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Fuzzy Inference System-based Geo Visualization Tool Development for Yamuna River Water Quality Analysis

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Abstract— An analysis of Yamuna River Water Quality through the use of a Fuzzy Inference System illustrates the capabilities of artificial intelligence in the development of novel Geovisualizer. Numerous Geovisualizer systems exist worldwide, but none can estimate water quality with artificial intelligence instead, relying on statistical data that vary with the scenario and have dubious accuracy. This logic has not been applied to the classification of Water Quality Standards by any designated government agency for water quality monitoring and management. A robust and integrated application program interface is developed by combining MongoDB and JavaScript library utilities Leaflet.js, Node.js, ArcGIS, ERDAS Imagine, and Fuzzy Algorithm; embellished with HTML and CSS. The Yamuna River is considered for the spatial-temporal aspect of the application. End users can authenticate with JSON web tokens. Spatial and non-spatial data are visualized by Inverse Distance Weighted Interpolation technique of ArcGIS. The Water Quality Index can be calculated using combinations of critically chosen input parameters integrated through frontend and backend functionality that incorporates fuzzy set theory with input from a Geovisualizer database and frontend platforms; not available on the existing geovisualization platform. With its scalability, extensibility, and execution speed, the resultant 121RRwebgis Geovisualizer outperforms conventional applications. Thus, a robust platform for global researchers is developed.

Keywords- Fuzzy Inference System, Geovisualization, JavaScript, MongoDB, Water Quality Index.

I. INTRODUCTION

With fast deteriorating water quality in developing nations, the need for artificial intelligence-based Geovisualizer tools is of crucial significance. The use of such applications offers tools and techniques for analyzing ample geospatial data. According to Schütze, E in 2007, the "geoinformatic revolution" deals with the geovisualization of spatial data, which has boosted WebGIS development frameworks. Conventional laboratory analysis involves fieldwork, sample collection, etc. Several million data points are generated to quantify physical, chemical, and biological data across the globe, which, without computational methods, turn into numerical waste. [1, 2, 3, 4]. In a novel attempt, JavaScript a scripting language is used to develop the frontend and backend, empowering webpages to perform desired actions. A Node.js and JSON-based server executes the browser and server, respectively. Node.js is the JavaScript runtime environment based on Google Chrome's JavaScript engine version 8 for scalability in network applications across varied Operating Systems. Web applications are enhanced in terms of security with Google Chrome. A WebGIS application is a good example of integrating HTML and CSS with simple functions and Application Programming Interfaces (APIs). JavaScript is the language of choice in modern browsers [5]. Additionally, JavaScript enables the entire stack development via inbuilt modules, enabling faster execution of numerous code lines. Geovisualization of parametrical values was implemented using MongoDB and Leaflet.js, a JavaScript mapping library. The MongoDB database uses BSON, a cross-platform, open-source, document-oriented database written in C++, to maximize performance. With its faster development, easier deployment, and greater scalability, MongoDB can outperform traditional databases like PostgreSQL and MySQL.

Furthermore, there is growing evidence that the Fuzzy Algorithm is the best tool to resolve a range of environmental issues, such as resolving vagueness, and personal bias, and clarifying multidimensional data [14,15,16]. Through the informed approach of concerned authorities on anthropogenic impacts on resources, the Fuzzy Algorithm has been applied to enhance environmental sustainability [17,18, 19]. A Fuzzy Algorithm can be applied to various scenarios with an uncertainty component in a simple, effortless, and comprehensible manner. With the resultant 121RRwebgis Geovisualizer platform, it is feasible to display multitemporal water quality data instantly and securely. With WebGIS

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technology, decision-makers can reduce the time and cost associated with data transfer, distance, and specificity of software or models on client systems. The Visualization technique and server-independent machine system enable global access to these results simultaneously. Thematic maps and graphs provide a rich depiction of the water pollution problem for the non-technical audiences [6,7] through better accessibility to geospatial data by means of open-source platforms like Leaflet, Google Map APIs, Yahoo! Maps, and Open Street Map [8, 9,10].

