Seasonal Variations and Water Quality Dynamics: Analysis of Kanota Dam in Relation to WHO Standards

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Seasonal Variations and Water Quality Dynamics:Analysis of Kanota Dam in Relation to WHO Standards

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Abstract: This study evaluates seasonal water quality changes at Kanota Dam and the impact of the COVID-19 pandemic, focusing on the interplay between environmental factors and pandemic-induced changes. To analyze and compare water quality during pre-monsoon, post-monsoon, and pandemic periods, highlighting deviations and their implications for water management. Five sample locations were used to measure indicators of water quality, such as Turbidity, Conductivity, Total dissolved solids (TDS), pH, Chloride, Hardness, and Biological markers. Additionally, the study examined how land usage changed between 2017 and 2023.Post-monsoon showed decreased Turbidity (21.2 NTU to 16.6 NTU) and increased TDS and conductivity (685 mg/L and 385 µmho/cm to 715 mg/L and 410 µmho/cm, respectively). During the pandemic, conductivity dropped to 1590 µmho/cm from 2200 µmho/cm in April 2019, Biochemical Oxygen Demand (BOD) increased from 7.68 mg/L to 9.29 mg/L, indicating a rise in organic pollution, while total coliforms and dissolved oxygen levels slightly decreased. Seasonal variations significantly affect water quality, with notable changes during the COVID-19 pandemic, including reduced microbial contamination but increased organic pollution. The study highlights the need for adaptive water management to address the pandemic's indirect ecological effects as well as upcoming planning difficulties pertaining to water resources.

Keywords: Water Quality, Seasonal Variations, Kanota Dam, Environmental Management, Turbidity, Conductivity,TDS

1. Introduction

Since ancient times, dams have been built to meet the needs of different civilizations[1]**.** Constructing dams is a strategy for adapting to climate change[2]**.** A strong connection exists between huge dams and societal development, particularly regarding water, food, and energy consumption[3]. The crucial significance of large dams in supporting societies has been acknowledged[4]**.** The water quality in natural reservoirs is influenced by a wide range of environmental factors, including seasonal fluctuations and human activity[5], highlighting its crucial importance in supporting ecosystems, agriculture, human health, and industrial operations[6][7].The significance of water quality cannot be overstated, given its direct impact on ecosystems, agriculture, human health, and industry[8][9]. Seasonal variations have a notable effect on water quality[10]. Before the monsoon season, water levels decrease, and pollutant concentrations rise due to reduced dilution. During the monsoon season, contaminants are diluted, but additional pollutants and nutrients from runoff are introduced[11][12][13]. The post-monsoon period displays these effects as ecosystems strive for equilibrium.

Evaluating water quality across different seasons involves assessing a range of parameters. Physical indicators like turbidity and Total Dissolved Solids (TDS) reflect the presence of particulate matter and solutes, while chemical parameters, such as pH and conductivity, offer insights into the water's chemical composition and its ionic content. Biological indicators, including Dissolved Oxygen (DO), Biological Oxygen Demand (BOD), and total coliform counts, are crucial for assessing physical activity and potential contamination by organic and fecal matter[14)15)]. Arab et al. (2019) conducted significant research linking phytoplankton diversity to seasonal nutrient changes, highlighting the influence of human activities on aquatic communities[16)17)]. The study by Tokatlı et al. 2021 reveals that the COVID-19 lockdown significantly improved water quality in Turkey's Meriç-Ergene River Basin by reducing metal(loid) pollution, especially near industrial areas, emphasizing the need for effective water management policies[18)]. Raza et al. 2022 study highlights how COVID-19 has indirectly worsened water quality due to the heightened use of sanitizers and soaps, leading to increased water consumption and wastewater generation. It underscores the urgency for improved wastewater treatment and comprehensive water management to safeguard water resources during and after the pandemic[19)]. Abualhaija et al. 2022 found that the COVID-19 lockdown improved irrigation water quality and reduced pollution in six Jordanian dams due to decreased human activities[20)].

Studies by Singh Sinsinwar et al. (2023) and Ouyang et al. (2006) have emphasized maintaining ideal pH levels in water treatment procedures. They have shown the efficiency of different treatment techniques in attaining pH values close to neutral[21)22)]. Furthermore, investigations into the ecological effects of infrastructural developments and climate changes, such as those conducted by Moldakhanova et al. (2023) and Fovet et al. (2020), highlight the need for ongoing monitoring and management of water resources to mitigate adverse impacts on ecosystems[23)24)]. Research by Rahman Caesar et al. (2023) on the contamination of the Porong Emphasizes the detrimental effects of heavy metals on aquatic life, showcasing the urgency for pollution mitigation measures[25)].

Numerous studies have shown how anthropogenic and natural elements interact dynamically to affect water quality, highlighting seasonal fluctuations and the effects of human activity on aquatic ecosystems. Notably, the study by Woldeab et al. (2018) showed notable seasonal changes in the water quality requirements of the Gilgel Gibe reservoir, highlighting the critical need for integrated watershed management to lower the risks of siltation and eutrophication[26)]. Rahman Caesar et al. (2023) studied heavy metal contamination in Indonesia's Porong River and its impact on water fish immune responses. The research, motivated by the river's exposure to urban, industrial, and agricultural activities, included water quality assessment, plankton analysis, and heavy metal exposure tests. The findings demonstrated pollution with metals like Pb, Cd, Hg, and Cu beyond safety limits, and every fish tested showed immunological responses to IL-1β, suggesting that pollution has a major negative influence on health [27)].

Further research, such as the investigation by Wardani et al. (2023), showcases the potential of white rot fungi to significantly reduce organic pollutants in the Sentiong River, offering a promising approach to environmental remediation[15)]. Moreover, Ngoc et al. (2023) contributed to the field of hydrology by developing an accurate model for water flow prediction through Piano Key Weirs, enhancing river basin management[28)]. Ortiz et al. (2007) adopted a sustainable environmental approach to water treatment, emphasising the need to reduce electricity usage and encouraging the use of renewable energy sources to reduce the environmental impact of water treatment plants[29)].

Ibrahim's 2022 study explores the COVID-19 pandemic's impact on the water sector, focusing on water availability, virus transmission through water, and environmental effects of treatments. It discusses wastewater concerns, offers techniques for detecting viruses in water, and lists the benefits and drawbacks of the pandemic for water management. In order to better prepare for the future, the report offers recommendations for improving pandemic response in the water industry[30)].

Hou et al.(2022) examined water quality variations in the Sunxi River watershed, Three Gorges Reservoir Area, from 2018 to 2021. They discovered that pollutant levels—chemical oxygen demand, total nitrogen, and total phosphorus—were consistently higher downstream and peaked during spring and summer. The study identified electrical conductance, dissolved oxygen, and water temperature as key factors influencing these variations, highlighting the need for focused water quality management in warmer months and downstream areas[31)]. Martinez-Tavera et al. (2017) investigated seasonal variations in water quality parameters of the Atoyac River basin in Central Mexico using multivariate statistical techniques. They found significant contamination from nearby industrial, agricultural, and urban areas, with extreme variations in pH, conductivity, and suspended solids across different seasons. The study highlights the potential of these techniques in guiding effective monitoring and restoration efforts for the river[32)]. Tiwari et al. (2022) investigate how dam construction on the Bhagirathi River affects water quality and fish populations, emphasizing seasonal impacts on key parameters like dissolved oxygen and turbidity. They highlight the detrimental effects on downstream fish habitats and advocate for sustainable management practices to support both local economies and ecological health[33)]. In their 2010 study, Nhiwatiwa and Marshall analyzed how hydrology affects water quality and plankton dynamics in two small dams on Zimbabwe's Munwahuku River. They found significant seasonal variations in water chemistry and plankton communities, influenced by water level fluctuations and retention times. High phosphorus levels suggested a risk of Cyanophyta colonization. The study emphasized the critical role of hydrological factors in determining plankton dynamics in small dams[34)].

