SPATIO- TEMPORAL WATER QUALITY ASSESSMENT OF RIVER GANGA AT DIFFERENT LOCATIONS IN WEST BENGAL, INDIA THROUGH WQI AND SPI

A DISSERTATION

SUBMITTED IN THE PARTIAL FULFILMENT OF THE REQUIREMENTS

FOR THE AWARD OF DEGREE OF

MASTER OF TECHNOLOGY

IN

ENVIRONMENTAL ENGINEERING

Submitted by

ABHIJEET TIWARI

2K21/ENE/02

Under the supervision of

Dr. LOVLEEN GUPTA

DEPARTMENT OF ENVIRONMENTAL ENGINEERING

DELHI TECHNOLOGICAL UNIVERSITY

(Formerly Delhi College of Engineering)

Bawana Road, Delhi-110042

MAY, 2023

DELHI TECHNOLOGICAL UNIVERSITY
(Formerly Delhi College of Engineering)
Bawana Road, Delhi-110042

CANDIDATE'S DECLARATION

I, **Abhijeet Tiwari, Roll No. 2K21/ENE/02** student of M. Tech (Environmental Engineering), hereby declare that the project Dissertation titled "Spatio-Temporal water Quality Assessment of river Ganga at different locations in West Bengal, India through WQI and SPI" which is submitted by me to the Department of Environmental Engineering, Delhi Technological University, Delhi in partial fulfilment of the requirement for the award of the degree of Master of Technology, is original and not copied from any source without proper citation. This work has not previously formed the basis for the award of any Degree, Diploma Associate ship, Fellowship or other similar title or recognition.

Place: Delhi

Abhijeet
ABHIJEET TIWARI

Date: 31-05-2023

DEPARTMENT OF ENVIRONMENTAL ENGINEERING

DELHI TECHNOLOGICAL UNIVERSITY
(Formerly Delhi College of Engineering),
Bawana Road, Delhi-110042

CERTIFICATE

I hereby certify that the Project Dissertation titled "Spatio-Temporal water Quality Assessment of river Ganga at different locations in West Bengal, India through WQI and SPI" which is submitted by **ABHIJEET TIWARI, Roll No. 2K21/ENE/02**, Department of Environmental Engineering, Delhi Technological University, Delhi in partial fulfilment of the requirement for the award of the degree of Master of Technology, is a record of the project work carried out by the student under my supervision. To the best of my knowledge this work has not been submitted in part or full for any Degree or Diploma to this University or elsewhere.

Place: Delhi
Date: 31.5.2023

DR. LOVLEEN GUPTA
SUPERVISOR

ACKNOWLEDGEMENT

I want to express my deepest gratitude to my supervisor Dr. Lovleen Gupta, Assistant Professor, Department of Environmental Engineering, Delhi Technological University, New Delhi, for her guidance, help, useful suggestions and supervision without which this report could not have been possible in showing a proper direction while carrying out project. I also must acknowledge the unconditional freedom to think, plan, execute and express, that I was given in every step of my project work, while keeping faith and confidence on my capabilities.

ABHIJEET TIWARI

2K21/ENE/02

ABSTRACT

An effort has been develop to access the water quality status of river Ganga in West Bengal India for drinking purpose using unified techniques. For this study, 14 parameters at 10 location from Beharampur to Diamond Harbour over 39 months (2020january –2023march) were considered. The eastern stretch of Ganga showed a variation of Water Quality Index (WQI) from 24.4539 to 1790.2545 and Synthetic Pollution Index (SPI) from 0.244539 to 1.7902545 in 36 months. . The map interpolated through GIS exposed that the entire river stretch in 36 months and location near to ocean during the entire period of 36 months were severely polluted (WQI >100 or SPI > 1).Turbidity ,DO and BOD concentration mainly contribute to the high scores of indices. Further, the origin of these ions was estimated through multivariate statistical techniques using SPSS . . It was recognized that the origin of these pollutant is mainly attributed to seawater influx, that of fluoride to human and industrial activities , and other parameters originated through geological as well as human activities. Based on the research, a few possible water treatment mechanisms are suggested to render the water fit for drinking.

Key words: IDW Geostatistics, river Ganga water quality, spatial interpolation, synthetic pollution index (SPI), water quality index (WQI), weighted arithmetic mean method

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLE

CHAPTER 1
INTRODUCTION

1.1 Background

Rivers are the world's primary supply of surface water that is perennial in nature and used for reservoir storage, irrigation, agricultural, and commercial purposes. They are essential to produce power, marine life, and navigation. Generally, River dependence increased with urbanization and industrialization. They are essential for preserving the natural balance and improving human welfare. A river system is also responsible for moving sediments, pollutants, waste, and other materials from one place to another in Gangetic plains. The groundwater aquifers' maintenance or recharge is also the responsibility of rivers. However, the water chemistry of the riverine environment is influenced by a variety of lithological traits, the evaporation process, habitat ecological factors, and the varying rates of rock weathering. Due to anthropogenic activities including sewage waste discharge, industrial activity, riverbed mining, and water quality degradation, rivers are under a tremendous amount of stress today. This has an impact on both aquatic life and human life.

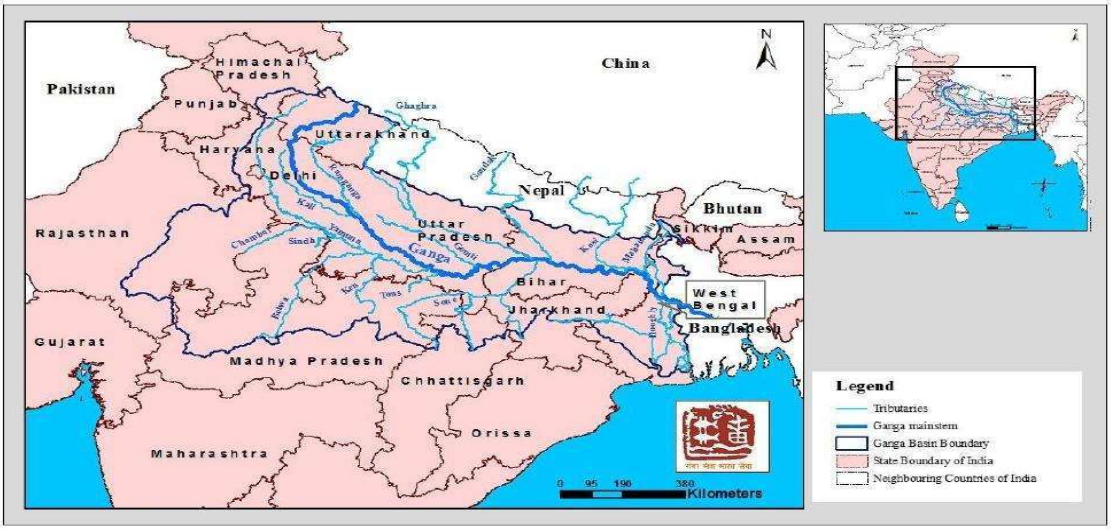

Fig. 1.1 Geographical position of River Ganga in India

As one of the most major perennial rivers in the nation, the Ganga River has a special place in Hinduism and is a powerful representation of Indian culture. Its source is in the Himalayas in the Indian state of Uttarakhand, and it eventually empties into the Bay of Bengal after flowing across the north Indian Gangetic plain with a catchment area of 2525 km^2. According to discharge, it is the world's largest river. During the monsoon, the Ganga River transports an immense quantity of sediments made up of stone, gravel, and sand. The sediment dunes are created when these materials are deposited in rivers. The physical properties of the river are continually altered by these sediment dunes, which results in bank erosion and a flood state. Water is thought to be the primary prerequisite for the development of both humankind and industry. In recent decades, as the population and industry have grown, so has the need for freshwater too. The rivers, which provide water for both agricultural and human life, satisfy this requirement. The quality of river water has decreased as a result of pollution released from industrial and human activities, which has an impact on both aquatic and terrestrial life. According to the WHO, CPCB, BIS, and ICMR, over 70% of India's river water was polluted by pollution, and part of it was unfit for human consumption. The water quality index is a method for determining the river water's quality that has been proven to be effective and practical. This approach provides concerned policymakers with information regarding the general quality of water. Water quality indicators are calculated using a variety of mathematical formulae that take into account numerous physical, chemical, and biological characteristics. Initially, Horton (1965) and Brown et al. (1970) suggested using a WQI. Since then, a wide range of WQI computation techniques have been created. The method for calculating WQI was differentially suggested by the scientist. Long-term surveys and water quality monitoring programs are a good way to gain a better understanding of river hydrochemistry and pollution, but they typically result in enormous data sets that are challenging to analyze. Through the use of multivariate statistical analysis, the issue of data reduction and interpretation of observations with many elements in both physical and chemical processes may be addressed.

1.2 Distribution and Drainage Pattern of Ganga River

With a length of 8, 62,769 km2, the Ganga River basin makes up about 26% of India's drainage area. Before eventually coming together with seawater in the Bay of Bengal, it travels through the five states of India. Apart from the main streams, Bhagirathi and Alaknanda, which are melting streams from the Himalayan Glacier, it has five significant tributaries. After emerging from Gaumukh and gushing out from beneath the Gangotri Glacier, the River Bhagirathi travelled for 18 kilometers to reach Gangotri, another 75 kilometers to reach the first hydroelectric power plant on it at Maneri, and yet another 113 kilometers to the confluence with the Alaknanda at Devprayag. Santopath Glacier releases the river Alaknanda. The

Saraswati River joins the Alaknanda near Mana Village and flows for five km to Badrinath. The second tributary that joins the Alaknanda 35 kilometres (km) downstream of Badrinath is called Dhauliganga. After travelling another 150 km, the River Alaknanda meets the River Bhagirathi at Devprayag. River Ganga is the name of the river formed at the confluence of the two rivers in Devprayag. It descends through the Shivalik Mountains and arrives in Rishikesh. At Haridwar, the Bhimgoda barrage on the Ganga River diverts around 80% of the water, causing the river to flow in a braided pattern and with less discharge. It travels from Haridwar to Narora in a southerly route, passing via the city of Bijnore. From there, it descended in a southeasterly direction to meet the River Ramganga at Kusumkher and also confluence with the Kali River at Kannauj to increase the Ganges River's flow. It flows through well-known urban industrial hubs like Kanpur, Allahabad, and Varanasi where both home and industrial activities have an impact on the river's quality. At Kanpur, the Lower Ganga Canal and the Upper Ganga Canal converge once more. At Prayagraj, a city renowned for its mythology and the annual Kumbh Mela, it joins the river Yamuna. At Sirsa, the River Tonnes joins it as it turns east and travels towards Varanasi. It has a 1000 km flow across the state of Uttar Pradesh and forms a 110 km natural state boundary with Bihar. Near Patna City, the Rivers Gandak and Sone also connect to it. Additionally, the Ganga's Himalayan tributary, the Kosi, joins the Ganga in Kursela. Before entering the State of West Bengal, it travels 405 km via Bihar. In two streams, it separates. The first stream, the Hooghly River, continues to flow into the Bay of Bengal from south of India. The Sunderbans Delta, the world's biggest natural halophytic mangrove forest, is formed by the Hooghly River. Rapid urbanisation and industrialization have made the Ganga basin, and notably the areas around the River Ganga, stand out during the past several decades. River is a valuable natural resource, but owing to fast industrialization and urbanization, it is losing all of its physical and natural qualities. Anthropogenic activities like the untreated flow of industrial effluent into the River Ganga have an influence on both the water quality of the River and its symbiotic ecosystem. To comprehend the water quality and features of the river Ganga, one must view the river as a dynamic, interconnected river system. Numerous variables either directly or indirectly affect the Ganges River's water quality. Urban centers, agriculture, trade, and industry are all produced by perennial rivers like the Ganga. Since the previous forty years, several little villages have grown into huge metropolis. The main factor limiting industrialization is zoning and the lack of big tracts of flat land in Uttarakhand State. The river from Rishikesh to Haridwar gave rise to the major electrical and drug industries. The Gangetic Plain is the most industrialized area since it is home to several agricultural businesses, including distilleries and sugar mills. Kanpur city is widely recognized for its textile and leather industry and supplies 80–90% of India's exports of leather. Major urban areas in the deltaic region and the lower plains, respectively, include Patna and Kolkata have several industries that span all industrial sectors. 260 MLD of industrial sewage is typically dumped into the Ganga River. On the banks of rivers, there are hundreds of large companies, and 68 of those have been designated as excessively polluting industries (CPCB, 2013). Industrialization has put a strain on Ganga's capability for self-purification, and the river has lost its natural power to digest organic garbage.

Various Analytical and environmental data are treated with multivariate statistical methods. In order to reduce the number of dimensions in a data collection, principal component analysis can be employed. To do this, lower-order principle components must be kept while higher-order ones are ignored, and the data set's other properties that most significantly affect variance must be removed. In the examination of data relating to several factors, it is highly helpful. As they are unbiased approaches that may show relationships between samples and factors, they have been frequently employed. By describing the association between a large number of variables in terms of a limited amount of underlying factors or primary components, it is used to minimize the dimensionality of the data set without sacrificing much information. Principal component analysis has been used extensively in recent years in several research to compare various water quality measures. In order to distinguish between hydrogeological and hydro-geochemical processes using frequently gathered groundwater quality data, PCA has been effectively employed. In order to explain the link between the numerous physicochemical factors that have been monitored and environmental condition influence on the coastal water quality, a statistical model that is based on the PCA for coastal water quality data from the Cochin coast in South West India was created. The examination of nutrient gradients inside a eutrophic reservoir found the main pesticide composition generating the observed data fluctuations using PCA. The PCA approach has also been used to assess geographical and temporal patterns of heavy metal pollution. These methods are widely used by researchers to study the quality of ground water.

Various Water Quality Index methods are categorized to fulfill the local and international standard as follows –

- National Sanitation and Foundation Water Quality Index (NSFWQI) (Brown et al.,1970)
- Weight Arithmetic Water Quality Index (WAWQI) (Abbasi, & Abbasi 2012)

- Canadian Council of Ministers of the Environment Water Quality Index (CCMEWQI) (CCME,2001)
- Oregon Water Quality Index (OWQI) (Cude CG, 2001)
- Nemerow and Sumitomo’s, Prati’s Implicit Index of Pollution (Abbasi, & Abbasi 2012)
- McDuffie and Haney’s (Abbasi, & Abbasi 2012)
- The Florida Stream Water Quality Index (FWWQI) (Abbasi, & Abbasi 2012)
- The River Ganga Index (of Ved Prakash et al.) (Abbasi, & Abbasi 2012)
- River Pollution Index (RPI) (Abbasi, & Abbasi 2012)
- The WQI of Said et al. (2004) (Abbasi, & Abbasi 2012)

The main objective of this study are as follows:

- To evaluate the spatio _temporal variation in the water quality of river at different location in West Bengal , India.
- To calculate the WQI and SPI at selected locations for the study area.
- To perform Geospatial assessment for spatial interpolation with the help of Inverse Distance Weighted (IDW) technique provided in Arc GIS.
- To identify the pollution source through multivariate statistical tool as in Factor Analysis (FC), supported by Component Analysis (CA) .
- To suggest the water treatment technologies to improve the water quality which fits for drinking purpose.

CHAPTER 2
LITERATURE SURVEY

2.1. Nitin Kamboj et al.[9] (2019) did an investigation on water quality assessment using the overall index of Pollution in the riverbed mining area of the Ganga River. He conducted his research which was carried out in 2017–2018 in the Haridwar district's mining-affected areas along the Ganga riverbed in order to evaluate the seasonal dynamics of surface quality using the Overall Index of Pollution (OIP). OIP analysis helped to establish topographic water quality. To demonstrate the actual effect of riverbed mining on chosen physicochemical parameters, five sampling locations were chosen, and the obtained water sample was analyzed in triplicate. OIP values for surface water quality were found to be good in the winter (1.13), acceptable in the summer (3.37), and slightly contaminated in the monsoon (7.94). The geographical analysis revealed that the chosen riverbed mining sites had high OIP scores in comparison to places where mining was not done. It was determined from his study that the riverbed mining practices had a detrimental impact on the Ganga River's surface water quality in the chosen area and that extra attention should be paid to ensuring ecological sustainability.

2.2. Ghulam et al [10]. (2019) observed that climate change is threatening groundwater aquifers in Pakistan's coastal districts. This study analysed and mapped the quality of groundwater in Pakistan's coastal region using physicochemical examination of 94 samples, two conventional numerical models, and GIS methods. According to the WQI model, 2.13%, 6.38%, 55.32%, 22.34%, and 13.83% of the water samples were excellent, good, seriously poor, or unfit for drinking. Furthermore, the SPI model discovered that 32%, 13.83%, 20.12%, 18.1%, and 15.95% of the samples were appropriate, improper, badly contaminated, or very polluted. According to the report, most areas' groundwater does not adhere to WHO standards. The area's high prevalence of water-related illnesses makes drinking contaminated groundwater dangerous for people's health. In groundwater, 89.4% of samples had greater EC, according to a physicochemical investigation. TDS concentrations surpassed 500 mg/L in about 88.3% of the samples, with the majority classified as hard based on overall hardness. The chloride levels were also over legal limits in the majority of the samples; up to 200 ppb arsenic was found in 23.4% of the water samples, with an average level of 15.53 ppb. The prevalence of skin, heart, kidney, skin, and gastroenteritis in the region shows that the drinking water is contaminated and that utilising it for residential purposes is hazardous to human health. The study's findings will assist in monitoring and regulating the vulnerability of water resources in the region, reducing the negative implications on human health. They will also help the government, lawmakers, and the general public understand the situation of groundwater pollution.

2.3. Noah Kyame Asare-Donkor et al. [8](2018) examined the hydro geochemical properties of surface water from the Birim River watershed and evaluated its suitability for drinking and agricultural use. Additionally, utilising pollution indices, the ecological risk assessment of Cd, Zn, Pb, and As in sediment was assessed. In a multivariate study, four components were identified that together accounted for 98.15% of the total hydro geochemistry and were influenced by human influences. The ionic strength of the surface water was found to be dominated by $HCO_3\ ^+$, $Cl\ ^+$, Ca_2^+, Mg_2^+, and $Na\ ^+$, ranging from neutral to moderately acidic. The Piper diagram identifies four main categories of surface water: Ca-Na-Mg-HCO_3, Na-HCO_3-Cl, Na-Cl-HCO_3, Na-Ca-Mg-HCO_3, and Na-Cl-HCO_3. The water quality index revealed that the majority of the surface water from settlements within the Birim River basin were of poor quality for drinking and domestic purposes. The Gibbs plot demonstrated that the major ion chemistry of surface water was primarily influenced by atmospheric precipitation. Calculations for irrigation appropriateness using the values for the ratios of sodium adsorption, residual sodium carbonate, and magnesium, as well as Wilcox and USSL models, showed that the surface water in the research region was suitable for agriculture. The relevant agencies and authorities should conduct ongoing monitoring so that different interventions may be implemented to stop the situation from getting worse in order to safeguard the occupants of the settlements inside the Birim River basin. Further he concluded that important details regarding the hydrochemistry and water quality of surface water as well as the ecological dangers posed by some heavy metal contents of sediment from various towns within the Birim River basin. The surface water samples hydro-geochemical study showed that the water was neutral to moderately acidic, and the Ca-Na-Mg-HCO3 (39%) and Na-Ca-Mg-HCO3 (23%) water types dominated the region's hydro-chemical facies.