Fuzzy set theory exhibits the possible outcomes based on input set combinations. Among the four major components of the Fuzzy Algorithm are the rules that define a set of conditional statements that are controlled by the fuzzy controllers to adjust results, and the Fuzzifier that categorizes raw data into fuzzy sets and passes them on to the control system. Inference provides a measure of how well fuzzy sets match defined rules, whereas de-fuzzing reverts machine data into human-comprehensible categories based on conditional statements. [11,12, 13]. The membership function projects the input data onto a graph between 0 and 1. An element's or parameter's degree of membership in a fuzzy set is usually quantified in terms of its universe of discourse and degree of membership.

A fault can be handled seamlessly due to robust processing and programmability. Testing and application of fuzzy rules with defined member functions lead to durable results, as for the water quality parameters examined in this study. Temperature (15–35°C), Chloride (5-75mmol/L), Alkalinity (50-250mg/L), Turbidity (40-200NTU), and Dissolved Oxygen (0-16mg/L) are the water quality parameters studied. Based on the Fuzzy Algorithm, the competitive effect of parameters on river segment water quality is analyzed. Developed by Brown et al., the Water Quality Index (WQI) has been around for decades. As reported by 20, 21, 22, and 23, the National Sanitation Foundation Water Quality Index (NSFWQI) was used by the US. National Sanitation Foundation Water Quality Index for pollution monitoring and later incorporated by the Central Pollution Control Board, India, which is the basis for this application.

Owing to the restrictions of predominated Water Quality Indexes used worldwide, particularly 'eclipsing' and 'ambiguity' of results in the Indian scenario [24], these indexes cannot be relied upon or used fully. For this 121RRwebgis, the Water Quality Index calculation included approximately 5000 unique combinations of conditional statements based on the above-stated parameters. Parametric range flexibility is limited to the Indian pollution scenario. Furthermore, by analyzing pollution levels diligently, hotspot zones in the stretch can be identified based on fuzzy calculations. As part of our investigation, we intend to fill a technical gap [5,24] between society and river channel pollution variables by presenting data on the Yamuna from Dak Patthar to Agra in a user-friendly interface along with a non-spatial dataset in flexible formats.

To achieve these objectives, the following goals were identified:

i) An analytical Geovisualizer tool development focused on interpreting river channel water quality is designed and developed.
ii) Understanding the role of the fuzzy set theory in determining water quality indices.
iii) Evaluate and investigate the competitive effects of essential physicochemical parameters, namely Temperature, Chloride, Alkalinity, Turbidity, and Dissolved Oxygen, on water quality variations.
iv) Demonstrate hotspot locations for deteriorated water quality.

II. STUDY AREA

From Dakpatthar to Agra, covering a distance of 600 km, frequent field campaigns were conducted to collect data as preliminary requisites from 12 illustrated in Fig.1 [46,47]. The investigation area is a low-lying zone of active deposition of alluvial sediment. According to Fig. 1, the stretch varies in elevation between 65 and 1973 meters. As the slope varies between 89.999 and 89.909, so does the aspect from -1 to 360. Following the CGWB Report of October 15, 2016, the Sarsuti River emerges from the Shiwalik hills along the Himachal-Haryana border and merges with the Ghaggar River near Pehowa, a paleochannel formed due to the river meandering toward the east as a result of plate tectonics [26]. This weakness in slope variation prevents contaminants from flowing through the waterbody, instead spreading horizontally to the surface and down the bedrock.

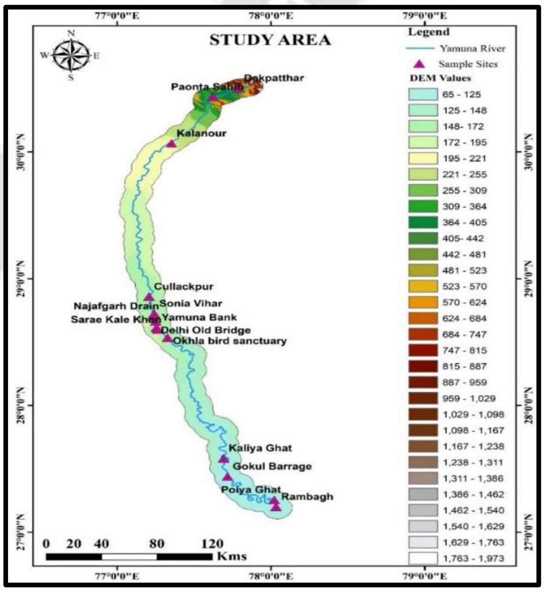

Figure 1. Study Area with a Digital Elevation Model and sample Sites.