Akutteh et al. (2022) studied contaminant dynamics in surface water at Weija, Ghana (2002-2016), using statistical analyses to compare physicochemical parameters of raw and treated water. The study revealed high variability in color, conductivity, and nutrients, with significant water quality deterioration from anthropogenic activities. Seasonal changes also affected water treatment costs. The findings are crucial for developing strategies to mitigate surface water pollution[35].

Despite extensive studies on water quality in dam reservoirs, there remains a significant gap in understanding the integrated effects of climatic conditions, particularly monsoon impacts, combined with human activities on water quality during a pandemic. Previous research has primarily focused on isolated impacts without considering the confluence of these factors under the extraordinary conditions of a global health crisis.

This study introduces a novel approach by examining the interplay between seasonal variations, pandemic-induced changes, and anthropogenic influences on water quality at Kanota Dam. It uniquely incorporates the analysis of pandemic periods alongside typical seasonal cycles, using advanced multivariate statistical techniques to dissect the underlying factors influencing water quality changes.

The significance of this research lies in its timely focus on understanding how extraordinary events, such as a pandemic, interact with natural seasonal cycles to affect water quality. This is crucial for developing more resilient water management strategies that can adapt to both expected seasonal changes and unexpected global events, ensuring the sustainability of water resources in crisis situations.

Taking into account the WHO's recommendations for water consumption, the quality of the water in Kanota Dam was investigated. It examines the impact of natural seasonal variations and the COVID-19 pandemic on water quality, aiming to understand how reduced industrial activity during the pandemic has affected the dam's water. The research objectives include evaluating seasonal water quality changes and assessing the pandemic's impact. The findings will provide insight into public health, policy-making, and the management of water resources. They will also help develop adaptable techniques for handling seasonal variations and responding to global emergencies.This study bridges environmental science, public health, and crisis management, offering a comprehensive view of how human activities and natural processes jointly influence water quality amidst the pandemic.

2. Study Area

Kanota Dam, located northeast of Jaipur, was completed in 2001 and is crucial for irrigation and water storage, with a capacity of 52 million cubic meters[36]. This area merges natural landscapes and urban development, making it vital for studying water quality impacts due to its diverse ecosystem and subtropical climate. The dam experiences varied seasonal weather patterns that significantly affect its water quality, influenced by rainfall, temperature, and runoff changes. Water samples are collected from five strategic points around the dam to analyze the effects of these environmental factors comprehensively. This setup provides insights into the interaction between natural and anthropogenic activities, highlighting the dam’s importance in regional water management. For the purpose of this analysis, water samples were collected from five strategic locations, denoted as A, B, C, D, and E. Figure 2 illustrates the variations in water quality within the dam and its inflowing channels. These locations were picked based on how well they could represent the various water input sources and uses for the water from the dam. The northern inlet, or point A, is where water enters the dam from the upstream catchment.This point often receives runoff from agricultural land and is likely to show seasonal variations in nutrient concentrations and turbidity levels. Point B is situated near the dam's center and is influenced by the open water body's conditions. It is an ideal point for monitoring parameters like DO, BOD, and TDS, which reflect the overall condition of the dam's aquatic ecosystem. Point C is on the western shore, close to a recreational area. This point is included to assess the impact of human activities, such as fishing and boating, on the water quality, especially concerning coliform counts and potential organic pollution. Point D is situated close to the dam wall at the southernmost point of the dam.This region is critical for understanding the sediment deposition patterns and the effects of water withdrawal for irrigation and other purposes. Point E is positioned at the eastern inlet, with an inflow from a more minor tributary. This point is crucial for determining the impact of potential point source pollution from nearby urban areas, including changes in conductivity and trace metal concentrations.

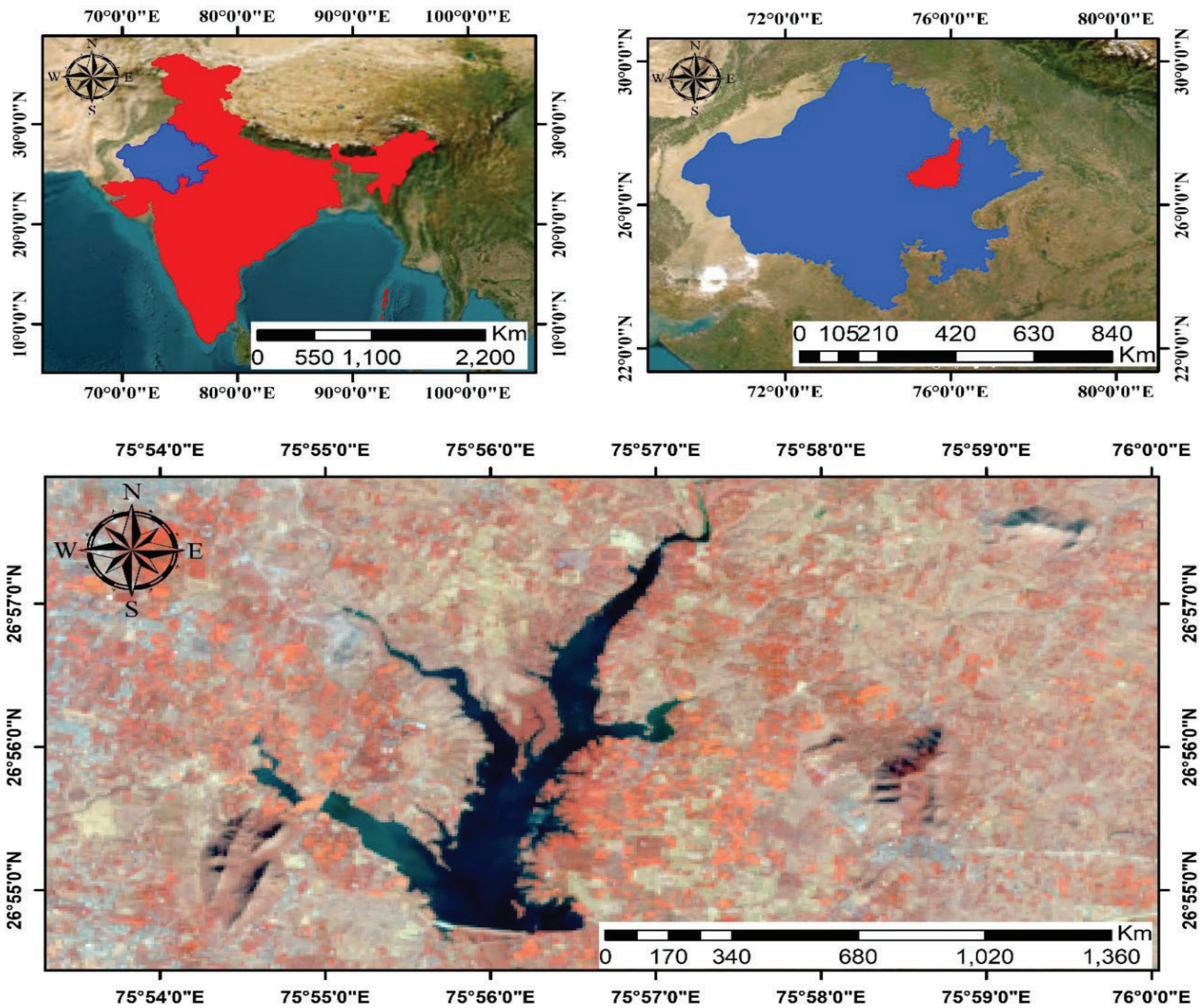

Fig. 1: Study Area Map of Kanota Dam

Table 1 Geographic Coordinates of Sample Collection Points at Kanota Dam

Point	Latitude	Longitude
A	26°54'51.40"N	75°55'40.42"E
B	26°55'32.91"N	75°55'0.99"E
C	26°56'30.28"N	75°55'47.70"E
D	26°57'0.30"N	75°56'51.75"E
E	26°55'52.91"N	75°56'25.46"E

Table 1 provides the exact geographic coordinates of the five sampling locations at Kanota Dam, labeled from A to E. These coordinates are crucial for referencing the specific areas within the dam's study region where water samples were collected, enhancing the clarity and reproducibility of the research. This detailed positioning aids in understanding the spatial distribution of water quality measurements taken for the study as shown in Fig. 2.

