 2.311	Low	3	12
		2.311 - 2.745	Very low	1	4
		Total		25	100
Geomorphology	30.7	Water bodies, Dams and Reservoir	Very high	9	21
		Alluvial Plain	High	7	17
		Pediment Pediplain Complex	High	7	17
		Flood Plain	High	7	17
		Coastal Plain	Moderate	5	12
		Low Dissected	Low	3	7

		Plateau/Moderately Dissected Plateau			
		Moderately Dissected Hills and Valleys	Low	3	7
		Salt Pan	Very low	1	2
		Total		42	10
Geology	2	Paleocene cretaceous extrusive rocks	Very High	9	65
		Quaternary sediments	Moderate	5	35
		Total		14	100
Rainfall (mm)	28.3	704.94-671.85	Very High	9	36
		671.85-637.39	High	7	28
		637.39-603.62	Moderate	5	20
		603.62-579.49	Low	3	12
		579.49-529.17	Very low	1	4
		Total		25	100

Table 7. Weightage allocation to various subclasses of the thematic layers

Parameter	Parameter weight (%)	Sub-class	Potential Groundwater Recharge	Saaty's scale	Relative weight
Lineament Density (km/km ²)	3.6	0.691-0.458	Very High	9	36
		0.458-0.292	High	7	28
		0.292-0.173	Moderate	5	20
		0.173-0.059	Low	3	12
		0.059-0.00	Very Low	1	4
		Total		25	100
Slope (%)	14.3	0- 5	Very High	9	36
		5 -11	High	7	28
		11- 16	Moderate	5	20
		16- 22	Low	3	12
		22- 27	Very Low	1	4
		Total		25	100
Landuse/ land cover	4.4	Wetlands	Very High	9	27
		Waterbodies	High	9	27
		Agricultural Land	Moderate	7	20
		Forest	low	5	15

		Wastelands/Others	low	3	9
		Build up	Very low	1	2
		Total		34	100
Soil (According to HSG)	6.5 C	B	Very High	9	50
		High	7	39	
		D	Very low	2	11
		Total		18	100

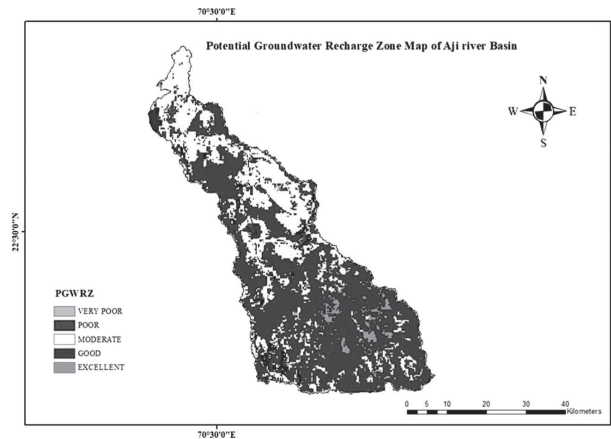


Fig 7. Potential groundwater recharge zones of the Aji River basin generated through ArcGIS 10.4.1

Table 8: Potential groundwater recharge zones of the Aji River basin

Sr. No.	PGWRZ	Area (km ²)	Area (%)
1	Excellent	50.50	2.36
2	Good	1376.78	64.56
3	Moderate	599.14	28.09
4	Poor	90.67	4.25
5	Very Poor	15.32	0.71

Runoff potential in the basin

To assess the probability of runoff, a probability analysis was conducted using runoff data spanning the past 40 years (1981-2020) shows the runoff calculated at a 75 % confidence level was found to be 152.97 MCM, and the weightage average runoff depth was found to 0.072 m. The total weighted runoff generated in the Aji River basin was found to be 514.07 MCM, as shown in (Table9).

Table 9. Weighted runoff in the Aji River basin

Sr. No.	Location	Runoff (m)	Area (km ²)
1	Rajkot	0.2685	664.97
2	Gondal	0.2271	104.93
3	Dhrol	0.2726	244.79
4	Paddhari	0.2402	527.84
5	Lodhika	0.1928	213.67
6	Jodia	0.2208	225.33
7	Mitana	0.1802	150.89
Weighted Runoff of Aji River basin = 514.07 MCM			

In the present investigation, we determine the rainfall-runoff potential of the Aji River Basin and demarcate the potential groundwater recharge zones using remote sensing and GIS. Many researchers used the integration of MCDA, AHP, RS, and GIS to demarcate potential groundwater recharge zones and storage structures [20, 6, 21, 9]. A similar study was conducted by [6] of the Mand catchment of the Mahanadi River basin using RS and GIS and suggested groundwater potential zones with very low, low to medium, medium to high, and very high groundwater potential encompassing an area of 962.44 km², 2019.92 km², 969.19 km², and 1380.42 km², respectively. The present investigation showed five distinct zones based on groundwater recharge potential. 'Excellent' (50.50 km², 2.36 %), 'Good' (1376.78 km², 64.56 %), 'Moderate' (599.14 km², 28.09 %), 'Poor' (90.67 km², 4.25 %), and 'Very Poor' (15.32 km², 0.718 %). A similar study using RS, GIS, and MCDA showed four groundwater potential zones such as very- high (523.58 km²), high (798.22 km²), moderate (646.04 km²), and low (456.66 km²) were suggested. Based on these, suitable storage structures and area distributions such as check dams, percolation ponds, flood and furrows, and ditch and furrows were suggested [22].

Future studies should focus on the various hydrological models to forecast future surface-water abstraction scenarios within a complex river basin amidst climate change. Development of GIS-based hydrological models based on precipitation, evapotranspiration, land use, soil properties, and topography and groundwater level data of available and future climate data of the semi-arid and arid zones may help in suggesting a suitable location-specific climate-resilient cropping system based on the crop's water requirement and water availability in the groundwater for the next 30 years to ensure the livelihood security of farmers.

4. Conclusion

Combining Remote Sensing and GIS technologies has demonstrated a rapid and cost-efficient approach to groundwater prospecting and exploration. The Aji River basin exhibits a weighted average rainfall of 622.68 mm and a corresponding runoff of 241.07 mm. The calculated weighted runoff volume for the basin is 514.07 million cubic meters (MCM). A significant portion of the area is favorable to groundwater recharge. Specifically, the Excellent groundwater recharge potential zone covers 50.50 km² (2.36%), the good zone spans 1376.780 km² (64.56%), and the Moderate zone comprises 599.14 km² (28.09%). Areas with poor and very poor groundwater recharge potential are 90.67 km² (4.25%) and 15.32 km² (0.718%), respectively (Table 8). The estimated runoff in the basin is 152.97 MCM at a 75% probability of exceedance. Therefore, this area may be used to harness the groundwater potential.

References

1. United Nations. Department of International Economics, United Nations. Department for Economic & Policy Analysis. (2001). World population prospects (Vol. 2). United Nations, Department of International, Economic and Social Affairs.
2. Paramesh, V., Kumar, P., Shamim, M., Ravisankar, N., Arunachalam, V., Nath & Kashyap, P. (2022). Integrated farming systems as an adaptation strategy to climate change: Case studies from diverse agro-climatic zones of India. *Sustainability*, 14(18), 11629. [10.3390/s141811629](https://doi.org/10.3390/s141811629).
3. Ahamad, F., Tyagi, S. K., Singh, M., & Sharma, A. K. (2023). Groundwater in Arid and Semi-arid Regions of India: A Review on the Quality, Management and Challenges (pp. 11-52). https://doi.org/10.1007/978-3-031-43348-1_2
4. Dangar, S., Asoka, A., & Mishra, V. (2021). Causes and implications of groundwater depletion in India: A review. *Journal of Hydrology*, 596, 126103. <https://doi.org/10.1016/j.jhydrol.2021.126103>
5. Berghuijs, W.R., Collenteur, R.A., Jasechko, S. et al. Groundwater recharge is sensitive to changing long-term aridity. *Nat. Clim. Chang.* (2024). <https://doi.org/10.1038/s41558-024-01953-z>
6. Baghel, S., Tripathi, M. P., Khalkho, D., Al-Ansari, N., Kumar, A., & Elbeltagi, A. (2023). Delineation of suitable sites for groundwater recharge based on groundwater potential with RS, GIS, and AHP approach for Mand catchment of Mahanadi Basin. *Scientific Reports*, 13(1), 9860. <https://doi.org/10.1038/s41598-023-36897-5>
7. Chandio, I. A., Matori, A. N. B., WanYusof, K. B., Talpur, M. A. H., Balogun, A.-L., & Lawal, D. U. (2013). GIS-based analytic hierarchy process as a multicriteria decision analysis instrument: a review. *Arabian Journal of Geosciences*, 6(8), 3059-3066. <https://doi.org/10.1007/s12517-012-0568-8>
8. Pande, C. B., Moharir, K. N., Singh, S. K., & Varade, A. M. (2020). An integrated approach to delineate the groundwater potential zones in Devdari watershed area of Akola district, Maharashtra, Central India. *Environment, Development and Sustainability*, 22(5), 4867-4887. <https://doi.org/10.1007/s10668-019-00409-1>
9. Rani, M., Joshi, H., Kumar, K., Pande, A., & Rawat, D. S. (2019). Development of recharge and conservation site suitability model for groundwater retrieval and evaluation of artificial recharge potential in a complex hydro-geological spring-fed river basin. *Arabian Journal of Geosciences*, 12(18), 589. <https://doi.org/10.1007/s12517-019-4784-3>
10. Rajasekhar, M., Gadhiraaju, S. R., Kadam, A., & Bhagat, V. (2020). Identification of groundwater recharge-based potential rainwater harvesting sites for sustainable development of a semiarid region of southern India using geospatial, AHP, and SCS-CN approach. *Arabian Journal of Geosciences*, 13(1), 24. <https://doi.org/10.1007/s12517-019-4996-6>
11. Saha, A., Ghosh, M., & Chandra Pal, S. (2021). Identifying Suitable Sites for Rainwater Harvesting Structures Using Runoff Model (SCS-CN), Remote Sensing and GIS Techniques in Upper Kangsabati Watershed, West Bengal, India (pp. 119-150). https://doi.org/10.1007/978-3-030-62397-5_7

12. Anonymous. (2021). Topographic and Bathymetric Survey of Reservoirs for Water Resources Department, Govt. of Gujarat at Saurashtra Region, Gujarat - Narmada Water Resources, Water Supply and Kalpsar Department Aji-1 Reservoir Available at https://nhp.mowr.gov.in/docs/NHP/Sedimentation%20Studies/Report/1062/P34320_WRD%20Survey%20report_Aji%201_Rev%204%20with%20annexures.pdf, accessed
13. Vithlani, N. S. and Rank, H. D. (2018). An assessment of water balances for Aji Basin using SWAT model. *Green Farming*, 9(4): 726-730.
14. Arulbalaji, P., Padmalal, D., & Sreelash, K. (2019). GIS and AHP Techniques Based Delineation of Groundwater Potential Zones: a case study from Southern Western Ghats, India. *Scientific Reports*, 9(1), 2082. <https://doi.org/10.1038/s41598-019-38567-x>
15. Horton, R. Drainage Basin Characteristics. *American Geophysical Union Trans.* 1932; 13: 350-361.
16. Greenbaum, D. (1985). Review of remote sensing applications to groundwater exploration in basement and regolith. *British Geological Survey Report*, OD-85, (8): 36.
17. Saaty, T. L. (1980). *The analytic hierarchy process* mcgraw hill, new york. *Agricultural Economics Review*, 70(804), 10-21236.
18. Malczewski, J. (1999). *GIS and multicriteria decision analysis*. John Wiley & Sons.
19. Raghunath, H. M., (2006). *Hydrology: principles, analysis and design*. Revised 2nd ed. New Delhi, New Age International. PP: 108.
20. Achu, A. L., Thomas, J., & Raghunath, R. (2020). Multi-criteria decision analysis for delineation of groundwater potential zones in a tropical river basin using remote sensing, GIS and analytical hierarchy process (AHP). *Groundwater for Sustainable Development*, 10, 100365. <https://doi.org/10.1016/j.gsd.2020.100365>
21. Bera, A., Mukhopadhyay, B. P., & Barua, S. (2020). Delineation of groundwater potential zones in Karha river basin, Maharashtra, India, using AHP and geospatial techniques. *Arabian Journal of Geosciences*, 13(15), 693. <https://doi.org/10.1007/s12517-020-05702-2>
22. Anand, B., Karunanidhi, D., & Subramani, T. (2021). Promoting artificial recharge to enhance groundwater potential in the lower Bhavani River basin of South India using geospatial techniques. *Environmental Science and Pollution Research*, 28(15), 18437-18456. <https://doi.org/10.1007/s11356-020-09019-1>
23. *Handbook of Hydrology* (1972). Soil Conservation Department, Ministry of Agriculture, New Delhi.
24. Farhat, B., Souissi, D., Mahfoudhi, R. et al. GIS-based multi-criteria decision-making techniques and analytical hierarchical process for delineation of groundwater potential. *Environ Monit Assess* 195, 285 (2023). <https://doi.org/10.1007/s10661-022-10845-8>
25. Akhtar, S., & Rampurawala, A. (2024). Integrating Remote Sensing Data and MODFLOW Modeling for Sustainable Groundwater Resource Management and Monitoring in the Guinea Region, West Africa. *Journal of Geography, Environment and Earth Science International*, 28(1), 50-64.

Comparative study of ZnO, TiO₂, and WO₃ nanocatalysts for degradation of aqueous nitrobenzene solution under sunlight

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Abstract

Worldwide removal of organic pollutants from water is a burning issue. The usage of semiconducting oxide-based nanocatalysts resolves this problem to a large extent. The physicochemical properties of nanocrystalline ZnO, TiO₂, and WO₃ synthesized by soft chemical routes have been investigated by powder X-ray diffraction, scanning/transmission electron microscopy, BET surface area analysis, thermo-gravimetry/ differential thermal analysis and UV-Vis- diffuse reflection spectroscopy. The photocatalytic degradation of aqueous nitrobenzene solution using nano-crystalline ZnO, TiO₂, and WO₃ under sunlight has been investigated. It is revealed that in 4 h reaction time, the degradation of nitrobenzene using ZnO, TiO₂, and WO₃ is 43%, 27%, and 13% respectively in the presence of sunlight irradiation.

Keywords Semiconducting oxide, Nanomaterial, photocatalyst, degradation, sunlight

1. Introduction

Environment pollution is increasing with every passing year and causing irreversible repercussions and serious damage to our planet. There are four kinds of environmental pollution specifically, air, soil (land), noise, and water. Pollution in water is a result of industrial waste products set free into lakes, rivers, and other water resources, which has made ocean life no longer gracious. Human beings pollute water with wide-ranging get rid of waste material, blossoms, embers, and other household goods. In many rural areas, one can still find people bathing and cooking in the same water, making it exceptionally dirty. Acidic rain also multiplies water pollution. Additionally, thermal enrichment and the depletion of dissolved oxygen aggravate the already worsened condition of the water bodies. Water pollution can also indirectly happen as an offshoot of land pollution by surface runoff and leaching to pore water.

The International Agency for Research on Cancer (IARC) has categorized nitrobenzene (NB) as a Group 2B extremely harmful human carcinogen. Industries producing aniline use 96 % of NB as an intermediate are liberating this cancer-causing chemical into the atmosphere. In addition, in the atmosphere, it may be present due to the nitration of the usual air pollutant benzene. According to the U.S. OSHA (Occupational Safety and Health Administration), an acceptable threshold limit of NB is 5 mg/cm³ of air [1]. While U.S. EPA (Environmental Protection Agency) suggests the maximum allowed limit of NB in streams and lakes to be 17 parts per million (ppm) to stave off possible health issues from potable or consuming fish polluted with NB. However, in wastewater release from the chemical industries, this limit is beyond 100 ppm. Consequently, degradation of nitro-aromatic compounds, particularly nitrobenzene is of specific attention. Besides, it can easily absorb from the skin and cause severe damage to human organs such as eyes, lungs, kidneys, and liver and increases heart bit rate if exposed for a longer time. Even a tiny amount of NB can result in weakness, dizziness, internal bleeding, headache, vomiting, and so forth. Annually,

the production industries of plastics, dyes, insecticides, herbicides, and pharmaceuticals release 9500 tons of NB into the environment [2].

Innumerable types of photocatalysts including sulfide- nitride-or oxide-based semiconductors, graphene oxide-based materials, conducting polymers, composites, metal-organic frameworks, layered materials (layered double hydroxide, perovskites, etc) have cropped up after the discovery of splitting of water by titania (TiO_2) electrodes in 1972 for the first time by Fujishima and Honda [3]. Since then in the last five decades (1972 -1924) a huge number of research and review articles have been available on the photocatalytic activity of nanocrystalline TiO_2 and ZnO . A few very recent reviews and research reports can be found in [4-7 and references there in]. For the degradation of organic pollutants from the water, different irradiation sources [1] and different experimental methods have been employed [1,8]. Nanoparticles of TiO_2 with a large band gap (rutile phase, 3 eV, anatase phase, 3.2 eV) can only be activated by UV light which accounts for less than 5 % of the solar spectrum. Similarly, ZnO consists of a broadband gap of 3.4 eV which limits its activity within the UV region ($\lambda < 0.4 \text{ m}$). Not long ago, tungsten trioxide (WO_3) and its composites captivated acceptance owing to its excellent properties such as its non-toxic nature, economical and steadiness in acidic and oxidative conditions, and specifically its smaller energy band gap of 2.8 eV[9]. WO_3 seems a promising photocatalyston account of large visible light absorption ($\lambda = 0.4 \text{ }\mu\text{m}$ to $0.8 \text{ }\mu\text{m}$) which accounts for 45 % of the solar spectrum. However, a smaller effective surface area and relatively low energy density values limit the application of pure WO_3 . In literature, very scanty information is available on the photocatalytic performance of WO_3 [9-13]. Thus, in the present work, direct sunlight has been used as a common, natural, and cost-free source of irradiation of nanocatalysts.

The global market of solid catalysts in 2022 was exhibited at 36.8 billion USD. In the next decade, it is expected to reach about 59.7 billion USD and grow swiftly. In addition, it is approximated that more than 20 % of the total national product of industrial countries bank somehow or another on catalysis.

In this communication, a comparative study of photocatalytic activity of nanocrystalline ZnO , TiO_2 , and WO_3 synthesized by wet-chemical routes has been carried outfor the degradation of aqueous nitrobenzene solution in the presence of enhanced sunlight. Due to the difference in energy band gap value, and particle and pore morphology of nanocatalysts, different degrees of photocatalytic performance are expected.

2. Experimental details

TiO_2 nanoparticle was synthesized by sol-gel method [14]. 120 mL of isopropanol and 25.2 mL of titanium tetra-isopropoxidewere added in a 500-mL round-bottom flask. Subsequently, a mixture of isopropyl alcohol (90 mL), water (90 mL), and 1 mL of nitric acid was added dropwise to the above mixture under vigorous stirring. The resultant reaction mixture was kept stirring for 2 h followed by aging at room temperature for 24 h. The solvent from the reaction mixture was evaporated using a rotatory evaporator. The catalysts were thoroughly washed with isopropanol and water, then dried at 353 K for 12 h and finally calcined at 773 K for 2 h under an air atmosphere with a ramp rate of $2^\circ\text{C}/\text{min}$.

0.3 moles of zinc nitrate hexahydrate ($\text{Zn}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$) was dissolved in 60 ml of water at 300 K, under continuous magnetic stirring (sol A). In a separate beaker already having 2.97 gm of polyethylene glycol was dissolved in 20 ml water and 0.6 mole of cyclohexylamine (CHA) (sol B). The (sol B) was poured into the zinc solution (sol A), resulting in a white precipitate upon magnetic stirring. An additional quantity of 80 ml water was added to the reaction mixture, which

was left stirring for 96 h. The precipitate was centrifuged and then washed with water. The precipitate was dehydrated at 300 K under vacuum for 24 h [15]. This dried sample was then calcined at 773 K under air for 3 h. The temperature was ramped from 300 K to the target temperature with a heating rate of 5°C/min.