Asare-Donkor, N. K., Ofosu, J. O., & Adimado, A. A. (2018). Hydrochemical characteristics of surface water and ecological risk assessment of sediments from settlements within the Birim River basin in Ghana. Environmental Systems Research, 7(1), 1-17.

2.4. Kosha and Geeta[5](2015) measured six water quality indicators from 2005 to 2008 in order to establish a water quality index (WQI): pH, dissolved oxygen, biochemical oxygen demand, electrical conductivity, nitrate nitrogen, and total coliform. For the river basin length, the WQI was calculated using the weighted arithmetic water quality index method. According to this study, the bulk of the parameters were significantly impacted by human activity and sewage discharge into the river. The stations with the lowest water quality were those in highly populated areas, followed by those in moderately urban areas, and finally those in somewhat rural areas. Heavy human activity, illegal sewage and industrial effluent discharge, a lack of basic sanitation, exposed river sites, and urban runoff were all identified as major factors to water quality degradation.

2.5. R. Bhutiani et al.[6] (2014) done study on the Water Quality Index (WQI) by examining sixteen physico-chemical parameters on the River Ganga index by considering the National Sanitation Foundation (NSF), Ved Prakash, weighted arithmetic index, and WQI to determine if the water is fit for drinking. He used river Ganga's quality variation at monitored places of Haridwar (India) by using three water quality indices of 11 year period. As per his analysis he examined 16 physico-chemical parameters such as temperature, conductivity, turbidity, velocity, total solids, TDS, pH, D.O., B.O.D., C.O.D., alkalinity, hardness, phosphates, nitrates, free CO_2 and chlorides. WQI for the study period from Year 2000 to Year 2010 obtained by River Ganga index. Further it was found that from 2000 to 2010, the River Ganga Index were 51.69, 51.96, 50.68, 52.55, 50.78, 51.42, 52.26, and 52.82,51.50, 52.64, and 52.05, respectively, show water quality to be between medium and good. As per NSF Index readings for same years were 78, 74, 75, 76, 72, 75, 74, 73, 74, and 74, respectively indicating good water quality. WQI values as per Weighted Arithmetic Index method were 8.13, 70.35, 58.19, 66.84, 73.05, 60.09, 72.63, 69.5, 56.28, 64.72 and 63.44, indicating good water quality. While the NSF Index and the River Ganga Index both indicated equal water quality, the weighted Arithmetic technique awarded the Ganga river low water quality, with water quality deteriorating from Year 2000.

2.6 .Monika Dubey et al.[7](2013) done study on water quality and pollution status of the Tapi River (Gujrat) which has a geographical position of 72º 38' to 78º 17' E longitudes and 20º 5' to 22º 3' N latitudes. Data collection has been done from January to June 2011 related to physio-chemical parameters such as temperature, turbidity, conductivity, pH, total alkalinity, DO, BOD, COD, chloride, total hardness, phosphate, Nitrate-N, Nitrite-N, ammonia, sodium and potassium. By conducting an analysis, he found that the water quality of the Tapi River exceeded its permissible limit. Most of the parameters are beyond WHO and BIS acceptable limits, that is why they are fit for drinking purposes and domestic uses. Further management of industrial waste and domestic sewage is required to assess the protection of water quality from hazardous substances and chemicals.

2.7. Prerna et al.[4](2013) calculated the water quality index (WQI) of post-monsoon water samples to analyse changes in the Ganges river along its length from Allahabad to the Yamuna confluence. Temperature, pH, electrical conductivity, dissolved oxygen, total dissolved solids (TDS), main cations like Na+, K+, Mg2+, Ca+, major anions like F-, Cl-, Br-, SO4 2-, NO3 -, PO4 2-, and alkalinity were all measured using standard protocols. The results were compared to Bureau of Indian Standards (BIS) and World Health Organisation (WHO) drinking water guideline values. Certain characteristics from the observed quantities were chosen to compute WQI for differences in water quality at each given sample location. The studies showed a significant reduction in water quality at several of the locations. In Allahabad, the WQI for Ganges river water varied from 86.20 to 157.69, indicating poor water quality. Pearson's Correlation Matrix was created to identify potential interrelationships between measured water quality metrics. The WQI has been shown to be a valuable tool for monitoring water quality and forecasting trends in water quality variation along the Ganges River.

2.8. Deepshikha and Arun[3](2011) saw that the River Yamuna in Delhi's NCT had degraded and become unclean as a result of enormous volumes of domestic effluent entering the river. Despite repeated attempts (from 1993 to the present) in the form of Yamuna Action Plan (YAP) phases I and II, river quality in the NCT has not improved. Environmental management has prioritised river water quality repair. The current study examined the Yamuna River's water quality index (WQI) in the NCT to investigate how the YAP I and II projects affected it. The study focuses on describing the degree of pollution in the river using WQI during a 10-year period (2000-2009). The research also identifies the primary contaminants impacting river water quality as it flows through the city. For the pre-monsoon, monsoon, and post-monsoon seasons, the indicators were computed at four river locations: Palla, ODRB, Nizamuddin, and Okhla. Water quality ranged from fair to marginal in Palla, but it was bad in all other areas. Key stretch parameters included BOD, DO, total and faecal coliforms, and free ammonia.

2.9. Aswani Kumar et al.[4] (2009) studied the water quality index of river Ravi in the Madhopur district and assessed single parameters which tell the desired property of water quality. He collected the data from January 2003 through December 2005 from Madhopur in the Indian state of Punjab. The samples were taken from the river's surface water. WQI was calculated using the eight most crucial variables: pH, total dissolved solids (TDS), total hardness, calcium (Ca), magnesium (Mg), total alkalinity, dissolved oxygen (DO), and electrical conductivity (EC). The River Ravi's WQI readings varied from 54.8 to 97.88 respectively. WQI values indicated that, with the exception of the two to three months where they were less than 70, the water at the sample location was free of any pollutants. Every time there are human activities, such as dam operations, water becomes somewhat contaminated, which lowers the WQI score. It was discovered that the parameter with the lowest amount of need provides a significant statistical value to the index. Further, he concluded that WQI may be used as a method to compare the water quality of various sources.

2.10. A. Mishra et al.[1] (2008) have done a case study on the river Ganga to assess the water quality using the principal component analysis technique. Statistical analysis was done to analyze the river Ganges' water quality using multivariate principal component analysis and to draw out the variables that are most crucial for determining how the river's water quality varies. In order to evaluate the enormous and complex data matrix generated during the monitoring of the Ganges River in Varanasi, multivariate statistical methodologies are applied. Six sampling sites along a river that is impacted by anthropogenic and seasonal factors collected water samples every three months for two years, which were then analyzed for 16 physicochemical and bacteriological variables. The characteristics that are most crucial for determining how water quality varies were extracted from the dataset using Principal Component Analysis (PCA). Four principal factors—nutrient factor (39.2%), sewage and fecal contamination (29.3%), physicochemical sources of variability (6.2%), wastewater pollution from industrial sources, and organic load (5.8%), which together represent the total variance of water quality in the Ganges River—were found to be responsible for the data structure and to account for 90% of the total variance of the dataset. The current study demonstrates that PCA approaches are helpful tools for identifying significant characteristics that affect surface water quality.

2.11. Shrestha and Kazama[2](2006) developed multivariate statistical methodologies for assessing temporal/spatial changes and analysing a large complex water quality data set collected over an 8-year period (1995-2002) of monitoring of 12 parameters at 13 different locations (14 976 observations). Based on the closeness of water quality parameters, hierarchical cluster analysis identified 13 sample sites as significantly less polluted (LP), medium polluted (MP), and highly polluted (HP). When applied to cluster analysis data sets, five, five, and three latent factors explained 73.18, 77.61, and 65.39% of total variance in water quality data sets from the LP, MP, and HP sectors, respectively. For both geographical and temporal experiments, discriminant analysis yielded the best results. It achieves over 85% temporal and 81% spatial accuracy with only six parameters (discharge, temperature, dissolved oxygen, biochemical oxygen requirement, electrical conductivity, and nitrate nitrogen). As a result, DA reduced the dimensionality of the enormous data set, identifying a few indicator items responsible for significant fluctuations in water quality. This study highlights the need of multivariate statistical techniques in measuring water quality, identifying pollution sources and drivers, and interpreting temporal and geographical changes in water quality for successful river water quality management.

CHAPTER 3

METHODOLOGY

3.1 STUDY AREA

This research work is carried out in the lower portion of the Ganga River in West Bengal, India, between latitudes 87°550′ E, longitude 24°480′ N, and latitude 87°460′ E, longitude 21°410′ N. A total ten number of stations were selected for this study in order to effectively monitor the river, which was subtly planned by the central pollution control board (CPCB). The river basin has a three-season subtropical humid climate with an average annual rainfall of roughly 1,500 mm, among cold, hot dry seasons and monsoon. Older alluvial (Middle-Upper Pleistocene deposits) and more recent alluvium make up the geology. The water quality of the river has significantly deteriorated because of extensive contamination brought on by anthropogenic activities such as the discharge of sewage and untreated industrial effluents, mass idol immersion during religious festivals, mass bathing, the dumping of dead corpses, etc. Additionally, this stretch gets more than 87 MLD (millions of liters per day) of waste water from 22 highly polluted sectors, with the chemical industry accounting for around 70% of all discharges and the pulp-paper industry for 20% (CPCB 2013). Other sectors include distilleries, food, dairy, and beverage, sugar, textile, and bleaching and dyeing make up the remaining percentage. Despite these harmful actions, several cities in the Murshidabad, Baharampur, Bardhaman, Nadia, Hooghly, North 24 Parganas, Kolkata, and Howrah districts continue to rely on this stretch as their main supply of drinking water. A total of 1,136 million liters/day of river water are processed and provided to the ecosystems through Kolkata's three waterworks, Palta, Garden Reach, and Baranagar (UNU 2000). Similarly, Howrah has two water works, Padhmapukur and Serampore, supplying about 270 million liters of water/day (UNU 2000). Therefore, water quality assessment and documentation of management practices are required to safeguard human health.

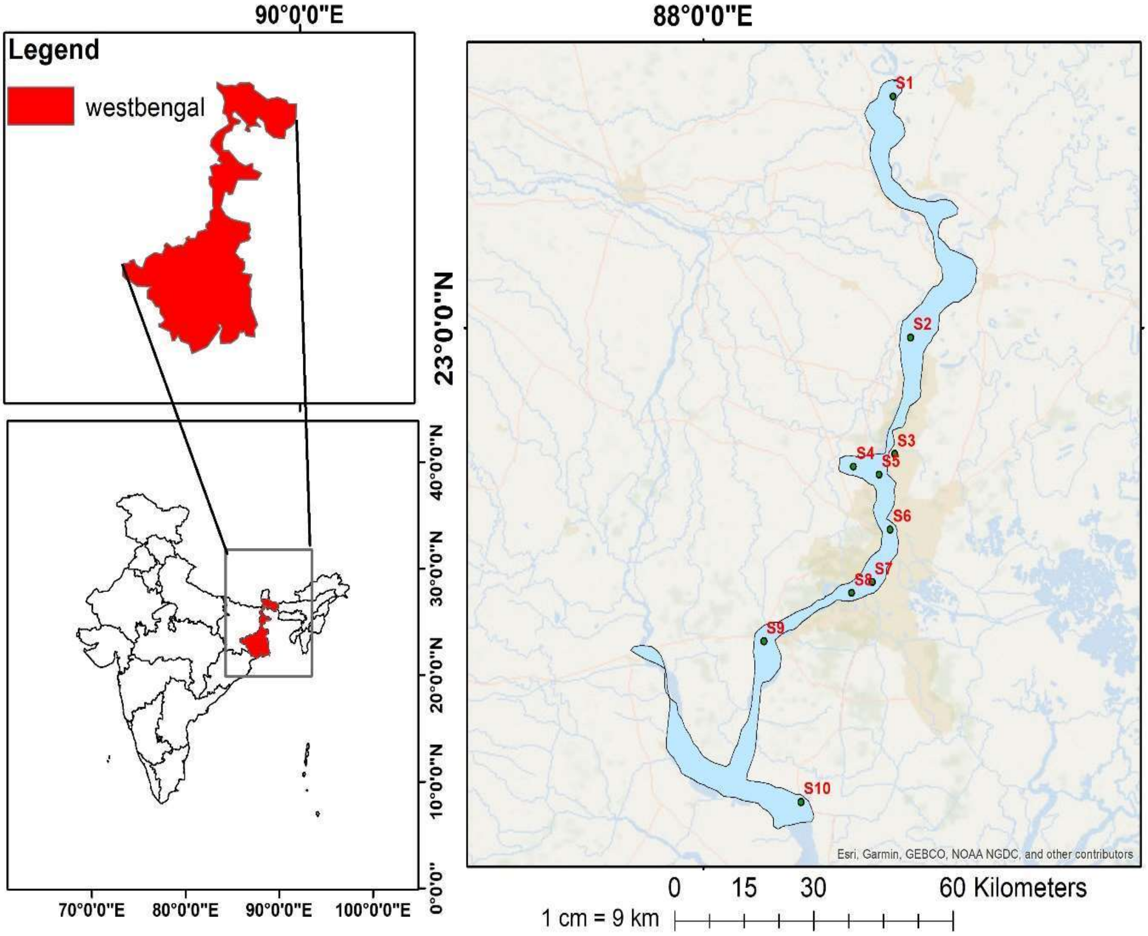

Fig. 3.1 Map showing study area and sampling locations

Table 3.1. Details of monitoring stations of river Ganga in West Bengal stretch

S.no	Location	Activities
1	Howrah Shivpur	Bathing, Washing, Navigation, Fishing
2	Garden Reach	Bathing, Washing, Fishing
3	Serampore	Bathing, Washing, Navigation
4	Palta	Bathing, Washing, Navigation, Fishing
5	Nabadwip	Bathing, Washing, Navigation
6	Dakshineshwar	Bathing, Washing, Navigation
7	Triveni	Bathing, Washing, Navigation, Cremation
8	Baharampore	Bathing, Washing, Navigation

9	uluberia	Bathing, Washing, Navigation
10	Diamond harbor	Bathing, Washing, Navigation, Fishing

Table 3.2. Geo-coordinate and demarcation of 10 different stations

Demarcation	Station Name	Latitude	Longitude
S1	Nabadip Ghosapara monipurghat	23.3951	88.368
S2	Tribeni Burning Ghat	22.98441	88.40182
S3	Palta west bengal	22.7859	88.37128
S4	Baharampore	22.76422	88.29112
S5	Serampore	22.75052	88.34058
S6	Dakshineshwar	22.65731	88.36241
S7	Shivpur - Howrah	22.56742	88.32712
S8	Garden Reach	22.54855	88.28764
S9	Uluberia	22.46643	88.11706
S10	Diamond Harbour	22.19269	88.18949

3.2 Selection of Stations and Parameters for Calculation of WQI AND SPI

The West Bengal Pollution Control Board (WBPCB) is authorized the monitoring of water quality along the ridge of river Ganga in the easternmost part of the River line. The database from the WBPCB was used to get the physio-chemical and biological monitoring parameters for the period of 2020 to 2023. The monthly data used in this study refers to surface water samples that were taken at the frequency of 15 days among the 10 monitoring stations. The parameters which are taken for calculation of WQI and SPI are those which have the maximum impact on human health, which are ammonia, BOD, DO, total dissolved solids (TDS), chloride, fluoride, sodium, sulphate, total hardness, conductivity, temperature, nitrate, PH, sulphate as mentioned by World Health Organisation (WHO). These two indexes (WHO, SPI) rely on the weighted average integration of the water quality elements. The unit weighting in this investigation was based on the WHO-approved drinking water quality standard. The factor with a high unit weightage has a significant influence on the quality of drinking water.

3.3 WATER QUALITY INDEX

- The Water Quality Index (WQI) is the solitary and estimable rating indices that is used to illustrate the overall water quality scenario in a single term which helps us in accessing the water quality for different uses of water. It uses the different water quality parameters (BOD, COD, DO, pH, N, N-NO^{3-}, N-NO2-, N-NH^{4+}, SO_4^{-2}, Cl^-, Cr, Pb^{2+}, Cd^{2+}, Ni^{2+}, Fe, Mn, Zn^{2+}, and As^{2+})
- The contemporaneous computation of all physicochemical and biological parameters using this approach is often not limited; they may alternatively be done independently. When using this method, it is crucial to take into account the variations in physicochemical parameters that result from a variety of natural processes, including erosion [8] as well as those related to hydrology, topography, lithology, climate, hydrographic basins, geological rocks, and hydrological processes.
- But the most important parameters are those which originated from anthropogenic activities. Horton created the WQI index for the first time in the US in 1965 [12]. Since that time, more calculus techniques have been developed to produce the same water quality index (WQI) [13].
- Based on the selection of different parameters and their respective impact on the final value of indices, several other methods are developed
- As of now, experts have not recommended a reliable, globally applicable approach for assessing water quality. Furthermore, no technique for assessing the quality of water provides 100% objectivity and accuracy [8].

3.3.1 WQI ESTIMATION METHODS

3.3.1(a) NSF-WQI (National Sanitation Foundation- Water Quality Index consists of the following nine quality indicators: temperature, TDS (total dissolved solids), pH, turbidity, phosphates, nitrates, CBO5 (biochemical oxygen consumption), Coliforms, and OD (dissolved oxygen) [14, 16-18]. Each parameter's impact on the change of the water quality is varied, hence a particular weight was given to each one when calculating the NFS-WQI index, as shown in Table 1 . On the basis of formula 1, this index is determined.

$$\text{NSF-WQI}=\sum_{i=0}^{n} WiQi \qquad (1)$$

where: WQI-NFS is a number between 0 and 100; Wi is the parameter weighting factor (Table 3); The quality parameter i's sub-index, Qi, is determined by the conversion curves (curves that convert parameters based on values in the range of 0-100).
The NFS-WQI index value placed the analyzed body of water in one of the five groups shown in Table 4 based on the value.

Table 3.3: Weight scores of the nine NSF-WQI parameters

Parameter	Weight
Dissolved oxygen (OD)	0.17
Coliforms	0.16
pH	0.11
Biochemical oxygen demand (BOD)	0.11
Temperature	0.1
Nitrates	0.1
Total phosphate	0.1
Turbidity	0.08
Total solids (TDS)	0.07

Table 3.4: Water quality value (NFS –WQI)

Value- NFS -WQI	Water Quality
90-100	Very good
70-90	Good
50-70	Medium
25-50	Bad
0-25	Very bad

The data pertaining to the parameters under analysis are summed up inside a single number in a quick, objective way that is also replicable. the assessment of variations in water quality in various locations; The index value represents the possible consumption of water. There are certain drawbacks, including the lack of a complex scale of water quality parameters and the lack of a complex scale of water quality parameters.