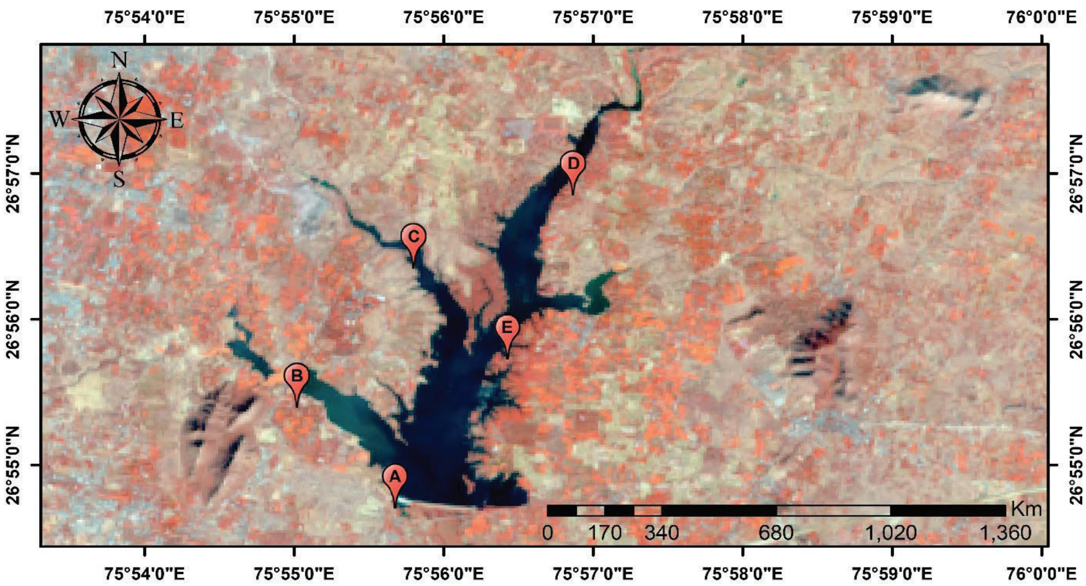

Fig. 2: Study Area Kanota Dam, highlighting sample collection points.

3. Research Methodology

The methodology was initiated by acquiring two pivotal datasets. Data on water quality from five different sampling sites and LULC data from ESRI, as shown in Fig. 3. LULC data was procured to discern the landscape alterations near Kanota Dam over six years, from 2017 to 2023. At the same time, Water Quality Data was carefully collected from five distinct sources.This entailed the measurement of turbidity, pH, chloride levels, and TDS to determine adherence to WHO standards. Furthermore, the study encompassed an extensive examination of trace metal concentrations and biological constituents of the dam's water to portray an all-encompassing water quality scenario. Following the data collection phase, an in-depth processing and analytical phase ensued, focusing on the water quality parameters mentioned previously concerning WHO standards. A comparative evaluation of the water quality at a number of dam monitoring stations located throughout Rajasthan during the COVID-19 pandemic was included in the scope of the analysis, which was expanded to include this evaluation. In the midst of a global crisis, this comparison provided an incisive look at how human activity affects water quality. After the analysis, recommendations were formulated, focusing on water management strategies to mitigate the identified challenges and enhance the aquatic ecosystem's integrity surrounding Kanota Dam.

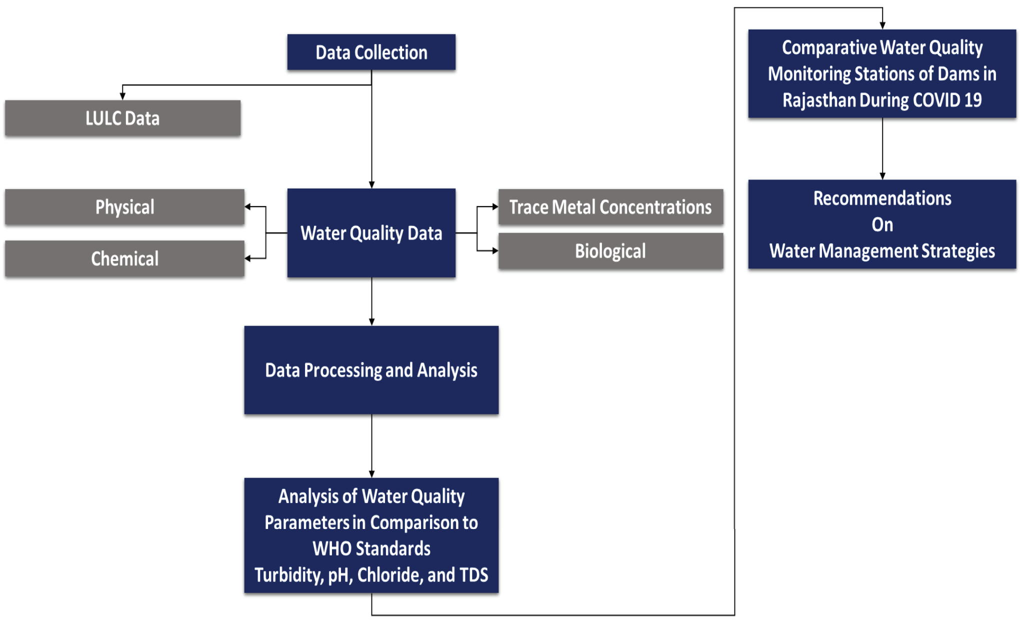

Fig. 3: Flow chart of the methodology used in this study, detailing the steps from data collection to analysis for water quality assessment at Kanota Dam

4. Result and Discussion

4.1 LULC map between 2017 and 2023

The LULC data between 2017 and 2023 showed considerable shifts around Kanota Dam, as shown in Fig. 4. Land cover changes between 2017 and 2023, showing an expansion of water bodies from 29.301 to 40.783 hectares and vegetation cover from 5.789 to 9.099 hectares, suggesting enhanced water conservation and vegetation growth.Conversely, cropland has decreased from 361.287 to 298.603 hectares, which may reflect agricultural shifts or urbanization, supported by the increase in built-up areas from 65.901 to 99.471 hectares as shown in Fig. 5.