In an ice bath, 30 mL of 0.1M Na₂WO₄ was cooled to < 4 °C for 10 min. Then, 4 mL of 3.0 M hydrochloric acid was added dropwise into the Na₂WO₄ solution with constant magnetic stirring for 1 h to form a white gel. The precipitates were washed with distilled water until the supernatant reached a pH of 4 [16]. The washed precipitates were dispersed in 20 mL of water and the mixture contained in RB was heated to 398 K for 24 h. After cooling to 300 K, the mixture was centrifuged to recover the precipitates. After drying at 353 K for 6 h, the product was annealed at 773 K in air for 3 h. The temperature was ramped to the target temperature by keeping the heating rate at 5°C/min.

PXRD analysis of all synthesized catalysts was done with a Rigaku Miniflex II system using Cu K α radiation. The operating voltage and current were 40 kV and 30 mA, respectively. The diffraction patterns were recorded in the 2 θ range of 10-90° with step size and step time of 0.033° and 1 s was used for data collection of synthesized catalysts. Thermo-Gravimetric Analysis (TGA) and Differential Thermal Analysis (DTA) profiles of ZnO were obtained on Mettler Toledo Star System® (Switzerland) in the temperature range of 50-800°C with a heating rate of 10°C min⁻¹ under N₂ flow. The data analysis was carried out with the NETZSCH Proteus® software. BET surface area, pore volume, and pore diameter were calculated from N₂ sorption isotherms at 77 K by ASAP 2010, Micromeritics (USA). Before the analysis, the catalysts were in-situ activated to desorb the moisture (if any physisorbed moisture is present) under vacuum (1×10⁻³ mmHg) at 393 K for 4 h. Surface area and pore size were calculated by BET (Brunauer-Emmett-Teller) equation and BJH (Barrett-Joyner-Halenda) method, respectively. FE-SEM images were obtained using a JEOL JSM 7100F scanning electron microscope (USA) after dispersing the catalyst in acetone by sonication and deposited on a grid. Transmission electron microscopy (TEM) and high-resolution TEM (HR-TEM) images of the catalysts were obtained with a JEOL JEM 2100 transmission electron microscope (USA) by dispersing the sample in Acetone by sonication, and then allowing a drop of the suspension to evaporate on a lacy carbon film supported on a 300-mesh copper TEM grid. The band gap energy of all calcined catalysts was determined from UV-Vis-DRS using Shimadzu UV-2550 (Japan), a UV-visible spectrophotometer equipped with an integrating sphere, and BaSO₄ was used as a reference sample. The spectra were recorded at room temperature in the wavelength range of 250-800 nm. The band gap energy was determined using UV-Vis-DRS and calculated according to the following equation: Band gap energy (E_g) = hc/λ , where E_g is the band gap energy (eV), h is the Planck's constant (4.1357×10^{-15} eV s), c is the light velocity (2.998×10^8 m/s), and λ is the wavelength (nm).

The photocatalytic activity of synthesized nanocatalysts was evaluated by computing the decrease in the concentration of nitrobenzene under direct sunlight irradiation in February 2024 in a photocatalytic reactor. Before sunlight irradiation, 10 mg of catalyst and 100 mL of aqueous solution of nitrobenzene (10 ppm) were taken in a round-bottom flask, ultrasonicated for 2 min, and continuously stirred in the dark for 30 min. To determine the adsorption capacity of the catalyst, a 5 mL sample was withdrawn by a syringe for absorbance analysis. Subsequently, the reaction mixture was kept under direct sunlight. The reaction mixture was continuously stirred, and the samples were withdrawn in regular time intervals (1- 4 h) of photocatalytic degradation reactions. Before analysis, the catalyst was separated by centrifugation. The concentration of nitrobenzene was determined using a calibration curve of nitrobenzene.

3. Results and discussion

Figure 1 displays the powder X-ray diffraction (PXRD) profiles of uncalcined and calcined bare TiO_2 , WO_3 , and ZnO catalysts. The results revealed that uncalcined TiO_2 and ZnO displayed an amorphous nature, whereas the WO_3 catalyst showed a crystalline nature. Besides, the same catalysts calcined at 773 K exhibited crystallinity having predominately their respective crystalline phases which were well matched with JCPDS standard file (00-021-1272 for TiO_2 , 83-0950 for WO_3 and 80-0074 for ZnO) [14-16]. From the PXRD peaks of calcined bare TiO_2 at 2θ values of 25.2° , 35.9° , 41.2° , 54.4° , 56.6° and 69.0° are indexed to planes of anatase phase. Besides this, another peak at 27.3° was also found which was attributed to the formation of the rutile crystalline phase. In general, the formation of the phases of TiO_2 depends significantly on the synthesis parameters.

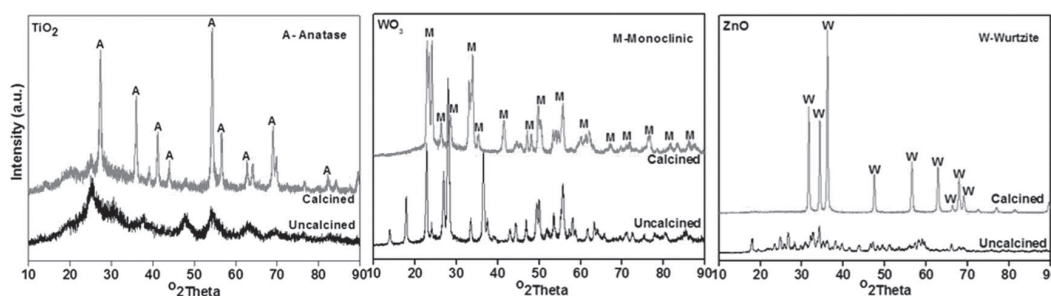


Figure 1. PXRD profiles registered at 300 K for uncalcined and calcined TiO_2 , WO_3 , and ZnO catalysts.

The crystalline phases of WO_3 displayed peaks at 23.3° , 24.1° , 26.3° , 28.5° , 33.0° , 33.9° , 41.2° , 48.0° , 49.7° , 50.3° , 55.7° and 62.13° which are corresponding to monoclinic type crystal structure. The diffraction peaks of ZnO showed a wurtzite structure. The observed broadness of diffraction lines and the background noise in diffraction patterns of all the samples are attributed to the nanocrystalline nature of particles because there is an inadequate number of crystallographic planes to result in sharp diffraction peaks.

Typical TGA-DTA plots for a ZnO catalyst are shown in figure 2. Thermal analysis showed the total weight loss in the range of $\sim 10\%$. DTA curves of the catalyst exhibited one peak at around 250°C (523 K) that may be attributed to the releasing of physisorbed water and structural water in the bulk of the lattice molecules and the formation of crystalline ZnO . TGA-DTA curves recorded for TiO_2 and WO_3 nanoparticles demonstrate almost identical characteristics (not shown).

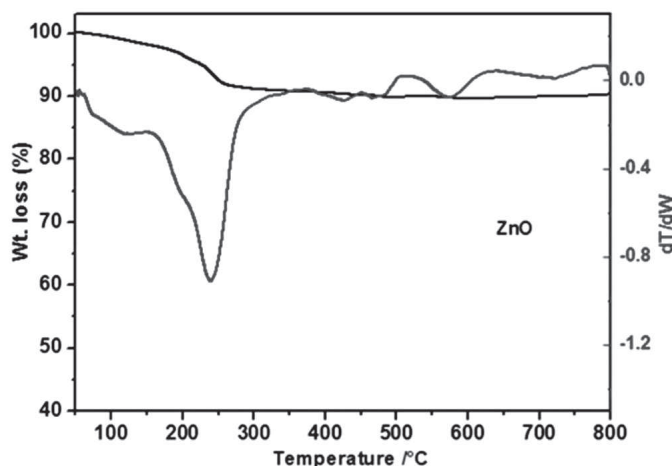


Figure 2. TGA-DTA profiles of ZnO catalyst.

The N_2 adsorption-desorption studies of synthesized catalysts are given in figure 3. The BET surface area of photocatalysts follows the order of TiO_2 ($21.8 \text{ m}^2/\text{g}$) > ZnO ($10.8 \text{ m}^2/\text{g}$) > WO_3 ($9.2 \text{ m}^2/\text{g}$). However, the catalysts have an average pore diameter of 71.6 nm, 34.2 nm, and 9.0 nm for ZnO , WO_3 , and TiO_2 , respectively. While nanoparticles of TiO_2 show type IV isotherm ZnO and WO_3 nanoparticulates exhibit type III isotherm. This suggests that TiO_2 nanoparticles possess distinct surface area and pore morphology as compared to WO_3 and ZnO nanoparticles.

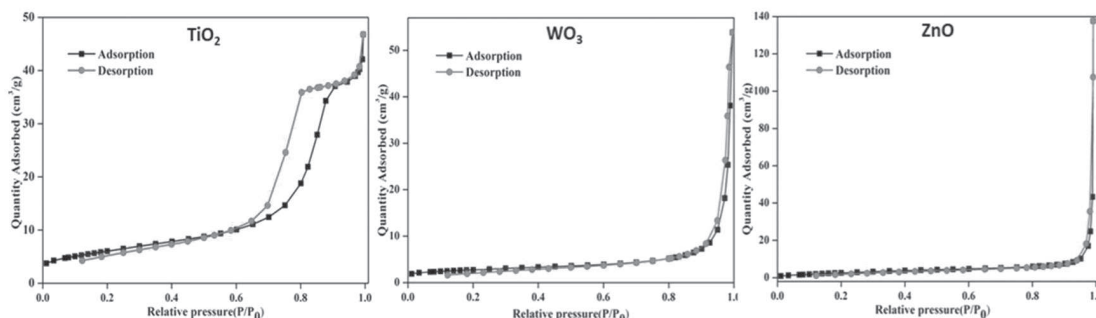


Figure 3. N_2 adsorption-desorption isotherm of TiO_2 , WO_3 , and ZnO at 77 K.

SEM images of all three calcined catalysts showed agglomerated spherical-shaped particles (Fig. 4). The particle size of TiO_2 was small as compared to WO_3 and ZnO having almost the same particle size. We have also found some hexagonal shape morphology in the ZnO sample which was similar to earlier reported in the literature [17].

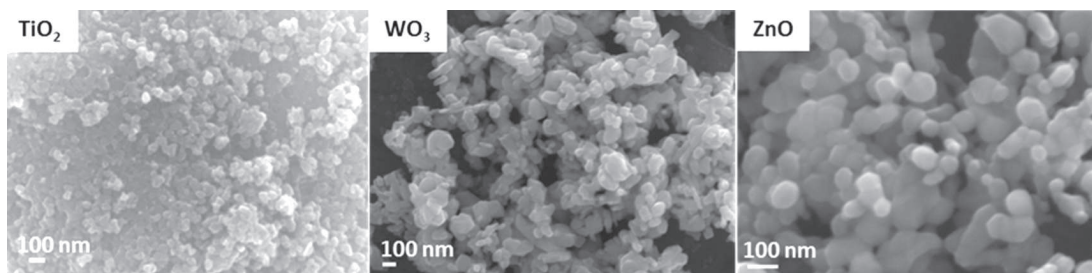


Figure 4. SEM images of calcined TiO_2 , WO_3 , and ZnO catalysts.

A TEM micrograph of calcined WO_3 catalyst (Fig. 5a) showed the aggregates of particles varying in different crystal sizes which was also confirmed by the SEM image. The high-resolution TEM image (Fig. 5b) exhibited the lattice fringes, the width between two fringes, confirmed the synthesized WO_3 catalyst possesses a highly crystalline nature.

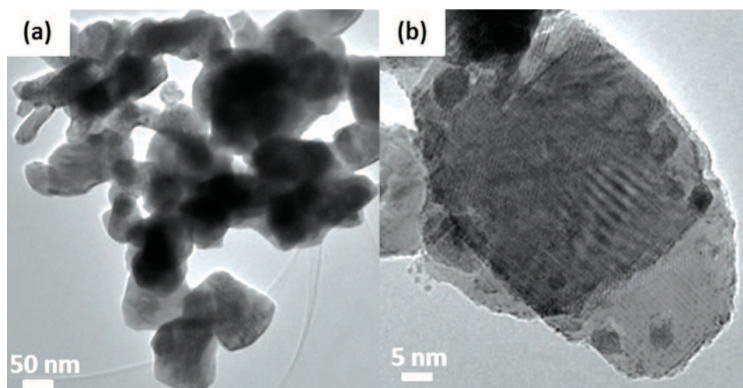


Figure 5(a) TEM and (b) HR-TEM images of calcined WO_3 catalyst.

The TEM image of the calcined ZnO catalyst was found to have distorted hexagonal shape particles (Fig. 6a), which is consistent with the regular polyhedral morphology observed in the SEM image (Fig. 4, ZnO). The high-resolution TEM image (Fig. 6b) exhibited the lattice fringes due to the highly crystalline nature of ZnO as shown by PXRD.

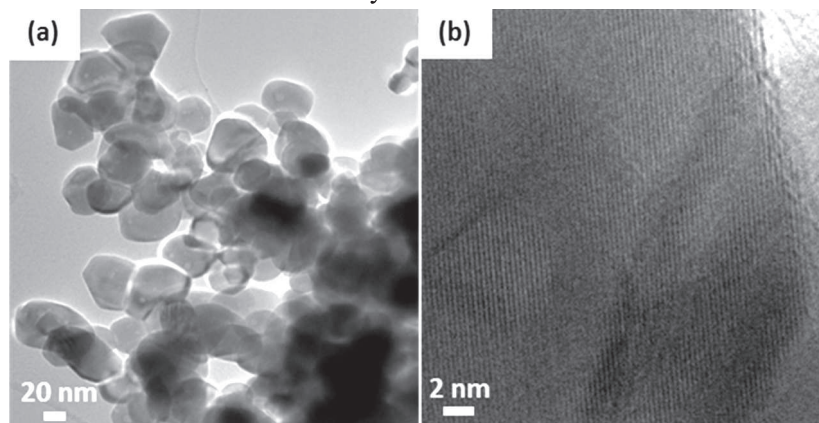


Figure 6(a) TEM and (b) HR-TEM images of calcined ZnO catalyst.

The bandgap of the synthesized photocatalytic materials was determined using UV-visible diffuse reflectance spectroscopy. The UV-vis diffuse reflectance spectra of the synthesized TiO_2 , WO_3 , and ZnO catalysts are shown in figures 7-9 respectively. The corresponding band-edge and band gap of catalysts were estimated and included in Table 1. It was found that the lowest band gap (2.79 eV) was attributed to the WO_3 catalyst as compared to the TiO_2 (3.03 eV) and ZnO (3.18 eV).

Table 1 Band edge, band gap energy, and corresponding species of TiO_2 , WO_3 , and ZnO catalysts.

Catalyst	Band edge (nm)	Band gap (eV)	Species	Color of the sample
TiO_2	409	3.03	Rutile	White
WO_3	444	2.79	Monoclinic	Pale yellow
ZnO	386	3.18	Wurtzite	White

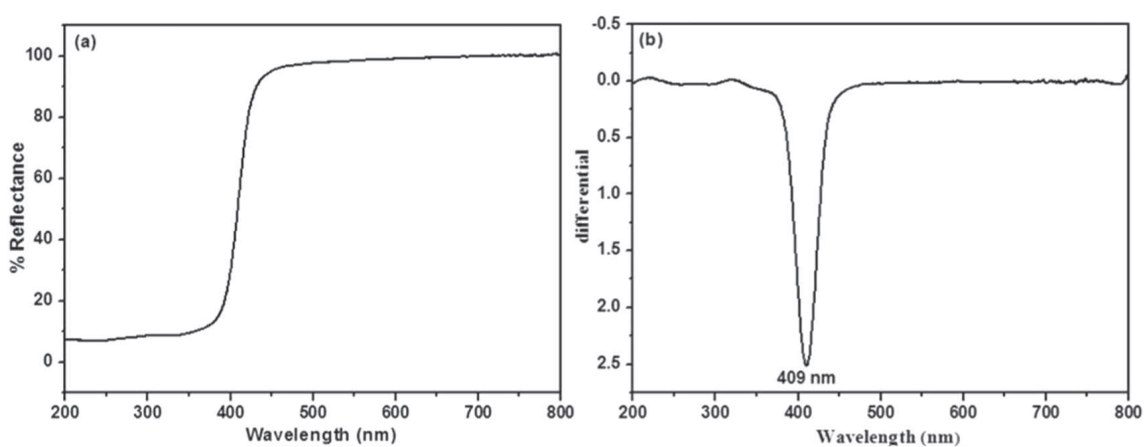


Figure 7. (a) UV-DRS and (b) differential spectra of calcined TiO_2 catalyst.

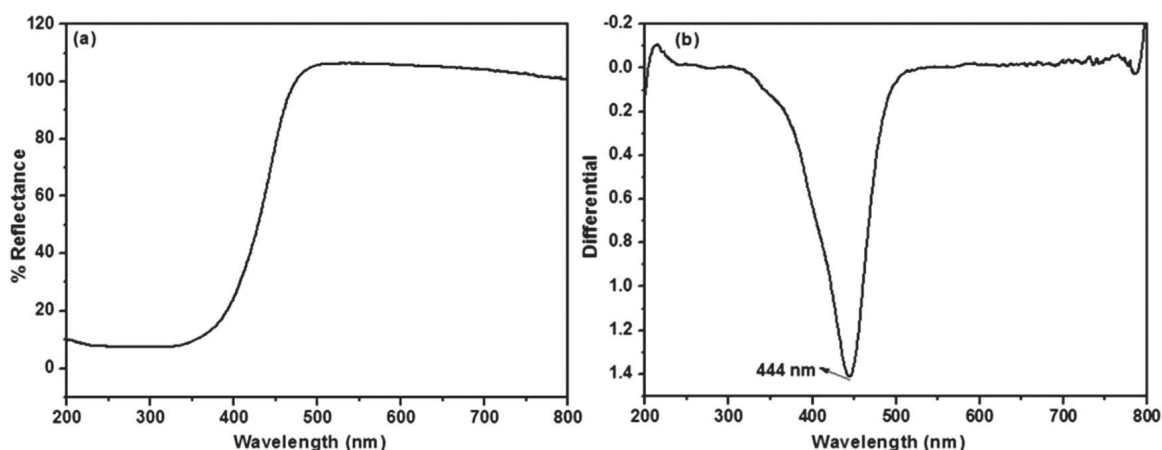


Figure 8. (a)UV-DRS and (b) differential spectra of calcined WO₃ catalyst.

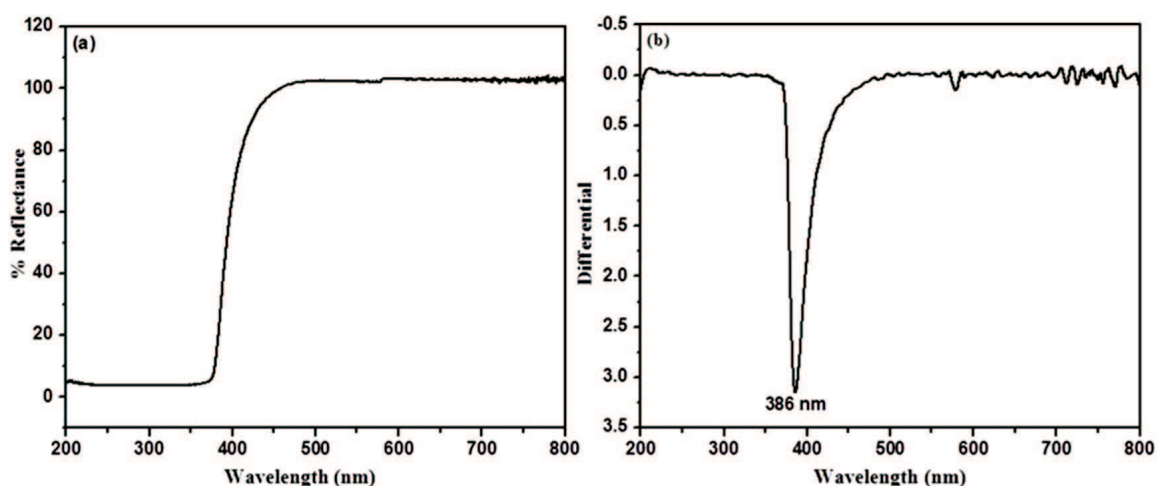


Figure 9. (a)UV-DRS and (b) differential spectra of calcined ZnO catalyst.