3.3.1(b) OWQI (Oregon Water Quality Index) is used to characterize the standard of Oregon's surface water bodies as well as those from other regions. In this descriptive approach for water quality, eight physical, chemical, and biological parameters are used: temperature, dissolved oxygen (OD), biochemical oxygen demand (BOD), pH, ammonia, nitrate, nitrogen, total phosphorus, total dissolved solids (TDS), and Coliforms. This index was proposed using the NSF-WQI model as a starting point. The difference is in the calculus approach and the parameter weights, which are not even taken into account in this instance. Formula 2 provides the mathematical formulation for this approach, which makes use of the idea of the arithmetical average.

$$\text{OWQI}=\sqrt{\frac{n}{\sum_{i=0}^{n}\frac{1}{Si2}}} \quad (2)$$

where Si is the sub-index of the ith parameter and n is the number of parameters (n=8).

In Cude's essay from 2001, the calculus approach of the sub-index for each parameter is described in great depth.

The quality of the analyzed water is indicated by the acquired value following the index computation of the water using the Oregon Water Quality Index technique, as given in Table 5 below-

Table 3.5: The corresponding values to water quality in conformity with OWQI

OWQI	Water Quality
90-100	Excellent
85-89	Good
70-84	Fair
60-70	Poor
59-0	Very Poor

The main Advantage is the most influenced characteristics can have the most influence on the OWQI thanks to the use of weighted harmonic to combine sub-indices; the equation is sensitive to changes in the environment and major effects on water quality. Demerit is that it cannot offer conclusive evidence on modifications to habitat, biodiversity, or toxic concentrations.

3.3.1(c) The weighted Arithmetic Water Quality Index Method gives details on how to evaluate the quality of a body of water. According to the following formula, this technique employs the most frequently observed water quality parameters (pH, BOD, COD, DO, P-PO_4^{3-}, N-total, N-NO^{3-}, N-NO^{2-}, N-NH^{4+}, SO_4^{2-}, Cr^-total, Pb^{2+}, Cd^{2+}, Ni^{2+}, Fe-total, Mn-total, Zn^{2+}, As^{2+})

$$WAWQI=\frac{\sum WiQi}{\sum Wi} \quad (3)$$

where: The water quality index (WQI) has a value between 0 and 100; Each parameter's unique relative value for the water quality is represented by qi; i denotes the total number of parameters considered; Wi is a factor that assesses a parameter's proportional weight in the creation of the WQI index; Applying the following formula 4, we can compute qi.

$$Qi=100*(V_i-V_0) / (S_i-V_0) \quad (4)$$

where: Si denotes the recognized standard value for the water category that the analysed water sample was included in; V_i is the value of the parameter that was experimentally obtained; V_0 denotes the parameter's ideal value. Formula 5 is used to determine the Wi factor:

$$Wi=\frac{K}{Si} \quad (5)$$

where K is a constant which can result from applying formula 6.

$$K=\frac{1}{\sum\frac{1}{S_i}} \quad (6)$$

The water ecological state may be determined based on the result of the Weighted Arithmetic WQI approach, as shown in Table 6.

Table 3.6: Water Quality Rating as per Weight Arithmetic Water Quality Index Method

WQI	Value Water quality
0-25	Excellent
26-50	Good
51-75	Poor
76-100	Very Poor
>100	Unsuitable for drinking

The main advantage of this method is that It incorporates the values of several physio-chemical water quality parameters into a mathematical equation that depicts the ecological status of the water; It emphasizes the significance of each parameter in the assessment and management of water

This index does not contain all the factors that may be used to define the quality of a body of water, hence it may not offer enough information on the actual status of the water quality.

3.3.1(d) The Canadian Council of Ministers of the Environment Index (CCME-WQI)

utilizes the following parameters for determining the water quality in a stream: temperature, conductivity, colour, turbidity, dissolved oxygen (OD), pH, alkalinity, Ca, Na, Mg, K, SO_4, Cl^-, F^-, Dissolved Organic Carbon, P, Nitrates, Nitrites, N, SiO^2, Al, As, Ba, Be, Cd, Co, Cr, Cu, Fe, Hg, Li, Mn, Mo, Ni, Pb, Se, Sr, V, Zn. Three primary elements, F_1, F_2, and F_3, are used to determine this and may be directly subtracted using certain methods. The percentage of variables (failed variables) that do not satisfy the objectives (referential values) at least once throughout the period is represented by the factor F1 (How many?), and it is often computed using formula 7.

$$F_1 = \frac{\text{Number of failed variable}}{\text{Total number}} \qquad (7)$$

F2 (How often?) is the factor representing the percentage of individual tests which do not meet the goals at all (failed tests).

$$F = \frac{\text{Number of failed Test}}{\text{Total number of Test}} \qquad (8)$$

F_3 (How much?) is the factor which represents the amount through which the test values did not respect their guideline values. This is calculated in three steps:

i. When the test value must not exceed the objective

$$\text{excursion} = (Failed\ Test\ Value\ /\ \text{objective}) - 1 \qquad (9)$$

ii. When the test value must not fall below the objective:

$$\text{excursion} = (\text{objective}/\ Failed\ Test\ Value) - 1 \qquad (10)$$

iii. The collective amount of excursions which are out of compliance is calculated according to the following formula:

$$\text{nse} = \sum excursion\ /number\ of\ tests \qquad (11)$$

The value obtained by calculating the index in compliance with the above presented formulas frame the analysed water in one of the specific quality categories included in Table 7.

Table 3.7: The corresponding values of water quality in conformity with CCME-WQI Index

CCME -WQI - Value	Water Quality
95-100	Excellent
80-94	Good
60-79	Fair
45-59	Marginal
0-44	Poor

The main advantage of this method that is is easy to calculate and It has a high adaptability to different water uses.

Table 3.8. Standard given by WHO and unit weight assigned to various parameters for calculation of WQI and SPI

Parameters	Standards (Si)	Unit weighted(Wi)
Ammonia	1.5	0.31068
BOD	5	0.09322
Conductivity	2000	0.00023
DO	5	0.09322
Nitrate	50	0.00932
PH	7.5	0.06213
Temperature	25	0.01864
Chloride	250	0.00184
Fluoride	1.5	0.31067
Sodium	200	0.00233
Sulphate	250	0.00186
TDS	600	0.00077
Total Hardness	200	0.09322
Turbidity	5	0.09322

All the parameters are in mg/l except PH, Total Hardness (mg/l as $CaCO_3$), Conductivity (µs/cm).

3.4 SPI Model

Following the selection of parameters and the unit weighting of each parameter, the SPI is calculated using the following equation –

$$\text{SPI} = \sum_{i=0}^{n} \frac{V_o}{S_0} * w_i \quad (12)$$

Table 3.9. Categorization of WQI and SPI for estimation of water quality

WQI	SPI	Water Quality	Explanation
0-25	0-0.25	Excellent	The water can be used for drinking without any treatment
25-50	0.25-0.50	Good	The water can be used for drinking after disinfection only
50-70	0.50-0.70	Fair	The water can be used for drinking after primary treatment followed by disinfection
70-100	0.70-0.1	Marginal	The water can be used for drinking after primary as well as secondary treatment
>100	>10	Poor	The water in absence of other source can be used for drinking with proper primary, secondary as well as tertiary and advanced water treatment

where Vo denotes the analytical value of the factors affecting water quality and Vs denotes the standard value of the WHO-recommended water quality parameters listed in Table 8.

The suggested level for the water quality parameter Vo, over which the water is unfit for drinking, was used to determine the critical value of SPI. The critical value was calculated to be 1 by integrating all of the water quality polluting characteristics used for the study with the unit weightage using Equation (4). Additionally, four identical quartiles were used to categorise the data (Table 9). Global problems include things like resource depletion and the ozone layer.

3.5 Geospatial assessment

The WQI or SPI data set may be integrated with GIS to better communicate the water quality state of the Ganga River in West Bengal, India, to stakeholders or policymakers (Tiwari et al. 2015). The ArcGIS 10.2 spatial analyst tool's Inverse Distance Weighted (IDW) interpolation method is used to perform the spatial interpolation. IDW forecasts the value of the unmeasured sites by weighing the distance between the measured locations.

The weights are thought of as being inversely proportional to the distance that may be measured from the power value, p. P is taken into account in this study as 2, which is the platform's default value for ArcGIS. The mathematical equation used by IDW to forecast the unknowable value.

3.6 Source identification: For the purpose of demonstrating a successful water quality management plan, the source was identified using a variety of multivariate statistical methods, including FA, backed by CA, and bivariate statistics, such as Pearson correlation. Prior to processing, the data set underwent a z-scale transformation to linearize it. These environmentrics reduce a large and complicated data set to a smaller and simpler data set without losing the original information, providing the most insightful information. A linear statistical model called FA condenses a large range of associated values into a manageable number known as principle components (PC).

Sample calculation of WQI

Table 3.10. WQI and SPI sample calculation

STATION	BAHRAMPORE	BAHRAMPORE	BAHRAMPORE	BAHRAMPORE	BAHRAMPORE	BAHRAMPORE
DATE	23-03-2023	15-03-2023	22-02-2023	08-02-2023	18-01-2023	10-01-2023
Ammonia-N	0.15	0.16	0.15	0.52	0.13	0.15
BOD	1.45	1.4	2.35	2.7	1.75	1.85
conductivity	381.1	350.5	376.2	383.2	427.4	410.3
Dissolved O2(DO)	7.3	7.7	8.4	9.4	9.9	9.4
Nitrate-N	0.11	0.52	0.14	0.2	0.08	0.38

pH	7.81	7.62	7.56	8.06	8.38	8.18
Temperature	27	28	27	26	16	18
chloride	15.99	16.99	16.99	13.99	15.99	15.99
Fluoride	0.2	0.19	0.2	0.27	0.22	0.22
Sodium	15.3	15.7	15.5	15.3	15.7	15.6
Sulphate	25.52	25.58	22.65	24.92	24.26	24.28
(TDS)	216	208	192	208	228	270
Total Hardness as CaCO3	152	158	144	149.02	172	133.33
Turbidity	63.51	17.44	6.63	15.53	19.89	21.19
WQI	129.4095807	55.66624789	40.19195417	64.99317652	61.57200093	63.85168474
SPI	1.294095807	0.556662479	0.401919542	0.649931765	0.615720009	0.638516847

Table 3.11. Formula Sheet

TYPE	UNIT	Sn	1/Sn	Wi = K/Sn	Vo	Vn	Vn/Sn	Qn=Vn/Sn *100	WnQn
Ammonia-N	mg/l	1.5	0.666667	0.271335	0	0.15	0.1	10	2.71335
BOD	mg/l	5	0.2	0.0814	0	1.45	0.29	29	2.360614
Conductivity	µs/cm	2000	0.0005	0.000204	0	381.1	0.19055	19.055	0.003878
Dissolved O2(DO)	mg/l	5	0.2	0.0814	14.6	7.3	0.157534	15.75342	1.282337
Nitrate-N	mg/l	45	0.022222	0.009044	0	0.11	0.002444	0.244444	0.002211
pH	Unit	68.5	0.014599	0.005942	7	7.81	0.54	54	0.320849
Temperature (Water)	ºC	200	0.005	0.002035	0	27	0.135	13.5	0.027473
Chloride	mg/l	250	0.004	0.001628	0	15.99	0.06396	6.396	0.010413
Fluoride	mg/l	1	1	0.407002	0	0.2	0.2	20	8.14005
Sodium	mg/l	7.5	0.133333	0.054267	0	15.3	2.04	204	11.07047
Sulphate	mg/l	250	0.004	0.001628	0	25.52	0.10208	10.208	0.016619

Total Dissolved Solids(TDS)	mg/l	600	0.001667	0.000678	0	216	0.36	36	0.02442
Total Hardness as CaCo3	mg/l	200	0.005	0.002035	0	152	0.76	76	0.154661
Turbidity	NTU	5	0.2	0.0814	0	63.51	12.702	1270.2	103.3949
SUM(1/Sn)			2.456987						129.5223

CHAPTER 4

RESULT AND DISCUSSION

4.1 Physico Chemical Analysis

In the current study, a detailed analysis of physico-chemical parameters is carried out to assess the water quality of the mentioned stretch of the Ganga River, which includes ten locations, as shown in box plots which displays the six-number summary(maximum, minimum, mean, median, first quartile, and third quartile) of the data set from the years 2020 to 2023.

4.1.1 Ammonia : The mean value of ammonia was found max at Garden Reach and varies from 0.1 mg/l to 0.72 mg/l, which is below the permissible limit as per WHO.

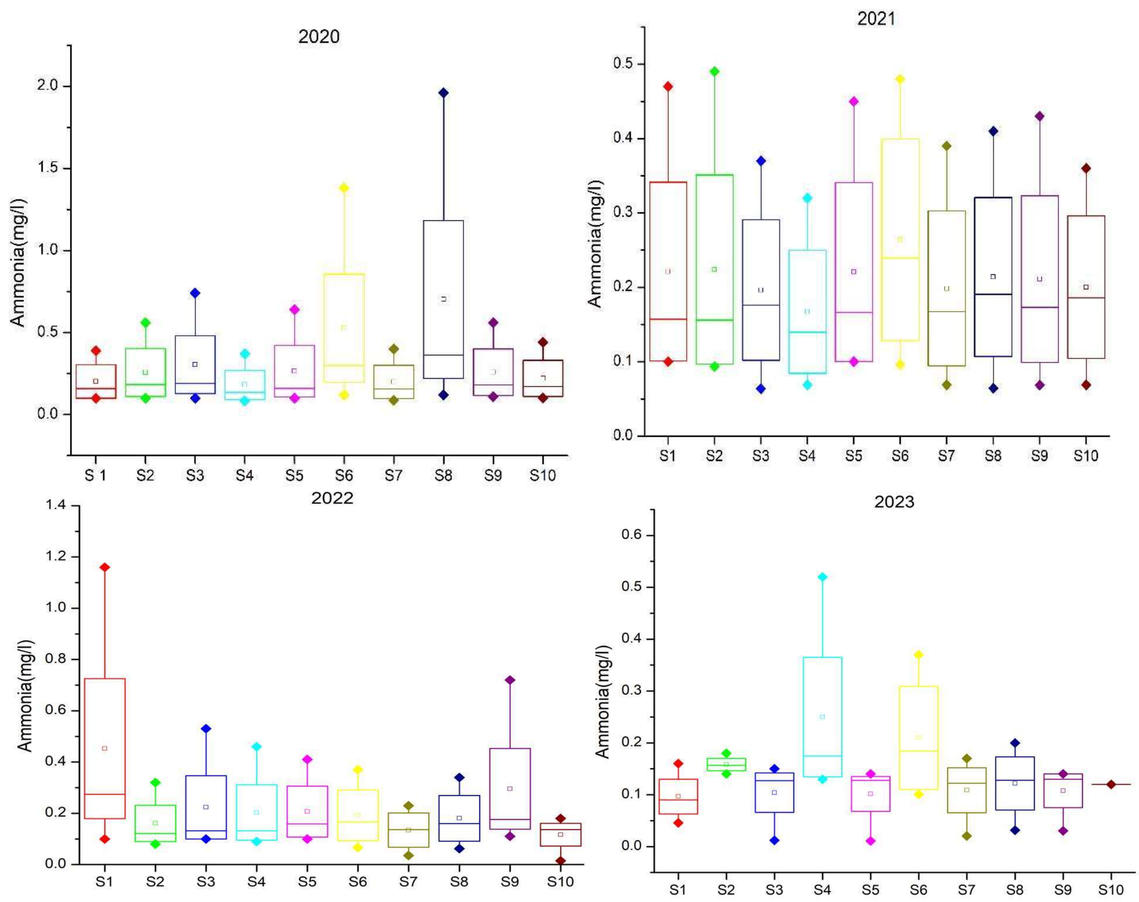

Fig.4.1 Box Plot of Ammonia (mg/l)

4.1.2 BOD

The value of Biological Oxygen Demand was found to be increasing from S1 to S10 in most of the cases , as in moving downstream from border of Bihar to Bay of Bengal , both population density and industrial sewage discharge increases

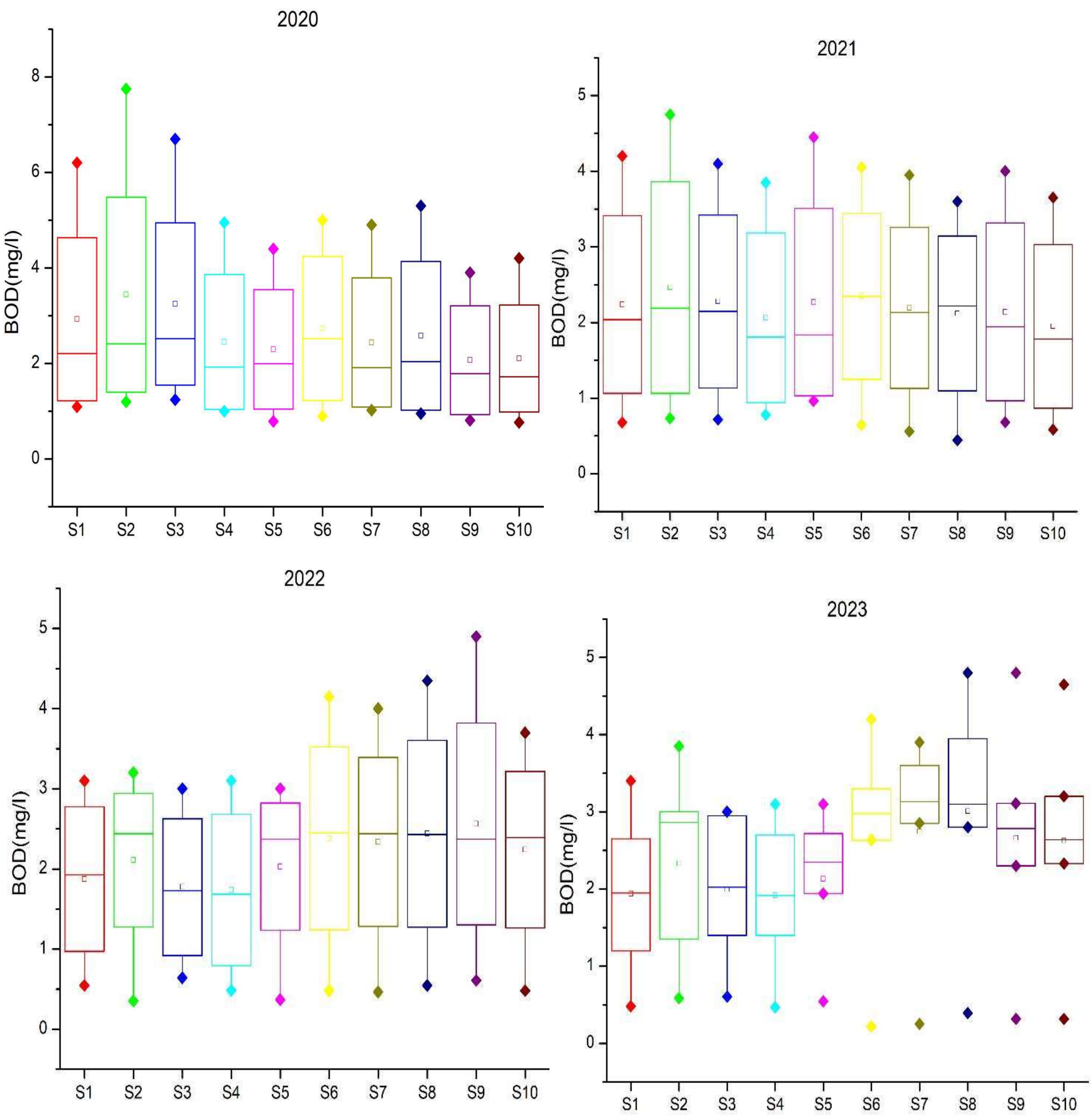

Fig.4.2 Box plot of BOD (mg/l)