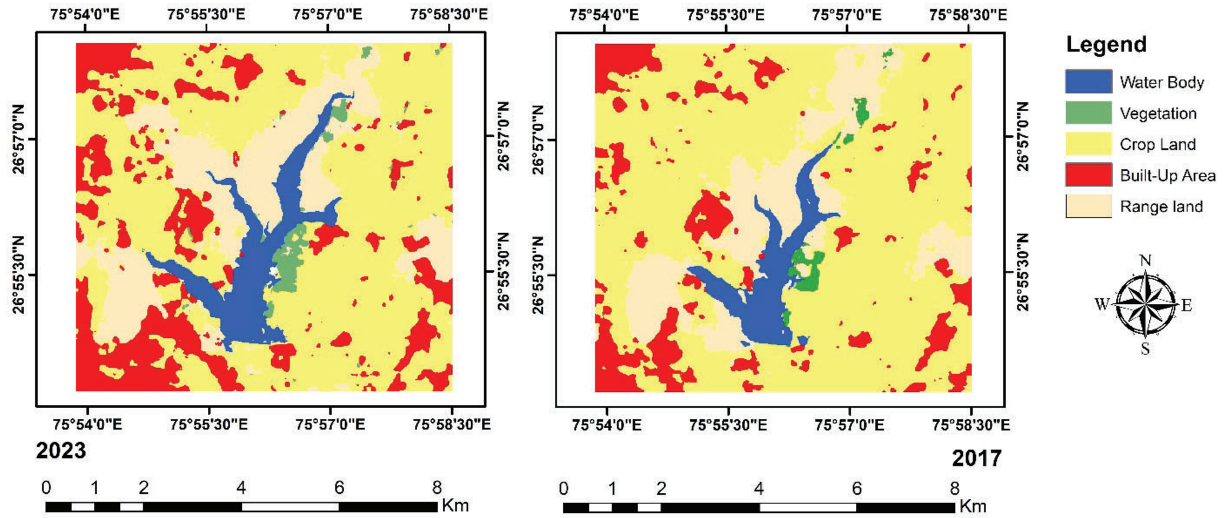

Fig. 4: Land Use and Land Cover Changes at Kanota Dam, 2017-2023

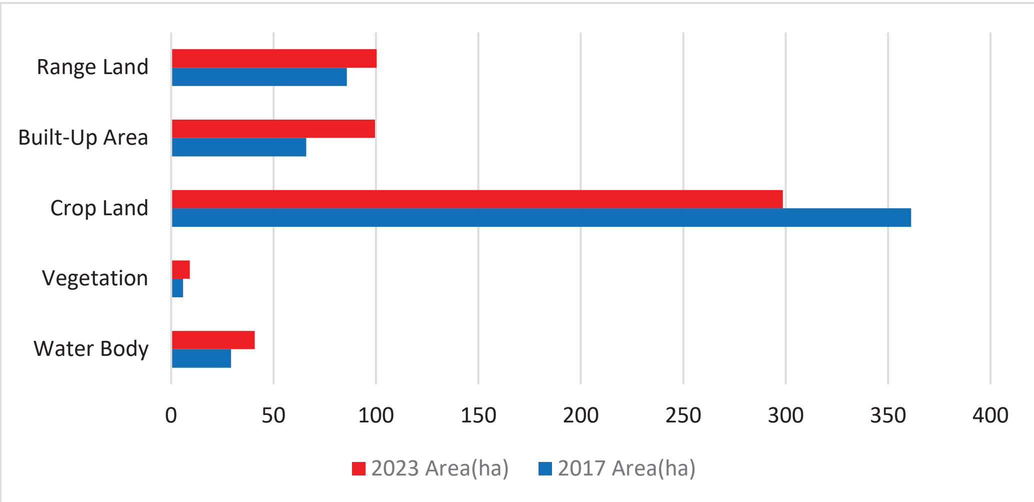

Fig. 5: Comparative graph showing the area(ha) change of different class

Additionally, rangeland has grown from 85.828 to 100.268 hectares, indicating a possible increase in grazing areas or natural range expansion.These alterations show significant anthropogenic and ecological dynamics during the preceding six years.

4.2 Comparative Analysis of Kanota Dam Parameters of Water Quality Throughout the Year

This study examined a number of important factors in the months leading up to and following the monsoon in order to determine how pure the water at Kanota Dam was. The purpose of the study was to determine seasonal fluctuations and potential impacts on water management.

4.2.1 Physical Parameters:

Kanota Dam water's turbidity decreased from a Pre-Monsoon mean of 21.2 NTU to a Post-Monsoon mean of 16.6 NTU, and Figure 6 shows a reduction in suspended particulates possibly due to settling and reduced inflow after the monsoon. The conductivity increased from 385 μS in the Pre-Monsoon season to 410 μS in the Post-Monsoon season, indicating a higher concentration of ions, likely due to dissolved minerals from monsoon runoff.TDS increased from 685 mg/L to 715 mg/L post-monsoon, corroborating the observed rise in conductivity and indicating increased mineral content.

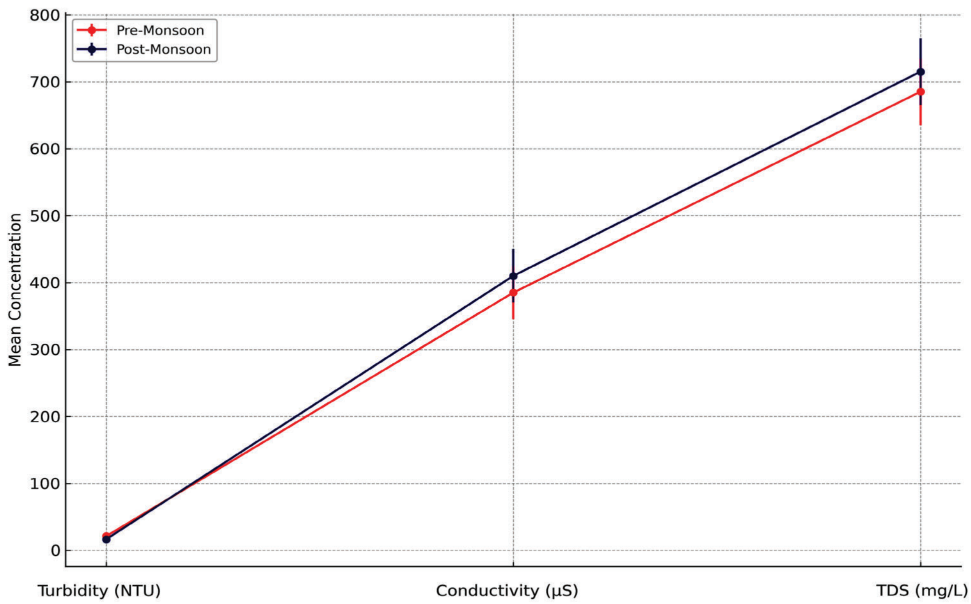

Fig. 6: Seasonal Variations in Physical Water Quality Parameters of Kanota Dam

4.2.2 Chemical Parameters:

Figure 7 shows the changes in chemical parameters at Kanota Dam from the pre-monsoon to the post-monsoon periods. Notably, turbidity decreased from 21.2 NTU to 16.6 NTU, indicating clearer water post-monsoon. The pH increased slightly from 7.4 to 7.8, suggesting a shift towards alkalinity. Chloride concentration rose from 24.2 mg/L to 28.6 mg/L, while nitrogen levels slightly decreased from 1.1 mg/L to 1 mg/L. Total Dissolved Solids (TDS) also increased from 685 mg/L to 715 mg/L, reflecting higher mineral content post-monsoon. These shifts underscore the impact of the monsoon on water quality, crucial for environmental and water resource managemen.

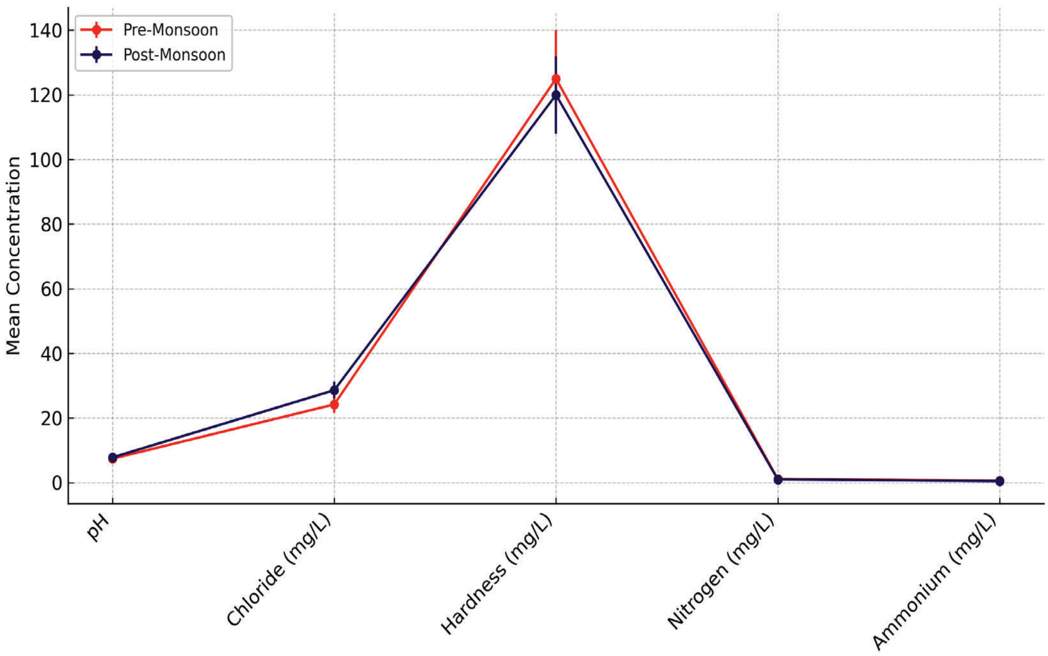

Fig. 5: Seasonal Variations in Chemical Water Quality Parameters of Kanota Dam

4.2.3 Biological/Organic Parameters:

The analysis of biological and organic parameters at Kanota Dam, as depicted in Fig. 8 demonstrates significant seasonal fluctuations. Dissolved Oxygen (DO) levels increased from 6.6 mg/L before the monsoon to 7.6