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III. DATA AND METHODS

A. DataSet

For sample collection and preservation, transportation, and analysis, the APHA [27] protocol and Trivedy and Goel guidelines, 1986 [28] were imitated. A shallow water column depth of 30 cm was maintained to minimize contamination of samples collected by grab sampling using sterilized HDPE bottles of 500ml. An air space of approximately 1% was left in the container. While transported in ice-cold conditions, the samples were preserved with concentrated Nitric Acid (HNO_3) to a pH less than 2 to minimize adsorption at the container surface. A vigorous sampling of water was performed every 4 months for 3 years. Using in situ measurements and laboratory experiments, physicochemical water quality parameters including Temperature, Chloride, Alkalinity, Turbidity, and Dissolved Oxygen were determined. An onsite recording of parametric values was conducted using a Horiba Multi-Parameter probe. The temperature, turbidity, and dissolved oxygen were measured by the Horiba probe. The temperature ranged from -5 to 50 °C and turbidity ranged from 0 to 800 NTU with an accuracy of ± 1 NTU. With an accuracy of± 0.2 ppm with the Dissolved Oxygen range of 0 -50 ppm [29] and laboratory experiments; chloride and alkalinity were determined. Sulfuric acid titration was used to determine Alkalinity and Silver Nitrate titration was used to determine Chloride. There have been studies on the above parameters [1,2,4] and many others that have described the relationship between various variables and how they impact water quality. There is evidence that chloride in water originates from sewage and industrial runoff as well as agricultural runoff.

B. Methodology

The detailed methodology of the application development life cycle is explained in Fig. 2. The extracted analytical results from the Landsat 8 OLI satellite data, primary field data, secondary data from the Central Water Commission, and satellite data obtained through the USGS earth explorer portal were analyzed and processed using ArcGIS and ERDAS Imagine software. With Leaflet.js, the thematic maps were generated from the consolidated data by putting them through a geodatabase and MongoDB separately. To implement the Fuzzy Algorithm on front and backend platforms cohesively with security checks of JSON web tokens, JavaScript shell scripting, and Node.js were applied to provide the structural framework.

With the help of the Fuzzy Algorithm, a consolidated Water Quality Index was generated with critically chosen parameters, namely Temperature, Chloride, Alkalinity, Turbidity, and Dissolved Oxygen. Water Quality Index calculation using the Fuzzy Algorithm is shown in Fig. 3. In this Fuzzy Algorithm, there are five input parameters and one output parameter. The parameters were scaled between 0 and 100 to replicate a standardized scale order to derive the logarithmic index equation. The following are the controlling steps of the Fuzzy Algorithm:

(i) Fuzzification and designing of Triangular Member Functions:
A Triangular Member Function (MF) is designed to determine the degree of membership between input parameters. The Universe of Discourse (UD) is designed to accommodate crisp values from 0 to 100. The four MFs comprise the values 0–34, 34–60, 60–82, and 82–100 for Temperature Index. The seven MFs for the chloride index: are 0–40, 40–60, 60–72, 72–82, 82–89, 89–95, and 95–100. Four MFs were formed based on the Alkalinity Index: 0 - 43, 43 - 68, 68 - 86, and 86 – 100. Additionally, there were 4 Turbidity Index MFs, ranging from 0–43 to 43–68, 68–86 to 86–100. Using the novel Deoxygenation Index, the Dissolved Oxygen value was subtracted from 20 to produce 4 MFs between 0 and 73, 73–87, 87–95, and 95–100. 6 MFs were designed for the output WQI: 0–20, 15–35, 30–50, 45–65, 60–80, and 75–100.