The photocatalytic activity of synthesized catalysts was evaluated by degradation of aqueous solution of nitrobenzene under direct sunlight irradiation. The photocatalytic reaction was carried out under the following two conditions: (i) stirring of nitrobenzene with TiO₂, WO₃, and ZnO photocatalyst separately in the dark to measure the adsorption of nitrobenzene molecules and (ii) irradiation of nitrobenzene in the presence of synthesized catalysts under direct sunlight. These nanomaterials are exhibited to be efficient by making use of sunlight energy to produce electron/hole (e⁻ / h⁺) pairs on the surface of the photocatalyst. These pairs can be used for the oxidation and reduction process which in turn give rise to a generation of reactive oxygen species (ROS), like [•]OH and O₂^{•-}. The radicals thus formed then aid in the decomposition of contaminants. The photo-induced formation of electron-hole pair in semiconductors, TiO₂, ZnO, and WO₃ nanoparticles is illustrated in figure 10.

The results revealed that in the first case 2.3 %, 21 %, and 9.2 % of nitrobenzene was adsorbed on the surface of TiO₂, ZnO, and WO₃ photocatalyst, respectively. This indicates that the adsorption of nitrobenzene was higher in the case of ZnO as compared to TiO₂ and WO₃ catalysts. Absorbance versus wavelength plots for the photocatalytic activity of TiO₂, WO₃, and ZnO catalysts are shown in figure 11.

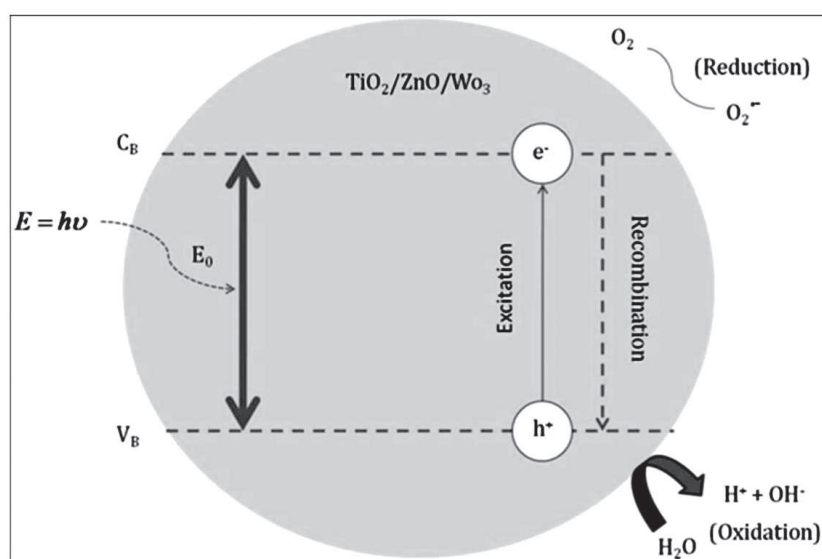


Figure 10. General scheme for methods of photodegradation of organic compounds.

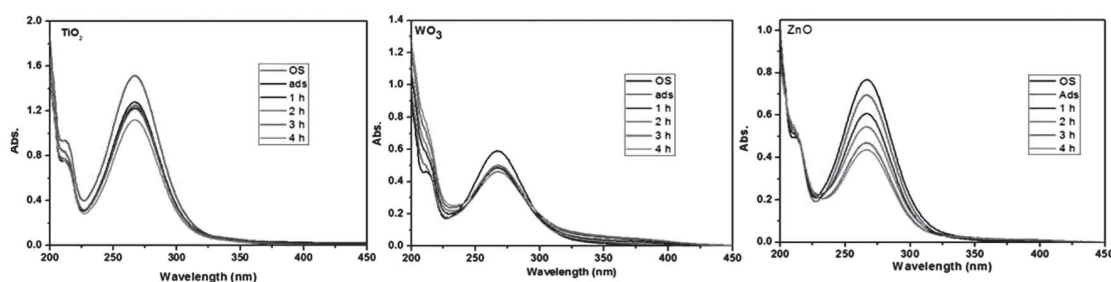


Figure 11. Absorbance versus wavelength for the photocatalytic activity of TiO_2 , WO_3 , and ZnO nano-catalysts.

In the second protocol, nitrobenzene degradation, irrespective of catalysts used, was increased with increasing the reaction time from 1 to 4 h (Fig. 12). The degradation of nitrobenzene was significantly higher with ZnO catalyst. It was found that the degradation rate of nitrobenzene was $\text{ZnO} > \text{WO}_3 > \text{TiO}_2$. The experimental study showed that in 4 h reaction time, the degradation using TiO_2 , WO_3 , and ZnO was 13 %, 27 %, and 43 % respectively. This may be due to the higher adsorption of nitrobenzene on the surface of ZnO catalysts as discussed above. A little while back, Wang et al. [18] demonstrated that diffusion of antimicrobials increases in materials having large average pore sizes. On the same line of arrangement, for the ZnO catalyst with the highest value of average pore diameter (71.6 nm) maximum amount of nitrobenzene gets absorbed into the surface, and thus the maximum degradation rate is found. Though ZnO has an effective surface area which is half of the effective surface area of TiO_2 , ZnO has shown a maximum rate of degradation. This leads to the conclusion that along with specific surface area (or reduced particle size) adsorption of pollutants onto and absorption of pollutant into the catalytic surface play a significant role in governing photocatalytic activity. Concerning the chemical reactivity of nanoparticles, nanoparticles with irregular shapes have extra kinks and edges as compared to particles having flat-smooth surfaces. These local sites generally own reactivity that is greatly dissimilar from those of the terraces. Reactive atoms are trapped on these stepped surfaces. This is also a possible cause of better performance of ZnO nanocrystals.

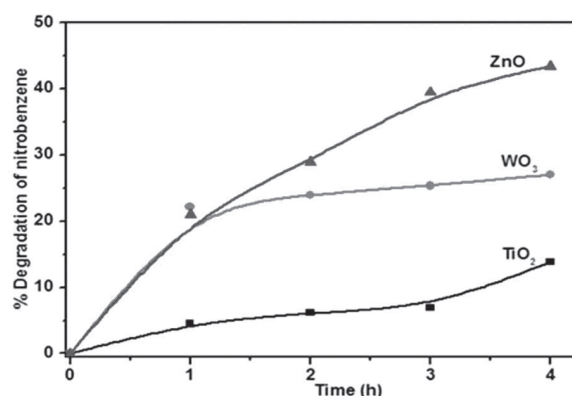


Figure 12. Percentage degradation of nitrobenzene under direct sunlight irradiation using synthesized TiO₂, WO₃, and ZnO nanocatalysts.

4. Conclusion

TiO₂, ZnO, and WO₃ photocatalysts were synthesized by wet-chemical routes. The nanocrystalline nature was confirmed by powder X-ray diffraction profiles, transmission electron microscopy, and BET surface area analysis. In the presence of direct sunlight, the highest photocatalytic activity of degradation of nitrobenzene demonstrated by ZnO nanoparticles is mainly due to nitrobenzene absorption into and adsorption onto the surface of the catalyst as well as the highly reactive surface of distorted hexagonal-shaped nanoparticles.

References

1. R.J. Tayde, R.G. Kulkarni and R.V. Jasra, Ind. Engg. Chem. Res. 45 (2006) 922.
2. B.E. Haigler and J.C. Spain, Appl. Environ. Microbial. 57 (1991) 3156.
3. A. Fujishima, and K. Honda, Nature 238 (1972) 37.
4. R. Ghamparpoor, A. Fallah, and M. Jamshidi, ACS Omega 9(24) (2024) 25457.
5. M.J. Kadhim, M. A. Mahdi, A.M. Selman, S. Kaj, Al-Ani, J.J. Hassan, M.A. Ahmed, Iran. J. Catal. 13(1) (2023).
6. K. Tanji, T. El Mrabet, Y. Fahoul, I. Jellal, M. Benjelloun, M. Belghiti, M. El Hajam, Y. Naciri, A. EL. Gaidoumi, B.El.Bali, H. Zaitan, and A.Kherbeche J. Water. Proc. Engg. 53 (2023) 103682.
7. W. Al Zoubi, A.A.S. Al-Hamdani, B. Sunghun, and Y.G. Ko, Rev. Inorg. Chem. 41(4) (2021) 213.
8. R.J. Tayade and D.L. Dey, Mater. Sci. Forum. 657 (2010) 62.
9. O. Samuel, M.H.D. Othman, R. Kamaludin, O. Sinsamphanh, H. Abdullah, M.H. Puteh, and T.A. Kurniawan, Ceram. Int. 48(5) (2022) 5845.
10. V. Duffa, S. Sharma, P. Raizada, V.K. Thakur, A.A.P. Khan, V. Saini, A.M. Asiri, and P. Singh, J. Environ. Chem. Engg. 9(1) (2021) 105018.
11. M. Farhadian, P. Sangpour, and G. Hosseinzadeh, J. Energy Chem. 24(2) (2015) 171.
12. I.M. Szilagy, B. Forizs, O. Rossler, A. Szegedi, P. Nemeth, P. Kiraly, G. Tarkanyi, B. Vajna, K.V. Josepovits, K. Laszlo, A.L. Toth, P. Baranyai and M. Laskela J. Catalysis 294 (2012) 119.

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13. P. Shandiya, S. Sambyal, R. Sharma, P. Mandayal and B.Fang J. Hazar. Mater. 428 (2022) 128218.
 14. T.S. Natarajan, K. Natarajan, H.C.Bajaj, and R. J. Tayade, J. Nanopart. Res. 15 (2013) 1669.
 15. A. Bagabas, A. Alshammari, M.F. Aboud, and H. Kosslick, Nanoscale Res. Lett. 8 (2013) 516.
 16. W. Sun, M.T. Yeung, A.T. Lech, C.-W.Lin, C. Lee, T. Li, X. Duan, J. Zhou, and R.B. Kaner, Nano Lett. 15 (2015) 4834.
 17. T.B. Ghosh, S. Dhabal, and A.K. Datta, J. Appl. Phys. 94 (2003) 4577.
 18. L. Wang, V. Fogliano and J. Heising and M. Dekker, Food Chem. 351 (2021) 129316.

Exploring the Role of Cow Dung in Modulating Soil Water Characteristics Across Varied Soil Types

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Abstract

Water scarcity is a critical worldwide problem that is worsened by causes such as increasing population, climate change, and unsustainable agriculture methods. The depletion of water resources in several areas presents a substantial risk to the security of food, the advancement of the economy, and the sustainability of the environment. To tackle water shortage, it is necessary to implement inventive solutions in several sectors, particularly agriculture since it is responsible for most water use worldwide. This study investigates the impact of cow dung amendment on soil water dynamics across twelve different soil types. The Relative Water Content (RWC), Gravimetric Water Content (GWC), field capacity (FC), and porosity were tested for different soil types at different levels of cow dung addition expressed as a percentage of the total weight (D1(0%), D2(5%), D3(10%), D4(15%), and D5(30%)). Results show significant variations in soil water characteristics among different soil types and dung concentrations. Higher levels of cow dung led to increased RWC, GWC, and porosity with notable shifts in FC. The findings provide insights into the complex interactions between soil properties and organic amendments, offering valuable implications for sustainable soil management practices and agricultural productivity optimization.

Keywords Soil water dynamics, Cow dung, Water retention, Soil Water Management

1. Introduction

The global water problem, worsened by issues such as excessive extraction, pollution, and climate change, poses substantial challenges to ecosystems, agriculture, and human well-being on a global scale[1]. An essential component of tackling the water problem entails investigating sustainable agriculture techniques that not only guarantee water security but also help reduce its effects[2]. Organic soil additives, such as cow dung, have garnered interest due to their ability to enhance soil moisture retention and decrease water use in agricultural activities therefore mitigating the challenges posed by water shortages[3]. Nonetheless, comprehending the complex correlation between the utilization of cow dung and the alleviation of water scarcity need a comprehensive knowledge to guide efficient soil management approaches. Organic soil additives show potential for improving soil moisture levels and reducing the consequences of the water crisis. The process of breaking down organic waste, such as cow dung, may influence the movement of water in the soil and the pace at which it is absorbed, which in turn affects the ability of the soil to retain water and the amount of water that runs off[4]. It is crucial to strike a delicate equilibrium between water consumption efficiency and the potential danger of nutrient leaching to maximize the effectiveness of water resource management[5]. As shown in figure 1 The soil texture triangle is a graphical tool used to classify soils based on their proportions of sand, silt, and clay. It helps in determining the soil texture category, such as loam, clay, or sandy loam, by plotting the percentages of these three components[6].

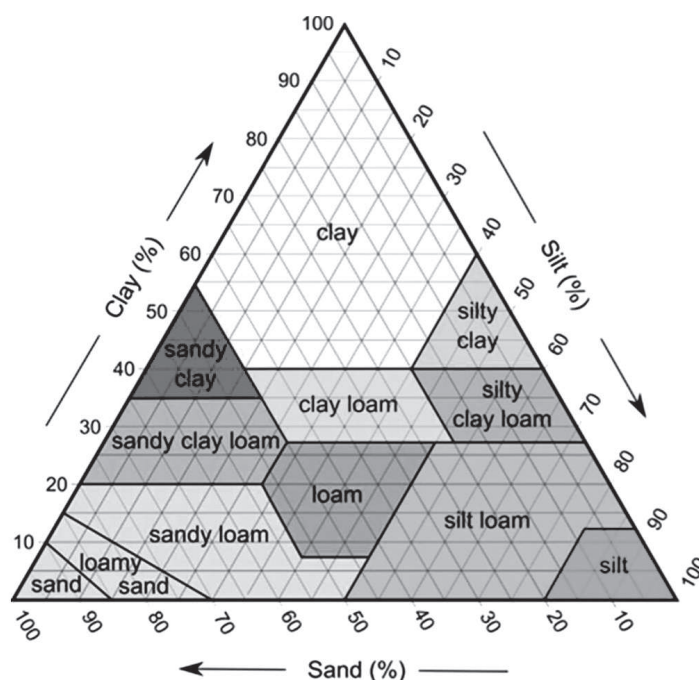


Figure 1. SOIL TEXTURE TRIANGLE.

In many regions, water scarcity is already a reality, leading to conflicts over water rights, compromised ecosystem health, and diminished access to safe drinking water[7]. Moreover, climate change exacerbates the water crisis by altering precipitation patterns, increasing the frequency and intensity of droughts, and melting glaciers, which serve as vital water sources for millions of people. As a significant user of freshwater resources, the agriculture sector has an essential effect on both increasing and alleviating the water problem[8]. Traditional agricultural methods, which include the excessive use of water, chemical substances, and the cultivation of a single crop, lead to the deterioration of soil quality, contamination of water sources, and the depletion of underground water reservoirs[9,10]. On the other hand, sustainable agricultural approaches, such as organic farming and agroecology, provide effective solutions for preserving water resources, promoting soil health, and increasing water usage efficiency[10].

2. Materials and Methods

Basic soil samples standing for clay, silt, and sand were collected from local sources from soil repositories. The soil samples were air-dried, sieved to remove debris, and homogenized to ensure uniformity. A wide variety of soil types were replicated by combining clay, silt, and sand in twelve distinct blends, each with its own unique proportions. Fresh cow dung was collected from local dairy farms and air-dried to remove excess moisture. The dried cow dung was finely ground and sieved to achieve a uniform particle size distribution. Cow dung was included into each soil mixture with varying percentages of 0%, 5%, 10%, 15%, and 30% by weight, and were designated as D1 to D5. Each soil blend with the respective cow dung treatments was thoroughly mixed in containers to ensure even distribution of the amendment. Multiple replicates were prepared for each treatment combination to account for variability. The containers (Figure 2) were placed in a controlled environment to simulate natural conditions and minimize external influences. Data analysis was conducted using appropriate statistical methods to determine significant differences in soil properties and SWI among treatments.

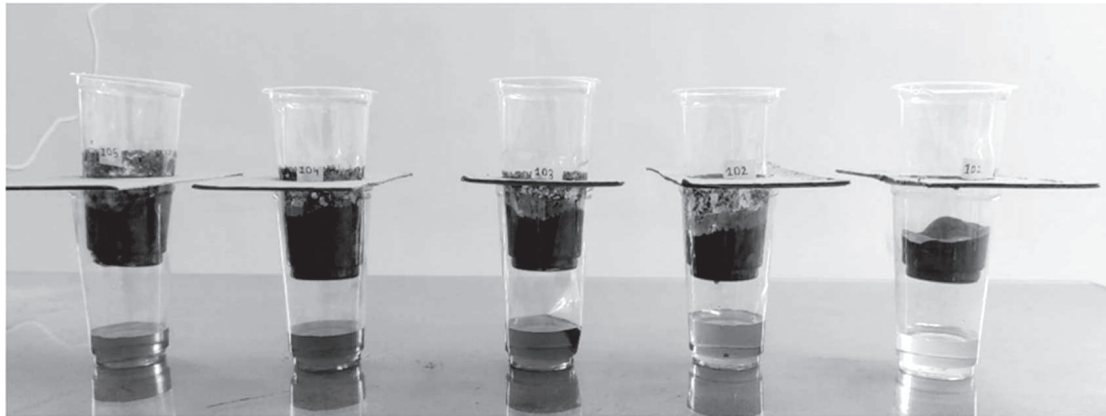


Figure2 Experimental setup for all soil texture added with cow dung (D1, D2, D3, D4, D5).

The parameters such as RWC, GWC, FC, and porosity, offering insights into soil water dynamics and structural integrity.

1. **RWC:** RWC is a measure of the amount of water present in the soil compared to its maximum water holding capacity

$$RWC = \frac{CWC}{WHC (max)}$$

Where, Current water content (CWC), and Water holding capacity (WHC)

2. **GWC:** GWC represents the ratio of the weight of water in the soil to the dry weight of the soil sample.

$$GWC = \frac{m_{wet} - m_{dry}}{m_{dry}}$$

Where, m_{wet} (Mass of the wet sample), and m_{dry} (Mass of the dry sample)

Field Capacity: FC is the maximum amount of water that soil can retain against the force of gravity after excess water has drained away. It represents the soil's ability to hold water for plant uptake.

$$FC = \frac{V_1 - V_2}{W} * BULK DENSITY$$

Where, V_1 = Initial water volume

V_2 = Residual water volume

W = Weight of soil

Porosity: Porosity is a measure of the voids within a soil sample. It indicates the soil's ability to hold water and air, which is crucial for root growth and nutrient exchange.

$$Porosity = \frac{GWC}{WHC * BULK DENSITY}$$

Understanding and monitoring soil parameters such as RWC, GWC, FC, and porosity is crucial for sustainable agriculture and environmental conservation. These parameters provide valuable insights into soil health, water dynamics, and structural integrity, ultimately influencing

crop productivity, ecosystem resilience, and water resource management. RWC indicates the immediate water availability for plant uptake and irrigation scheduling, while GWC quantifies soil moisture content, essential for nutrient availability and soil structure. FC determines the soil ability to retain water against gravity, guiding irrigation practices and groundwater recharge. Porosity, influences soil aeration, drainage, and root penetration, critical for plant growth and microbial activity.

3. Results and discussion

The RWC in soil is a crucial parameter that directly affects plant growth, soil health, and various environmental processes[11]. It refers to the amount of water present in the soil compared to its maximum water holding capacity. This metric provides valuable insights into soil moisture levels, which are essential for plant hydration and nutrient uptake[12].

As shown in Figure 3, the addition of cow dung generally enhances water retention. A significant impact was detected across all kinds of soil at the 10% cow dung concentration (D3). Particularly high-water-content soils, such as Sandy Clay Loam and Loam, indicate that 10% cow dung is optimal for improving water retention. compared to Clay, which regularly exhibits reduced water content, nonetheless derives advantages from the use of cow dung. Soils like Silt and Loamy Sand demonstrate substantial increases, especially at higher dung levels. The highest water retention is recorded in Loamy Sand at 5% cow dung, indicating its superior capacity for water absorption when augmented with organic matter. These findings underscore the potential of cow dung as an effective soil amendment for improving water-holding capacity, which is crucial for agricultural sustainability and productivity. The reality that different soil types have varying impacts shows how important it is to adjust cow dung treatments based on soil conditions for best outcomes. This study provides valuable insights into the role of organic amendments in soil water management, emphasizing that a 10% cow dung addition may serve as an optimal level for most soil types.