mg/L after, suggesting a more supportive environment for aquatic life. Biochemical Oxygen Demand (BOD) decreased from 4.4 mg/L to 3.8 mg/L, and Chemical Oxygen Demand (COD) from 12.8 mg/L to 11.8 mg/L, both indicating a reduction in organic pollution and an overall improvement in water quality following the monsoon. These changes highlight the dynamic nature of water quality in response to seasonal patterns, emphasizing the need for ongoing monitoring and adaptive management strategies

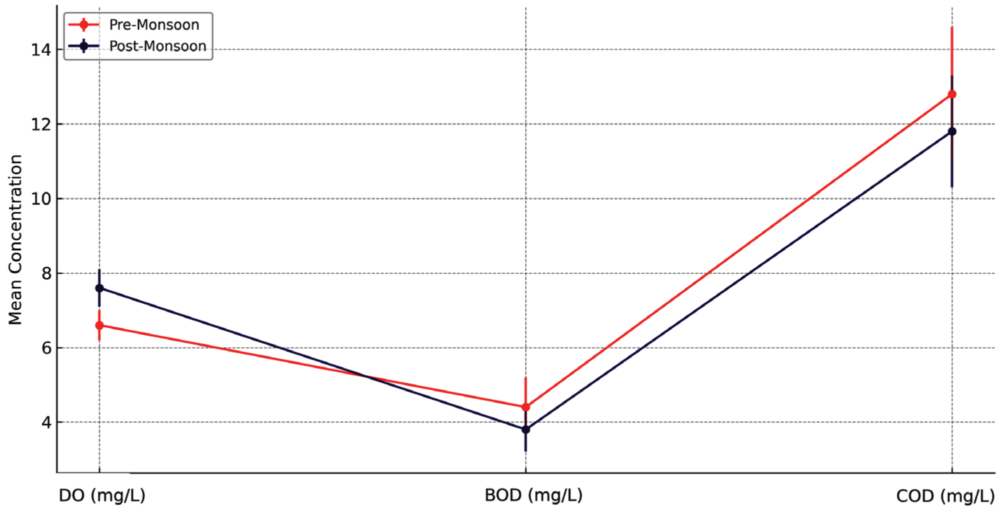

Fig. 6: Seasonal Variations in Biological/Organic Parameters of Kanota Dam

4.3 Analysis of Parameters of Water Quality in Comparison to WHO Standards

The Dam Water Turbidity, pH, Chloride, and TDS are combined with the WHO[37]. Table 2 displays the differences in drinking water quality before and after the monsoon, as well as the WHO standards for dam water quality. The following table summarizes the findings: -

Table 2 WHO standards for drinking water quality[38][39]

Parameter	Pre-Monsoon Mean	Post-Monsoon Mean	WHO Standard	Difference from WHO (Pre-Monsoon)	Difference from WHO (Post-Monsoon)
Turbidity (NTU)	21.2	16.6	5	16.2	11.6
pH	7.4	7.8	8.5	-1.1	-0.7
Chloride (mg/L)	24.2	28.6	250	-225.8	-221.4
TDS (mg/L)	685	715	600	85	115

Pre-monsoon and Post-Monsoon values significantly exceeded the WHO guideline of 5 NTU, with values of 21.2 NTU and 16.6 NTU, respectively. This indicates a high concentration of particulate matter in the water, which may affect its suitability for consumption and necessitate further treatment. The pH levels in both seasons fell within the WHO's recommended range of 6.5 to 8.5, suggesting that the water's acidity is suitable for drinking purposes. The chloride levels were significantly below the WHO recommended limit of 250 mg/L. This suggests that the water is unlikely to have taste problems related to chloride levels. The Nitrogen concentration in Nitrate levels was below the WHO standard of 11.3 mg/L, suggesting a low risk of nitrate contamination. The TDS concentrations exceeded the WHO palatability threshold of 600 mg/L, suggesting potential taste issues, yet remained below the health concern level of 1000 mg/L.

4.4 Seasonal Variations in Trace Metal Concentrations

Analysis of trace metal concentrations in Kanota Dam waters revealed clear seasonal variations before and after the monsoon, as shown in Fig. 9 and Fig. 10. The concentrations and standard deviations of each metal are displayed in two distinct bar graphs, categorising primary metals (Na, K, Ca, Fe) separately from minor metals (Cr, Cu, Mn, Ni, Pb, Zn).

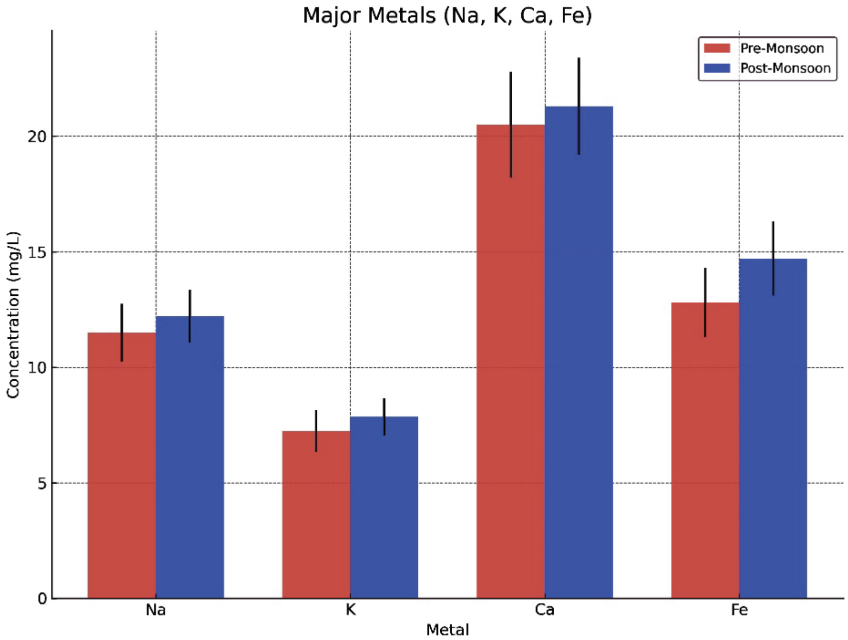

Fig. 7: Seasonal Concentration Variations of Major Metals in Kanota Dam Water

Pre-monsoon metal concentrations were consistently lower than post-monsoon levels. Figure 9 illustrates an increase in Sodium (Na) levels from 11.50 mg/L to 12.20 mg/L, Potassium (K) from 7.25 mg/L to 7.85 mg/L, Calcium (Ca) from 20.50 mg/L to 21.30 mg/L, and Iron (Fe) from 12.80 mg/L to 14.70 mg/L.This escalation in post-monsoon concentrations suggests enhanced runoff and mineral leaching from the catchment area, consequent to the monsoon rains. This escalation in post-monsoon concentrations suggests enhanced runoff and mineral leaching from the catchment area, consequent to the monsoon rains .