4.1.3 CONDUCTIVITY

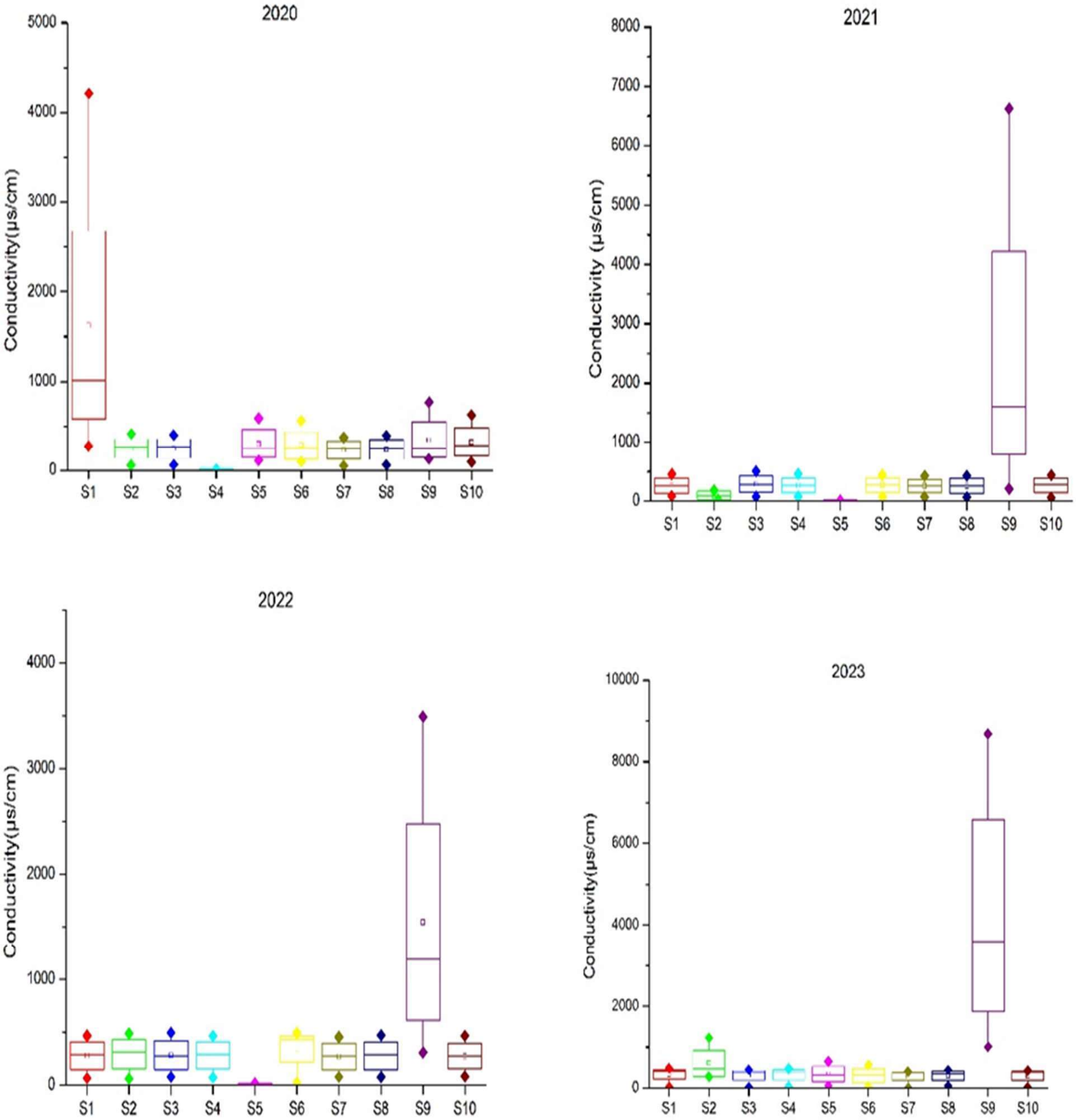

Fig.4.3. Box plot of conductivity (µs/cm)

4.1.4 DISSOLVED OXYGEN

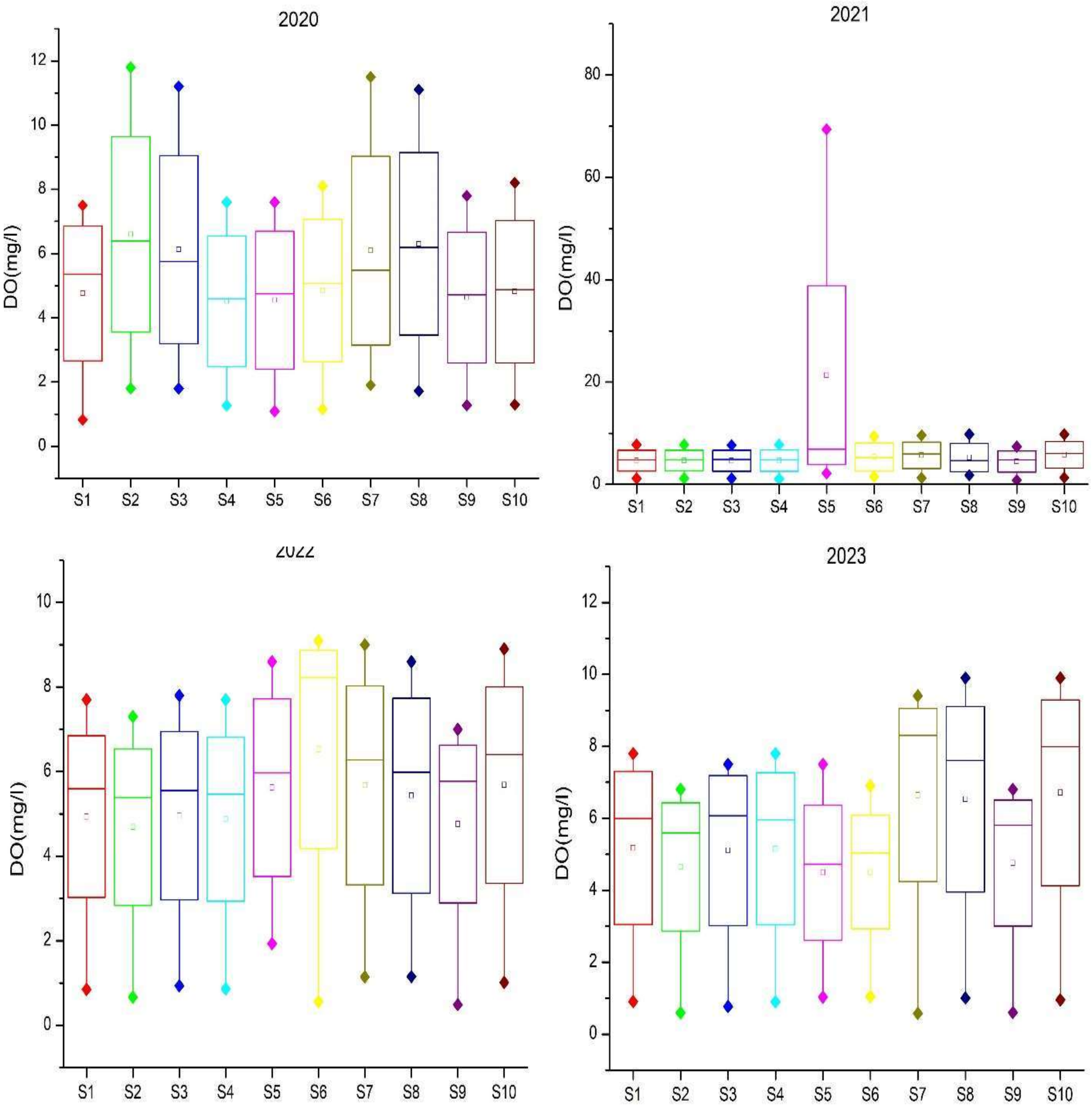

Fig.4.4. Box Plot of Dissolved Oxygen (mg/l)

4.1.5 NITRATE

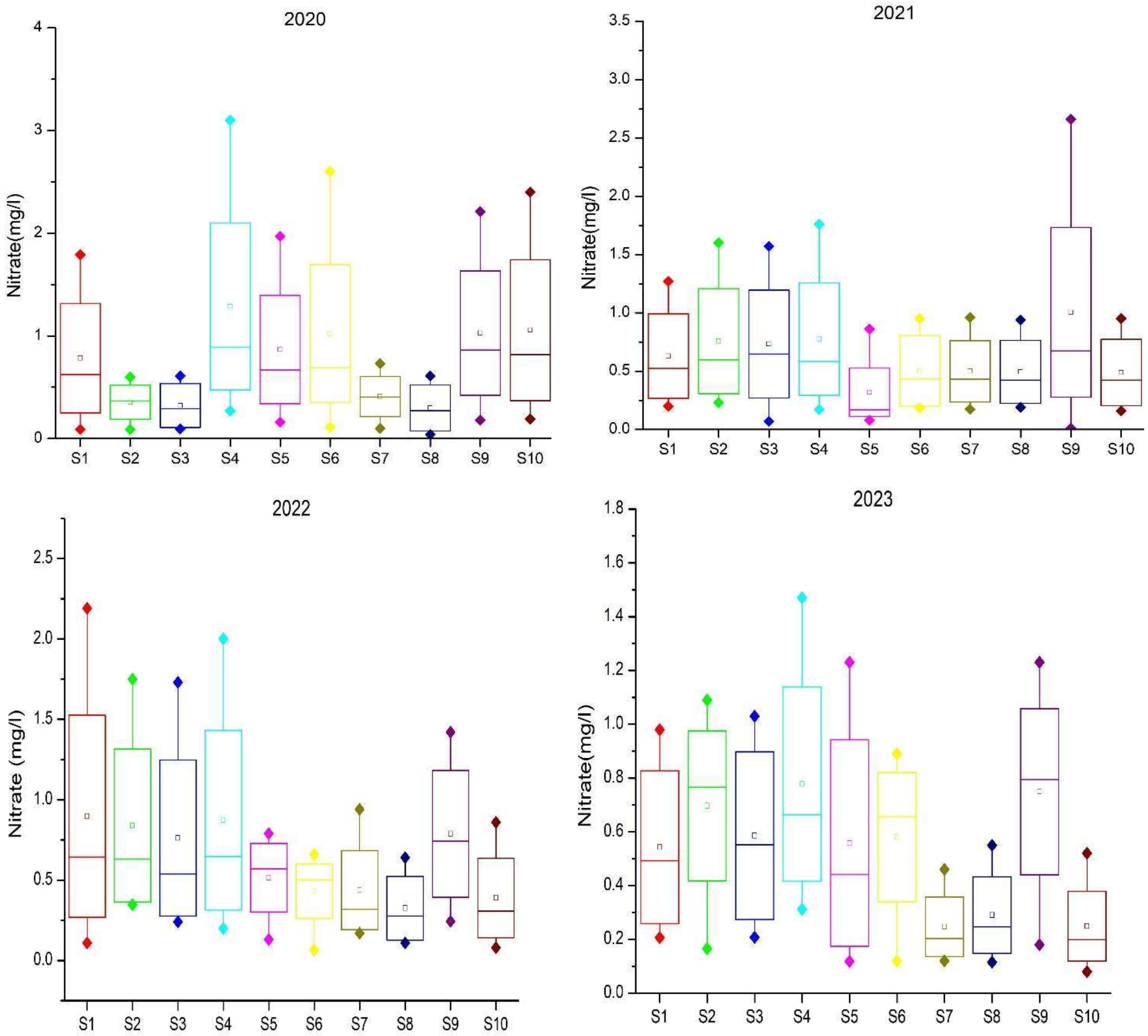

Fig.4.5. Box Plot of Nitrate (mg/l)

The majority of the nitrate in the Ganges River originates from wastewater from homes, busineses, agriculture, and aquaculture. Low levels of nitrate nitrogen were also found in all of the locations, with a mean range from 0.25 to 1.11 mg/L, which may be the result of phytoplankton and other primary producers using the substance.

4.1.6 PH : Except station diamond harbor (S10) the mean value of PH value was found in permissible limit

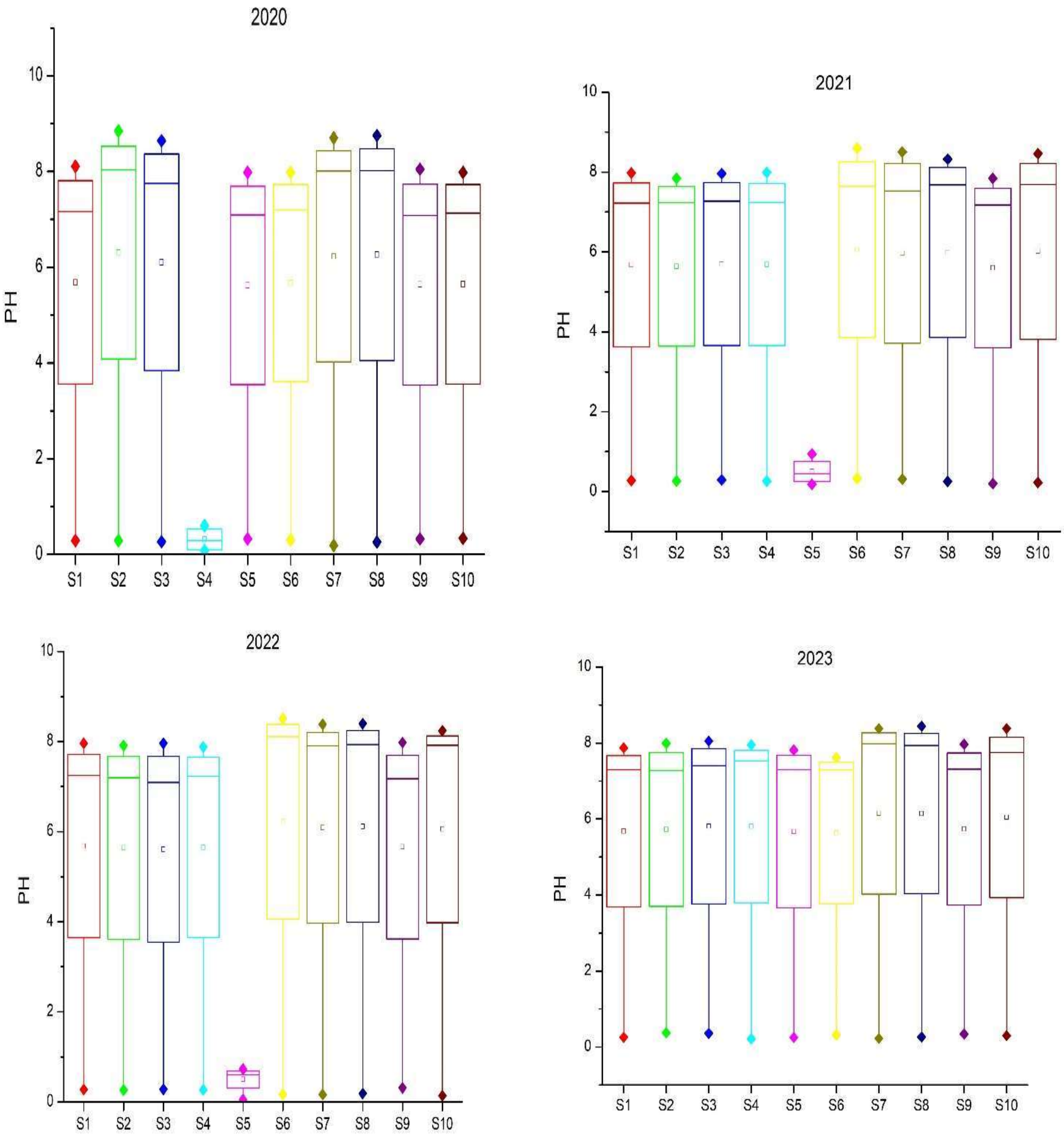

Fig.4.6. Box Plot of PH

4.1.7 TEMPERATURE

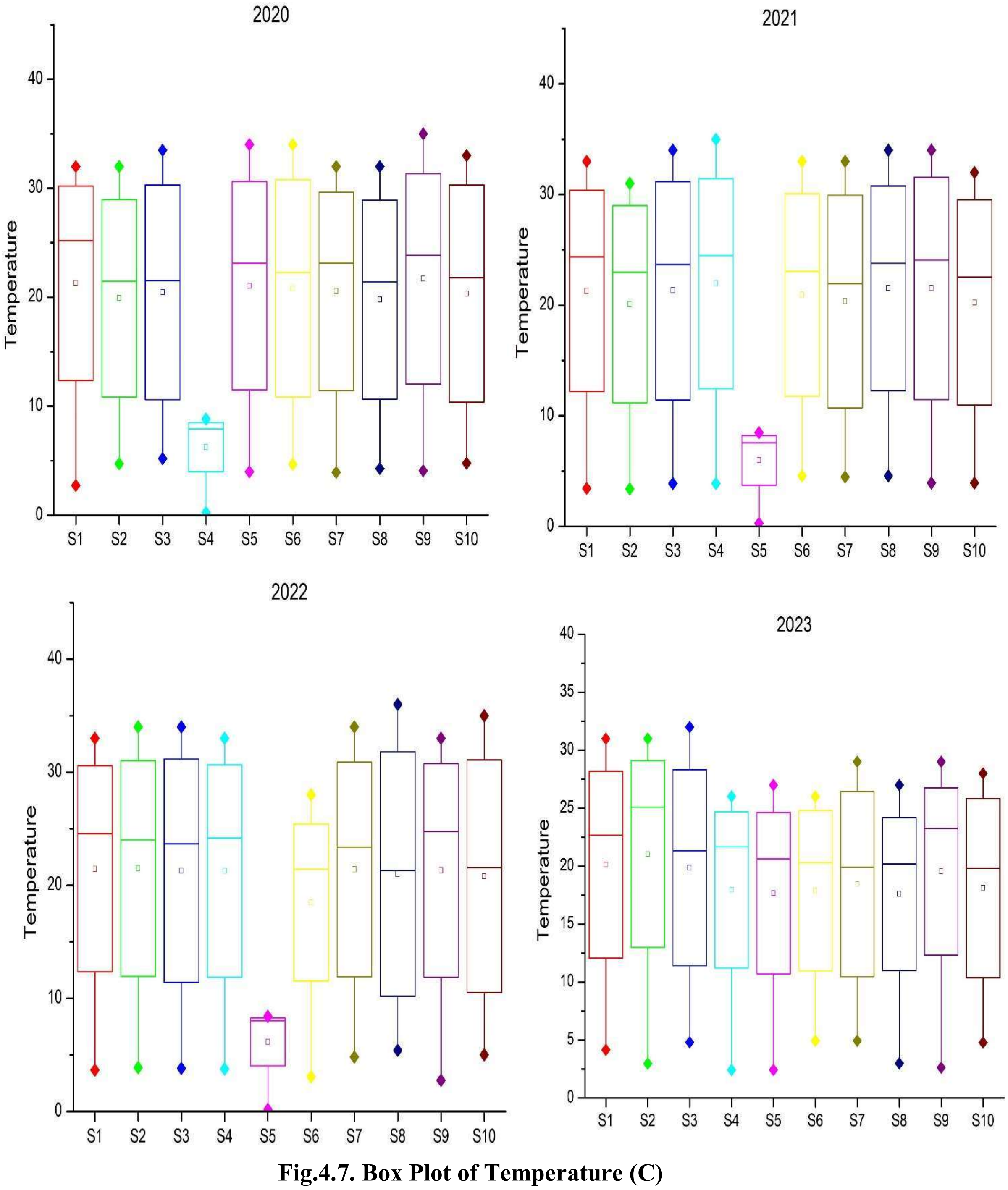

Fig.4.7. Box Plot of Temperature (C)

