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Assessment of Physico-chemical Water Quality and its Correlation to Carbon Sequestration in Western Yamuna Canal, District Yamuna Nagar, Haryana, India

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ABSTRACT

Fresh water resources play a pivotal role in sustaining life, supporting agriculture, industrial development and maintaining ecological balance yet they remain highly vulnerable to anthropogenic pollution. The fresh water canal systems are crucial for regional water security and are regulators of biogeochemical cycling. The present study evaluated the variations in selected physico-chemical characteristics of the Western Yamuna Canal (WYC) water in district Yamuna Nagar, Haryana over an annual period from July 2024 to June 2025 with special emphasis on their implications for freshwater carbon sequestration. Water samples were collected on fortnightly basis from three representative sites along the canal and various parameters including temperature, dissolved oxygen (DO), pH, total dissolved solids (TDS), electrical conductivity (EC), alkalinity, total hardness, chloride and free carbon dioxide were analyzed following standard protocol. Results revealed pronounced seasonal variations affected by climatic conditions and anthropogenic inputs. Elevated temperature reduced DO and increased free carbon dioxide levels during summer months indicated organic matter decomposition and microbial respiration potentially limiting carbon sequestration efficiency. Alkalinity and hardness levels suggested buffering capacity favouring inorganic carbon stabilization (carbon sequestration). The periodic deterioration in water quality due to anthropogenic pressures may shift the canal from a carbon sink to a carbon source. The investigation highlighted the need to integrate water quality assessment studies with carbon cycle considerations for sustainable management of canal under intensified industrial, agricultural and urban pressures.

Key words: Western Yamuna Canal, hydrological factors, carbon sequestration, physico-chemical water quality

INTRODUCTION

Water is considered as the most vital natural resource for sustenance of life on earth. Aquatic ecosystems constitute the major portion of biosphere and include both marine and freshwater ecosystems. Although freshwater ecosystems such as rivers, lakes, canals, streams and wetlands form a small fraction of the earth's surface yet they have always played a crucial role in human civilization and provide numerous direct and indirect benefits essential for human survival. Rivers and canal systems in particular serve as important conduits for distribution of water in densely populated and agricultural regions of the country. However, they are in jeopardy due to rapid urbanization, expanding industrial activities and modern agricultural practices leading to significant degradation in water quality (Babita and Upadhyay, 2022). Canals are the linchpins of regional water security but highly vulnerable to pollution due to their controlled flow, limited self-purification capacity and prolonged water residence time making them highly susceptible to pollution (Sruthi *et al.*, 2023).

India is bestowed with 10 major river systems which are considered as the life supporting system. The river Yamuna is a major tributary

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of the Ganges and originates from Yamunotri glacier near Bandarpoonch peaks of the Mussoorie range in lower Himalayas which is at an elevation of approximately 6,387 m above sea level in Uttarkashi district (Panwar and Upadhyay, 2022). From its source, the river flows through a series of valleys for nearly 200 km before continuing along a total course of about 1,376 km. The Yamuna basin has a drainage area of 366,233 km^2, constituting nearly 42% of the Ganga basin and about 11% of India's total land area (Upadhyay and Babita, 2022). In its upper reaches, the Yamuna flows past Paonta Sahib and enters Yamuna Nagar district of Haryana at Hathnikund/Tajewala where its waters are diverted for irrigation into the Western Yamuna Canal (WYC) and Eastern Yamuna Canal (EYC). The WYC is one of the oldest and most significant canal systems in northern India. The WYC command area lies between 28°202 –30°292 N latitude and 75°482 –77°352 E longitude and covers the eastern, central and southern regions of Haryana. The WYC meanders through the city Yamuna Nagar which is the second largest industrial city of Haryana. In Yamuna Nagar, the canal passes through highly industrialized region that hosts paper mill, sugar mill, plywood industries, textile processing industries, electroplating and metal-based industries, along with numerous small-scale enterprises. The effluents from these industries find their way into the canal directly or indirectly. In addition to these effluents, the canal receives surface runoff from agricultural fields and partially treated or untreated domestic sewage from nearby residential areas. These combined inputs significantly alter the physico-chemical characteristics of water thereby affecting its ecological integrity and suitability for various purposes.

Physico-chemical characteristics of canal water such as temperature, pH, total dissolved solids, electrical conductivity, dissolved oxygen, alkalinity, hardness and nutrient concentrations are key indicators of water quality. These parameters not only provide the measure of degree of pollution and anthropogenic stress but also regulate the essential biological processes within an aquatic ecosystem. Variations in these parameters affect the metabolic activities of aquatic organisms, nutrient cycling and overall productivity of the ecosystem. Prolonged deviations from normal ranges can lead to eutrophication, hypoxia and biodiversity loss, eventually affecting the aquatic ecosystem services (Zhang *et al*., 2025).