(ii) Fuzzy Algorithm implementation in the development code:
By implementing the Fuzzy Algorithm in JavaScript shell Scripting, crisp values were generated using conditional statements; logical AND operator between parameters, and approximately 5000 statement codes.

(iii) The Minimum Implication for Results:
To calculate the minimum degree of membership of the Fuzzy Algorithm set in the output space, the crisp resultant values derived from step 2 are used as an output. Tests are performed until the last set of rules is generated to generate a degree of membership for each input parameter, followed by the production of the MF with the lowest membership degree.

(iv) Maximum aggregation of results:
Based on the resultant value from step 3, a unified resultant set is created by analyzing each fuzzy set for maximum aggregation. In the last step of the Fuzzy Algorithm, the WQI is generated by de-fuzzing the resultant values of steps 3 and 4, minimum implication and maximum aggregation.

(v) Defuzzification:
WQI calculation is performed using the Center of Gravity Technique to yield the crisp value of the center of the area under the MF of the unified fuzzy set. In terms of robustness and the calculation of output based on aggregating input parameters, the Center of Gravity is the most preferred defuzzification technique.
The center of gravity was calculated using.

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$$COG = \frac{\sum_{i=1}^{n} Zn\, C(Zx)}{\sum_{i=1}^{n} C(Zx)} \quad (1)$$

where, x= Number of MF values in the Output parameter.
n = Resultant output at each MF value.
For the development of various indices, logarithmic conversion of values was performed for the five input variables summarized below:

$Temp_i$ = (ln (Temperature) - 1.176) * (1 / 0.0036); (2)
Cl_i = (ln (Chloride) - 0.69897) * (1 / 0.011760913); (3)
$Turb_i$ = (ln (Turbidity) - 1.602) * (1 / 0.00699); (4)
Alk_i = (ln (Alkalinity) - 1.69897) * (1 / 0.00699); (5)
Deoxy = (20 – Dissolved Oxygen); (6)
DO_i = (ln (Deoxy) - (-1)) * (1 / 0.022); (7)

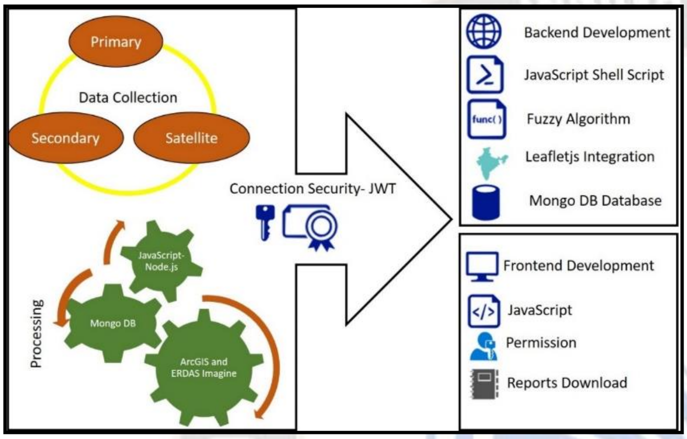

Figure 2. Fuzzy Algorithm-based Geovisualizer Application Framework

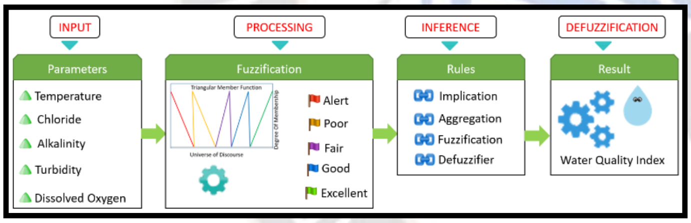

Figure 3. Detailed explanation of the Fuzzy Algorithm application for Water Quality Index calculation.