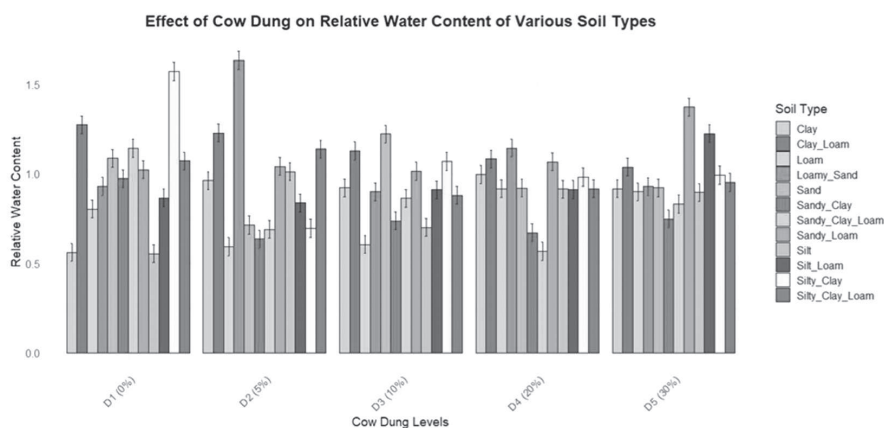


Figure. 3 RWC with different percentages of cow dung

Across the experiments (D1 to D5), there are variations in RWC for each soil type. For instance, in some experiments, certain soil types may show higher or lower water content values due to differences in irrigation regimes or precipitation patterns. Overall, the bar graph provides a clear visual representation of the RWC data, aiding in the understanding of soil moisture dynamics and guiding decisions related to agricultural practices and land management. A linear regression mode (Figure 4) was used to examine the connection between RWC and cow dung on soil water retention across soil types.

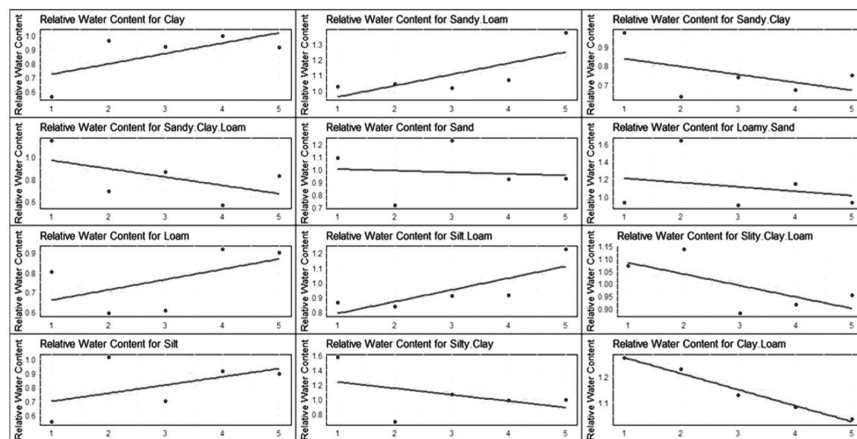


Figure. 4linear regression analysis of RWC vs amount of cow dung added various soil.

The gravimetric measurement of water content is essential for comprehending the dynamics of soil moisture, as it offers valuable information about the water that is accessible to plants for their development and other biological activities[13,14]. The GWC is affected by many variables, including soil texture, structure, organic matter concentration, and environmental circumstances such as precipitation and evaporation rates [15,16].

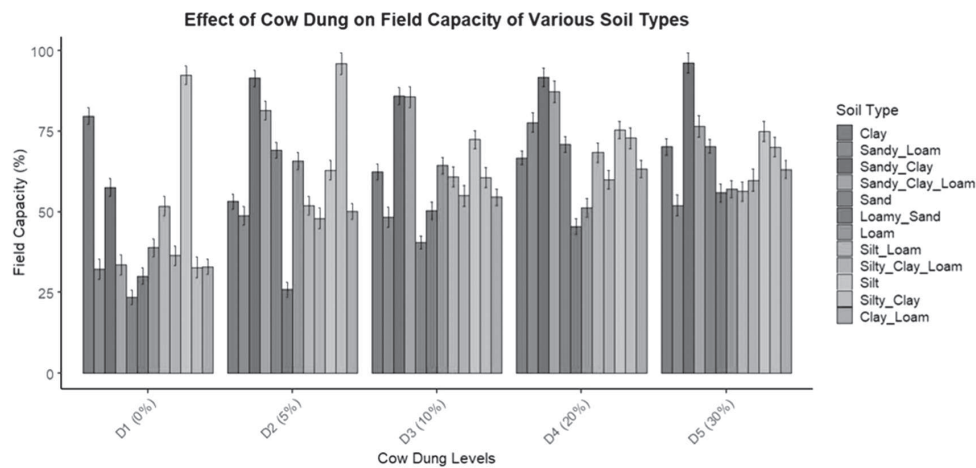


Figure 7FC with different percentages of cow dung for different soil.

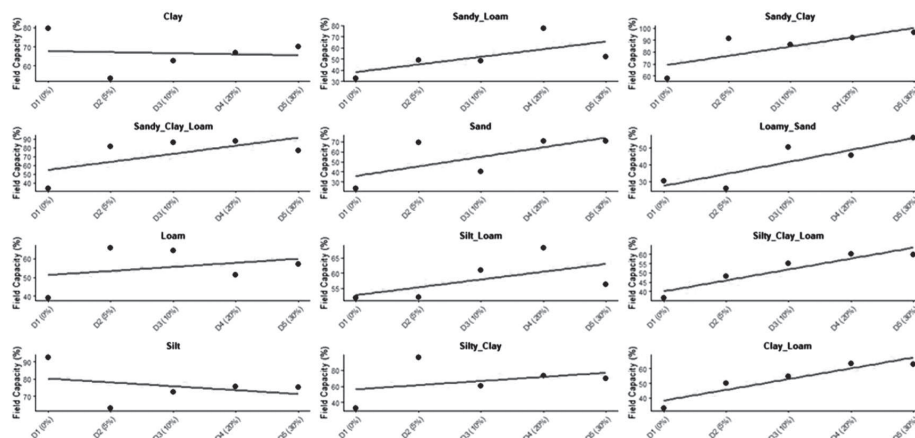


Figure 8linear regression analysis of FC vs amount of cow dung added various soil.

Figure (7) provides insights into the impact of varying levels of cow dung on the field capacity of different soil types. In the first bar graph, it is evident that increasing cow dung levels generally lead to an improvement in field capacity across most soil types. Soils such as Sandy Clay Loam, Loam, Silty Clay Loam, and Clay Loam exhibit substantial increases in field capacity as cow dung levels rise from 0% (D1) to 30% (D5). This shows that these soil types benefit significantly from organic amendments, likely due to enhanced soil structure and increased water retention capabilities. Soils like Clay and Silt show a less pronounced response, indicating that these soils already possess relatively high water-holding capacities and may not benefit as much from additional organic matter. The variations in response among different soil types underscore the importance of soil texture in determining how effectively cow dung can enhance water retention.

The plot (Figure 8) with trend lines further supports these observations. The red trend lines in each soil type plot indicate the general direction of the field capacity change with increasing cow dung levels. For most soils, the positive slope of the trend line confirms the beneficial impact of cow dung. However, for Clay and Silt, the trend is nearly flat or slightly negative, reinforcing the idea that these soils are less responsive to cow dung amendments.

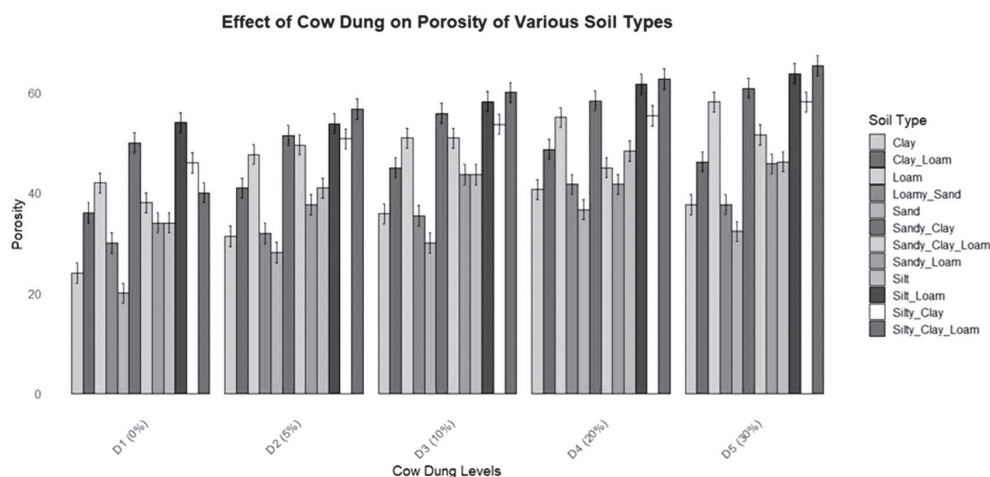


Figure 9 Porosity with different percentages of cow dung for different soil.

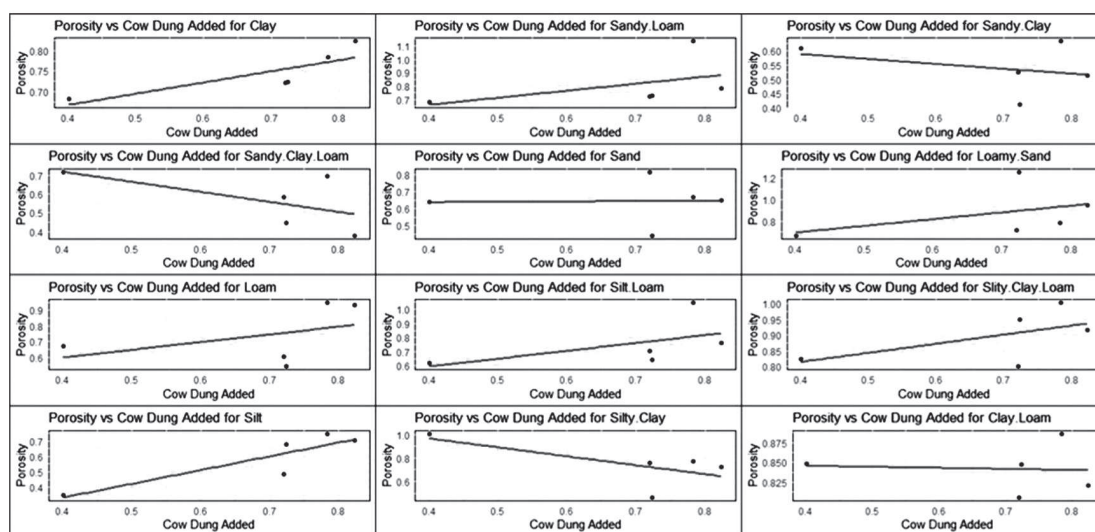


Figure 10 linear regression analysis of Porosity vs amount of cow dung added various soil.

Upon careful examination of the data (Figure 9), The data indicates a consistent pattern of enhanced porosity as the percentage of cow dung increases in all soil types. In addition, soils with characteristics such as SandyClayLoam, Sandy Loam, and Sandy Clay show major enhancements in porosity, specifically when cow dung levels reach 20% and 30%. In contrast, Clay and ClayLoam soils exhibit somewhat smaller increments. The error bars represent the extent of variability in the measurements. Among the several types of soils, SandyClayLoam and SandyLoam shows greater consistency in porosity. These data indicate that the inclusion of cow dung has a beneficial impact on soil porosity, with the magnitude of this benefit varying depending on the type of soil.

The statistical metrics analysis conducted on the porosity of soil samples with varying percentages of cow dung content reveals a significant difference in porosity among the groups.

4. Conclusion

Cow dung, with its abundant organic matter, enhances soil fertility and structure, resulting in improved nutrient availability, water retention, and aeration. This, in turn, promotes plant development and increases crop output. Furthermore, cow dung acts as a nutrition source for soil microbes, boosting their activity and speeding up the breakdown of organic matter. Hence, this enhances the Soil Plant Interface by promoting the efficient circulation of nutrients and the creation of soil organic carbon. Soil with cow dung added to it is healthier and more productive, which improves SWI and encourages long-term approaches to soil management.

References

- [1] Cosgrove W J and Loucks D P 2015 Water management: Current and future challenges and research directions *Water Resour. Res.***51** 4823-39
- [2] Qadir M, Sharma B R, Bruggeman A, Choukr-Allah R and Karajeh F 2007 Non-conventional water resources and opportunities for water augmentation to achieve food security in water scarce countries *Agric. Water Manag.***87** 2-22
- [3] Hamid Y, Tang L, Hussain B, Usman M, Lin Q, Rashid M S, He Z and Yang X 2020 Organic soil additives for the remediation of cadmium contaminated soils and their impact on the soil-plant system: A review *Sci. Total Environ.***707** 136121
- [4] Grassarová A, Hanc A, Innemanova P and Cajthaml T 2020 Composting and vermicomposting used to break down and remove pollutants from organic waste: a mini review *Eur. J. Environ. Sci.***10** 9-14
- [5] Hajkowicz S and Collins K 2007 A review of multiple criteria analysis for water resource planning and management *Water Resour. Manag.***21** 1553-66
- [6] Gavrilescu M 2021 Water, soil, and plants interactions in a threatened environment *Water***13** 2746
- [7] Liu J, Yang H, Gosling S N, Kummu M, Flörke M, Pfister S, Hanasaki N, Wada Y, Zhang X and Zheng C 2017 Water scarcity assessments in the past, present, and future *Earths Future* **5** 545-59
- [8] Zhang C-Y and Oki T 2023 Water pricing reform for sustainable water resources management in China's agricultural sector *Agric. Water Manag.***275** 108045
- [9] Gavrilescu M 2021 Water, soil, and plants interactions in a threatened environment *Water***13** 2746

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- [10] Patel S K, Sharma A and Singh G S 2020 Traditional agricultural practices in India: an approach for environmental sustainability and food security *Energy Ecol. Environ.***5** 253-71
 - [11] Migliorini P and Wezel A 2017 Converging and diverging principles and practices of organic agriculture regulations and agroecology. A review *Agron. Sustain. Dev.***37** 1-18
 - [12] Patel S K, Sharma A and Singh G S 2020 Traditional agricultural practices in India: an approach for environmental sustainability and food security *Energy Ecol. Environ.***5** 253-71
 - [13] Migliorini P and Wezel A 2017 Converging and diverging principles and practices of organic agriculture regulations and agroecology. A review *Agron. Sustain. Dev.***37** 1-18
 - [14] Rasheed M W, Tang J, Sarwar A, Shah S, Saddique N, Khan M U, Imran Khan M, Nawaz S, Shamshiri R R and Aziz M 2022 Soil moisture measuring techniques and factors affecting the moisture dynamics: A comprehensive review *Sustainability***14** 11538
 - [15] Bittelli M 2011 Measuring soil water content: A review *HortTechnology***21** 293-300
 - [16] Topp G C 2003 State of the art of measuring soil water content *Hydrol. Process.***17** 2993-6.

Green Chemistry Approaches Towards Advanced Wastewater Treatment

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Abstract

Concept of Green Chemistry has taken the position of the most appropriate and useful tool in the field of sustainability. This concept is based upon fundamental 12 principles that can affect the whole scenario of environmental outcomes of any chemical product. As far as the global pollution problems are concerned, the most affected system becomes water pollution that must be taken into consideration as it affects all living bio systems. As most of the human and industrial waste ends up into natural water systems resulting in a greater extent of contamination that is being most difficult to handle and restore into its natural form. To address these complications, we must act appropriately for that. Thus by applying the concepts of green chemistry in the wastewater treatment techniques to minimize all the possible hazards we can reach the destinations of sustainability not only in environmental aspects but also in economical way. Application of advanced oxidation processes, well designed membrane techniques and use of naturally available materials instead of harmful non degradable chemicals are the emerging trends into the sustainable wastewater treatment in this article, we have discussed the same along with the basic introduction to green chemistry principles.

Keywords Green Chemistry, Wastewater treatment, Sustainable membranes, Bio coagulants, Bio Adsorbents

1. Introduction

In the era of fastest development, the industrial sector has been at its peak to fulfill all the requirements of the huge population on earth. Presently basic consumables, machinery, food products, textile products everything is being manufactured on a large scale by industries for which water is involved in any stage throughout the complete process. As water is a distinctive substance, it can be renewed and purified by itself through the natural water cycle process but that is a very slow process as compared to the extent to which water is being contaminated by harmful chemicals consequently it gives rise to water pollution challenges. Thus the major sources of water pollution can be attributed to discharge of untreated sanitary and toxic industrial wastes and it becomes necessary to work upon it very seriously. However green chemistry is standing up as a cost effective and sustainable solution to not only water pollution but also for all other environmental problems. In this paper we have discussed green chemistry approaches that can be applied for the treatment of wastewater.

2. Green Chemistry

From the last few decades awareness for environmental protection has increased by using the concept of "Green Chemistry". The new laws and regulations have an Aim to protect the ecosystem from harmful chemicals and develop new compounds by the approach of Green chemistry which are less dangerous to human health and the environment [1]. Green Chemistry concept

applies to the whole life cycle of any chemical product i.e. from design to degradation after its use. Principles of green chemistry aim to reduce or eliminate the use of harmful chemicals as well as reducing harmful and toxic products. The development of more eco-friendly and efficient products with less wastage is the focused target of Green Chemistry.

2.1. Principles of Green Chemistry

1. **Pollution Prevention:** It is to prevent waste and to treat and clean up waste after it has been created.
2. **Atom Economy:** It should be designed to maximize the incorporation of all materials used in process into the final product.
3. **Less Hazardous Chemical Synthesis:** The synthetic method should be designed to use and generate substances that process little or no toxicity to human health and the environment.
4. **Designing Safer Chemicals:** Chemical products should be designed to affect their desired function while minimizing toxicity.
5. **Safer Solvents and Auxiliaries:** The use of auxiliary substances should be made Unnecessary wherever possible.
6. **Design for Energy Efficiency:** energy requirements of chemical processes should be recognized at low temperature and pressure.
7. **Use of Renewable Feed stocks:** A raw material of feedstock should be renewable.
8. **Reduce Derivatives:** The unnecessary derivatizations like use of blocking groups, protection, and de-protection should be avoided whenever impossible.
9. **Catalysis:** The catalytic reagents are superior stoichiometric reagents.
10. **Design for Degradation:** The chemical products should be designed so that at the end of their function they break down into harmless degradation products and do not persist in the environment.
11. **Real-time analysis for Pollution Prevention:** Analytical methodologies need to be further developed to allow for real-time, in process monitoring and control prior to the formation of hazardous substances.
12. **Inherently Safer Chemistry for Accident Prevent:** The substances used in the Chemical process should be chosen to minimize the potential for chemical accidents, Explosion and fires[1].

3. Overview to Wastewater Treatment Methods

Waste water treatment is a conversion of waste water into useful form with no or minimum harmful effects on the environment. Water contaminated with industrial effluents, agricultural runoffs, human and animal wastes, medical and pharmaceutical wastes is being treated with various methods. In general, conventional wastewater treatment comprises physical, chemical, and biological processes and operations in order to remove possible soluble and insoluble impurities like colloids, organic matter, nutrients, soluble contaminants (metals, organics) etc. from effluents. Basic overview of wastewater treatment is illustrated in fig.1 [2]. The overall treatment can be divided in steps called- Preliminary treatment or pre-treatment (Physical and mechanical), Primary treatment (Physicochemical and chemical), Secondary treatment (Chemical and biological), Tertiary or final

treatment (physical and chemical) and lastly Treatment of the sludge formed[3]. Conventional, established and newly emerging techniques available are shown in Fig. 2.