Most recently the interest of scientific community oriented towards freshwater ecosystems due to their role in the global hydrological-cum-carbon cycle. The aquatic ecosystem has a great potential to work both as reservoir and sources of carbon depending on their physicochemical attributes along its biodiversity (Dubey and Pathak, 2025). The optimum physicochemical factors of aquatic reservoir facilitate the planktonic primary productivity along the biological fixation of atmospheric carbon dioxide which results out as storage of carbon in aquatic biomass (quantitative and qualitative) and sediments. The hydrological attributes like alkalinity and hardness take part to the stabilization of dissolved inorganic carbon as bicarbonates and carbonates which encourage long-term carbon sequestration. On the contrary, the polluted water with degraded hydrological features characterized by unexpected augmented temperature, nutrient enrichment (eutrophication), low dissolved oxygen (high biological oxygen demand) and high organic load enhances microbial respiration and decomposition process consequential in the release of carbon dioxide back into the atmosphere (Jana *et al.*, 2020; Yang *et al.*, 2020; Islam, 2025).

The canals are important in relation to ecological, economic and climatic perspectives yet their water quality and efficacy in biological carbon fixation (carbon sequestration) have not been adequately worked out in the Haryana region. The research investigations have been mostly focused on major river systems and lakes worldwide, whereas canals have received relatively little scientific attention (Franco-Cisterna *et al.*, 2024). Because of the ever rising anthropogenic pressures and increasing climate vulnerability, there is an urgent need of organized and updated assessment of water quality in canal networks. Therefore, the current research investigation was designed to provide a comprehensive status of the physico-chemical hydrological characteristics of streaming water of WYC in Yamuna Nagar district of Haryana over an annual cycle. The study was focused on monthly variations in the chosen hydrological parameters to correlate the influence of industrial, domestic and agricultural activities on canal water quality and natural carbon sequestration.

MATERIALS AND METHODS

The present investigation on the physico-chemical characteristics of WYC was conducted in district Yamuna Nagar of Haryana during July 2024 to June 2025. Three representative sampling sites were selected along the canal stretch for regular monitoring, namely, Site-I (S1) located at old Saharanpur road bridge, Site-II (S2) at the railway bridge and Site-III (S3) situated near old Hamida barrage, Yamuna Nagar. Water sampling was carried out at fortnightly intervals and three independent samples were collected from each site during every sampling event. Water temperature, pH, TDS and electrical conductivity were measured on site using a digital thermometer, pH meter, TDS meter and conductivity meter, respectively. Dissolved oxygen was immediately fixed at the sampling sites and subsequently determined in the laboratory by the modified Winkler's iodometric method. The water samples were collected in clean, air-tight borosilicate glass bottles (250 ml capacity). The samples were analyzed at the Bioanalytical Laboratory, Department of Biosciences and Technology, Maharishi Markandeshwar (Deemed to be University), Mullana, Ambala (Haryana), India for various parameters including alkalinity, total hardness, free carbon dioxide, chloride and nitrates using standard titrimetric and volumetric techniques. The observed data were statistically processed to compute mean values, standard error (SE), regression equation and coefficient of determination (R^2). Numerical tools were applied to assess month-wise variations in the hydrological attributes of the Yamuna canal during the study period.

RESULTS AND DISCUSSION

The water quality characteristics of the WYC Yamuna Nagar was analyzed onsite and offsite and assessed using standard protocol during the study period as given in Table 1. The results showed pronounced monthly and seasonal oscillations primarily governed by climatic conditions, regulated canal flow and continuous anthropogenic inputs from industrial, domestic and agricultural sources. The observed water temperature exhibited a distinct seasonal pattern throughout the study period ranging between 10.2-28.9°C. The highest temperature (28.4±0.09°C) was observed during summer and early monsoon period, while the lowest temperature (10.6±0.18 °C) was recorded in the month of January (Fig. 1). Similar trends in water temperature were reported from the WYC and adjoining stretches of the Yamuna river by Panwar and Upadhyay (2022) and Kumar and Singh (2025). High temperature during summer and early monsoon period resulted in accelerated mineralization of organic carbon and increased release of carbon dioxide into the water column. Thus, higher temperatures in the WYC favoured carbon turnover rather than long-term carbon storage during that period.