4.1.8 CHLORIDE

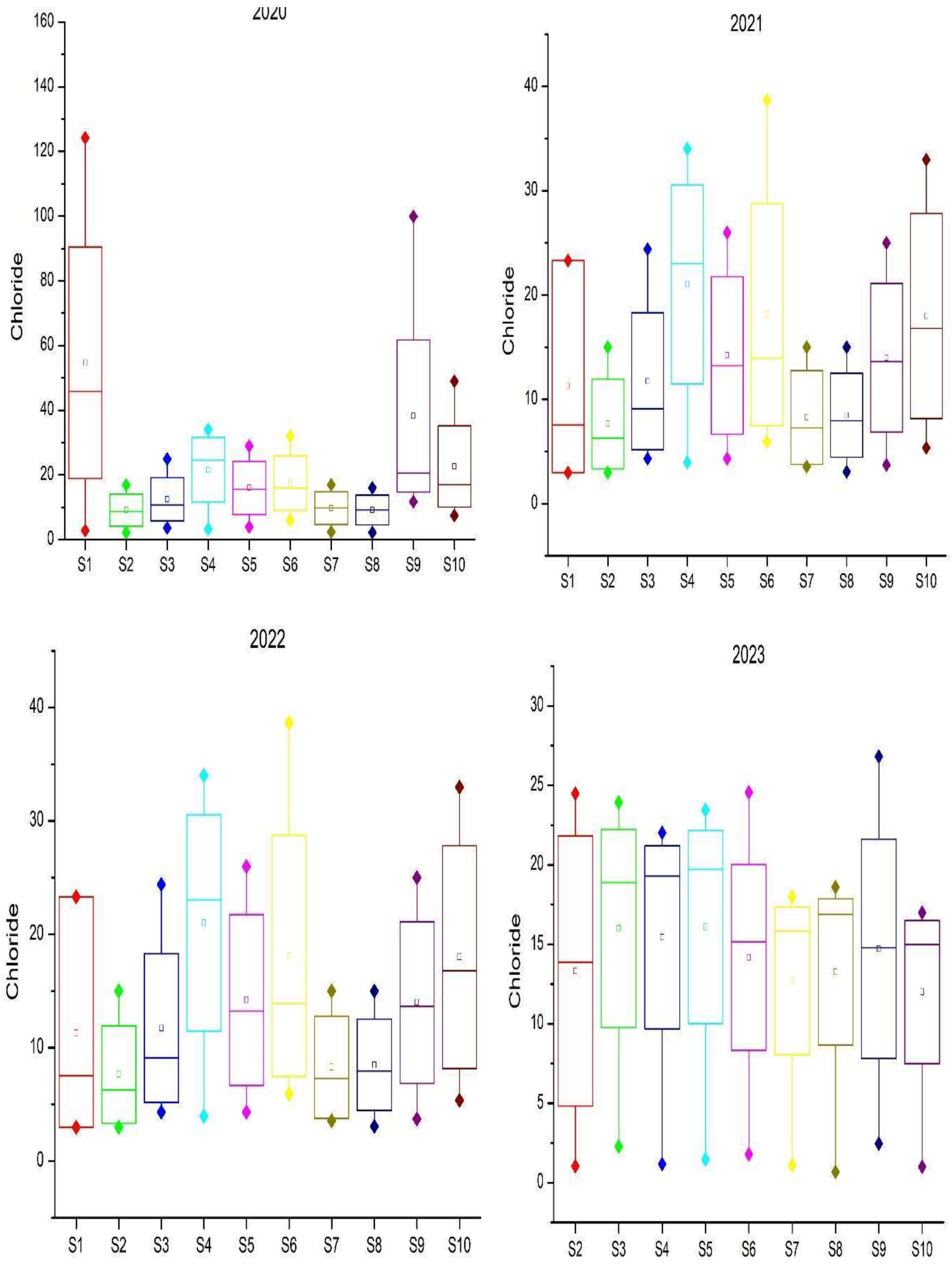

Fig.4.8. Box Plot of Chloride (mg/l)

4.1.9 FLUORIDE

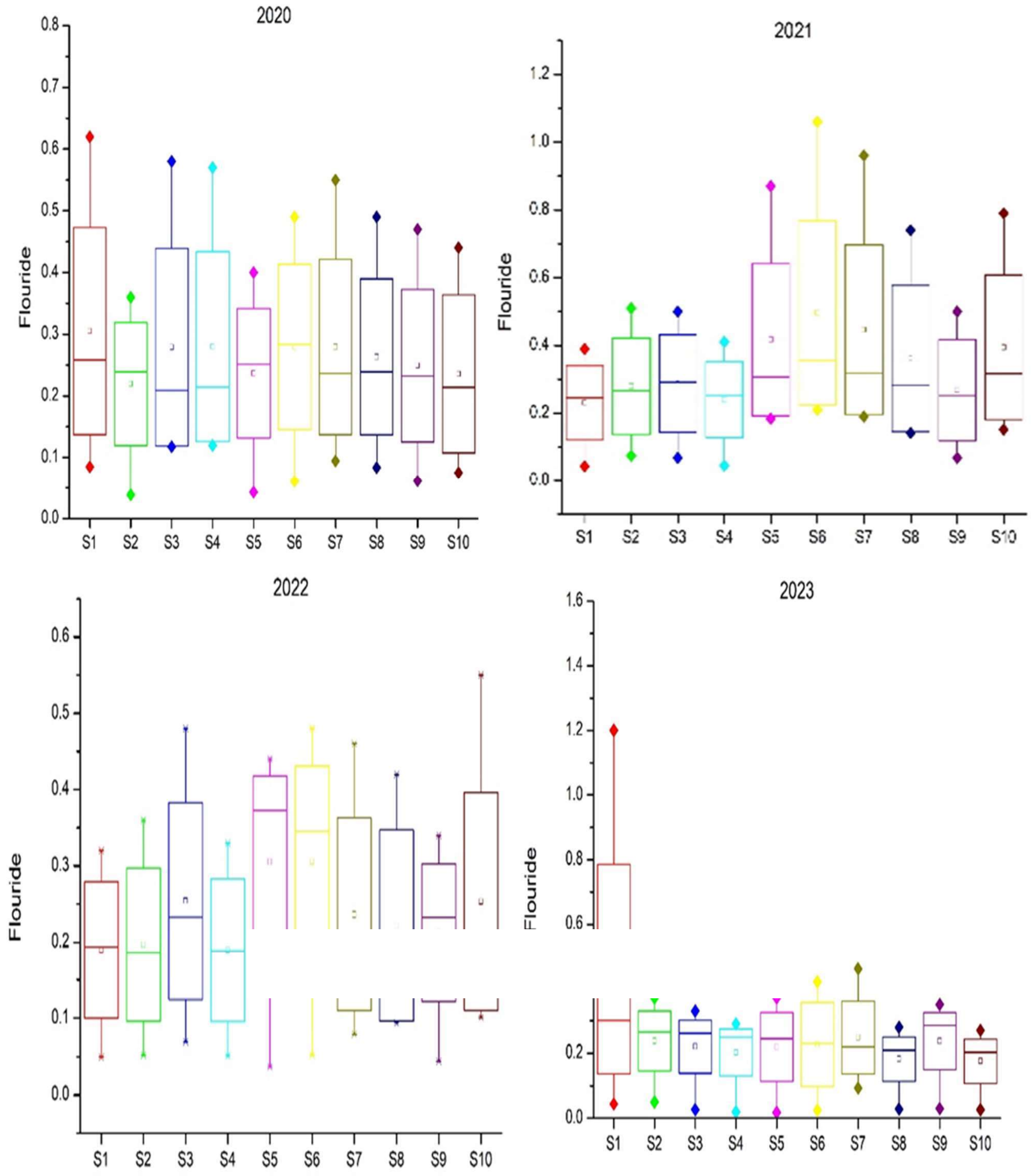

Fig.4.9. Box Plot of Fluoride (mg/l)

4.1.10 SODIUM

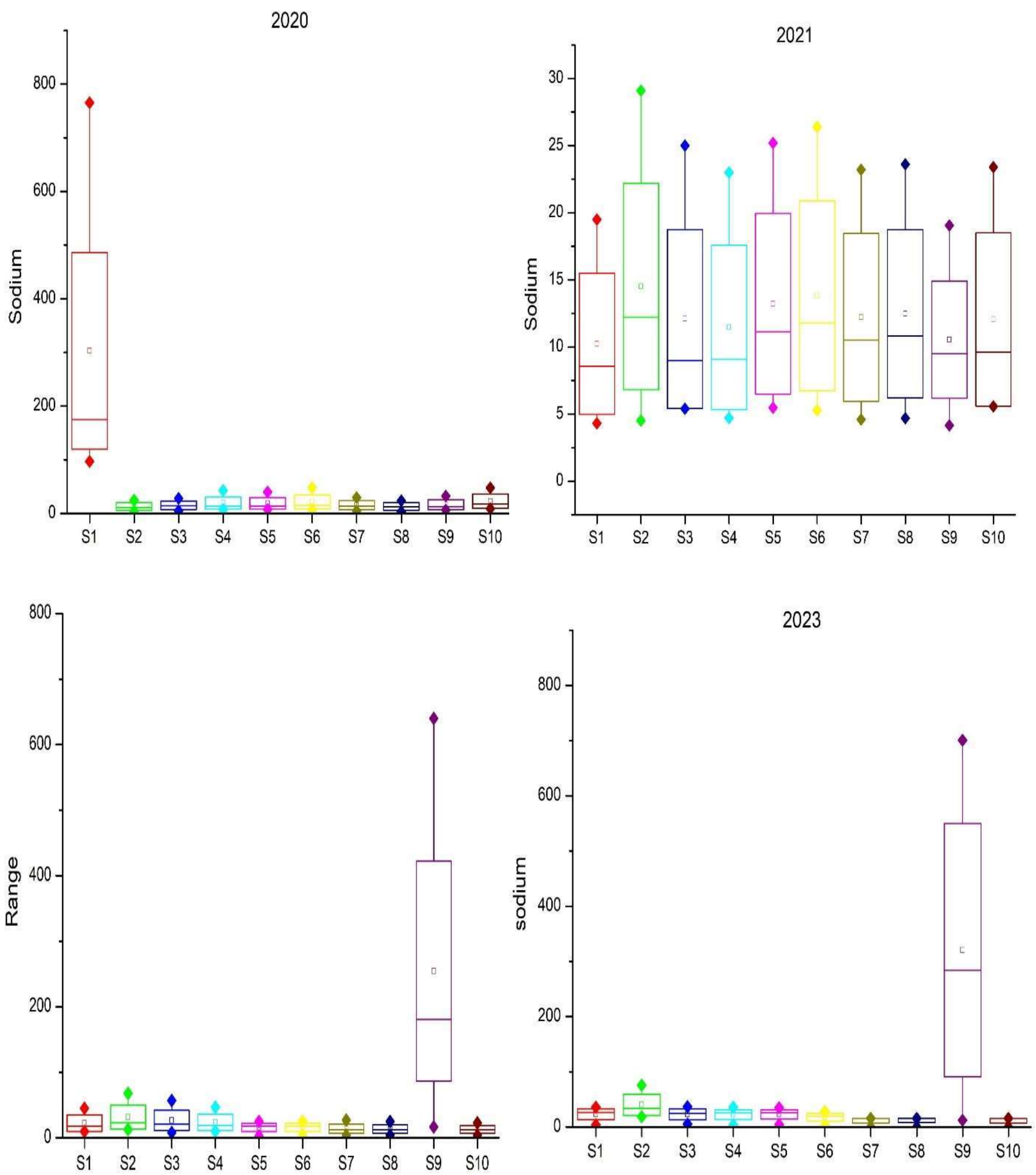

Fig.4.10. Box Plot of Sodium (mg/l)

4.1.11 SULPHATE

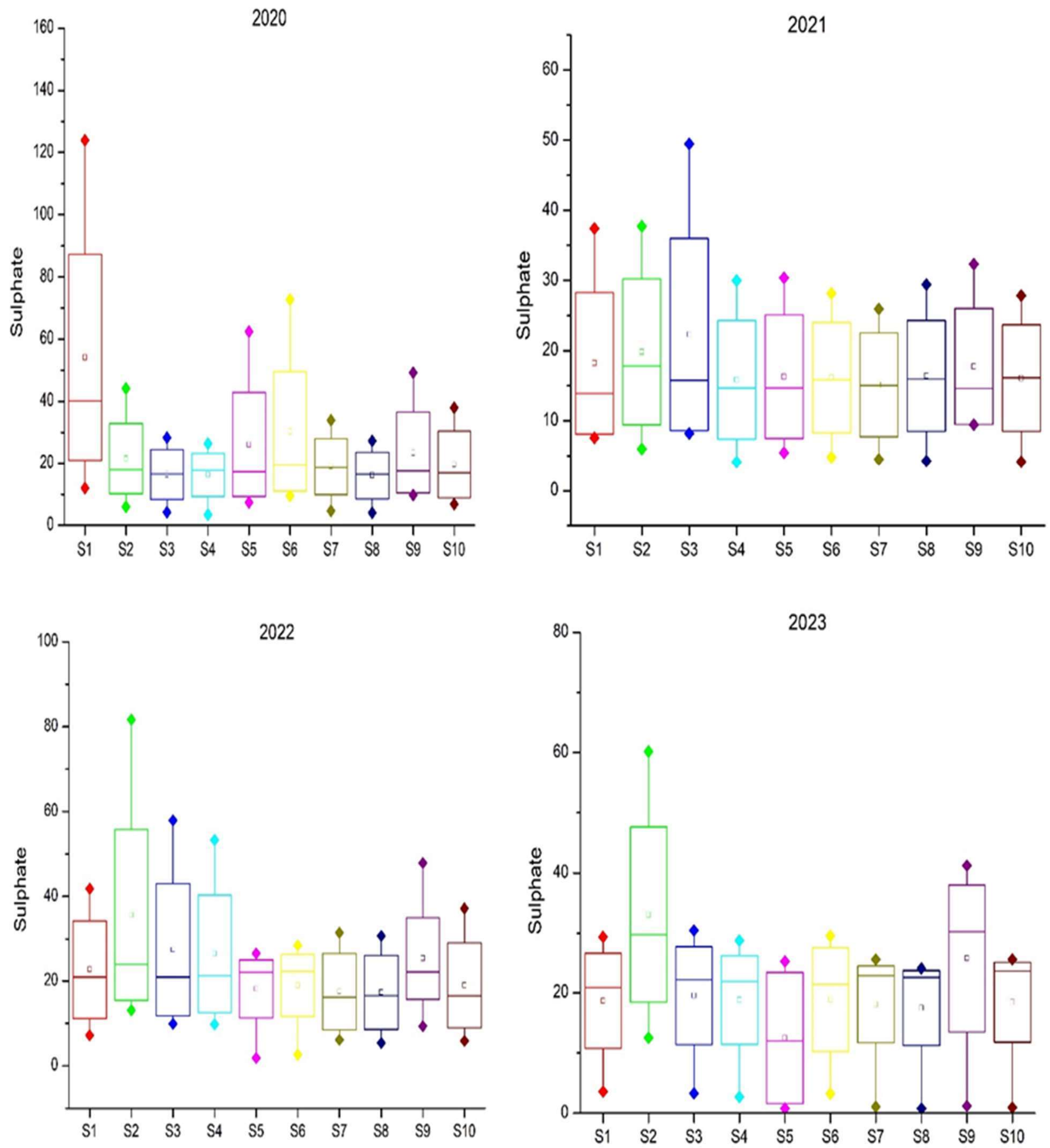

Fig.4.11. Box Plot of Sulphate (mg/l)