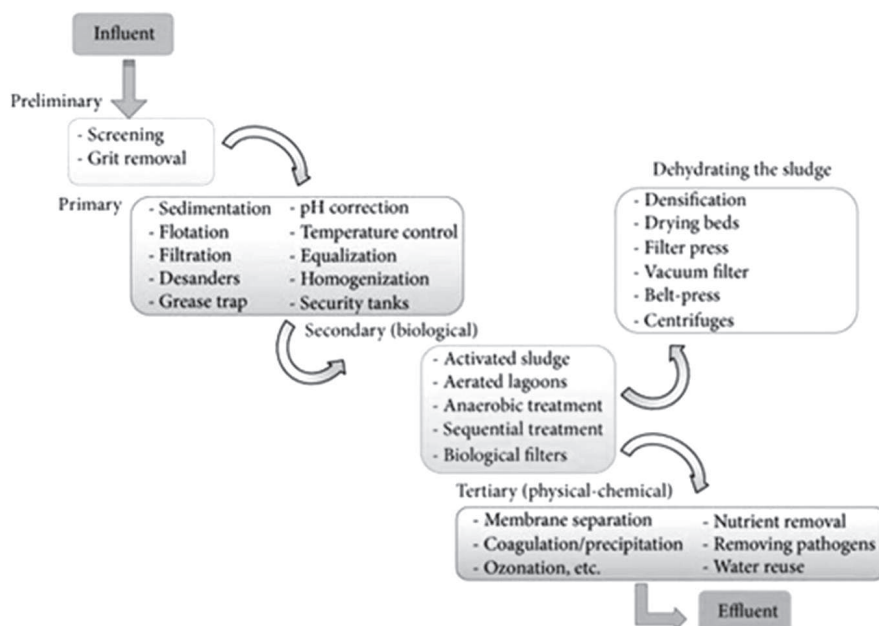


Fig.1 Process of Wastewater Treatment

Each treatment has its own constraints not only in terms of cost, but also in terms of feasibility, efficiency, practicability, reliability, environmental impact, sludge production, operation difficulty, pre-treatment requirements, formation of potentially toxic byproducts, more time consumptions and high energy requirements[5], some of which are summarized in Table 1. Application of any single technique can be inefficient so that combinations of different methods can be more effective and efficient i.e. the combination of adsorption and AOP processes can be considered an excellent way to completely remove pharmaceutical products even at trace concentrations [2]. Also there is definitely a requirement of more sustainable methods to be developed based upon Green chemistry principles.

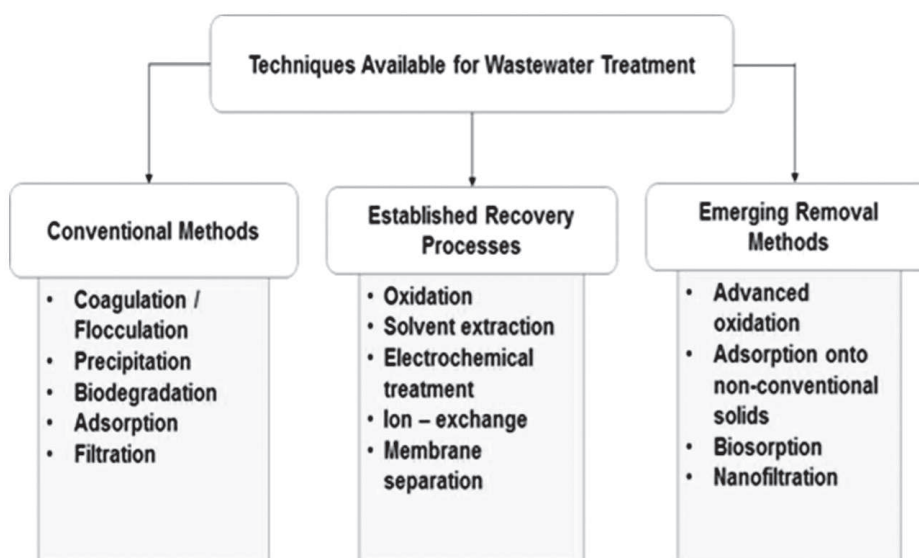


Fig.2 Presently available techniques in wastewater treatment.

Table 1: Advantages and disadvantages of various methods[4].

Process	Advantages	Disadvantages
Chemical Precipitation	- Simple equipment - Economical and efficient - Not metal selective	- Chemical consumption - Ineffective at low concentration of metal ions - High sludge production
Coagulation/flocculation	- Simple process - less expensive capital cost - Bacterial inactivation capability	- Require application of non reusable chemicals - Low removal of arsenic - High sludge production
Chemical oxidation	- Simple, rapid and efficient - Good elimination of color and odour - Increases biodegradability of product	- Chemicals required - Pre treatment required - Formation of unknown intermediates - No effect on salinity
Biological methods	- Large number of species can be used - High removal of biological oxygen demand and suspended solids	- Necessary to create an optimally favourable environment - Slow process - Poor decolourization
Adsorption/Filtration	- Technologically simple - Highly effective process with fast kinetics - Wide variety of target contaminants	- Relatively high investment - Non destructive and non selective process - Rapid saturation and coagulation of the reactors
Membrane Filtration	- Small space requirement - Simple, rapid and efficient - Eliminates all types of dyes, salts and mineral derivatives	- Investment costs are high - High energy requirements - Disposal of used membranes is required

4. Innovative Green Chemistry Approaches

4.1. Advanced Oxidation Processes

Advanced oxidation processes (AOPs) are defined as a process of degradation of organic matter by in situ generated highly reactive oxidizing species[6]. AOPs are based on the generation of highly reactive oxygen species (ROS), such as hydroxyl radicals ($\text{HO}^\bullet$), superoxide radicals ($\text{O}_2^{\bullet-}$) and singlet oxygen ($^1\text{O}_2$). ROS participate in the degradation of organic matter, which mostly leads to creation of CO_2 and H_2O or more biodegradable species with less environmental impact [7]. As the first principle of green chemistry suggests prevention of harmful products, AOPs convert organic pollutants into simpler non-hazardous products i.e. CO_2 and H_2O even without any specific solvent requirement and by utilization of renewable energy source like sunlight. AOPs satisfy the principle of safer solvent and energy efficiency also.

Among main two classes of AOPs - homogeneous and heterogeneous, The homogeneous processes in the AOP are the reactions involving oxidants and catalyst in the same phase [8], while

in heterogeneous processes, reactants and catalysts are in different phase and the reactants and products adsorb and desorb on the catalyst's active sites [9]. Reactions involving O_3 /UV, H_2O_2 /UV and Fenton reaction are examples of Homogeneous AOPs and catalytic oxidation, photocatalytic oxidation are examples of Heterogeneous AOPs Fig 3.

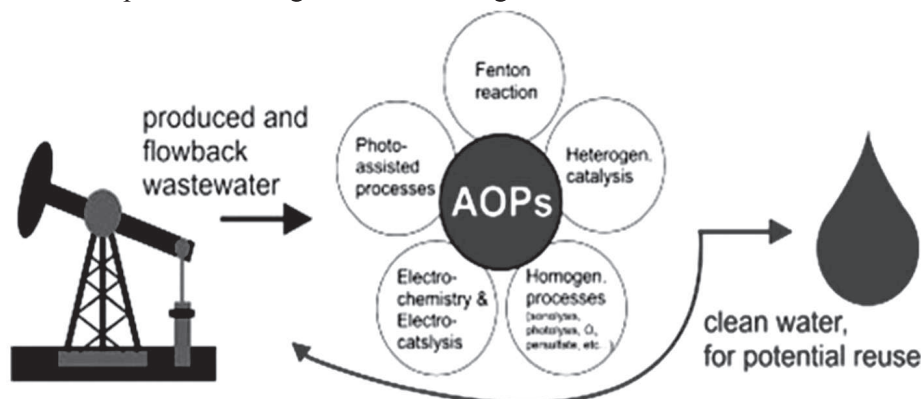


Fig. 3 Types of AOPs[10]

The different methods by which AOPs can be carried out along with its mechanism are mentioned in Fig 4 they basically differ in the process adapted to generate reactive oxygen species. AOPs using an eco-friendly oxidant, hydrogen peroxide, represents a major approach to degrade the water pollutants such as azo dye[11]. Since removal of azo-dye contaminants from water is most difficult by other conventional methods, this application is of most importance. Similarly, another such organic contaminant catacholcan be removed by using advanced photo-oxidation with hydrogen peroxide in presence of UV light [12].

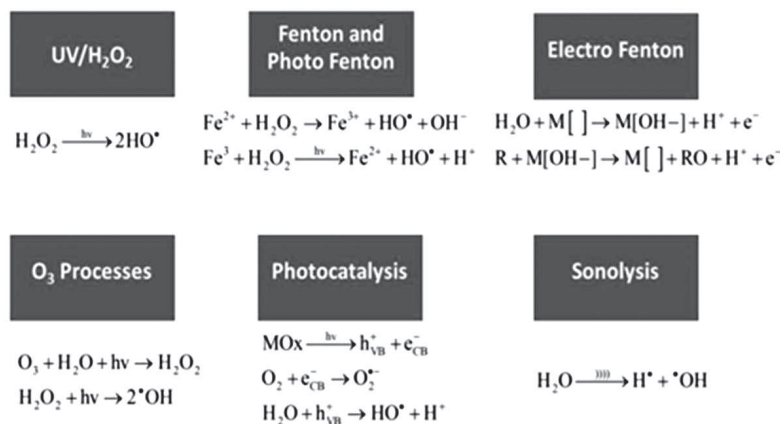


Fig.4 Types of AOPs with its mechanism[14]

4.2. Eco Friendly Coagulation and Flocculation Agents

Flocculation and Coagulation in water treatment are used to remove suspended solids through a process that destabilizes the suspended particles in water solutions. The term coagulation refers to the coming together, or gathering of particles, and flocculation refers to the settling of these accumulated particles Fig 5. The most common process of coagulation is carried out by using positively charged bivalent ionic compounds like aluminum sulphate or ferric chloride as coagulating agents and letting coagulated sludge to settle down at the bottom but these chemicals can be accumulated into sludge formed which need to be managed further to prevent environmental impacts of such metallic ions.

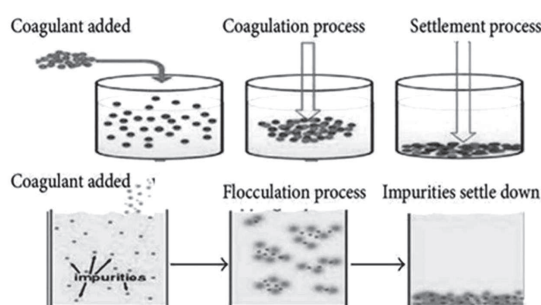


Fig.5 Process of Coagulation and Flocculation[17]

Thus the basic principle of green chemistry of prevention of unwanted waste production is not satisfied here. Moreover, the cost of these single use chemicals can impact the overall cost of the process. In order to modify this method according to green chemistry principles, the development and utilization of natural coagulants mostly from plant origin have good prospects as a green technology with a viable sustainable application as water pollution control[15]. Reportedly, *P. sarmentosum* was suggested to be the best natural coagulant which achieved the highest removal of turbidity with a low dosage used among several other locally available plant based coagulants like *A. indicia*, *S. palustris*, *D. linearis*, *S. polyanthum*, *M. esculenta*, *P. sarmentosum*, and *M. malabathricum*. Study also suggests that combined coagulation using natural as well as chemical coagulants together can be more efficient and time saving [16]. Application of locally available plant products without any specific manufacturing process can lower the cost of treatment to a greater extent.

4.3. Agricultural Waste Products as Bio Adsorbents

The widely used and accepted as well as efficient method of waste water treatment is the adsorption process. It is simple and effective for many types of pollutants. Adsorption of pollutants on the surface of solid adsorbents is the basic principle behind this method. Evolution of this fundamental method with the principle of green chemistry can be done by replacing chemical adsorbents with naturally occurring plant based materials especially agricultural-by-products such as rice-husks, peels of yam, orange, banana, plantain, potatoes etc., corn cobs, saw-dusts, and many others. Using these kind of agricultural waste products have shown the good adsorption of metal ions like lead, cadmium, zinc, selenium among others from the wastewater and these adsorbed ions can also be recovered from solids that would result in easy disposal of used adsorbents by the natural bio degradation process [13].

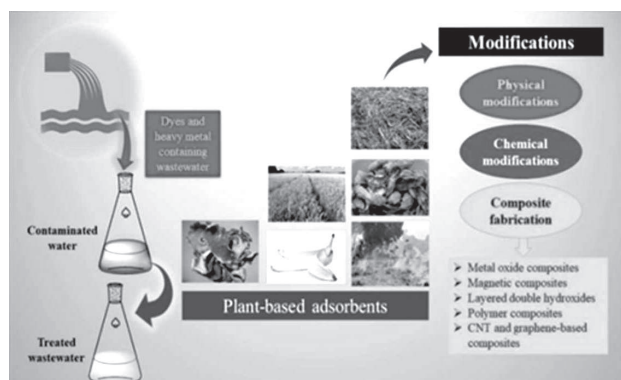


Fig.6Agricultural waste products as bio adsorbents[18]

Such renewable, biodegradable, cheap and readily available at little or no cost materials are of interest in the process of wastewater treatment Fig 6. Their uses as adsorbents can implicate the principles of green chemistry and green environmental practice. The use of these agricultural-by-products as adsorbents for the removal and recovery of these toxic metal ions from aqueous environments are called bio sorption techniques. The bio sorption techniques consist of a group of applications which involve the detoxification of hazardous chemicals namely Lead, Cadmium, Zinc among others instead of transferring them from one medium to another using these agricultural by-products[19]. Best part of this process is the cost of materials which is near to negligible additionally it can ultimately omit the need of disposal or management of such agricultural waste in the solid field.

4.4. Sustainable Membrane Technology

Highly technical yet simple technique of water purification is membrane filtration which works on the separation of pollutants rather than converting or altering the form of pollutants. Membrane technology incorporates mechanical assistance to improve the speed and efficiency of the process which makes it more technical and advanced technique. Membranes are basically semi permeable barriers that can allow specific particles only to pass through; this membrane-based separation is characterized by sharp selectivity, while being associated with simple equipment and conveniently compact structures [20]. It is a common water treatment method because of its high efficiency and low energy requirement. Despite of having lots of advantages, membrane technology stands behind in the row of greener technologies because most of the membranes are made up of petroleum based materials that are non-biodegradable also, manufacturing process of membranes include large amount of organic solvents that violates the principles of green chemistry furthermore, disposal of used or malfunctioned membranes is also a problem. In order to convert this highly efficient technique into most sustainable techniques too, many approaches have been taken Fig. 7.

One of which can be the use of bio based polymers for membrane manufacturing generally from plant- poly isoprene based Polymers[20] this single modification can overcome nearly all the environmental problems related to manufacturing of petroleum based non biodegradable membranes. Animal based Chitosan [21] or bacterial sourced-Poly Lactic Acids (PLAs) can also replace the toxic membrane materials.



Fig.7 Agricultural waste products as bio adsorbents[17]

Another way to imply green chemistry principles could be the use of safer solvents instead of toxic organic chemicals in the membrane manufacturing process [22]. This can be useful in the cases when the replacement of membranes with natural materials is not possible due to specific selectively requirement. Applying this modification can definitely minimize the drawbacks involved in membrane manufacturing but still be questionable in terms of disposal as well as cost of the process.

In the case of management of used membranes, the principle of designing safer chemicals can be useful. As in the stage of designing of materials used in membranes one can prevent the materials from being of short life and non-reusable. Thus by keeping the principles of green chemistry in mind, highly durable and long lasting membranes that can also be recycled to use many times have been developed[23]. This can ultimately reduce the cost of membrane as it results in the requirement of lesser quantity of membranes utilized in the process.

5. Conclusion

According to the current scenario of environmental conditions and its horrible outcomes, all possible actions should be taken in application. In order to restore water quality by dealing with all kinds of water pollutants newer technologies and strategies are proved to be effective. As a fruitful outcome of Green Chemistry, techniques like advanced oxidation processes that can give results almost up to hundred percent removals of organic pollutants are one of the best strategies. Also, most utilized membrane techniques can be polished with the concepts of Green chemistry by working upon membrane manufacturing and disposal processes. Moreover, sustainability in wastewater treatment with the use of naturally available bio materials can also be most reliable in the future. Development of techniques like advanced oxidation processes and sustainable membrane technologies can bring the water pollution management to the next level as it can be operated in relatively lower steps, has better efficiency and is applicable to a large spectrum of pollutants. Also hybridization of various techniques in order to develop some generalized methods with wide spectrum of applicability can reduce many problems like inappropriate method selection or high cost of various water treatment plant establishments etc. All these improvements in wastewater management can bring environmental and economical benefits with no doubt.

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References

- [1] M. Singhal, A. Singh, S. P. Khan, E. Sultan, and N. K. Sachan, "Green chemistry potential for past, present and future perspectives.," *Int. Res. J. Pharm.*, vol. 3, no. 4, pp. 31-36, 2012.
- [2] M. Berni, I. Dorileo, G. Nathia, T. Forster-Carneiro, D. Lachos, and B. G. M. Santos, "Anaerobic digestion and biogas production: Combine effluent treatment with energy generation in UASB reactor as biorefinery annex," *Int. J. Chem. Eng.*, vol. 2014, no. June, 2014, doi: 10.1155/2014/543529.
- [3] V. Gunarathne, A. Ashiq, and M. P. Ginige, "Green Adsorbents for Pollutant Removal," vol. 18, no. February, 2018, doi: 10.1007/978-3-319-92111-2.

-
- [4] G. Crini and E. Lichtfouse, "Advantages and disadvantages of techniques used for wastewater treatment," *Environ. Chem. Lett.*, vol. 17, no. 1, pp. 145-155, 2019.
- [5] Z. Guo, Y. Sun, S. Y. Pan, and P. C. Chiang, "Integration of green energy and advanced energy-efficient technologies for municipal wastewater treatment plants," *Int. J. Environ. Res. Public Health*, vol. 16, no. 7, pp. 1-29, 2019.
- [6] M. Sievers, "Advanced Oxidation Processes," *Treatise Water Sci.*, vol. 4, pp. 377-408, 2011, doi: 10.1016/B978-0-444-53199-5.00093-2.
- [7] P. R. Rout, T. C. Zhang, P. Bhunia, and R. Y. Surampalli, "Treatment technologies for emerging contaminants in wastewater treatment plants: A review," *Sci. Total Environ.*, vol. 753, p. 141990, 2021, doi: 10.1016/j.scitotenv.2020.141990.
- [8] S. M. Aramyan, "Advances in Fenton and Fenton Based Oxidation Processes for Industrial Effluent Contaminants Control-A Review," *Int. J. Environ. Sci. Nat. Resour.*, vol. 2, no. 4, 2017, doi: 10.19080/ijesnr.2017.02.555594.
- [9] A. R. Ribeiro, O. C. Nunes, M. F. R. Pereira, and A. M. T. Silva, "An overview on the advanced oxidation processes applied for the treatment of water pollutants defined in the recently launched Directive 2013/39/EU," *Environ. Int.*, vol. 75, pp. 33-51, 2015, doi: 10.1016/j.envint.2014.10.027.
- [10] N. Mohammed, N. Grishkewich, and K. C. Tam, "Cellulose nanomaterials: Promising sustainable nanomaterials for application in water/wastewater treatment processes," *Environ. Sci. Nano*, vol. 5, no. 3, pp. 623-658, 2018, doi: 10.1039/c7en01029j.
- [11] R. K. Sharma, S. Gulati, A. Pandey, and A. Adholeya, "Novel, efficient and recyclable silica based organic-inorganic hybrid Nickel catalyst for degradation of dye pollutants in a newly designed chemical reactor," *Appl. Catal. B Environ.*, vol. 125, pp. 247-258, 2012, doi: 10.1016/j.apcatb.2012.05.046.
- [12] A. Mandal, K. Ojha, A. K. De, and S. Bhattacharjee, "Removal of catechol from aqueous solution by advanced photo-oxidation process," *Chem. Eng. J.*, vol. 102, no. 2, pp. 203-208, 2004, doi: 10.1016/j.cej.2004.05.007.
- [13] I. A. Okoro and S. O. Okoro, "Agricultural By Products As Green Chemistry Absorbents for the Removal and," *Cont. J. Water, Air Soil Pollut.*, vol. 2, no. 1, pp. 15-22, 2011.
- [14] P. K. Pandiset al., "Key Points of Advanced Oxidation Processes (AOPs) for Wastewater, Organic Pollutants and Pharmaceutical Waste Treatment: A Mini Review," *ChemEngineering*, vol. 6, no. 1, 2022, doi: 10.3390/chemengineering6010008.
- [15] M. B. Bahrodin, N. S. Zaidi, N. Hussein, M. Sillanpää, D. D. Prasetyo, and A. Syafiuddin, "Recent Advances on Coagulation-Based Treatment of Wastewater: Transition from Chemical to Natural Coagulant," *Curr. Pollut. Reports*, vol. 7, no. 3, pp. 379-391, 2021, doi: 10.1007/s40726-021-00191-7.
- [16] A. Ahmad, S. R. S. Abdullah, H. A. Hasan, A. R. Othman, and N. 'Izzati Ismail, "Potential of local plant leaves as natural coagulant for turbidity removal," *Environ. Sci. Pollut. Res.*, vol. 29, no. 2, pp. 2579-2587, 2022, doi: 10.1007/s11356-021-15541-7.
- [17] B. Othmani, M. G. Rasteiro, and M. Khadhraoui, "Toward green technology: a review on some efficient model plant-based coagulants/flocculants for freshwater and wastewater

-
- remediation," *Clean Technol. Environ. Policy*, vol. 22, no. 5, pp. 1025-1040, 2020, doi: 10.1007/s10098-020-01858-3.
- [18] S. Yadav, A. Yadav, N. Bagotia, A. K. Sharma, and S. Kumar, "Adsorptive potential of modified plant-based adsorbents for sequestration of dyes and heavy metals from wastewater - A review," *J. Water Process Eng.*, vol. 42, no. May, p. 102148, 2021, doi: 10.1016/j.jwpe.2021.102148.
- [19] J. C. Igwe and A. A. Abia, "A bioseparation process for removing heavy metals from waste water using biosorbents," *African J. Biotechnol.*, vol. 5, pp. 1167-1179, 2006.
- [20] A. C. Chinyerenwaet al., "Structure and thermal properties of porous polylactic acid membranes prepared via phase inversion induced by hot water droplets," *Polymer (Guildf)*, vol. 141, pp. 62-69, 2018, doi: 10.1016/j.polymer.2018.03.011.
- [21] Q. Long, Z. Zhang, G. Qi, Z. Wang, Y. Chen, and Z. Q. Liu, "Fabrication of Chitosan Nanofiltration Membranes by the Film Casting Strategy for Effective Removal of Dyes/ Salts in Textile Wastewater," *ACS Sustain. Chem. Eng.*, vol. 8, no. 6, pp. 2512-2522, 2020, doi: 10.1021/acssuschemeng.9b07026.
- [22] M. A. Rasool, P. P. Pescarmona, and I. F. J. Vankelecom, "Applicability of organic carbonates as green solvents for membrane preparation," *ACS Sustain. Chem. Eng.*, vol. 7, no. 16, pp. 13774-13785, 2019, doi: 10.1021/acssuschemeng.9b01507.
- [23] W. Xie et al., "Toward the Next Generation of Sustainable Membranes from Green Chemistry Principles," *ACS Sustain. Chem. Eng.*, vol. 9, no. 1, pp. 50-75, 2021, doi: 10.1021/acssuschemeng.0c07119.