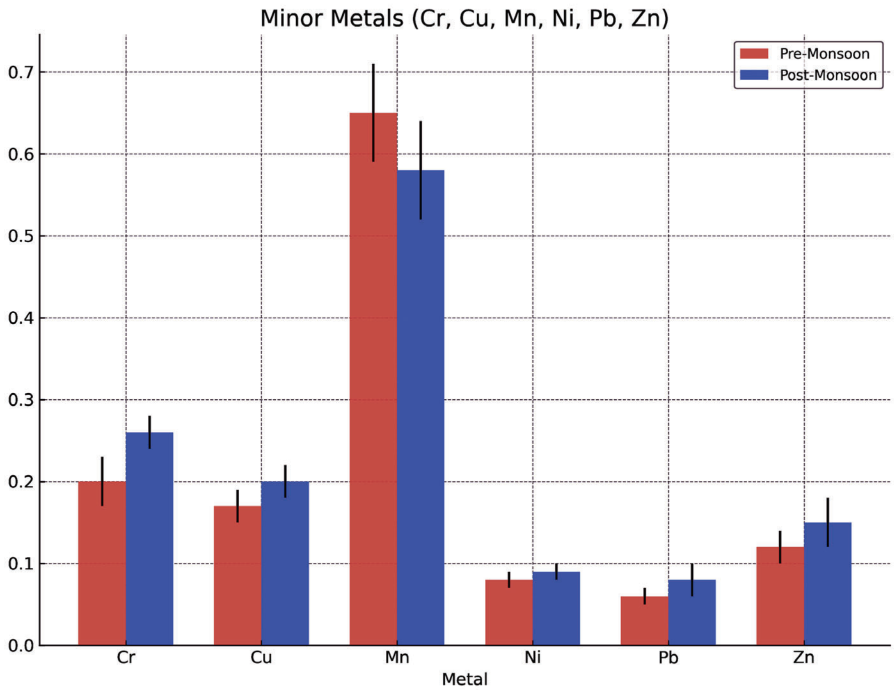

Fig. 8: Seasonal Concentration Variations of Minor Metals in Kanota Dam Water

On the other hand, Manganese (Mn) in the minor metals subset declined from 0.65 mg/L pre-monsoon to 0.58 mg/L post-monsoon, as shown in Fig. 10, which may indicate precipitation and sedimentation processes. Following the monsoon, the concentrations of other minor metals increased, with lead (Pb) going from 0.06 mg/L to 0.08 mg/L and chromium (Cr) rising from 0.20 mg/L to 0.26 mg/L.

4.5 Compliance with WHO Standards

The concentrations of trace metals in Kanota Dam waters generally align with WHO recommendations for drinking water quality. According to the WHO guidelines, the permissible limit for Iron in drinking water is 0.3 mg/L, indicating that the levels found in both pre-monsoon and post-monsoon periods significantly surpass this threshold (which was 12.80 to 14.70), which could necessitate treatment to ensure potability—for other metals such as Copper and Zinc(which was 0.17 to 0.20 and 0.12 to 0.15, respectively) WHO prescribes limits of 2 mg/L and 3 mg/L, therefore, which are significantly above the observed concentrations in the dam water, suggesting that these particular metals do not pose an immediate risk to water quality in their current state.

The seasonal influx of metals into the Kanota Dam indicates the influence that monsoonal patterns exert on water quality. The increased concentrations of major metals post-monsoon are consistent with enhanced weathering and runoff processes, typical of monsoon dynamics. The high levels of Iron after the monsoon season are concerning as they surpass the quality standards set by the WHO for drinking water and may require corrective measures.The observed variability in the concentrations, as indicated by the standard deviations, is relatively low, suggesting that the water quality is characteristically stable across the seasons, barring the influence of monsoonal conditions. The decrease in Manganese concentration post-monsoon is an anomaly that might be attributed to the complex interplay of geochemical processes within the dam's aquatic system. The biogeochemical cycling of Manganese could involve redox transitions influenced by seasonal oxygen levels and organic matter content, potentially leading to its sedimentation and lower post-monsoon concentrations.

4.6 Comparative Water Quality Monitoring Stations of Dams in Rajasthan During COVID-19

Figure 11 demonstrates that the water at Kanota Dam exhibited mild organic pollution during the pre-monsoon period, with a BOD level of 4.4 mg/L. Variability in BOD levels throughout this period is likely caused by shifting environmental circumstances or human activity.

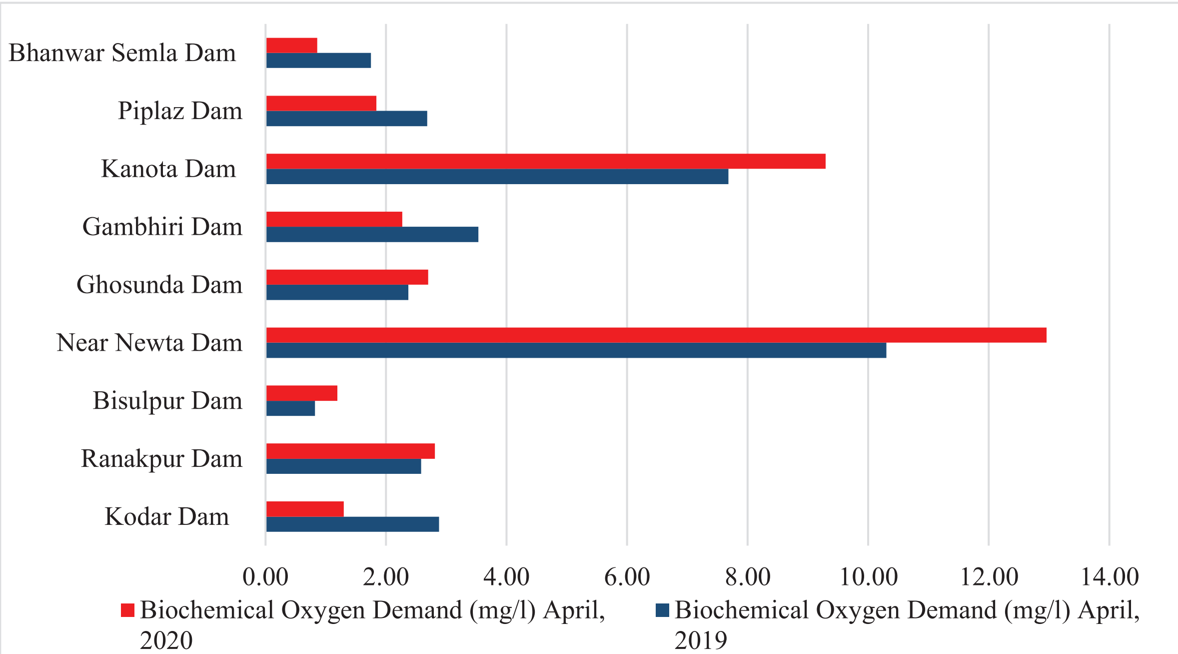

Fig. 9: Comparative BOD of Dams in Rajasthan.*Source:* Rajasthan State Pollution Control Board

The BOD level dropped to 3.8 mg/L after the monsoon. The dilution of organic contaminants by monsoon rains and the natural purification processes in the aquatic system is probably to blame for this reduction in BOD, which shows an increase in water quality.