IV. Results

A thorough literature review of available Geovisualizers related to Water Assets with their manifold functionalities was conducted. Thus, a comparative analysis of the International and National Geovisualization Platforms to this 121RRwebgis is presented in Table I. enlisting the details about the scope of the project, the input parameters, the associated databases, etc. In Fig. 4, the temperature value for 2018 at the Paonta Sahib Site is displayed on the Geolocation page. The Water quality Index calculation through the application of the Fuzzy Algorithm is shown in Fig. 5, which further displays the result of the Water Quality Index as 1, which is the best.

Water Quality changes in the stretch from 2018 Nov to Mar 2021 were studied based on changes in temperature, chloride, turbidity, alkalinity, and dissolved oxygen concentrations. For competent analysis, the stretch is divided into 3 sections of about 200 km each namely Upper, Central, and Lower. The water quality of all sampled sites has deteriorated over the years. Parameter threshold values, however, increased downstream. Due to pristine conditions, minimal anthropogenic intervention, and widespread agricultural practices, the upper section has shown excellent quality. March 2021 is the best month for the upper stretch, with an index value of less than 40. Larger population concentrations and industrial setups have primarily contributed to a higher index value in the central and lower sections during the study period. A quality index value between 30 and 100 was maintained in the central and lower sections. As a general rule, March tends to be better than September regarding quality. Both the central and lower sections of the river reached maximum contamination in September 2020. The quality of the water of the entire stretch, however, improved significantly in March 2021. The improvement in water quality between March 2020 and March 2021 could be attributed to Covid 19 nationwide lockdown and farmer agitation that led to the withdrawal of the migrant labor force to their native areas. These closures also resulted in the closure of small and medium businesses located in the areas where untreated waste is released into rivers and agricultural runoff is contaminated.

TABLE I COMPARATIVE ANALYSIS OF GEOVISUALIZATION PLATFORMS

Comparison Parameters	**International Geovisualization (GEMStat- UNEP)**	**Indian Geovisualization (WRIS)**	**Present Study (121RRwebgis)**
Area Covered	UNEP Regional Offices	India	Yamuna river basin
Parameter Studied	516-CUAHSI Hydrosphere Ontology	40	14
Input Parametrical combination utility	Absent	Absent	Present
Database Fetch Up	Countries voluntarily provide water quality data to the GEMS/Water Data Centre, at the International Centre for Water Resources and Global Change	Monitoring stations operated by the Central Water Commission; primarily	Through field visits and CWC databases collected from high-altitude river streams/channels

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		covers plain and low altitude geographical location	
Modeling and Validation Tool	Absent-only data displays	Absent-only data displays	Fuzzy Algorithm delivers a range of data through MongoDB
WQI Algorithm	Absent	Absent	Fuzzy method
Need to improvise in the current	New comprehensive dataset to be included in the obsolete repository from		A new dataset has been added to a global repository
Cite Reference	https://gemstat.bafg.de/applications/public.html	https://indiawris.gov.in/wris/#/RiverMonitoring	Hereafter referred to as 121RRwebgis
Performance Assessment (WQI Modeler)	No indexing model applied	No indexing model applied	Modelers, scientists, program officers, etc. can use the Fuzzy Algorithm to calculate WQI with a set of parameters applied to the study area for robust analysis of the water quality.

Analysis of the Upper Stretch

Fig. 6 shows that between November 2018 and March 2021, the average temperature from Dakpatthar to Kalanour varied between 17.9 and 21 °C under various climatic conditions. Kalanour's maximum temperature in November 2018 was 21°C and Dakpatthar's minimum temperature in September 2020 was 17.9°C, both gradually increasing downstream. From 230 mg/L at the Kalanour site in November 2018 to 124 mg/L at the Dakpatthar site in September 2020, the chloride concentration in the sampled sites decreased over time. All sites recorded a significant decrease in Chloride concentrations between November 2018 and March 2019. At the Paonta sahib site, turbidity peaked at 26 NTU in November 2018, whereas the Dakpatthar site recorded 1.6 NTU in March 2021. As Northern India undergoes its spring-to-summer climatic transition, river water is probably mixed with suspended soil particles in March, which has resulted in a rise in overall values. For the Kalanour site, the alkalinity concentration was 181 mg/L $CaCO_3$ in March 2019, while it was 63 mg/L $CaCO_3$ at Dakpatthar in September 2020. It was documented in March 2020 that Turbidity and Alkalinity have a well-recognized positive correlation. The Dakpatthar site maintained its pristine condition in September 2020 with 8.6 mg/L of Dissolved Oxygen. However, the least was noted for the Kalanour site at 7.1 mg/L in November 2018. Downstream from Dakpatthar's headwaters, a comprehensive increase was observed in all parameters. In the Upper Section, the water quality index is consistently below 40, demonstrating the presence of unblemished conditions and an insignificant level of anthropogenic intervention, while a wide area of the region is in agrarian use. The Water Quality Index value for the overall section is acknowledged as being the best in March 2021.