Water Purification Using Conventional Methods With Cutting-Edge Technologies

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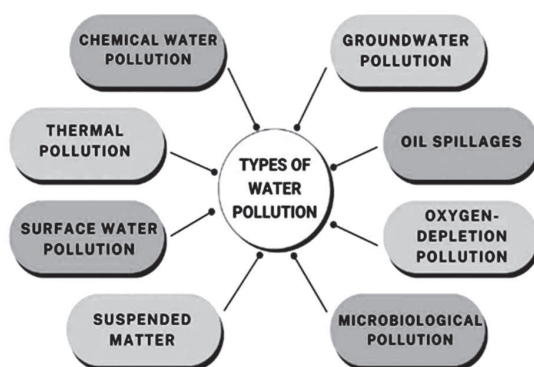
Abstract

In the twenty-first century, water pollution is a major problem since water is a necessity for all living beings, including humans and other plants and animals. However, these days it is very difficult to get inexpensive, pure, clean, and hygienic water due to the rise in water pollution. Therefore, in light of the growing problem of contaminated water, we have helped to investigate a few methods of water purification. The suggested solution provides an efficient and cost-effective way to address the problem of purifying water. The suggested water purification method combines cutting-edge technologies like nanotubes, Nano fiber membranes, acoustic nanotubes, etc. with conventional water filtration techniques like sedimentation, coagulation, chlorination, and reverse osmosis.

Keywords Water Purification, Conventional methods, Emerging Technologies, Water Filtration

1. Introduction

Since water is a basic need of every living being, its availability, efficiency, purity, and degree of hygiene must all be noted. These days, finding clean water in the surrounding area is quite difficult. Safe water scarcity is a global problem these days. The fresh and clean water is becoming more contaminated and dangerous to drink due to an increase in water pollutants. Any material that contaminates land, water, or the air and renders the environment unsafe or unfit for human use is considered a pollutant. Six main types of pollution affect water: surface water, ground water, microbiological pollution, nutrient pollution, and suspended matter pollution. Water that exists naturally on the surface of the earth is impacted by surface water pollution. Groundwater pollution occurs when hazardous substances and particles seep into the earth from the surface as a result of rainfall. The most prevalent kind of water contamination is chemical. Even though plants and aquatic life depend on nutrients, too much of them can be harmful. Microbiological pollution is defined as pollution brought on by bacteria, viruses, and protozoa that are present in sediments, undersea vegetation, and waste products from humans and animals. Eliminating all of these contaminants from the water is extremely important. Water filtration and purification are the terms used to describe the cleaning process. Water filtration refers to techniques that eliminate larger contaminants, such as bacteria, sediment, rust, and chemicals, as well as solid particles using physical barriers, chemical processes, or biological processes. Water purification refers to techniques used to eliminate biological pollutants and extract minerals from water.



Types of Water Pollution

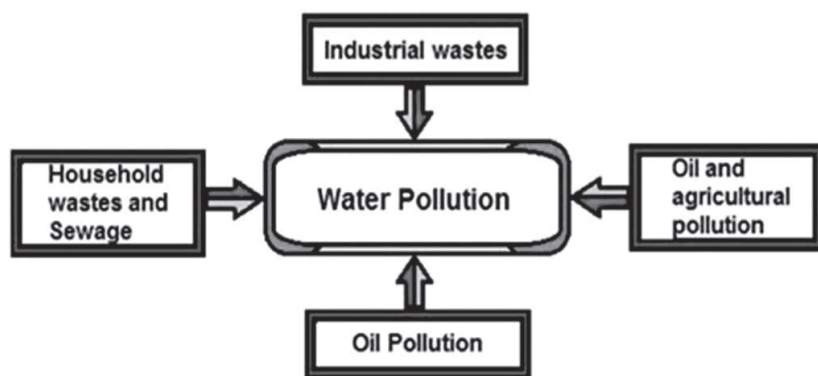
Fig. 1. Types of water pollutants

Water can be purified using a variety of techniques. Some of the widely used techniques include boiling, desalination, distillation, filtration, reverse osmosis, UV purification, chlorination, and the addition of iodine or tablets for water purification.

The paper discusses and describes a few methods for filtering and purifying water. The paper lists and describes every method for purifying water. In the paper, all water purification techniques- conventional and modern - are contrasted and summarized.

2. Content

2.1 Major Causes of Water Pollution

Fig. 2 Major causes of Water Pollution ^[7]

The major sources of water pollution were shown in Fig. 1. Domestic, municipal and industrial wastes are the predominant wastes disposed into water channels, lakes, rivers and streams. Many hazardous chemicals from textile, petrochemical, pharmaceutical industries, refineries and mines has been discharged directly into water leads to water pollution and serious effects to humans, plants, animals and aquatic organisms.^[7]

2.1.1. Major Water Pollutants

Water pollutants are substances that alter the physical and chemical characteristics of water thus deteriorating their quality. Release of industrial effluents into fresh water systems decreases the availability of clean water. Major environmental pollutants and their toxic effects were listed in Table 1. ^[7]

Table 1. Major Water Pollutants^[7]				
Sr. No.	Major Pollutants	Sources	Toxic Effects	
			Human	Environment
1	Heavy metals	Industrial effluents, pesticides, mining, sewage sludge	Carcinogenic diseases, Organ impairment	Oxidative stress in plants, Bioaccumulation
2	Dyes	Industrial effluents from textile, painting, paper, printing and tanning industries	Carcinogenic, mutagenic, Organ dysfunction	Reduced photosynthetic activity, Increases BOD and COD, Overall suppressed plant growth
3	Oil	Transportation oil spills, Industrial effluents	Respiratory problems, Carcinogenic, Neurological, eyes and nose irritation	Destroys aquatic habitat, Reduces Dissolved Oxygen (DO) in water
4	Plastics	Disposal of packaging material and industrial wastes into ocean	Liver dysfunction, Lung problems, deafness, impaired immune function	Blocks respiratory system in aquatic organisms
5	Pesticides and Herbicides	Agricultural practices	Endocrine system disruption, Organ impairment	Bio-magnification, decreases biodiversity
6	Pathogenic Microorganisms	Domestic discharge, sewage, hospital wastes	Serious effect on human metabolism	Reduction in DO content

2.2 Illustration

Listed tables show the comparison of various water purification techniques to remove water pollutants from the water and make water usable. Table 1 shows the various water purification techniques used by ancestors of various regions and countries. Water purification techniques were chosen based on a few parameters like the soil, environment, their geographic area, etc. Numerous techniques are listed in Table 2 that were being used by the ancestors.

Table 2. Water Purification Methods used by Ancestors ^[14]				
Time Period	Method Name	Details	Cost	Effectiveness (At Present)
The Egyptians (1500 B.C.)	Sand and gravel	Act as permeable layers for water purification	Cost-free	Less Effective
Ancient Greece (500 B.C. to 500 A.D.)	Hippocratic sleeve (Cloth)	Sand and gravel leave little space, allowing water to pass but holding solid particles back	Cost-free	Less Effective
Ancient Egypt (1854 A.D.)	Sedimentation	Alum was used to solidify the particles and make them settle at the bottom of the vessel.	Economical	Less Effective
Ancient China (1250-1000 B.C.)	Fermentation	Use natural microbes to outperform the bad bacteria and microorganisms in water, making it safe for drinking	Costly and technical skill required	Less Effective
Ancient India (400 BC)	Active Charcoal Filtration	Water purification using Charcoal	Economical	Less Effective
Ancient India (2000 B.C.)	Storage in Copper Vessels	Anti-microbial properties	Cost-free	Less Effective
Ancient Hippocrates & Unan	Sunlight Exposure	Destroy most germs that cause disease	Cost-free	Less Effective
Ancient Indonesia	Jempeng stone filter method	Muddy water filters through the porous wall	Costly	Less Effective
Ancient Egypt / Arab	Vessels Method	A simple method of water treatment resembling storage and filtration method	Low cost	Less Effective

Table 3 displays various water purification techniques that use different scientific methods and techniques. Methods are briefly explained along with cost estimation and their effects.

Table 3. Water Purification Methods using New Technologies^[14]			
Method Name	Details	Cost	Effect
Boiling	Kills disease - causing organisms like bacteria, viruses, and parasites	Economical	Less Effective
Storage/ Sedimentation	Uses gravity to remove suspended solids from water	Cost-free	Less Effective
Coagulation/ Flocculation	Chemical and Physical processes used to remove suspended solids from water during the purification process	Costly Technical Expertise required	Less Effective
Chlorination	Adding a measured amount of chlorine to water to produce a residual sufficient to kill bacteria, viruses, and cysts	Economical	Less Effective
Reverse Osmosis	The contaminants present in water are removed by pushing water under pressure through a semipermeable membrane	Costly Technical Expertise required	Less Effective
Ultraviolet Disinfection	Uses UV light to kill bacteria, viruses, and other microorganisms in water	Costly Technical Expertise required	Less Effective
Distillation/ Sublimation	Distillation is a method of separation based on differences in the boiling points of substances. Sublimation is defined as heat or energy required to change the state from solid to gas	Costly Technical Expertise required	Less Effective
Churning	Water is taken in any container and agitated violently either manually with a stirrer or by a machine and left to settle down. After sometime all the impurities will be settled down and water will be clear and sweet	Economical	Less Effective

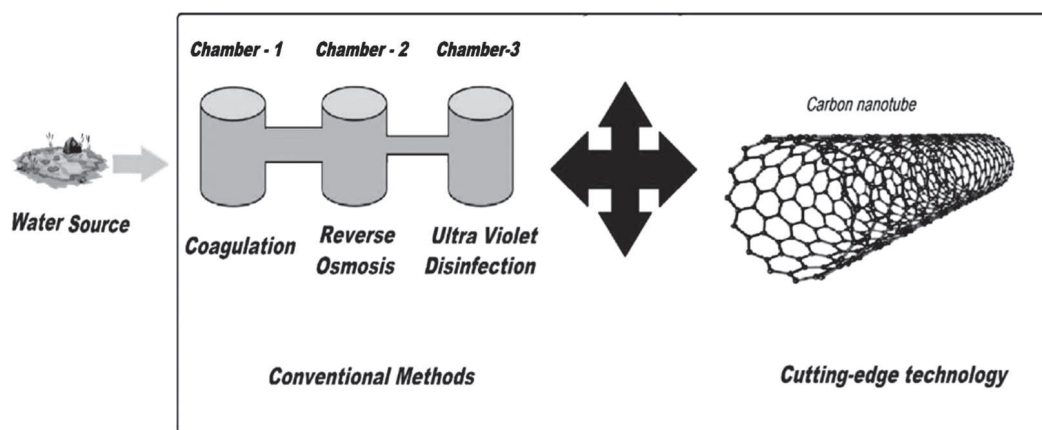
Table 4 exhibits the future of water purification techniques. A few recent technologies are listed and compared below. Each method is briefly described along with its estimated cost and effect.

Table 4. Water Purification Methods using Cutting-edge Technologies ^[2]			
Method Name	Details	Cost	Effect
Nano fiber membranes	Water treatment, standalone filtration device, filter cartridge, ultrafiltration, and pre-filtration	Costly and require technical expertise	Highly Effective
(Nano)zeolites	Disinfection processes	Costly and require technical expertise	Highly Effective
Carbon nanotubes and membranes	Desalination, point-of use, and highly biodegradable pollutants (pharmaceuticals, antibiotics)	Costly and require technical expertise	Highly Effective
Nano scale zero Valente iron particles	Treatment & remediation of wastewater (chlorinated hydrocarbon, perchlorates)	Costly and require technical expertise	Highly Effective
Nano-filtration membranes	Reduction of color, heavy metals, hardness, and odor	Costly and require technical expertise	Highly Effective
Polymeric Nano adsorbents (dendrites)	Elimination of heavy metals and organics	Costly and require technical expertise	Highly Effective

The tables' data show the method and techniques of each type of water purification process. From the data we have derived the results like its effectiveness and cost. From the data we can observe that no method is having the benefits, effectiveness and efficiency as well as the cost.

2.5. Proposed Work

The details in the comparison tables state that no technology is enough alone to cleanse the water. Every technology, from the most antiquated to the most modern, has a distinct purpose. Every technique has benefits and drawbacks of its own. While chemical methods are typically used to remove metals, colors, and turbidity from water, physical methods are typically used for water filtration. Biological methods are those that purify water by using natural processes. Biological methods typically provide an environmentally friendly and economical process. A few antiquated techniques provide affordable yet ineffective solutions, whereas contemporary technology provides efficient but typically more expensive solutions. Our suggested approach calls for a system that combines the best features of both antiquated and contemporary technology to provide a workable and affordable solution. We are proposing an improved water purification system that is both economical and efficient by fusing traditional techniques with cutting-edge technologies. The suggested solution addresses both water purification and water filtering. The proposed solution uses the Vessels Method which was being used by Ancient Egyptian and Arabian people. Ancient Indian society employed a similar approach. We may agree that the best and most effective methods of water purification were used by the ancient Indians based on the relics uncovered at the Indian heritage site Dholavira.



WATER PURIFICATION USING CONVENTIONAL METHODS WITH CUTTING-EDGE TECHNOLOGIES

We filter water using the 3 chamber method. Three distinct chambers will pass water. Water will be gathered in the first room from the original water source. A little conduit will carry the water from the first chamber to the next. Large, heavy pollutants and debris will be filtered out of the water in the first chamber by the narrow channel which will get collected and sorted. Coagulation techniques will be used to remove remaining impurities from the water. Aluminum sulfate (alum) is the most common coagulant used for water purification. Reverse osmosis technology will be employed in the second chamber to eliminate impurities from the water. Water is purified via the reverse osmosis (RO) technique, which applies pressure on a semipermeable membrane. Two streams of water are produced by this process: treated water (also known as "permeate") and reject water (also known as "concentrate" or "brine"). The method or technology used to purge drinking water of ions, mineral chemicals, and other impurities is called reverse osmosis. More pressure is used in this process, which forces the water to pass through the semipermeable membrane against the laws of nature of osmosis. After that, the water is transferred to the third chamber. In chamber 3, the water is treated with an ultraviolet disinfection method that eliminates bacteria, viruses, and other microorganisms. After treating the water using age-old techniques, the end product will be filtered water. The water has been filtered and partially purified using primitive methods.

In order to clean water for reuse on the International Space Station, NASA has developed a method.[15] With this technology, carbon nanotubes are integrated into an acoustically driven molecular screen. CNTs are utilized for highly biodegradable pollutants, desalination, and point-of-use applications. These carbon nanotubes obstruct larger molecules and pollutants, allowing only water molecules to pass through. Rather than taking impurities out of water, this technology works by pushing water away from them. In addition, compared to other filtration methods, it uses less power. Furthermore, the filter system does not need to be flushed during this process. At thirty thousand times thinner than the average human hair, the nanotube fiber is currently the thinnest known fiber. When exposed to alternating electric current, nanotubes' rapid heating and low heat capacity is crucial properties, especially for acoustic applications.

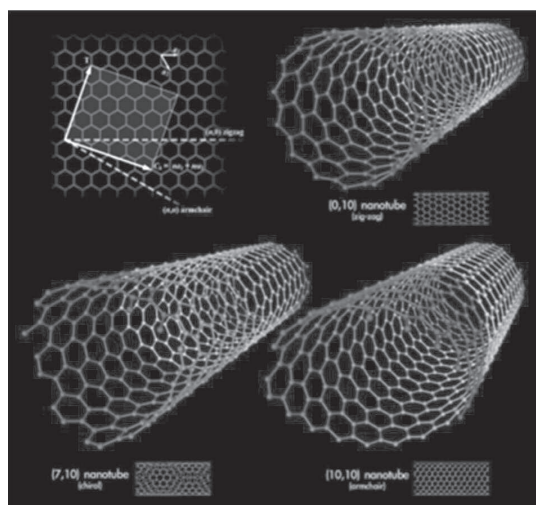


Fig. 3. Carbon Nanotubes [15]

This technology is distinct in that it uses acoustic (sound waves) to force water through a filter. An oscillator circuit connected to the filter matrix generates acoustic vibration. The water molecules move through the filter as a result of the acoustic vibrations breaking their bond. The elimination of the need for gravity, which is required in some other filtration processes to move water through the filtration device, is another benefit of adopting acoustic filtration. In order to clear the sediment from the filter inlet and restore the system flow rate, a cleaning cycle is started when the amount of water leaving the system drops to a predefined site point. Unlike other filtration systems, this one doesn't need the filter system to be flushed. Small diameter nanotubes and acoustics are combined in acoustic nanotube technology, which makes the process of eliminating impurities from water and creating highly pure water extremely effective and efficient.

3. Conclusion

A comparison of different water purification techniques reveals that use of any one technique cannot be sufficient enough to effectively purify water. Some purification techniques are expensive but yield high-quality results, while other techniques are less expensive but yield lower-quality results. Combining the technologies that provide the best solution for the water purification problem is the best way to obtain a better, optimized solution. The optimal desired solution that is both effective and economical can be obtained by fusing traditional methods with cutting-edge technologies.

Acknowledgments

We are eternally grateful to Mother Earth for bestowing upon us life, sustenance, education, and everything we require to lead fulfilling lives. We are thankful to each and every one who leads initiatives to conserve and purify the water which is the basic need of every living being. We sincerely show our gratitude to all those noble human beings who contribute in cleaning and purifying the water and water resources.