4.1.12 TOTAL DISSOLVED SOLID (TDS)

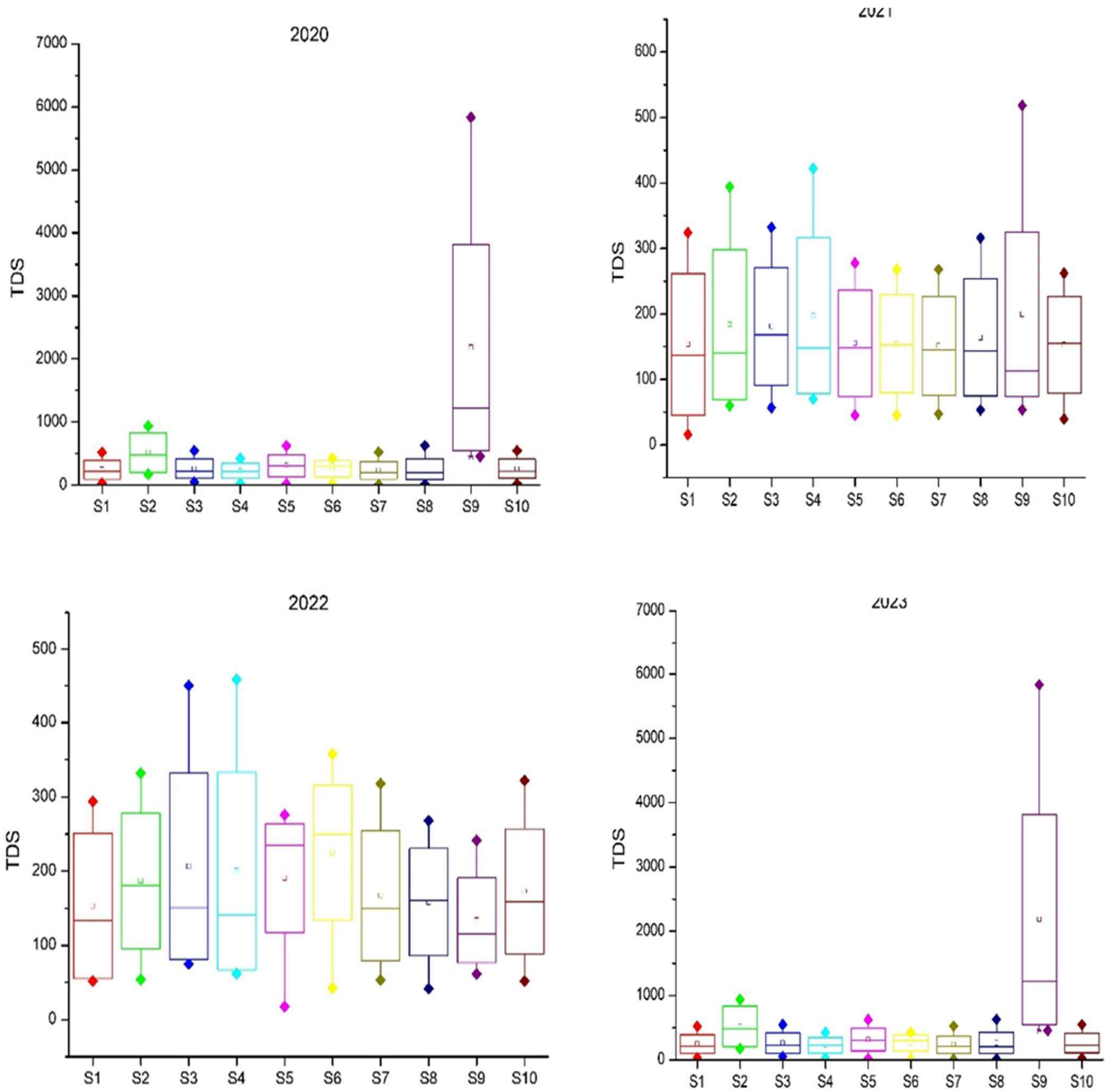

Fig.4.12. Box plot of TDS (mg/l)

4.1.12 TOTAL HARDNESS

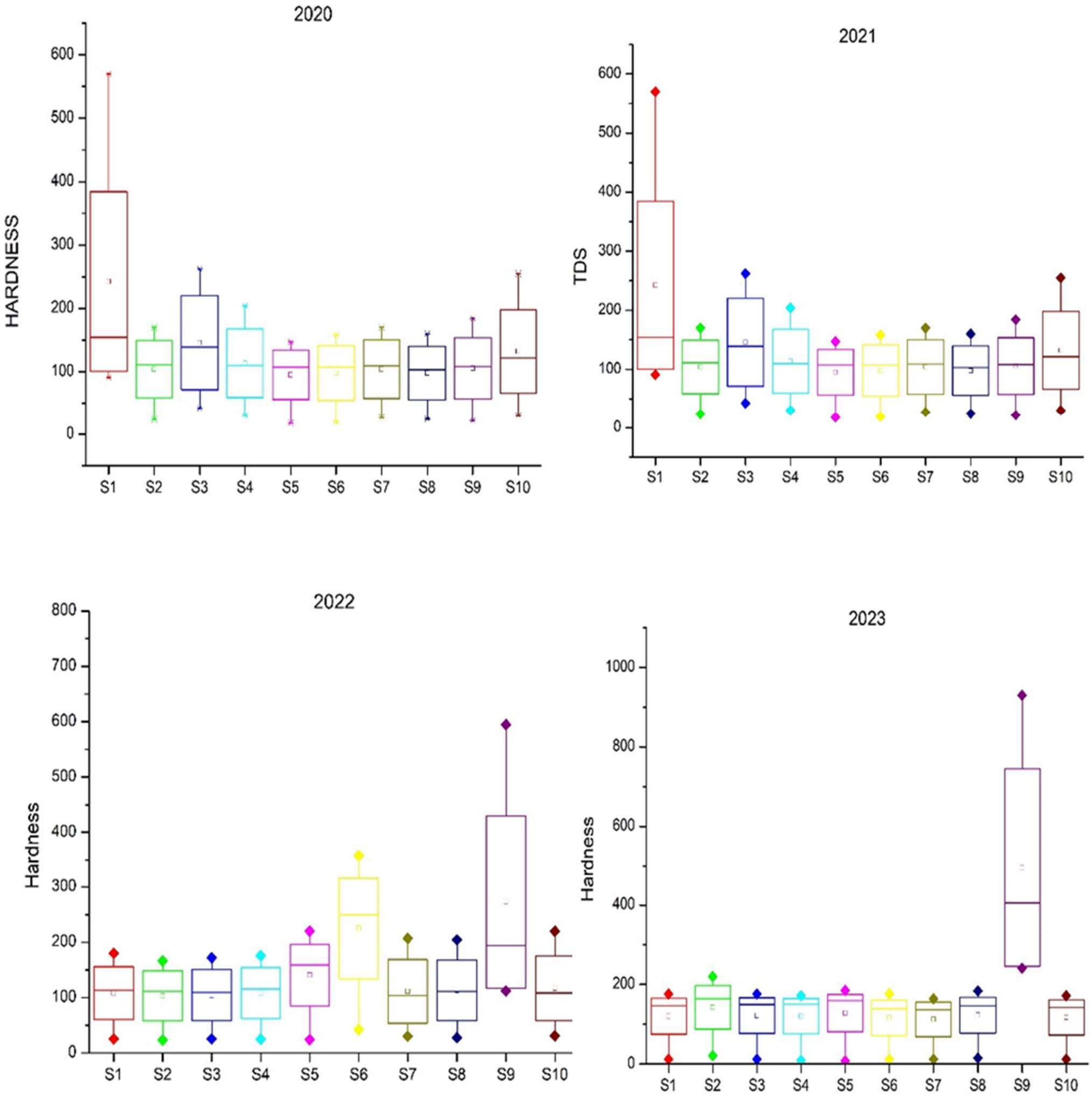

Fig.4.13. Box Plot of Hardness (as CaCO3)

4.1.13 TURBIDITY

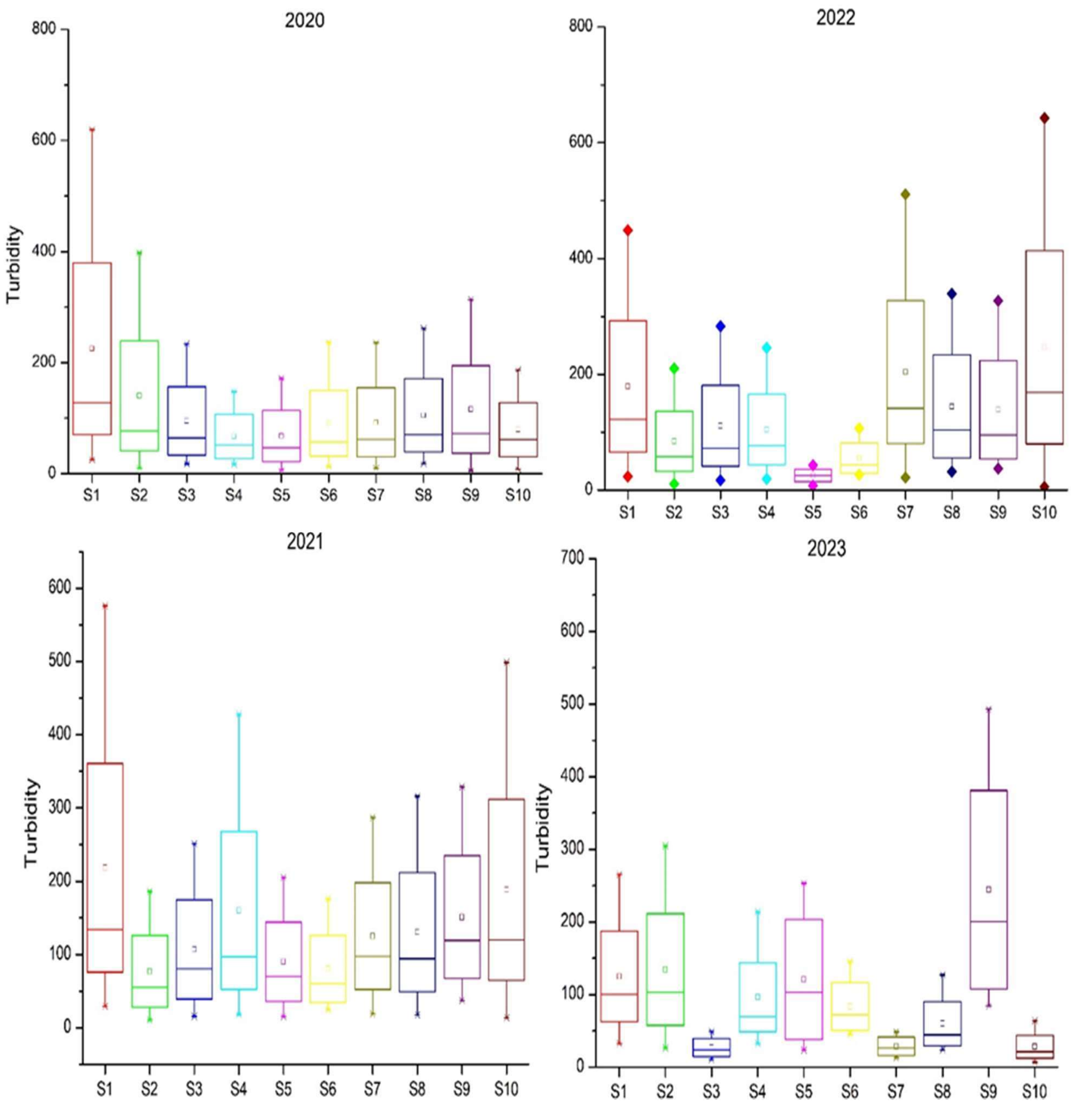

Fig.4.14. Box plot of turbidity (mg/l)