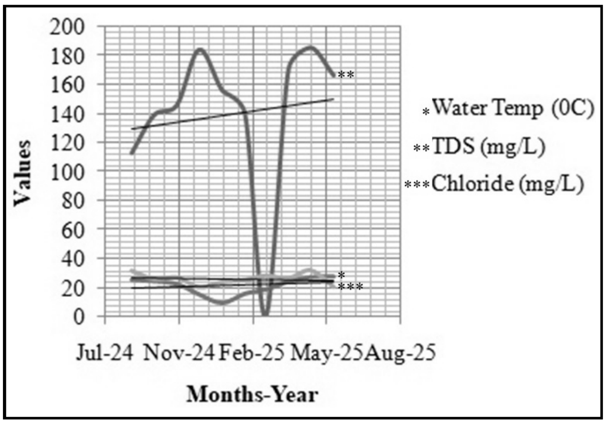

Fig. 1. Monthly variations and regression trends of Western Yamuna Canal water temperature (°C), TDS (mg/l) and chloride (mg/l) during July 2024 to June 2025.

The dissolved oxygen concentration varied widely during the study period that ranged from 3.77 to 10.17 mg/l. The peak value (8.48±0.45 mg/l) was recorded during winter in December, whereas minimum value (4.30±0.17 mg/l) occurred during summer in the month of June (Fig. 2). Higher dissolved oxygen levels during winter could be due to lower water temperature, increased solubility of oxygen and comparatively reduced microbial respiration. In contrast, declined concentration of dissolved oxygen in summer was negatively influenced by elevated temperature, increased organic and toxic load and intensified microbial activity leading to

Table 1. Physico-chemical assessment of Western Yamuna Canal water during July 2024 to June 2025

Months	Water temp. (ºC)	pH	TDS (mg/l)	Conductivity (µS/cm)	DO (mg/l)	Alkalinity (mg/l)	Total hardness (mg/l)	Chloride (mg/l)	Free CO_2 (mg/l)
2024									
July	28.4± 0.09	7.75±0.04	142.1± 2.68	296.2± 8.69	6.34± 0.35	119.46±2.13	177.80±4.74	31.84±3.77	14.94±3.13
August	27.5± 0.10	7.56±0.03	151.7± 3.24	301.8± 3.40	6.98± 0.07	80.99± 2.47	152.70±3.37	31.36±1.40	11.53±0.51
September	26.1± 0.08	7.89±0.16	112.7± 4.88	242.0± 9.14	5.35± 0.26	103.95± 1.20	117.88±5.04	32.05±1.49	10.55±0.50
October	25.1± 0.03	7.52±0.09	138.9± 2.82	296.4± 6.05	7.29± 0.24	94.11± 1.42	121.13±2.39	26.29±0.94	9.68± 0.17
November	23.2± 0.30	7.14±0.02	145.9± 3.64	307.8± 3.60	8.32± 0.29	92.43± 1.69	135.78± 4.20	27.48± 1.59	9.31±0.28
December	16.1± 0.46	7.21±0.04	184.0± 3.51	346.2± 7.99	8.48± 0.45	82.34± 1.06	153.08± 3.03	20.45±1.63	7.69±0.32
2025									
January	10.2± 0.18	7.16±0.04	156.16±19.35	237.67±24.92	6.02±0.41	117.83±3.15	171.11±16.8	24.18± 3.03	11.01±0.83
February	16.6± 0.10	7.40±0.05	139.83±4.56	254.00± 9.75	5.11±0.14	110.83±2.60	152.51±3.30	25.56± 0.62	13.12±1.23
March	19.4± 0.30	7.53±0.04	1191.67±6.34	321.17± 8.98	4.86±0.08	125.67±2.67	136.67±5.23	28.63± 0.44	14.91±2.60
April	24.9± 0.03	7.74±0.08	170.67±4.14	288.83± 13.74	5.53±0.17	126.50±3.80	134.50±5.60	26.88± 0.84	11.33±0.84
May	27.9± 0.10	7.69±0.03	185.50± 8.8	366.83± 15.61	5.13±0.24	139.83±11.07	165.67±4.76	32.36± 1.75	18.76±0.51
June	28.3± 0.06	6.93±0.15	166.33± 3.93	349.02± 7.83	4.39±0.17	138.00±5.38	156.00±2.35	20.75± 1.02	17.35±0.55

Where, ±, Mean±SE, TDS, Total Dissolved Solids; DO, Dissolved Oxygen, mS/cm, Microsiemens per ccentimeter, mg/l, mg per liter.