References

- [1] Conventional to cutting edge technologies in drinking water purification-a review K Padmaja,J Cherukuri, MA Reddy
- [2] Smart and innovative nanotechnology applications for water purificationS Kumar - 2023
- [3] Removing heavy metals: cutting-edge strategies and advancements in biosorption technologyK Staszak, M Regel-Rosocka - 2024

-
- [4] Organic-inorganic hybrid nanoflower production and analytical utilization: fundamental to cutting-edge technologiesIG Subramani, V Perumal, SCB Gopinath- 2022
 - [5] Heavy metal water pollution: A fresh look about hazards, novel and conventional remediation methodsC Zamora-Ledezma - 2021
 - [6] Critical review of advanced oxidation processes in organic wastewater treatment D Ma, H Yi, C Lai,X Liu, X Huo, Z An, L Li, Y Fu,B Li- 2021
 - [7] Effective water/wastewater treatment methodologies for toxic pollutants removal: Processes and applications towards sustainable developmentA Saravanan, PS Kumar, S Jeevanantham,S Karishma - 2021
 - [8] Advanced oxidation processes for water disinfection: Features, mechanisms and prospectsX Duan, X Zhou, R Wang,S Wang, N Ren - 2021
 - [9] Protein nanofibrils for next generation sustainable water purificationMPeydayesh,R Mezzenga- 2021
 - [10] Hydrogels as an emerging material platform for solar water purificationX Zhou,Y Guo,F Zhao,G Yu
 - [11] Science and technology for water purification in the coming decadesMA Shannon,PW Bohn,M Elimelech,JG Georgiadis
 - [12] Carbon nanotube membranes for water purification: Developments, challenges, and prospects for the future: Ihsanullah
 - [13] Nanomaterials as a cutting edge in the removal of toxic contaminants from waterAA Ansari, MA Shamim, AM Khan, K Anwar- 2023
 - [14] Evolution of water purification methods; International Journal of Unani and Integrative Medicine 2018; 2(2): 108-116; Dr.Faiyaz Ahmad Alig
 - [15] Acoustic Nanotube Technology
 - [16] Synthesisand application of titanium dioxide photocatalysis for energy, decontamination and viral disinfection: A reviewJ Arun,S Nachiappan,G Rangarajan - 2023
 - [17] Advanced Produced Water Management in the Oil and Gas Industry: A Comprehensive Examination of Cutting-Edge Treatment Technologies M Khammo, A Obedkov, R Aljarwan- 2024.

Significance of Hydrogel and its Applications for Sustainable Agriculture

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Abstract

In arid and semiarid regions and under rainfed conditions, water availability is one of the principal ecological constraints that hinder agriculture's sustainability. The super absorbent polymer (agricultural) is water-absorbing and is cross-linked to absorb aqueous solutions through bonding with water molecules. It is a new approach to water management under water-stressed conditions to conserve soil moisture in the active rooting zone of crops by reducing the evaporation, deep percolation, and runoff losses. Agricultural hydrogels are water retention granules which swell their original size to numerous intervals when they come in contact with water. It can absorb and retain a huge amount of moisture under plentiful rainfall and irrigation events and release it back to the soil for mitigating crop water demand when the rhizosphere zone dries up under drought conditions. It plays multifarious roles in agriculture including soil-water retainer, nutrient and pesticide carriers, seed coating, soil erosion reducer, and food additives. It has the extraordinary ability in improving different physicochemical, hydrophysical, and biological properties of soil, simultaneously decreasing irrigation frequency, enhancing the water and nutrient use efficiencies, and increasing the yield and quality of the field, plantation, ornamental, and vegetable crops. These biodegradable materials are nontoxic to the soil, crop, and environment. Hence, the addition of the hydrogel polymer will be a promising and feasible technological tool for augmenting crop productivity.

Keywords Climate change, Temperature

1. Introduction

In the arid and semiarid climates of the world, water scarcity is a major environmental problem due to the low amount of rainfall with irregular spatial and temporal distribution restricting overall plant growth [1, 2]. In limited water supply conditions, the modern approach of water-saving deficit irrigation technologies is considered a critical component to ensure favorable soil moisture balance in the root zone with increased water use efficiency without hampering crop yield and its quality [3, 4]. Presently, the advancement of modern micro irrigation technologies such as low-pressure micro sprinkler and drip irrigation systems with optimum irrigation scheduling coupled with plastic mulching can solve the problems by reducing drastically the consumption of irrigation water and improved water use efficiency [5-7]. Another solution of the burning issues is to explore alternative irrigation technology of using highly swellable polymer materials to overcome the soil moisture stress for increasing production [8]. Recently, hydrogel polymer technology has been widely used in the agricultural sector as soil conditioner because of its multifunctional roles in excellent water absorbency and

water-retaining ability. The polymers maintain a very high water swelling and releasing capacity of moisture under water deficit conditions and consequently enhance water and nutrient use efficiency by checking evaporation loss, deep water percolation, and nutrient leaching under the arid and semiarid climates of the world by improving plant development and crop yield [9-11].

Hydrogel, popularly known as "root watering crystal," "water retention granules," or "raindrop," is a quasisolid phase amorphous material. It has three-dimensional networks of loosely held cross-linked versatile hydrophilic macromolecules interconnected by covalent bonds or physical interactions with specially designed absorbency and biodegradability. These are organic polymers and have a unique capability to absorb a large amount of moisture in their super absorbent structure within a short period when it comes in contact with freely available water. These materials desorb the stored moisture to the surrounding soil and rhizosphere zones during the soil drying process in a uniform manner over an extended period [12,13]. Having more available water in the soil helps in avoiding water stress at the time of moisture scarcity when it occurs for a longer period. The capacity of the hydrogel in capturing moisture arises from the hydrophilic functional groups attached to the polymer backbone while their resistance to dissolution arises from cross-links between network chains [14].

However, much emphasis is now given to natural polysaccharide polymers over synthetic polymers because of controlled release systems, safety to the environment, cost effectiveness, easy accessibility, and biodegradability [15]. Super absorbent hydrogels with fascinating structures and properties can be prepared from the polysaccharide with abundant hydroxyl groups. Polymer hydrogels that originated from cellulose have high absorbency, high strength, good salt resistance, nontoxicity, excellent biodegradability, which seriously hampers the sustainability of agriculture. Different physiological changes have been observed under moisture stress conditions, like reduction of water potential, stomatal closure, reduction of photosynthetic rate, morphological rate and, thus, decline yield and quality of the plant by and biocompatibility as compared with the synthetic polymer hydrogels [16]. Hydrogel forms an amorphous gelatinous mass on hydration when applied in soil, and it is capable of cyclic adsorption and desorption of water for a longer period. Hence, it is considered an effective tool in conserving adequate amounts of water quickly in soil and providing water and dissolved nutrients slowly to the plant over an extended period when the surrounding soil near the crop root zone starts drying up [17].

Functional Characteristics of a Hydrogel

The features of the ideal hydrogel materials should include the following:

- (i) The high water absorption capability. (ii) The desired rate of absorption and desorption capacity according to plant requirement. (iii) Lowest soluble content and residual monomer. (iv) High durability and stability during swelling and storage. (v) High biodegradability and biocompatibility. (vi) High performance over a wide temperature range. (vii) After swelling, water becomes neutral in pH. (viii) Colourlessness, odorlessness, and nontoxic. (ix) Upscale the soil's physical, chemical, and biological properties. (x) Photostability, rewetting capability for a long time, low-cost material, and eco-friendly.

How Do Water Retention and Release Behavior Work in a Hydrogel

- (i) The hydrophilic groups, viz., acrylamide, acrylic acid, acrylate, carboxylic acid, etc., of the polymer chain are responsible for water absorption in a hydrogel
- (ii) When the polymers come in contact with water, the water penetrates the hydrogel system by osmosis, and hydrogen atoms react and come out as positive ions
- (iii) This process leaves several negative ions along the length of the polymer chain. These negative charges repel each other and force the polymer chain to unwind and open up (Figure 1) and attract water molecules and bind them with hydrogen bonding [14]

- (iv) The hydrogel can absorb more than 400-1500 times their dry weight of water in this process and act as a miniature water reservoir. When the surrounding around the root zone begins to dry up, the hydrogel gradually dispenses up to 95% of its stored water to plant absorption [18, 19]
- (v) Under exposition to rewetting condition, rehydration starts and the process of storing water continues
- (vi) This polymer has the ability to increase water retention in soil which facilitates higher
- (vii) water uptake and water use efficiency, thus helping in reducing the water stress of plants and increasing crop growth and yield
- (viii) These undergo volume transition in response to physical and chemical stimuli depending on the prevailing environmental conditions [20]
- (ix) The hydrogels are biodegradable and decompose in the soil after working for 2-5 years and thus do not alter the physicochemical properties of the soil.

Classification of Hydrogel

Based on the source, hydrogel polymers used for agricultural purpose are classified into three types: (i) natural hydrogel, (ii) semiartificial hydrogel, and (iii) artificial hydrogel. The petroleum-based synthetic or artificial hydrogels that are mostly available in the market are categorized into three broad types based on their chemical composition and configuration as follows:

- 1) Starch-polyacrylonitrile graft polymers (starch copolymers)
- 2) Vinyl alcohol-acrylic acid copolymers (polyvinyl alcohols)
- 3) Acrylamide sodium acrylate copolymers (cross-linked polyacrylamides)

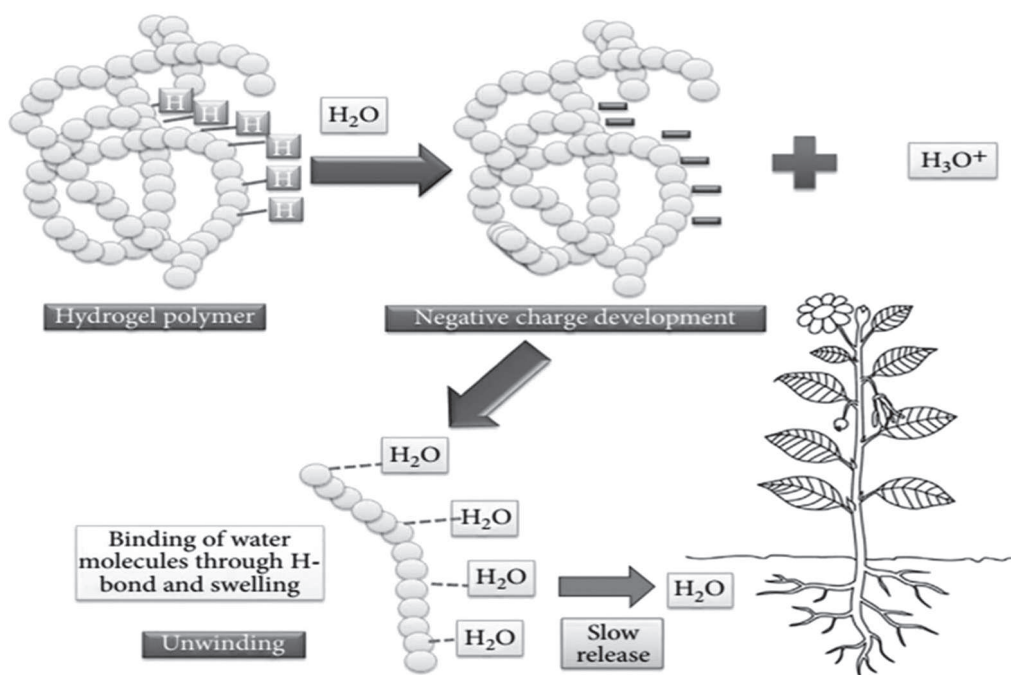


Figure 1: Mechanism of action of hydrogel upon soil-based application.

USE OF HYDROGEL IN MODERN AGRICULTURE

1. Soil Amendments.

For the improvement of soil properties, the application of suitable soil conditioners increases for a common solution [26]. Hydrogel polymers are known as hydrophilic, 3-dimensional, and cross-linked multifunctional polymers [27, 28] enabling them to hyperaccumulate excess soil-water accounts for volume hundreds of times their own weight [29]. The application of hydrogel (absorbent polymers) in agriculture is crucial because it can soak up water and make it available to plants over the long run [30]. Nowadays, hydrogel polymers are being applied as soil additives in agriculture to reduce water loss and nutrient conservation in soil and ameliorate the negative effects of dehydration and moisture stress on crops [31]. In particular, the use of hydrogel polymers in soils has several advantages, such as (i) it can absorb hundreds of times more water than its own weight and can act like a long-lasting gel [29], (ii) it can protect the soil from runoff flow, (iii) it is an effective soil fertilizer performance improver [32], and (iv) finally, it can improve the microbial activity in the soil [31]. Barakat et al. [33] have reported that problems related to conventional irrigation procedures can be bypassed with the application of some polymers. Several recent researches have reported the importance of using some hydrogel polymers to help absorb and retain water. Most importantly, hydrogel polymers can prevent water loss through percolation and act as a reservoir in the main root-zone region [34]. There are some more basic issues related to the importance of using hydrogel polymers to improve the effectiveness of soil fertilizers and increase the activity of microbial organisms in the soil. The application of hydrogel polymers can improve the physicochemical properties of the soil as well as the fertilization capacity [35]. Alternatively, the potential effects of hydrogel polymers on soil water conservation, fertilizer conservation, and reduction of their losses have also been taken under consideration [36]. Similarly, the use of hydrogel polymers plays an essential role in the growth of soil germ communities [37]. Yin et al. [38] researched recently to explore the biological effects of polyglutamic acid, an innovative hydrogel polymer component for the growth of corn and the improvement effects of beneficial soil microorganisms. The use of this organic polymer has proven that it can enhance soil conservation water, increase corn seedlings, and increase the population of plant growth-promoting microbial bacteria, such as *Bacillus*, *Pseudomonas*, and *Burkholderia* [39].

2. Reduction of Drought Stress.

Drought occurrences because of reduced water content in the soil can proceed to oxygen radicals and lipid peroxidation [40] production. This may have some detrimental effects on plant morphology, such as loss of plant height, reduction of leaf area, and ultimately leaf damage. Therefore, the application of hydrogels can serve as saving tools for higher plant growth and crop yield even in adverse climatic conditions [41]. Bearce and McCollum [42] have observed that hydrogel reduces the need for frequent irrigation and increases the shelf life of potted plants. Several researchers have reported the profit of hydrogel in horticulture; in addition, it may increase the water-holding capacity of the soil [42] and increase the water storage capacity of porous soils, reducing the chances of wilting for plants [41]. MacPhail et al.'s [43] greenhouse tests have shown the significance of using different doses of "Vitera 2 Hydrogel" to improve the survival of turfgrass and bluegrass under moisture stress conditions. Tomášková et al. [44] studied the effects of hydrogel treatment with sawdust, organic manure, compost, wheat straw, subsoil, and subsoil with a coating on the survival, growth, and physiological characteristics of 20 plant species and observed that all treatments have significantly improved drought sensitivity amongst species. They also summarized

that adding hydrogel at the time of planting is regarded to be an effective way for tree species in this region to combat high temperature and moisture stress conditions [44].

3. Enhancement of Fertilizer Availability.

Hydrogels can also be made as fertilizer components with the help of potassium and nitrogen ions. In particular, the chemicals that remain in the polymer network do not wash off immediately but are slowly released into the soil and then absorbed by the plants. Konzen et al. [45] studied the combined effects of hydrogels with different types of fertilizers based on the traditional herbaceous NPK, superphosphate, and potassium chloride and observed on *Mimosa scabrella* seedlings that their growth was increased because of higher water retention and nutrient uptake.

4. Importance of Hydrogel for Plant Performance

4.1. Seed Germination.

Hydrogel treatment has no parallel effect on seed germination [46]. Ismail et al. [47] reported that the super absorbent hydrogel composed of acrylamide and acrylic acid on starch using polyethylene glycol (PEG) has a positive effect on the germination of maize seeds and growth of young plants than seeds without hydrogel [46]. Alternatively, hydrogel-treated plants show satisfactory effects for the fresh and dried weight of leaves and roots [48]. Elshafie et al. [46] also experimented on the biological activity of some natural substances and/or antimicrobial hydrogels on the germination of seeds of *Phaseolus vulgaris* and concluded that the hydrogen gel-based oregano essential oil with the assistance of *Burkholderia gladioli* bacteria is superior in seed germinations.

4.2. Plant Growth.

The effects of different concentrations of hydrogels on Turfgrass and Baron Kentucky bluegrass were found as confirmed by MacPhail et al. [43]. They observed that seedling growth in concentrations between 0 and 50 kg per 100 m² was not negatively affected. In addition, Akhter et al. [30] concluded that the application of hydrogels has increased the plant growth by increasing the water-holding capacity of soil, particularly in sandy soils. However, Konzen et al. [45] recorded that use of hydrogel can improve the plant height, collar diameter, and fresh organic matter of *M. scabrella* seedlings under greenhouse conditions. Filho et al. [49] showed that two-stage brightness of 50% and 100% and 10 doses of hydrogel ranging between 0 and 6 g L⁻¹ for setting seedlings of *Enterolobium contortilicium* are helpful by evaluating the most appropriate dose of the hydrogel. They also found that the two tested doses of 2 and 3 g L⁻¹ showed optimal development of seedlings even in full sun and shady environments, respectively. Similarly, the application of 6 g L⁻¹ hydrogel at the level of *Corymbia citriodora* was able to improve the plant height and stem diameter by 23% [50]. In contrast, Sarvas et al. [51] registered that 7 g L⁻¹ of hydrogel per *Pinus sylvestris* led to plant death.

5. Impact of Hydrogel on Soil Microflora.

Microorganisms like bacteria, fungi, and actinomycetes populations are greatly influenced by the physical, chemical, and especially biological environments of soil which are responsible for the modification and decomposition of plant residues and other organic substrates leading to the formation of humus and release of nutrient elements to the soil for facilitating plant growth and development [52]. When the superabsorbent hydrogel polymers are incorporated in moist soil, it becomes swollen after absorbing and storing a large quantity of water and nutrients within a short period and allows the absorbed water and nutrients within it slowly to the soil, mitigating the water and nutrient requirements of the plant especially when the drought stress condition around the

rootzone periphery prevails. The peculiar water-nutrient reservoir and lending characteristics of the hydrogel polymers for the soil-plant system have been widely applied in the agricultural domain for substantial water and nutrient saving and ecological restoration [53]. Actually, the effects of superabsorbent polymers like hydrogel on the soil microbial ecosystem are not yet well understood as there is little information available about the positive effect of the superabsorbent application on the soil's biological and biochemical properties. The experimental findings of El-Hady et al. [52]

6. Novel Characteristics of Hydrogel for Agricultural Use

The hydrogels as soil conditions have the following characteristics - (i) Resistant to salt concentrations in soil (ii) Improve the physical, chemical, and biological properties of soil (iii) Promote seed germination, seedling growth, root growth, plant density, and yield (iv) Higher water absorption in water excess and gradual release under drought stress (v) Alleviate the plants from moisture stress and can tolerate prolonged moisture stress (vi) Delay onset of the permanent wilting point under intense evaporation in the arid environment (vii) Render more efficient water consumption (viii) Enhance water use efficiency by minimizing evaporation and leaching loss of water (ix) Reduce irrigation frequencies, fertilizer requirement of crop, and irrigation cost (x) Maximum stability and durability in soil (xi) No environmental hazards (xii) High performance at high temperatures (40-50°C), hence suitable for hot and dry climates.