4.1.15 WATER QUALITY INDEX (WQI)

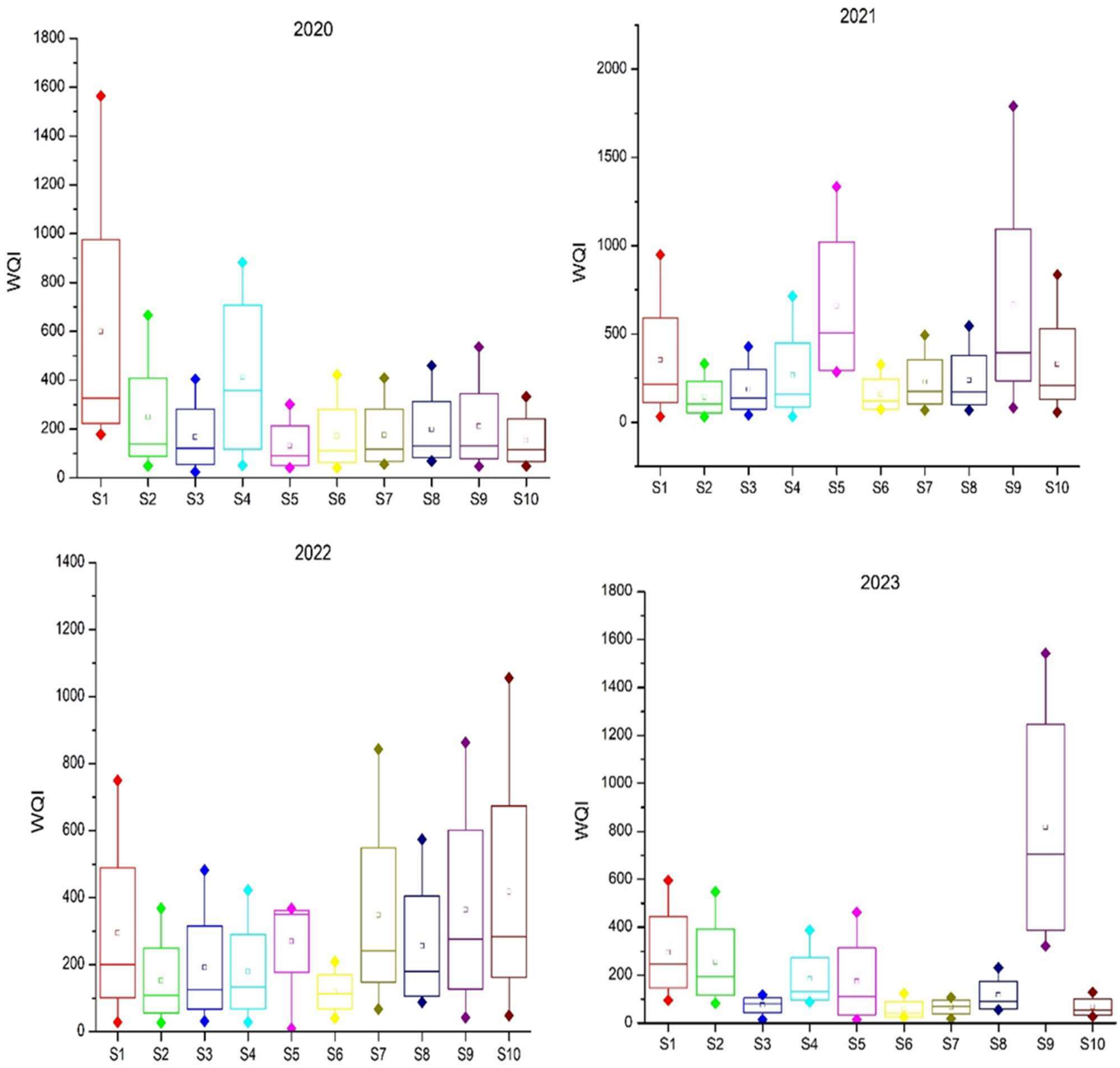

Fig.4.15. Box Plot of WQI

4.1.16 SYNTHETIC POLLUTION INDEX (SPI)

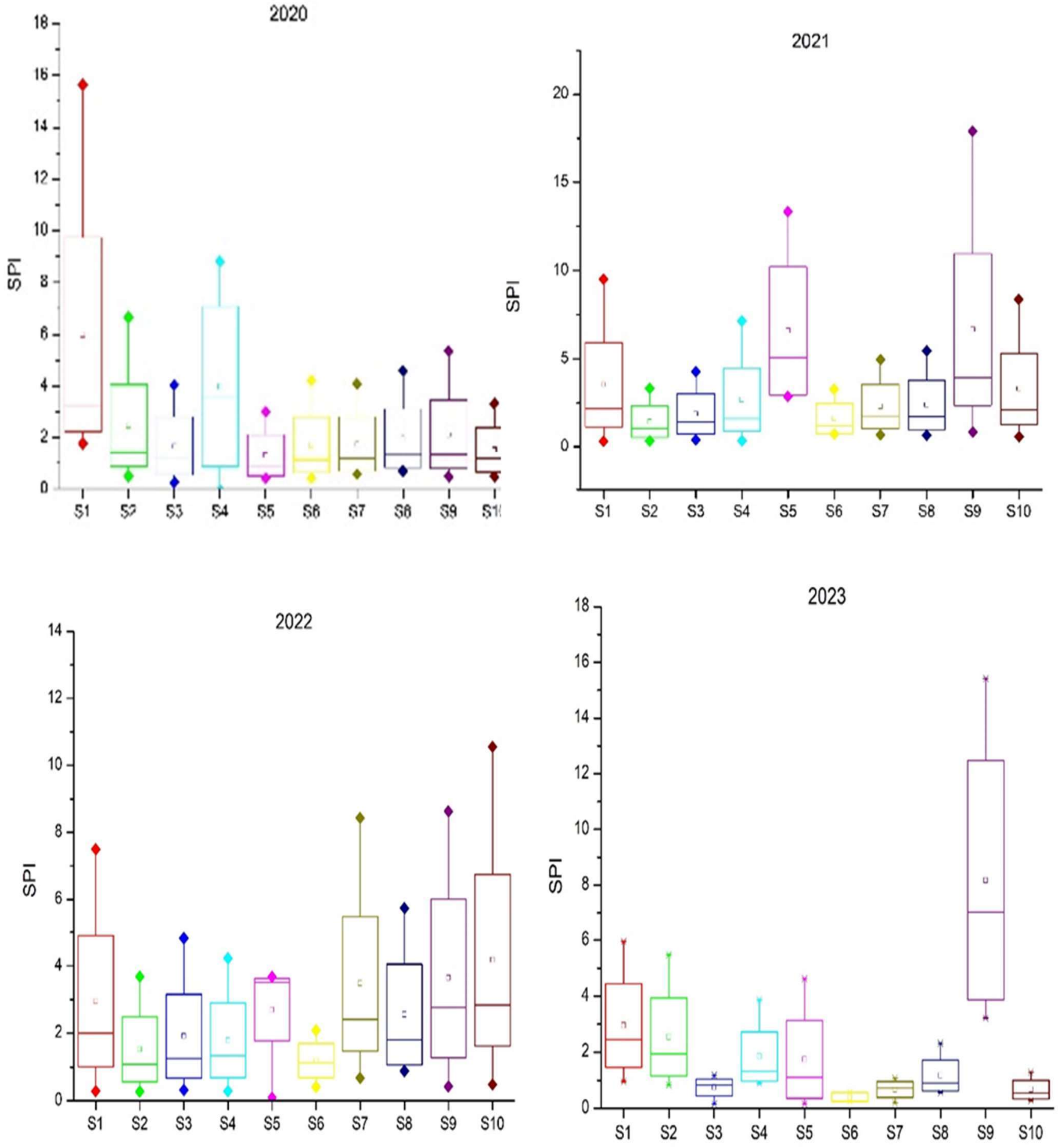

Fig.4.16. Box Plot of SPI

4.2 MULTIVARIATE INTERPOLATION AND INTERPRETATION THROUGH INVERSE DISTANCE WEIGHTED (IDW) USING ARC GIS

4.2.1 WQI IDW

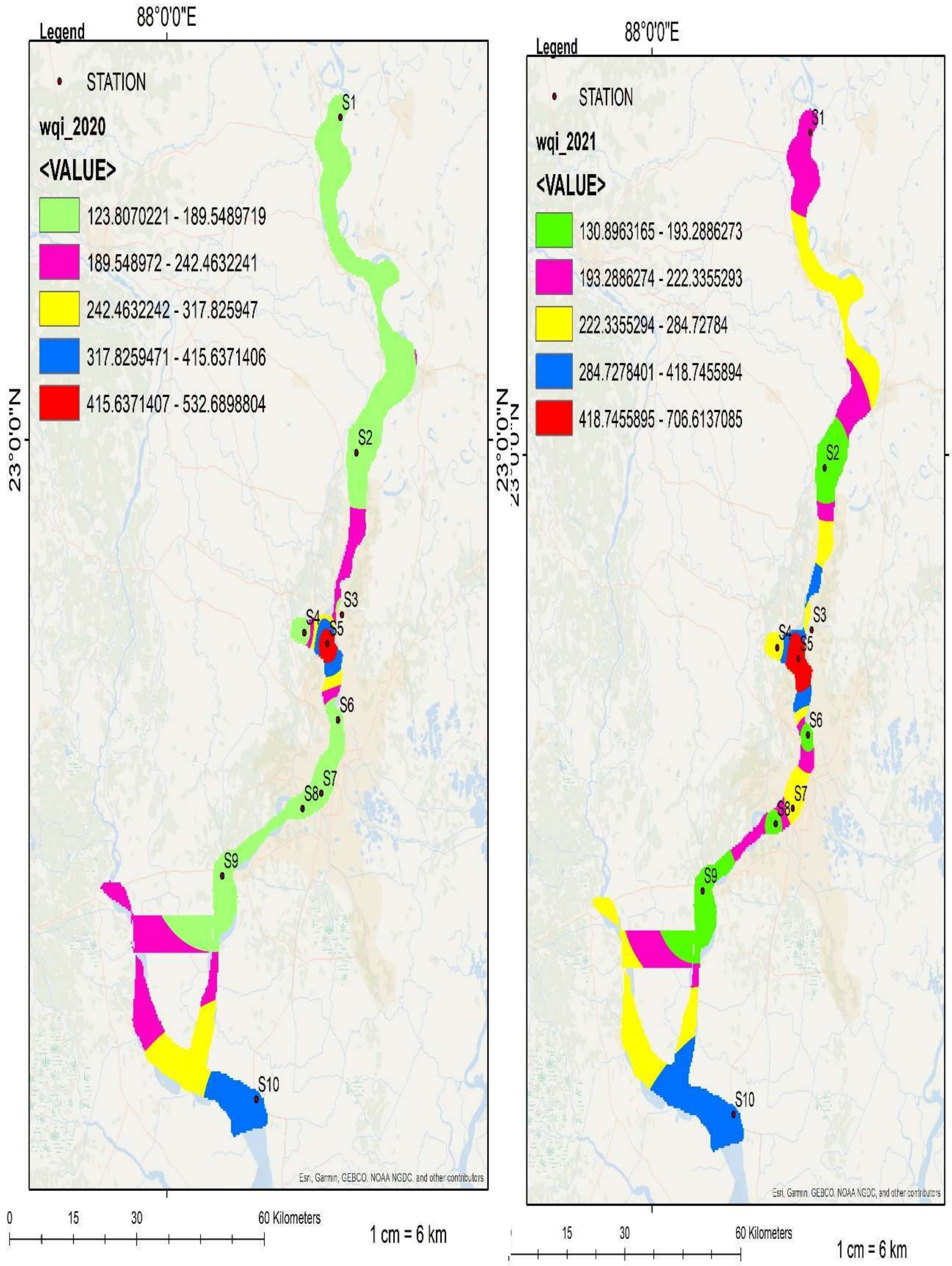

Fig.4.17. IDW of WQI 2020 and 2021

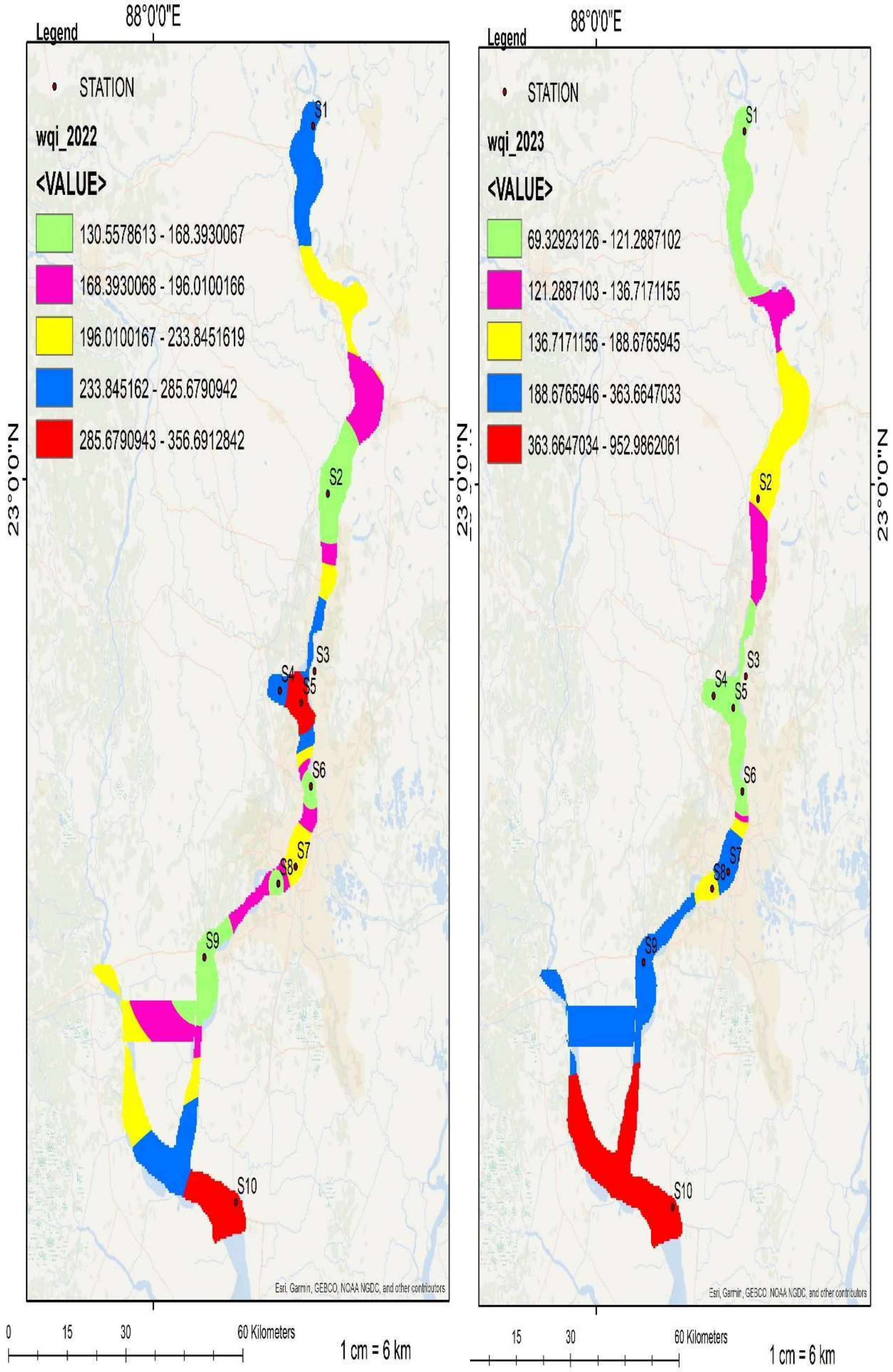

Fig.4.18. IDW of WQI 2022 and 2023

4.2.2 SPI IDW

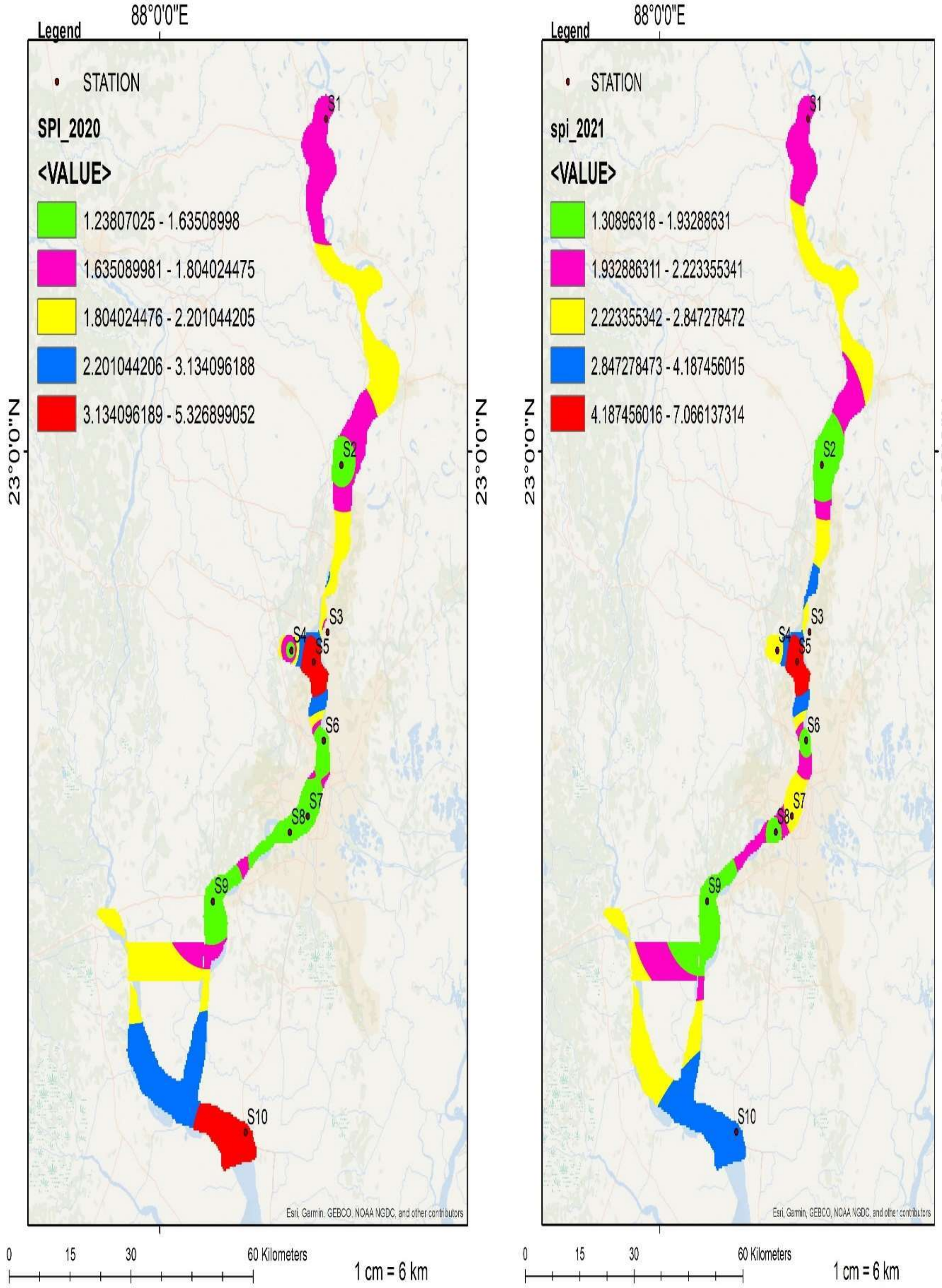

Fig.4.19. IDW of SPI of 2020 and 2021

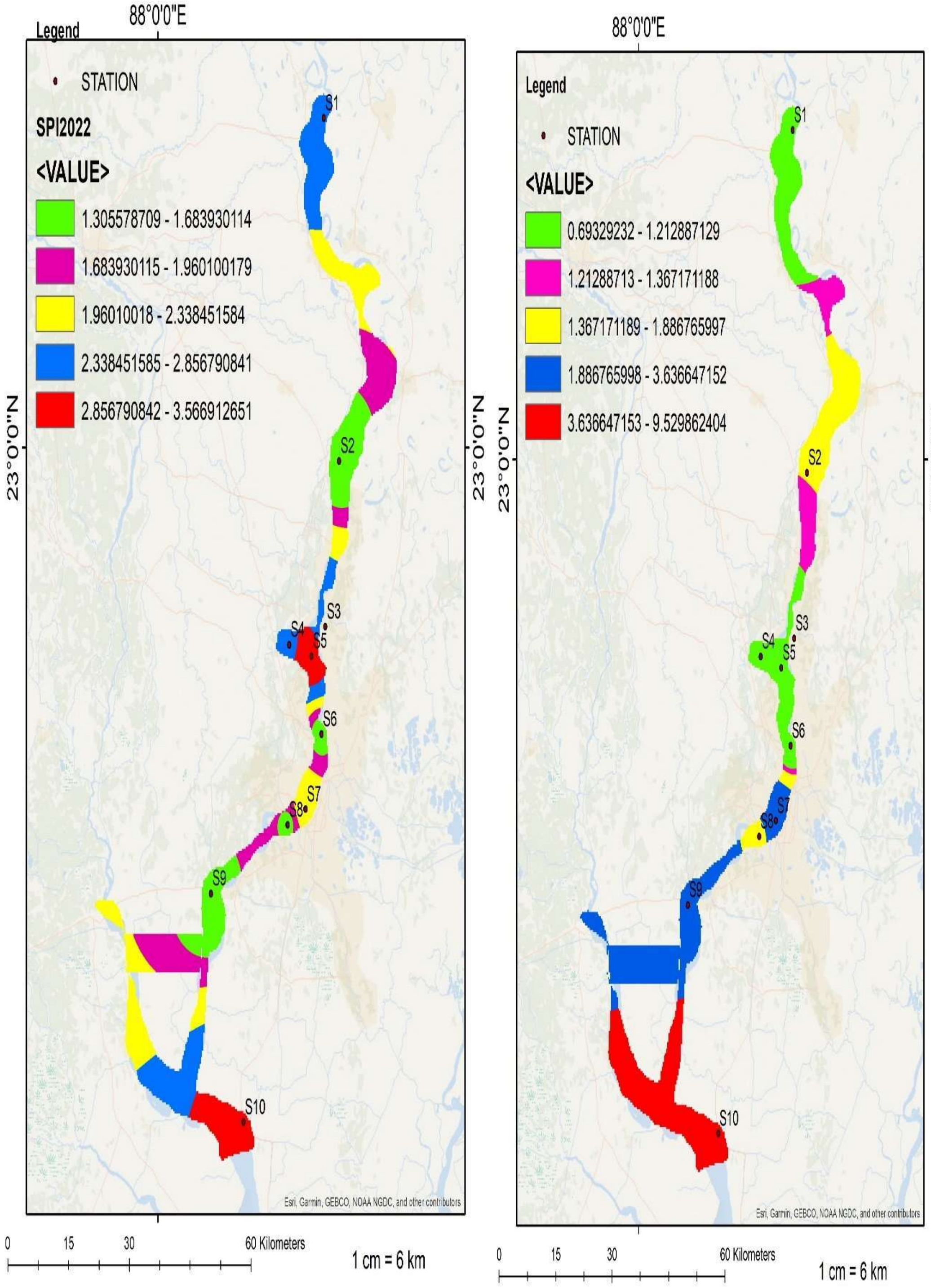

Fig.4.20. Box Plot of SPI 2022 and 2023

STATISTICAL OUTPUT FROM THE BOX PLOT

4.1.1 AMMONIA

The maximum value (1.88 mg/l) of ammonia was found at station Garden Reach (S8), was found slightly more than standard value at station Dakshineswar (S6) while on others it is evenly distributed on remaining parameters in the year 2020.

In the year 2021 at all the stations it was found below the permissible value and was maximum (0.48 mg/l) at S6 and min at S1 (0.1mg/l)

In the year 2022 and 2023 the values had not exceed the 1.5 mg/l but a significant change is observed at station Diamond harbour where the minimum value was found zero.

4.1.2 BOD

In 2020 at all the stations except S5,S9,S10 the maximum value had been exceeded inspite of having pandemic which indicates the strong positive pollution load on these stations (S1,S2,S3,S4,S6,S7,S8) having max ,min, mean value of 7.88 mg/l , 4.23 mg/l, 5.46 mg/l respectively.

In Post pandemic year 2021 the BOD values are found below the permissible values at all the selected locations.

In 2022 at maximum value was found at station S6 (4.32mg/l) and min value was at S3 (3.02mg/l).

In 2023 the maximum value was found at S2 and from station S5 to S10 the values are distributed non uniformly indicating unevenly sewage discharge form various industrial and municipal source.

4.1.3 CONDUCTIVITY

Except at S1 in 2020 , the max value was found at S9 over the year 2021 to 2023 , which is near to Bay of Bengal indicating the accumulation of dissolved salts and inorganic chemicals.

4.1.4 DISSOLVED OXYGEN

The deficiency in the dissolved oxygen with respect to saturated dissolved oxygen at 20.C (9.2mg/l) was found at S4, S5,S9 and S10 in year 2020 while in 2021 except at S5 , higher deficiency was found indicating higher BOD load over the stretch.

In the year 2022 and 2023 almost same pattern was followed , positively showing the avaibility of oxygen over the year indicating reduction in the pollution.

4.1.5 NITRATE

He majority of the nitrate in the Ganges River originates from wastewater from homes, busineses, agriculture, and aquaculture. Low levels of nitrate nitrogen were also found in all of the locations, with a mean range from 0.25 to 1.11 mg/L, which may be the result of phytoplankton and other primary producers using the substance.

4.1.6 PH

In the year 2020 the PH value was found minimum approximately 2.56 indicating high acidic load , same was found at the station S5 in year 2021 and 2022. In 2023 the PH value at all the station was below the standard limits

4.1.7 TEMPERATURE

Temperature (8.2C) was found min at S5 in year 2020 and 7.4C both in year 2021 and 2022 , hence low growth of microbial activities while in 2023 it was uniformly distributed over the 3 months.

4.1.8 CHLORIDE AND FLUORIDE

The value of chloride was found minimum at station s2 (20.2 mg/l) and maximum at (123.4 mg/l) at station s1, in the year 2020.while in the year 2021 the maximum value is found at station s6 (38.7 mg/l) while minimum at s2 (14.2 mg/l)

In the year 2022, maximum value was found 39.6 mg/l while minimum at s2(11.3 mg/l), in the year 2023 it is uniformly distributed over all the three months, hence it can be concluded in the year 2020 there is a non uniform distribution of concentration of chloride from the station s1 to s10, as the trend was not followed in following years, as the impact of chloride is minimum in affecting the quality of drinking water

The concentration of fluoride was found unevenly distributed in the year 2021, and 2022 and maximum value was found 1.4 mg/l and minimum was found 0.05 mg/l. over the period of 2020-2023 ,as fluoride has the direct impact on human health, if found more than 1.5 mg/l which was found majorly from the station s3 to s8, hence need to monitored properly.

4.1.9 SODIUM AND SULPHATE

The maximum value of sulphate was found at station 1 (122.3 mg/l) while minimal was at station s4.(24.6 mg/l) the maximum concentration of sulphate was found from the station s1 to s4 in all the 39 months, hence these stations are need to be taken care of.

In year 2020, 2022, 2023 the maximum value was found at station s1, s9 respectively, while it was evenly distributed in the year 2021, hence for sodium the most critical station is s9, as it nearby the bay of Bengal.

4.1.10 TDS AND HARDNESS

Except 2022 the maximum value of TDS was found at the station s9 ie (5623 mg/l)

The concentration of hardness was found at the station s1, in the year 2020 and 2021. While it was at station s9 in 2022 and 2023, hence this two monitoring stations have the maximum pollution load through dissolved solids and multivalent cations, hence along these 2 stations all the washing activities (discharge of detergents) should be reduced or banned.