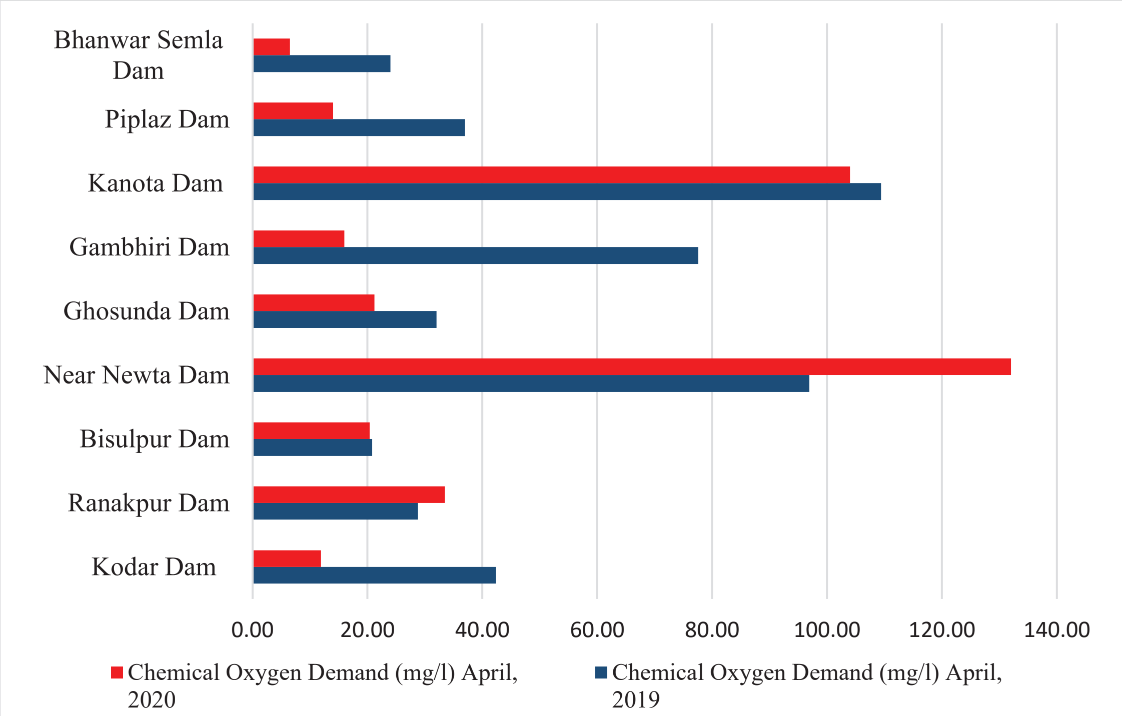

Fig. 10: Comparative COD of Dams in Rajasthan.*Source:* Rajasthan State Pollution Control Board

Figure 12 displays the Chemical Oxygen Demand (COD) for April 2019 and 2020 for several Rajasthani dams, including the water quality at Kanota Dam during the COVID-19 epidemic. While COD levels at some dams, including Kodar and Gambhiri, significantly decreased, suggesting less organic pollution, COD levels at other dams, like Near Newta and Ranakpur, increased. Although it was slightly lower than the previous year's 109.37 mg/L, Kanota Dam's COD remained high at 104.00 mg/L during the pandemic. This is significant above the pre-monsoon (12.8 mg/L) and post-monsoon (11.8 mg/L) values, indicating that the pandemic's impacts on water quality varied.

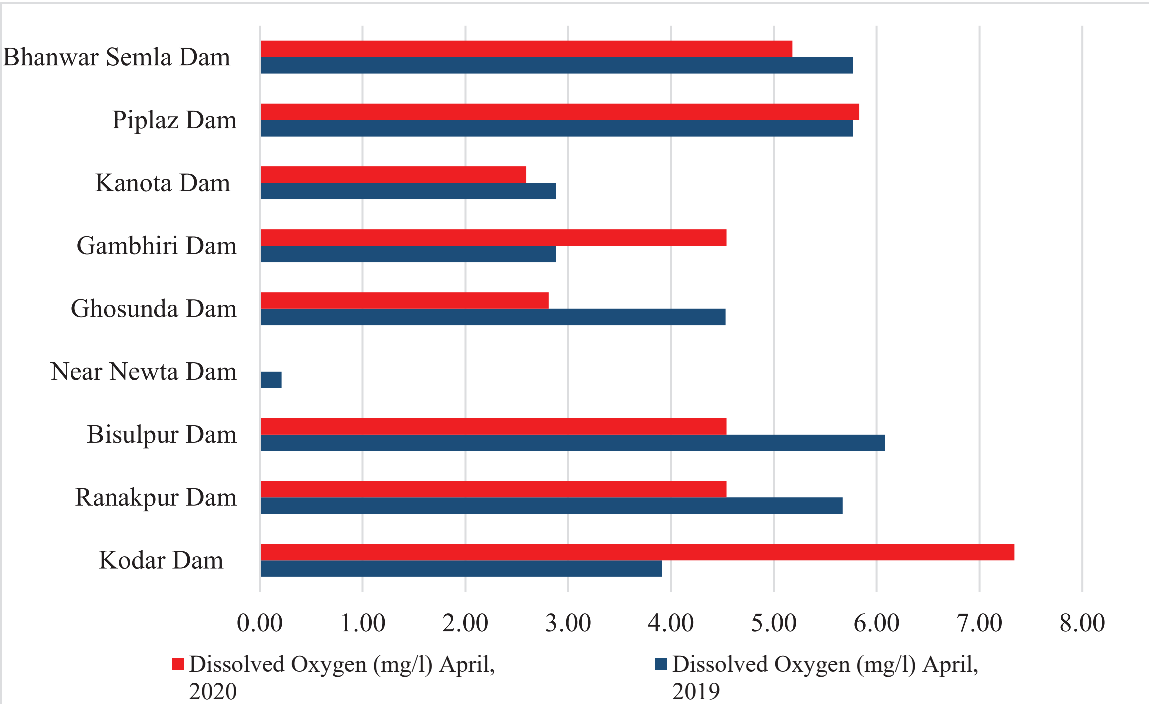

Fig. 11: Comparative Dissolved Oxygen of Dams in Rajasthan.Source: Rajasthan State Pollution Control Board

Dissolved oxygen (DO) levels in several Rajasthani dams for April 2019 and April 2020 are displayed in Fig. 13, together with particular pre- and post-monsoon measurements for Kanota Dam. The DO level at Kanota Dam was 2.88 mg/L in April 2019 and climbed to 7.6 mg/L during the monsoon, indicating improved water quality, probably due to the rainy season's natural impact. In April 2020, the dissolved oxygen (DO) level decreased to 2.59 mg/L as a result of the COVID-19 epidemic.Even if it is slight, this drop might indicate that the dam's water volume is less able to sustain aquatic life, possibly as a result of altered water consumption or waste habits during the epidemic.

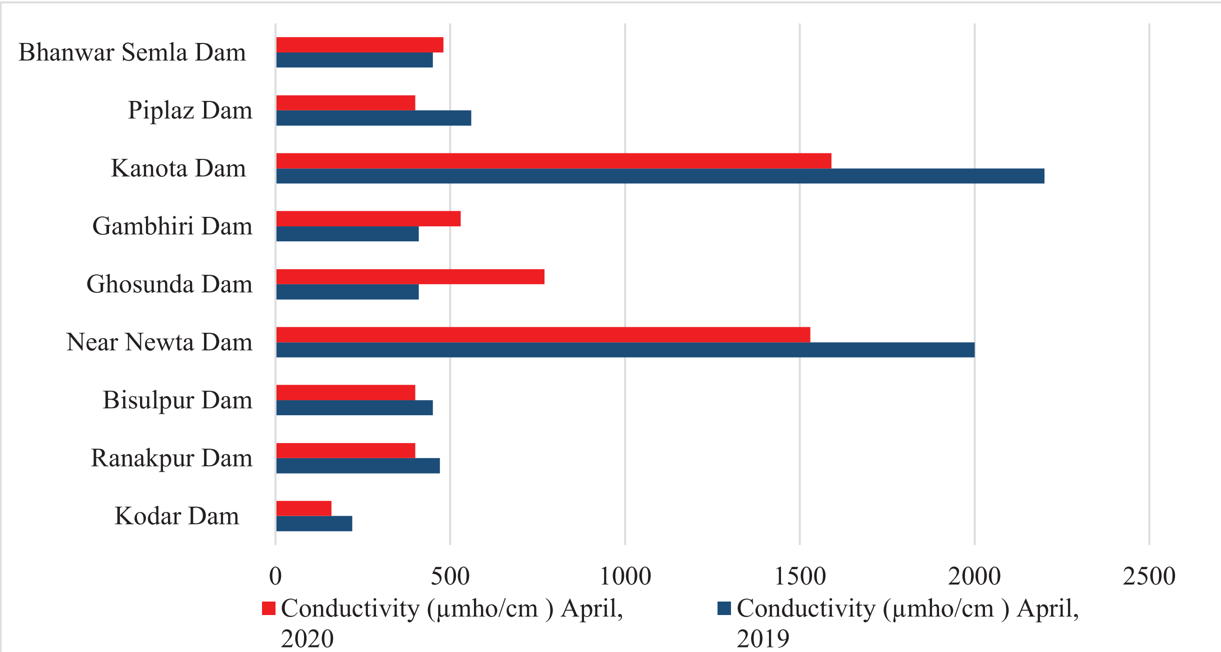

Fig. 12: Comparative Conductivity of Dams in Rajasthan. *Source:* Rajasthan State Pollution Control Board