7. Methods of Hydrogel Application in Agriculture

Hydrogels as soil conditioners are used for stabilizing surface soils to inhibit crust formation, to improve poor structure soil at greater depths by aggregation, to increase water-holding capacity, and to enhance plant growth and development. The rate of application of hydrogel in agriculture depends upon the soil texture. In clay soil, it is 2.5 kg ha⁻¹ at 6-8 cm soil depth, and for sandy soil, it is up to 5.0 kg ha⁻¹ at 4 cm soil depth. There are mainly two methods for applying hydrogels in soils: (i) Dry method to subsoil: a dry polymer such as polyallylamine (PAAm) or polyvinyl alcohol (PVA) is applied to the subsoil by mixing with sandy soil to 15-25 cm depth, moistening the soil for swelling before cultivation. After the polymer has swollen, the soil structure is improved and water penetration and retention capacity are increased (ii) Wet method to topsoil: the polymer solution is sprayed onto initially wetted topsoil, followed by drying for water-stable aggregate stability and immediate sowing. This wet method can reduce water consumption, decrease soil erosion, and increase soil hydraulic conductivity. In the spray technique, the hydrogel can also be mixed with micronutrients and pesticides

8. Benefits of Hydrogel in Agriculture

- (i) Hydrogels act as "miniature water reservoirs" near the root zone of plants. It can absorb both natural and supplied water 400-1500 times of its own weight and release it slowly on water shortage conditions by root capillary suction mechanism
- (ii) It can perform the cyclic process of absorption and desorption of water, can supply optimum plant available moisture for quick seed germination and seedling establishment, and can increase the growth and high yield of the crop
- (iii) In cold regions, the use of hydrogels does not freeze the moisture absorbed in the structure and makes easy accessibility to the plants, thereby regulating seedling growth temperature and preventing death by freezing
- (iv) It can decrease soil osmotic moisture; save irrigation water, labour, and production cost; reduce irrigation requirement of crops; mitigate drought conditions; prevent leaching and

runoff of water and nutrients; improve water and nutrient use efficiencies in plants; and restore soil microorganisms and enzymes

- (v) It can help the plant to withstand the prolonged moisture stress by delaying the onset of permanent wilting of the plant
- (vi) It can reduce the overuse of minerals including micronutrient fertilizers and pesticides
- (vii) It can prevent soil compaction, improve soil aeration, and release soil mineral nutrients
- (viii) It can enhance stronger and healthier plant growth and marketable yield

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References

- [1] J. W. L. Pereira, P. A. Melo Filho, M. B. Albuquerque, R. J. M.C. Nogueira, and R. C. Santos, "Biochemical changes in peanut genotypes submitted to moderate water stress," *Revista Ciência Agronômica*, vol. 43, no. 4, pp. 766-773, 2012.
- [2] E. Ferrari, A. Paz, and A. C. Silva, "Déficit hídrico no metabolismo da soja em semeaduras antecipadas no matogrosso," *Nativa*, vol. 3, no. 1, pp. 67-77, 2015.
- [3] L. S. Pereira, T. Oweis, and A. Zairi, "Irrigation management under water scarcity," *Agricultural Water Management*, vol. 57, no. 3, pp. 175-206, 2002.
- [4] P. Panigrahi, N. N. Sahu, and S. Pradhan, "Evaluating partial root-zone irrigation and mulching in okra (*Abelmoschus esculentus* L.) under a sub-humid tropical climate," *Journal of Agriculture and Rural Development in the Tropics and Subtropics*, vol. 112, no. 2, pp. 169-175, 2011.

-
- [5] S. Brahma, D. B. Phookan, M. Kachari, T. K. Hazarika, and K. Das, "Growth, yield and economics of broccoli under different levels of nitrogen fertigation," *Indian Journal of Horticulture*, vol. 67, no. 4, pp. 279-282, 2010.
- [6] M. H. Abd El-Wahed and E. A. Ali, "Effect of irrigation systems, amounts of irrigation water and mulching on corn yield, water use efficiency and net profit," *Agricultural Water Management*, vol. 120, no. 31, pp. 64-71, 2013.
- [7] G. Deshmukh and M. K. Hardaha, "Effects of irrigation and fertigation scheduling under drip irrigation in papaya," *Journal of AgriSearch*, vol. 1, no. 4, pp. 216-220, 2014.
- [8] S. Keivanfar, R. F. Ghazvini, M. Ghasemnezhad, A. Mousavi, and M. R. Khaledian, "Effects of regulated deficit irrigation and superabsorbent polymer on fruit yield and quality of 'Granny Smith' apple," *Agriculturae Conspectus Scientificus*, vol. 84, no. 4, pp. 383-389, 2019.
- [9] K. J. Bedi and F. Sohrab, "Evaluation of super absorbent polymer application on water holding capacity and potential in three soil type," *Journal of Science and polymer Technology*, vol. 3, pp. 163-173, 2004.
- [10] W. Abobatta, "Impact of hydrogel polymer in agricultural sector," *Advances in Agriculture and Environmental Science*, vol. 1, no. 2, pp. 59-64, 2018.
- [11] A. K. Saini, A. M. Patel, L. H. Saini, and S. H. Malve, "Growth, phenology and yield of summer pearl millet (*Pennisetum glaucum* L.) as affected by varied application of water, nutrients and hydrogel," *International Journal of Ecology and Environmental Sciences*, vol. 2, no. 3, pp. 248-252, 2020.
- [12] M. Sayyari and F. Ghanbari, "Effects of super absorbent polymer A200 on the growth, yield and some physiological responses in sweet pepper (*Capsicum annuum* L.) under various irrigation regimes," *International Journal of Agricultural and Food Research*, vol. 1, no. 1, 2012.
- [13] G. S. Gaikwad, S. C. Vilhekar, P. N. Mane, and E. R. Vaidya, "Impact of organic manures and hydrophilic polymer hydrogel on conservation of moisture and sunflower production under rainfed condition," *Advance Research Journal of Crop Improvement*, vol. 8, no. 1, pp. 31-35, 2017.
- [14] A. Kalhapure, R. Kumar, V. P. Singh, and D. S. Pandey, "Hydrogels: a boon for increasing agricultural productivity in water-stressed environment," *Current Science*, vol. 111, no. 11, pp. 1773-1779, 2016.
- [15] S. S. Ahmed and A. H. Fahmy, "Applications of natural polysaccharide polymers to overcome water scarcity on the yield and quality of tomato fruits," *Journal of Soil Sciences and Agricultural Engineering*, vol. 10, no. 4, pp. 199-208, 2019.
- [16] J. Li, M. Jiang, H. Wu, and Y. Li, "Addition of modified bentonites in polymer gel formulation of 2, 4-D for its controlled release in water and soil," *Journal of Agricultural and Food Chemistry*, vol. 57, no. 7, pp. 2868-2874, 2009.
- [17] F. Yazdani, I. Allahdadi, and G. A. Akbari, "Impact of superabsorbent polymer on yield and growth analysis of soybean (*Glycine max* L.) under drought stress condition," *Pakistan Journal of Biological Sciences*, vol. 10, no. 23, pp. 4190-4196, 2007.

-
- [18] D. Peterson, "Hydrophilic polymers - effects and uses in the landscape," *Restoration and Reclamation Review*, vol. 75, 2002.
- [19] M. S. Johnson and C. J. Veltkamp, "Structure and functioning of water-storing agricultural polyacrylamides," *Journal of Science and Food Agriculture*, vol. 36, no. 9, pp. 789-793, 1985.
- [20] E. M. Ahmed, "Hydrogel: preparation, characterization, and applications: a review," *Journal of Advanced Research*, vol. 6, no. 2, pp. 105-121, 2015.
- [21] R. L. Mikkelsen, "Using hydrophilic polymers to control nutrient release," *Fertilizer Research*, vol. 38, no. 1, pp. 53-59, 1999.
- [22] R. A. Azzam, "Agricultural polymers. Polyacrylamide preparation, application and prospects in soil conditioning," *Communications in Soil Science and Plant Analysis*, vol. 11, no. 8, pp. 767-834, 1980.
- [23] J. Abedi-Koupai, F. Sohrab, and G. Swarbrick, "Evaluation of hydrogel application on soil water retention characteristics," *Journal of Plant Nutrition*, vol. 31, no. 2, pp. 317-331, 2008.
- [24] M. Yangyuru, E. Boateng, S. G. K. Adiku, D. Acquah, T. A. Adjadeh, and F. Mawunya, "Effects of natural and synthetic soil conditioners on soil moisture retention and maize yield," *Journal of Applied Ecology*, vol. 9, no. 1, 2009.
- [25] A. A. Soubeih Kh, "Effect of fertilizer packages and polymers on onion yield and quality under Bahariya Oasis conditions," *Middle East Journal of Agriculture Research*, vol. 7, no. 4, pp. 1769-1785, 2018.
- [26] A. K. Bhardwaj, I. Shainberg, D. Goldstein, D. N. Warrington, and J. G. Levy, "Water retention and hydraulic conductivity of cross-linked polyacrylamides in sandy soils," *Soil Science Society of America Journal*, vol. 71, no. 2, pp. 406-412, 2007.
- [27] F. L. Buchholz, "The structure and properties of super absorbents polyacrylates," in *Buchholz and Graham. Modern Superabsorbent Polymer Technology*, pp. 167-221, John Wiley Sons Inc., Hoboken, NJ, USA, 1998.
- [28] L. Yang, Y. Han, P. Yang et al., "Effects of superabsorbent polymers on infiltration and evaporation of soil moisture under point source drip irrigation," *Irrigation and Drainage*, vol. 64, no. 2, pp. 275-282, 2015.
- [29] N. Thombare, S. Mishra, M. Siddiqui, U. Jha, D. Singh, and G. R. Mahajan, "Design and development of guar gum based novel, superabsorbent and moisture retaining hydrogels for agricultural applications," *Carbohydrate Polymers*, vol. 185, pp. 169-178, 2018.
- [30] J. Akhter, K. Mahmood, K. Malik, A. Mardan, M. Ahmad, and M. Iqbal, "Effects of hydrogel amendment on water storage of sandy loam and loam soils and seedling growth of barley, wheat and chickpea," *Plant, Soil and Environment*, vol. 50, no. 10, pp. 463-469, 2011.
- [31] R. Nagaraj Gokavi, K. Mote, D. S. Mukharib, A. N. Manjunath, and Y. Raghuramulu, "Performance of hydrogel on seed germination and growth of young coffee seedlings in nursery," *Journal of Pharmacognosy and Phytochemistry*, vol. 7, pp. 1364-1366, 2018.
- [32] J. Scott and G. Blair, "Phosphorus seed coatings for pasture species. I. Effect of source and rate of phosphorus on emergence and early growth of phalaris (*Phalaris aquatica* L.) and lucerne

- (*Medicago sativa* L.)," Australian Journal of Agricultural Research, vol. 39, no. 3, pp. 437-445, 1988.
- [33] M. R. Barakat, S. El-Kosary, T. I. Borham, and M. H. AbdElNafea, "Effect of hydrogel soil addition under different irrigation levels on grandnain banana plants," Journal of Horticultural Science & Ornamental Plants, vol. 7, no. 1, pp. 19-28, 2015.
 - [34] U. K. Mandal, K. L. Sharma, K. Venkanna et al., "Evaluating hydrogel application on soil water availability and crop productivity in semiarid tropical red soil," Indian Journal of Dryland Agricultural Research and Development, vol. 30, no. 2, pp. 1-10, 2015.
 - [35] A. E. Eneji, R. Islam, P. An, and U. Amalu, "Nitrate retention and physiological adjustment of maize to soil amendment with superabsorbent polymers," Journal of Cleaner Production, vol. 52, pp. 474-480, 2013.
 - [36] Y. Han, X. Yu, P. Yang, B. Li, L. Xu, and C. Wang, "Dynamic study on water diffusivity of soil with super-absorbent polymer application," Environment and Earth Science, vol. 69, no. 1, pp. 289-296, 2013.
 - [37] G. Chaithra and S. Sridhara, "Growth and yield of rainfed maize as influenced by application of super absorbent polymer and Pongamia leaf mulching," International Journal of Chemical Studies, vol. 6, pp. 426-430, 2018.
 - [38] A. Yin, Y. Jia, T. Qiu et al., "Poly- γ -glutamic acid improves the drought resistance of maize seedlings by adjusting the soil moisture and microbial community structure," Applied Soil Ecology, vol. 129, pp. 128-135, 2018.
 - [39] F. Yang, R. Cen, W. Feng, J. Liu, Z. Qu, and Q. Miao, "Effects of super-absorbent polymer on soil remediation and crop growth in arid and semi-arid areas," Sustainability, vol. 12, no. 18, p. 7825, 2020.
 - [40] Y. T. Wang and L. L. Gregg, "Hydrophilic polymers-their response to soil amendments and effect on properties of a soilless potting mix," Journal of the American Society for Horticultural Science, vol. 115, no. 6, pp. 943-948, 1990.
 - [41] K. C. Taylor and R. G. Halfacre, "Hydrophilic polymer effect on nutrient and water availability to *Ligustrum lucidum* 'compactum' grown in pine bark medium," Horticultural Science, vol. 18, 1986.
 - [42] B. C. Bearce and R. W. Mccollum, "A comparison of peat-like and noncomposted hardwood-bark mixes for use in pot and bedding-plant production and the effects of a new hydrogel soil amendment on their performance," Florists' Review, vol. 161, pp. 21-66, 1997.
 - [43] J. M. MacPhail, J. L. Emens, P. M. Harney, and M. J. Tsujita, "Effect of viterra 2 hydrogel on germination; seedling growth and sod establishment of Kentucky blue-grass," Canadian Journal of Plant Science, vol. 60, no. 2, pp. 665-668, 1980.
 - [44] I. Tomášková, M. Svatoš, J. Mack? et al., "Effect of different soil treatments with hydrogel on the performance of drought-sensitive and tolerant tree species in a semi-arid region," Forests, vol. 11, no. 2, 2020.
 - [45] E. R. Konzen, M. C. Navroski, G. Friederichs, L. H. Ferrari, M. D. O. Pereira, and D. Felipe, "The use of hydrogel combined with appropriate substrate and fertilizer improve quality and growth performance of *Mimosa scabrella* benth. seedlings," Cerne, vol. 23, no. 4, pp. 473-482, 2017.

-
- [46] H. S. Elshafie, M. Nuzzaci, G. Logozzo, T. Gioia, and I. Camele, "Biological investigations of hydrogel formulations based on bioactive natural agents against some common phytopathogens of *Phaseolus vulgaris* L. and seed germination," *Journal of Biological Research*, vol. 3, pp. 114-122, 2020.
- [47] H. Ismail, M. Irani, and Z. Ahmad, "Starch-based hydrogels: present status and applications," *International Journal of Polymeric Materials*, vol. 62, no. 7, pp. 411-420, 2013.
- [48] L. Cheng, S. J. Muller, and C. J. Radke, "Wettability of silicone-hydrogel contact lenses in the presence of tear-film components," *Current Eye Research*, vol. 28, no. 2, pp. 93-108, 2004.
- [49] R. A. P. Filho, F. A. Gondim, and M. C. G. Costa, "Seedling growth of tree species under doses of hydrogel and two levels of luminosity," *Revista Árvore*, vol. 42, no. 1, article 420112, 2018.
- [50] M. R. Bernardi, M. Sperotto-Junior, O. Daniel, and A. C. T. Vitorino, "Crescimento de mudas de *Corymbia citriodora* em função do uso de hidrogel e adubação," *Cerne*, vol. 18, no. 1, pp. 67-74, 2012.
- [51] M. Sarvas, P. Pavlenda, and E. Takáčová, "Effect of hydrogel application on survival and growth of pine seedlings in reclamation," *Journal of Forest Science*, vol. 53, no. 5, pp. 203-209, 2008.
- [52] O. El-Hady, S. A. Abo-Sedera, A. H. Basta, and H. El-Saied, "The role of rice straw-based hydrogels on some soil microorganisms strains," *Bio*, vol. 1, no. 1, pp. 78-84, 2011.
- [53] X. Li, J.-Z. He, Y.-R. Liu, and Y.-M. Zheng, "Effects of superabsorbent polymers on soil microbial properties and Chinese cabbage (*Brassica chinensis*) growth," *Journal of Soils and Sediments*, vol. 13, no. 4, pp. 711-719, 2013.
- [54] J. Achtenhagen and R. Kreuzig, "Laboratory tests on the impact of superabsorbent polymers on transformation and sorption of xenobiotics in soil taking ¹⁴C-imazalil as an example," *Science of the Total Environment*, vol. 409, no. 24, pp. 5454-5458, 2011.
- [55] E. Karadag, D. Saraydin, Y. Caldiran, and O. Guven, "Swelling studies of copolymeric acrylamide/crotonic acid hydrogels as carriers for agricultural uses," *Polymers for Advanced Technologies*, vol. 11, no. 2, pp. 59-68, 2000.
- [56] P. Baldrian and V. Valaskova, "Degradation of cellulose by basidiomycetous fungi," *FEMS Microbiology Reviews*, vol. 32, no. 3, pp. 501-521, 2008.
- [57] Y. Yang, H. Wang, L. Huang et al., "Effects of superabsorbent polymers on the fate of fungicidal carbendazim in soils," *Journal of Hazardous Materials*, vol. 328, pp. 70-79, 2017.
- [58] E. Barrios, "Soil biota, ecosystem services and land productivity," *Ecological Economics*, vol. 64, no. 2, pp. 269-285, 2007.
- [59] A. C. Kennedy and K. L. Smith, "Soil microbial diversity and the sustainability of agricultural soils," *Plant and Soil*, vol. 170, no. 1, pp. 75-86, 1995.
- [60] B. Šarapatka, L. Rak, and I. Bubenikova, "The effect of hydroabsorbent on selected soil biological and biochemical characteristics and its possible use in revitalization," *Ekologia*, vol. 25, no. 4, pp. 422-429, 2006.

-
- [61] A. Suman, P. Verma, A. N. Yadav, R. Srinivasamurthy, A. Singh, and R. Prasanna, "Development of hydrogel-based bio-inoculant formulations and their impact on plant biometric parameters of wheat (*Triticum aestivum* L.)," *International Journal of Current Microbiology and Applied Sciences*, vol. 5, no. 3, pp. 890-901, 2016.
- [62] Z. Moslemi, D. Habibi, A. Asgharzadeh, M. R. Ardakani, A. Mohammadi, and A. Sakari, "Effects of super absorbent polymer and plant growth promoting rhizobacteria on yield and yield components of maize under drought stress and normal conditions," *African Journal of Agricultural Research*, vol. 6, no. 19, pp. 4471-4476, 2011.
- [63] P. C. Parvathy, A. N. Jyothi, K. S. John, and J. Sreekumar, "Cassava starch based superabsorbent polymer as soil conditioner: impact on soil physico-chemical and biological properties and plant growth," *Clean-Soil, Air, Water*, vol. 42, no. 11, pp. 1610-1617, 2014.
- [64] C. R. Johnson and R. L. Hummel, "Hydrophylic polymers as a carrier for VA mycorrhizal inoculum," *Journal of Environmental Horticulture*, vol. 3, no. 4, pp. 166-168, 1985.
- [65] S. J. Kohls, D. D. Baker, D. A. Kremer, and J. O. Dawson, "Water-retentive polymers increase nodulation of actinorhizal plants inoculated with *Frankia*," *Plant and Soil*, vol. 214, no. 1/2, pp. 105-115, 1999.
- [66] V. T. H. Pham, P. Murugaraj, F. Mathes et al., "Copolymers enhance selective bacterial community colonization for potential root zone applications," *Scientific Reports*, vol. 7, no. 1, article 15902, 2017.
- [67] T. M. Neethu, P. K. Dubey, and A. R. Kaswala, "Prospects and applications of hydrogel technology in agriculture," *International Journal of Current Microbiology and Applied Sciences*, vol. 7, no. 5, pp. 3155-3162, 2018.
- [68] A. Rehman, R. Ahmad, and M. Safdar, "Effect of hydrogel on the performance of aerobic rice sown under different techniques," *Plant, Soil and Environment*, vol. 57, no. 7, pp. 321-325, 2011.

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The prime objective of the Pragna Sabha is to bring the intellectuals and scholars across the nation together and channelize their intellectual potential to strengthen the nation.

There is a popular belief among the people in our country that the first ray of light, in the sense of knowledge and research, appeared in the west and a process of development got initiated there and from there it went to the other parts of the world. This implied that there was darkness elsewhere and the west brought light to them. It led to another belief also that we did not have any tradition of knowledge and scientific study, because we had no vision of research and hence, we are indebted to the west only for the development as it is visible today here. This led us to mimic the west, because we perceived it as superior in every respect. To follow the west became a characteristic of the progressive and scientific temperament, while sticking to any native tradition came to be perceived as backwardness, orthodoxy and medieval thinking.

However, the facts are altogether different. In the hand the early century, our forefathers had proved through their deep study that India was on the top not only in the fields of philosophy and spirituality, but also in the fields of science and technology. Our ancient scholars, whom we call Rushies, had actually coordinated science and spirituality very well for the benefit of common masses. That had developed scientific temperament among them and that had internalized in them a bio-culture/environment friendly life style, the direct need of which is felt by the entire world today. As of now, many scholars have brought out before the intellectuals of the world the facts of ancient Indian sciences through various books and articles supported with strong evidences.

The Orientalist studies by the early European scholars had in a way established India for her intellectual prosperity and diversified studies in various domains of knowledge. They very well knew that India had solutions to all major critical issues of humanity in their knowledge systems like economics, psychology, technology, health in wider senses, medicine, transportation, agriculture, management, military and weaponry science, education, happiness science, ethics, administration, trade and industry, animal husbandry etc.

In the current context, it is essential to bring those efforts before our people and generate a new sense of pride among them. The assumed inferiority complex on our part has given rise to many issues, which may prove to be unmanageable in future, if not addressed right now. Pragna Sabha is an organization striving to resolve various problems of the society by bringing together the sincere researchers and applying their expertise to address various issues plaguing the society.

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