4.1.11 WQI ND SPI

The maximum value of WQI was found at station s1 in 2020 (1587),while it was s9 in 2021 (1566).

In the year 2022 and 2023 the maximum value was found at station s9.it was found that in year 2023, the value of WQI has been reduced at the station s10.

For the figures 4.17, 4.18, 4.19, 4.20

Inverse distance weighted IDW is used to show the distribution of interpolated values for unallocated location within the shape file. It shows the impact of one parameter at one station location while for other location values are distributed inversely, Similarly for other parameters. In total , it aggregated the overall interpolated over the shape file, colors shown shows the label, which can be set manually, otherwise it automatically distribute the whole data into 10 layers.

This approach is used to perform IDW over 10 stations, denoted by s1, s2, s3, s4, s5, s6, s7, s8, s9, s10.

Green color shows less value while red color shows high value of WQI.

Logically all the hydrochemical parameters used in the study, will show maximum value at drained off location ie at last station s10.

The study area is selected West Bengal, where ganga is drained off because in this location hydrochemical parameters shows maximum values.

For the year 2020, WQI values ranges from 123 to 532, for 2021 WQI ranges from 130 to 706, for year 2022 WQI ranges from 130 to 356, similarly for 2023 WQI ranges from 69 to 952. It can be concluded that from 2020 to 2021, density of chemical parameters is increasing , for 2021 to 2022 WQI values are decreasing, but again for 2023 value increased to 952. So currently ganga river containing heavy amount of chemicals.

Positively river has nature to flow continuously, so these values can getting low if river flow will increase or the pollutant entering to river ie waste water should be treated efficiently.

4.2.3 Principal Component Analysis for WQI and SPI

- The component whose Eigen value are greater than one are the critical principle component. The first principal component has the Eigen value of 5.329 and total variance of 38.062%.
- The second principle component has the Eigen value of 3.193 and cumulative variance of 60.867%, while third principal component has Eigen value of 1.279 and cumulative variance of 70.006%.
- First principle component majorly consist of 38.062% of total data set (parameters) which include Ammonia, BOD, Conductivity, DO which have concrete impact on deteriorating the water quality of river ganga..
- Second principle component includes 22.805% variability of data set which have strong affirmative impact on human health which includes (nitrate, chloride, sulfate, PH) may be due to discharge of raw sewage
- Due to the non-biological balance of the aquatic system, both principle components have negative effect on DO.
- Temperature , TDS , sodium may be regarded as secondary principal component and have less impact on drinking water quality.

Table 4.1. Extracted Principle Component

Total Variance Explained

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	5.329	38.062	38.062	5.329	38.062	38.062	5.248	37.489	37.489
2	3.193	22.805	60.867	3.193	22.805	60.867	3.251	23.221	60.710
3	1.279	9.138	70.006	1.279	9.138	70.006	1.301	9.296	70.006
4	.999	7.138	77.144						
5	.895	6.392	83.536						
6	.831	5.937	89.473						
7	.424	3.026	92.499						
8	.298	2.126	94.625						
9	.251	1.795	96.420						
10	.196	1.399	97.819						
11	.129	.923	98.742						
12	.097	.692	99.434						
13	.042	.297	99.731						
14	.038	.269	100.000						

Extraction Method: Principal Component Analysis.

4.2.4 Eigen vector of correlation matrix

Table 4.2. correlation matrix of different parameters

Correlation Matrix														
Correlation	Ammonia-N	BOD	conductivity	Dissolved O2(DO)	Nitrate-N	pH	Temperature	chloride	Fluoride	Sodium	Sulphate	(TDS)	Total Hardness	Turbidity
Ammonia-N	1.000	.148	-.033	.017	-.015	-.020	-.010	-.031	-.017	-.023	-.029	-.018	-.033	-.118
BOD	.148	1.000	-.003	-.034	-.025	.052	-.040	-.019	-.004	-.031	-.004	-.009	.048	-.146
conductivity	-.033	-.003	1.000	-.181	-.139	.165	.192	.930	-.005	.908	.825	.911	.856	.194
Dissolved O2(DO)	.017	-.034	-.181	1.000	.671	-.949	-.759	-.035	.019	-.048	-.052	-.039	.005	-.088
Nitrate-N	-.015	-.025	-.139	.671	1.000	-.724	-.577	-.024	.040	-.039	-.054	-.041	-.041	-.013
pH	-.020	.052	.165	-.949	-.724	1.000	.733	.009	-.033	.024	.040	.026	.033	.028
Temperature	-.010	-.040	.192	-.759	-.577	.733	1.000	.105	-.050	.099	.088	.090	-.010	.185
chloride	-.031	-.019	.930	-.035	-.024	.009	.105	1.000	-.003	.861	.797	.893	.852	.249
Fluoride	-.017	-.004	-.005	.019	.040	-.033	-.050	-.003	1.000	.001	-.011	-.002	.009	.010
Sodium	-.023	-.031	.908	-.048	-.039	.024	.099	.861	.001	1.000	.790	.882	.800	.219
Sulphate	-.029	-.004	.825	-.052	-.054	.040	.088	.797	-.011	.790	1.000	.788	.762	.120
(TDS)	-.018	-.009	.911	-.039	-.041	.026	.090	.893	-.002	.882	.788	1.000	.811	.198
Total Hardness as CaCO3	-.033	.048	.856	.005	-.041	.033	-.010	.852	.009	.800	.762	.811	1.000	.087
Turbidity	-.118	-.146	.194	-.088	-.013	.028	.185	.249	.010	.219	.120	.198	.087	1.000

4.2.5 Factor Analysis for water Quality

The factor analysis in this study follows Kaiser-Normalization where data set having Eigen values greater than one are retained.

It reduces the data base in 3 principal component with aggregated variance of 70.006 and KMO value more than 0.5, indicating the positive relation in statistical indicative.

Table 4.3. Output of Factor Analysis

Component Matrix[a]				**Rotated Component Matrix[a]**			
	Component				Component		
	1	2	3		1	2	3
Ammonia-N	-.044	.007	.613	Ammonia-N	.003	-.010	.615
BOD	-.012	-.026	.699	BOD	.036	.029	.698
conductivity	.977	.008	.030	conductivity	.964	.154	-.042
Dissolved O2(DO)	-.181	.932	-.012	Dissolved O2(DO)	-.025	-.949	-.004
Nitrate-N	-.159	.802	-.087	Nitrate-N	-.030	-.818	-.080
pH	.169	-.939	.060	pH	.016	.954	.053
Temperature	.215	-.830	-.107	Temperature	.066	.854	-.119
chloride	.945	.146	-.017	chloride	.953	.013	-.087
Fluoride	-.008	.055	-.071	Fluoride	-.004	-.056	-.070
Sodium	.929	.132	-.008	Sodium	.934	.023	-.078
Sulphate	.873	.116	.059	Sulphate	.883	.030	-.006
(TDS)	.935	.138	.021	(TDS)	.944	.019	-.049
Total Hardness as CaCO3	.887	.173	.117	Total Hardness as CaCO3	.909	-.023	.051
Turbidity	.246	-.067	-.607	Turbidity	.186	.102	-.623
Extraction Method: Principal Component Analysis.				Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalization.[a]			
a. 3 components extracted.				a. Rotation converged in 4 iterations.			

4.2.6 Component Loading Plot

- The eventuality of the principle component analysis are conferred in component loading plot showing the origin (source) of different pollutants.
- The first PC encompassed of Chloride, sulfate, TDS, Conductivity, total hardness, sodium and turbidity with Eigen value of 5.239 with sodium to chloride ratio between 0.87 to 0.99 indicating the pollution from sea water reflux into the river ganga at last monitoring location (Diamond Harbour).
- The second PC involve the parameters like nitrate and fluoride which originates from horticultural overflow and raw industrial effluent.
- The third PC consists of BOD and heavy metals whose concentration was found max station S9 and S10, which are at the most downstream point and along the industrial area and Bay of Bengal.

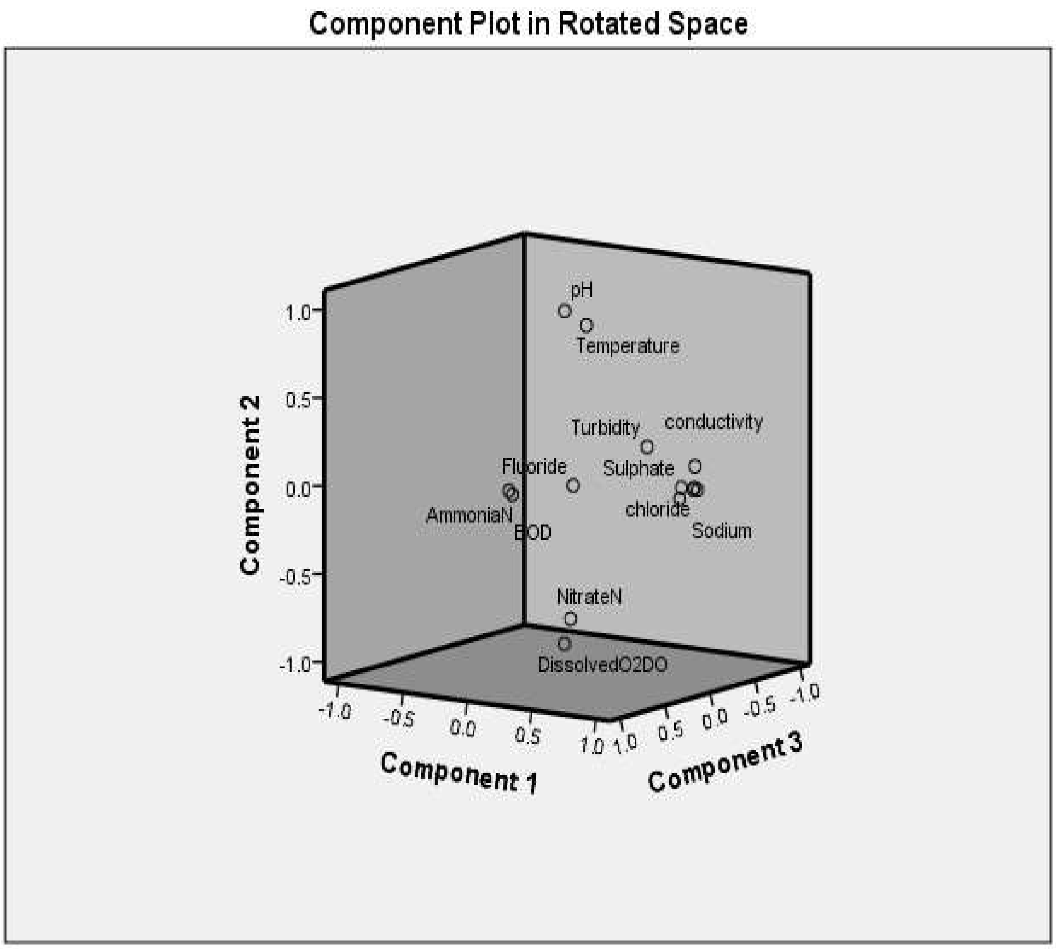

Fig 4.21. Output of loading component

4.2.7 DENDOGRAM

- It array the close relationship between the conductivity, sodium, TDS, sulpate and chloride as the first group that are supplement of geological and human activities.
- Ammonia and fluoride are in second group, originating from human activities.
- BOD, Turbidity, DO, Total Hardness are in third group, which is the most critical group, having maximum impact on human health, hence this group is to be monitored critically while suggesting the best treatment methodology.

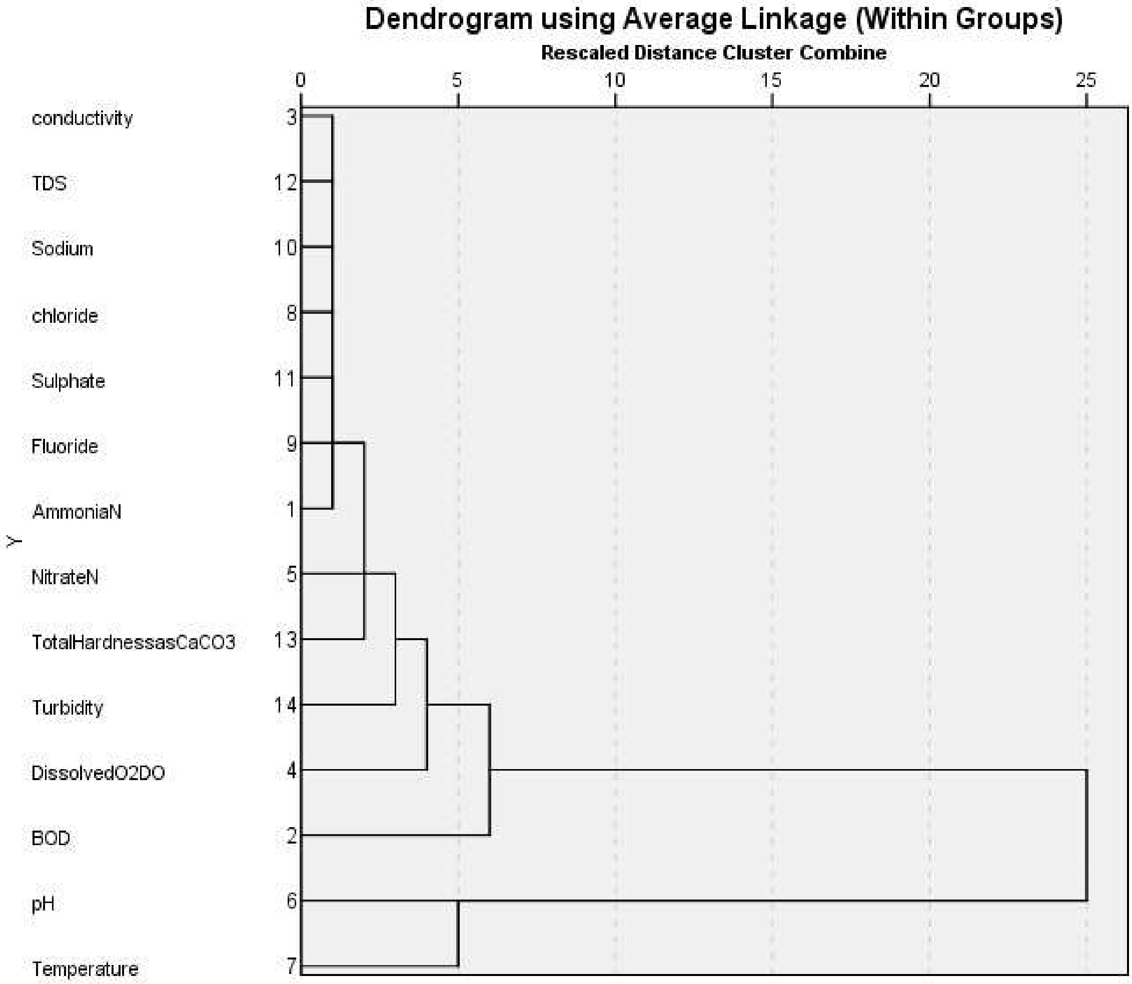

Fig 4.22. dendogram

CHAPTER 5

5.1 CONCLUSION

- With regards to rating of WQI and SPI , Excellent water quality of water was found at Garden Reach and worst quality at Diamond Harbour.
- The concentration of BOD, DO, and turbidity was found maximum at last most monitoring location (Diamond harbour).
- WQI and SPI is increasing from upstream to downstream ie from Howrah shivpur to Diamond harbour.
- From the PCA analysis three component were extracted out and other parameters were considered as non- principal component but due to variation in the anthropogenic activities and rapid growth in the industries , it may not be the case always , hence analysis is required for larger period of time.
- According to the PCA , the WQI and SPI were found worst due to discharge of raw sewage ,agricultural runoff and sea water reflux.
- PH of river ganga at all the locations varies from 6.56 to 8.24 which is follows the standard recommended by WHO.
- After overall analysis the quality was found unfit for drinking and various treatment methodologies were suggested to reduce the pollution load in river ganga at the selected study area.

5.2 RECOMMENDATIONS

- Bio diversity along the river ganga should be conserved so that the ecosystem can be rehabilitated such that endemic and endangered species can be conserved which indirectly self -purification capacity can be improved.
- STP and CETP should be installed at critical locations and proper monitoring should be done of existing one.
- Grossly polluting industries should be inspected on regular basis for consent verification of pollution norms and process adaptation, wherever required through third party institute.

REFERENCES

[1] A. Mishra, "Assessment of water quality using principal component analysis: A case study of the river Ganges," *Journal of Water Chemistry and Technology*, vol. 32, no. 4, pp. 227–234, Aug. 2010, doi: 10.3103/S1063455X10040077/METRICS.

[2] S. Shrestha and F. Kazama, "Assessment of surface water quality using multivariate statistical techniques: A case study of the Fuji river basin, Japan," *Environmental Modelling & Software*, vol. 22, no. 4, pp. 464–475, Apr. 2007, doi: 10.1016/J.ENVSOFT.2006.02.001.

[3] D. Sharma and A. Kansal, "Water quality analysis of River Yamuna using water quality index in the national capital territory, India (2000-2009)", doi: 10.1007/s13201-011-0011-4.

[4] D. Sharma, R. Gupta, • Ram, K. Singh, and A. Kansal, "Characteristics of the event mean concentration (EMCs) from rainfall runoff on mixed agricultural land use in the shoreline zone of the Yamuna River in Delhi, India", doi: 10.1007/s13201-011-0022-1.

[5] R. Das Kangabam, • Sarojini, D. Bhoominathan, S. Kanagaraj, and • Munisamy Govindaraju, "Development of a water quality index (WQI) for the Loktak Lake in India", doi: 10.1007/s13201-017-0579-4.

[6] R. Bhutiani, • D R Khanna, • Dipali, B. Kulkarni, and • Mukesh Ruhela, "Assessment of Ganga river ecosystem at Haridwar, Uttarakhand, India with reference to water quality indices," *Appl Water Sci*, doi: 10.1007/s13201-014-0206-6.

[7] K. A. Shah and G. S. Joshi, "Evaluation of water quality index for River Sabarmati, Gujarat, India," *Appl Water Sci*, vol. 7, no. 3, pp. 1349–1358, Jun. 2017, doi: 10.1007/S13201-015-0318-7/TABLES/5.

[8] "Noah Kyame Asare-Donkor - Google Scholar." https://scholar.google.com/citations?user=fItlDKcAAAAJ (accessed May 30, 2023).

[9] N. Kamboj and V. Kamboj, "Water quality assessment using overall index of pollution in riverbed-mining area of Ganga-River Haridwar, India," *Water Science*, vol. 33, no. 1, pp. 65–74, Jan. 2019, doi: 10.1080/11104929.2019.1626631.

[10] *Groundwater quality evaluation using the water quality index (WQI), the ...* [Online]. Available: https://www.tandfonline.com/doi/full/10.1080/10807039.2019.1588099. [Accessed: 30-May-2023]