Figure 14 shows that for Kanota Dam, the Conductivity levels were higher post-monsoon (2200µmho/cm) than pre-monsoon (1600µmho/cm). High conductivity can affect the aesthetic qualities of drinking water and may require additional treatment to meet quality standards.

The research conducted on the water quality of Kanota Dam over different seasons and during the COVID-19 pandemic offers intriguing insights. Seasonal variations, as expected, influenced water quality, with post-monsoon measurements indicating higher mineral content, likely due to monsoon runoff. This was evidenced by increased TDS and conductivity, along with decreased turbidity, which suggests a natural settling of suspended particles.

During the pandemic, there was a notable departure from typical seasonal patterns. Conductivity decreased significantly, which could be attributed to reduced industrial activity and less effluent discharge. During this time, there was a rise in BOD levels, indicating a higher amount of organic pollution possibly due to changes in waste disposal practices during the pandemic lockdowns.

Interestingly, while microbial contamination as measured by Total Coliforms showed a decrease, which could indicate less human activity near the water sources, Dissolved Oxygen (DO) levels also dropped slightly, signaling a potential impact on aquatic life.

The study underscores the critical influence of seasonal cycles and extraordinary events such as the COVID-19 pandemic on water quality. Most water quality parameters stayed within WHO standards, yet the pandemic's unique conditions illuminated increased organic pollution alongside decreased microbial and ionic content. The findings support the use of strategies for flexible water resource management that can handle expected seasonal variations and unexpected environmental effects of worldwide events such as pandemics.

The LULC changes from 2017 to 2023, further contextualizing these water quality dynamics. There's been an expansion of water bodies and vegetation, a decline in cropland, and an increase in built-up areas and rangeland around Kanota Dam. This suggests significant land management shifts, possibly in response to urbanization pressures and the evolving needs of the local ecosystem. These land cover dynamics have implications for the dam's water quality, affecting runoff patterns, pollution levels, and the overall health of the aquatic ecosystem.

Patrick McCully's research underscores the negative impacts of dams on water ecosystems, highlighting how they alter flow, temperature, and sediment, leading to reduced oxygen, harmful algal blooms, and increased mercury levels. These changes harm aquatic life and communities, urging a reevaluation of dam construction and management for river health[40]. The study investigates the effects of dams on the Bhagirathi River's water quality and fish populations in Uttarakhand. It finds dams negatively impact habitat by altering water parameters, suggesting balanced dam management can support fisheries, boost revenue, and enhance tourism[41].

The 2018 study on the Bui Dam, Ghana, shows local perceptions of worsened drinking water quality post-construction, with those farther from the dam more concerned about contamination, smell, and color of the water[42].

The interplay between environmental factors and human activities profoundly impacts the water quality of Kanota Dam. The study provides a clear picture of these complex interactions, highlighting the need for robust water management policies that adapt to both the predictable and the unprecedented.

4. Discussion

The analysis conducted at Kanota Dam reveals that seasonal fluctuations in water quality parameters such as turbidity, conductivity, and dissolved oxygen align with findings from similar environments, such as the Three Gorges Reservoir Area reported by Hou et al. (2022), which noted significant seasonal variability with pollutant concentrations peaking in warmer months. Similarly, Kanota Dam experienced notable seasonal peaks, especially post-monsoon[31].

The effects of the COVID-19 pandemic on water quality, characterized by an increase in organic pollution and a reduction in human activity indicators such as coliform counts, resonate with observations by Martinez-Tavera et al. (2017) in the Atoyac River basin, where reduced industrial activity during similar periods markedly altered water chemistry[32].

Unique insights from this study, in contrast to Nhiwatiwa and Marshall (2010), suggest that the reduction in industrial activities during the pandemic had a direct and favorable impact on water quality, a pattern not widely documented in other studies[34].

Further comparisons can be drawn with Siddik et al. (2022), who explored the effects of land use changes on groundwater recharge in northwestern Bangladesh. The study highlighted an 80.3% increase in built-up areas leading to substantial regional impacts on groundwater recharge, yet only a minimal basin-wide effect[43]. Similarly, Husen Maru et al. (2022) found that in Ethiopia's Awash Basin, urbanization from 1993 to 2016 increased surface runoff and total water yield, underlining the necessity for proactive flood management[44].

These cases collectively illustrate the consistent and unique aspects of the Kanota Dam study within the broader environmental science and water resource management discourse, emphasizing the importance of adaptive strategies in response to natural and anthropogenic changes.

5. Conclusion

This detailed investigation evaluates the dynamic changes in water quality at Kanota Dam, particularly focusing on the diverse impacts exerted by seasonal shifts and the global COVID-19 pandemic. The study meticulously analyzed variations in key water quality parameters, including turbidity, conductivity, total dissolved solids (TDS), pH, chloride, hardness, and biological markers across five strategically chosen sampling sites. Significant findings from this research illustrated a noticeable decrease in turbidity coupled with increases in TDS and conductivity following the monsoon season, indicative of an augmented mineral content in the dam's water. During the pandemic, there was a substantial reduction in conductivity from 2200 μmho/cm to 1590 μmho/cm. Simultaneously, Biochemical Oxygen Demand (BOD) escalated from 7.68 mg/L to 9.29 mg/L, pointing to an increase in organic pollutants. Despite these fluctuations, most water quality parameters successfully remained within the safe confines set by WHO standards, although there was a discernible decrease in microbial and ionic contamination during the pandemic.

Additionally, the examination of Land Use and Land Cover (LULC) changes from 2017 to 2023 provided further insights into the water quality dynamics within the region. It was observed that water bodies expanded from 29.301 hectares to 40.783 hectares, and vegetation cover grew from 5.789 hectares to 9.099 hectares, reflecting enhanced water conservation and vegetation growth. Conversely, the reduction in cropland from 361.287 hectares to 298.603 hectares likely mirrors shifts towards increased urbanization and altered agricultural practices, highlighting the pressing need for adaptable water resource management strategies capable of addressing both predictable seasonal variations and unexpected environmental effects, such as those resulting from global phenomena like pandemics.

The findings underscore the critical necessity for implementing robust and adaptive water management strategies tailored to accommodate both the predictable seasonal variations and extraordinary circumstances such as pandemics. The establishment of real-time water quality monitoring systems and the enhancement of buffer zones around water bodies are recommended as effective measures to mitigate pollutant runoff during the monsoon season and maintain optimal water quality. Such strategies not only aid in keeping water quality within WHO standards but also ensure the sustainability and resilience of water resources against changing environmental and socio-economic challenges. This comprehensive approach to water management could serve as a model for future research, policy development, and practical application, providing a structured framework to safeguard water quality and sustain the ecological health of the Kanota Dam region for future generations.

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Nomenclature

TDS	Total Dissolved Solids
Cu	Copper
Hg	Mercury
Cd	Cadmium
Pb	Lead

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