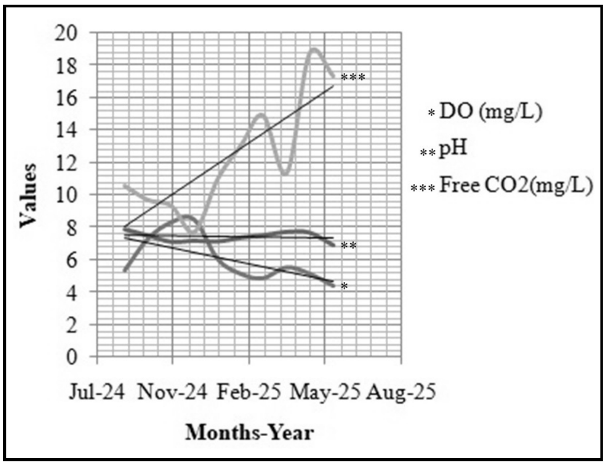

Fig. 2. Monthly variations and regression trends of western Yamuna canal water dissolved oxygen (mg/l), pH and free carbon dioxide (mg/l) during July 2024 to June 2025.

greater oxygen consumption. This pattern of inverse relationship between water temperature and dissolved oxygen was reported by many researchers from various water bodies including Yamuna river and WYC (da Silva Pinto and Gomes, 2017; Panwar and Upadhyay, 2022; Sharma *et al.*, 2024). The recommended level of dissolved oxygen in river and marine water should be more than 5.0 mg/l and generally between 8 to 12 (Schmidtko *et al*., 2017; Zhao *et al*., 2021). Periodic values of dissolved oxygen of canal water approaching or falling below the recommended limit of 5 mg/l indicated organic pollution stress in the canal. Reduced dissolved oxygen favoured heterotrophic respiration and inhibited aerobic biological production thereby limiting removal efficiency of nutrition and energy conservation along its overall carbon fixation reduction-cum-carbon sequestration (Salekar *et al.*, 2025).

The pH of canal water was analyzed with digital pH meter with a mean pH value ranging from 6.40 to 8.10 that indicated a neutral to slightly alkaline nature of water throughout the study period (Fig. 2). Slightly higher pH was observed during post-monsoon month in September which could be attributed to the Ganpati Mahotsav celebrated in the area and immersion of idols and statues in the canal, while comparatively lower values occurred in the month of June. Comparable pH stability in the Yamuna basin waters was reported by many researchers. The potential of hydrogen ion concentration (pH) played a significant role in regulating carbon sequestration. Neutral to slightly alkaline conditions favoured formation of bicarbonates and buffering of dissolved inorganic carbon (Boylan Aislinn, 2017; Abbas *et al*., 2025).

The concentration of chloride of canal water throughout the study period ranged between 18.20-38.60 mg/l with highest value (32.36±1.75 mg/l) in early summer month and a drop in the value (20.45±1.63 mg/l) was observed in December (Fig. 1). Elevated chloride levels indicated the sewage contamination and industrial inputs in the canal water, whereas the steep decline in concentration was attributed to the rainfall diluting the concentrations (Hong *et al.,* 2023; Duan *et al.,* 2024). Another most important parameter studied was free carbon dioxide that varied from 8.00-20.80 mg/l with maximum value (18.76±0.51 mg/l) in the month of May and minimum value (7.69±0.32 mg/l) in December (Fig. 2). This naturally occurring carbon dioxide along the bicarbonates in the present water body helped in growth and sustenance of aquatic plant life thereby assisting the biological fixation of carbon. High free carbon dioxide levels during summer reflected increased respiration process and decomposition of organic matter under reduced dissolved oxygen conditions. The distinct inverse relationship between dissolve oxygen and free carbon dioxide revealed the dominance of heterotrophic metabolism and carbon sequestration during the period of investigation (da Silva Pinto and Gomes, 2017; Shraddha *et al*., 2025; Silverthorn *et al*., 2025).

Total dissolved solids (TDS) and electrical conductivity (EC) showed a close direct relationship indicating dominance of ionic components due to anthropogenic activities. TDS ranged from 100 to 230 mg/l peak value (191.67±6.34 mg/l) was recorded in the month of March, while lowest value (112.70±4.88 mg/l) was recorded in the month of September (Fig. 1). A similar trend was shown by EC with highest value (366.83±15.61 mS/cm) during early summer in May and lowest (230.38±7.68 mS/cm) during monsoon (Fig. 3). Higher TDS and conductivity revealed the concentration of dissolved salts due to evaporation and reduced flow (Adjovu *et al.*, 2023). Along with that the construction work was going on during that period along the banks of canal which also resulted in the higher concentration. The lower values of both parameters were attributed to the heavy rainfall resulting in dilution and increased canal discharge. Similar seasonal trends were documented from different water bodies as well (Bhardwaj *et al*., 2018; Jaiswal *et al*., 2019). Elevated TDS and EC influenced the ionic interactions which got enhanced influencing the carbon equilibrium (Mohit and Suprita, 2022; Das and Biswas, 2023).

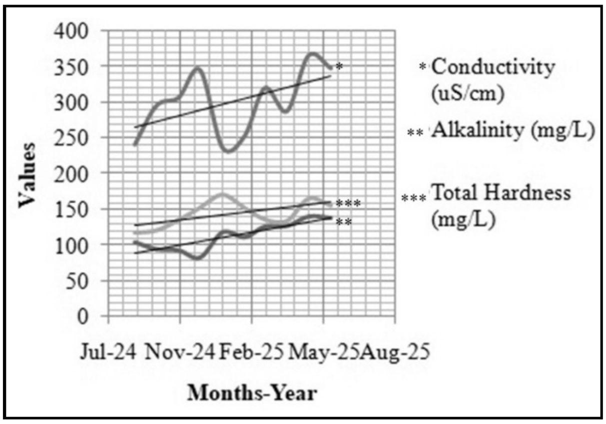

Fig. 3. Monthly variations and regression trends of western Yamuna canal water conductivity (uS/cm), alkalinity (mg/l) and total hardness (mg/l) during July 2024 to June 2025.

The other important parameter studied was total alkalinity which ranged from 72.70 to 180 mg/l with highest value (139.83±11.07 mg/l) recorded in early summer, while lowest value (80.99±2.47 mg/l) occurred during monsoon period (Fig. 3). Total hardness of the canal water was also evaluated that varied between 109-220 mg/l with maximum value (177.80±4.74 mg/l) in late summer and minimum value (117.88±5.04 mg/l) during monsoon. More or less alkalinity and hardness showed parallel trends (Fig. 3), indicating the dominance of calcium and magnesium bicarbonate buffering systems showing a typical pattern of semi-polluted waters (Tanya Kumar *et al.,* 2025).

The findings were further validated using regression equation and coefficient of determination (R^2) for each hydrological parameter revealed a positive trend for dissolved oxygen ($y = 0.031x - 1435$; $R^2 = 0.648$), TDS ($y = 0.074x - 3263$; $R^2 = 0.016$), conductivity ($y = 0.258x - 11526$; $R^2 = 0.267$), alkalinity ($y = 0.183x - 8285$; $R^2 = 0.727$) and total hardness ($y = 0.116x - 5189$; $R^2 = 0.353$), while a negative fashion for the pH ($y = -0.000x + 37.60$; $R^2 = 0.038$), water temperature (y = 0.012

x - 555.0; R^2 = 0.037), chloride (y = - 0.007 x + 363.8; R^2 = 0.028) and free CO_2 (y = -0.009 x + 458.3; R^2 = 0.385). Thus, the findings reflected that WTC water in Yamuna Nagar showed strong seasonal changes in temperature, DO, pH and ions due to climate and anthropogenic inputs. The increase in water temperature during summer season reduced DO and increased free CO, , limiting carbon sequestration, while alkalinity and hardness supported inorganic carbon storage. Therefore, pollution may alter the canal's role from a carbon sink to a carbon source, necessitating timely and strategic management.

CONCLUSION

The physico-chemical parameters of water collected from the WYC (Yamuna Nagar), Haryana were assessed along with their potent implications on carbon sequestration. Climatic conditions and anthropogenic pressures including industrial, domestic and agricultural activities led to significant variations in water quality in a monthly as well as seasonal manner. Dissolved oxygen, TDS, EC, alkalinity, hardness, chloride content and free carbon dioxide exhibited distinct fluctuation which further reflected the amalgamated influence of climate, season, industrial effluents, domestic sewage and agricultural runoff. Various heterotrophic metabolic activities including microbial respiration resulted in reduced aerobic productivity and therefore, lower inorganic carbon holding capacity. The measured pH was restricted to near neutral to slightly alkaline ranged with elevated values of salts and chloride indicating moderate pollution stress in the water body. The moderate alkalinity and associated hardness revealed natural buffering capacity of canal water system and it may support stability of inorganic carbon and dependent carbon sequestration potential. The current findings support that WYC (Yamuna Nagar), Haryana may serve as a significant sink for inorganic carbon in low flow season; but for the long-term sequestration benefit, anthropogenic pollution stress need to be reduced. The importance of integrating conventional water quality assessment with carbon sequestration process of canal ecosystems need to be disseminated among the scientists and policy makers. The study may provide useful insights for future monitoring programs and management of similar valuable fresh water resources.

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