Analysis of Central Stretch

In Fig. 6, a temperature minimum of 19.2°C in November 2018 and a maximum of 22.9°C in March 2020 are shown for the Okhla Bird Sanctuary site at the termination of the Central Section. With the gradual increase over the years, a downstream increase was observed. At the Cullackpur site for March 2021, chloride levels were measured to be 650 mg/L, with the maximum level measured at the Okhla Bird Sanctuary site in March 2019 at 2100.34 mg/L. During the study period, the Najafgarh drain, which transports an abundance of untreated industrial waste to the river body, showed a substantial increase in the chlorine estimate. Sarae Kale Khan, where the Nizamuddin drain flows into the river, exhibits an inordinate change in alignment with the Najafgarh drain. Because of stagnation at the Sonia Vihar site during the dry season with reduced flow, the suspended particles settle on the riverbed in March 2019. In March 2020 at Najafgarh, 28 NTU analyses quantified contamination from a drain and chemical mixing. Sonia Vihar reached its nadir in November 2018, with 97 mg/L $CaCO_3$ at its zenith in September 2019, while Yamuna Bank reached 297 mg/L $CaCO_3$ at its zenith. A possible cause of these variations in concentration could be the release of chemical waste from Small Scale Industries around the Delhi Old Bridge site. Cullackpur recorded a maximum of 7.7 dissolved oxygen in September 2020 and 1.5 in November 2018 at Delhi Old Bridge. In the Najafgarh drain, pollutants abruptly decrease dissolved oxygen, making the river inhospitable to organisms. These observations suggest that a significant proportion of contamination in the central section was caused by pollutants released from the Najafgarh drain and Nizamuddin drain. Using this index, we can understand how diurnal interactions between humans and the environment through means of industrialization and settlement have impacted the overall Water quality index value of 30 to 100.

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Analysis of Lower Stretch

Fig. 6 displays the lowest observed temperature value for Kaliya Ghat in November 2018 at 21.1°C while Rambagh measured 26.7°C in March 2019. In September 2019, the chloride concentration at Poiya Ghat was 2348.39 mg/L and the chloride concentration at Rambagh was 723 mg/L. Due to the presence of numerous cold storage outlets between Gokul Barrage and Poiya Ghat, these variations range from 2115.8 mg/L (in November 2018) to 2206.86 mg/L (in March 2019) to 2348.39 mg/L (in September 2019) to 1937.19 mg/L (in March 2020) are seen. It has been measured that the turbidity at Poiya Ghat has ranged between 18 NTU in November 2018 and 29.6 NTU in March 2020, indicating the intermixing of deicing salts with agricultural runoff. Rambagh reported 121 mg/L CaCO3 Alkalinity in March 2019, the lowest in the lower stretch, while Kaliya Ghat reported 270 mg/L CaCO3 in September 2019. Turbidity was aligned with a marginal decrease in alkalinity downstream. In November 2018, Gokul Barrage recorded a maximum dissolved oxygen level of 5.8, while Kaliya Ghat recorded a minimum level of 3.5 in March 2019. Throughout the stretch, the Water Quality Index value was maintained in the range of 30 to 100. A significant impact of the nationwide lockdown and movement of migrant laborers between September 2020 and March 2021, was noted where the apex was acclaimed for 6.9 at Gokul Barrage (September 2020) and 6.8 at Poiya Ghat (March 2021).

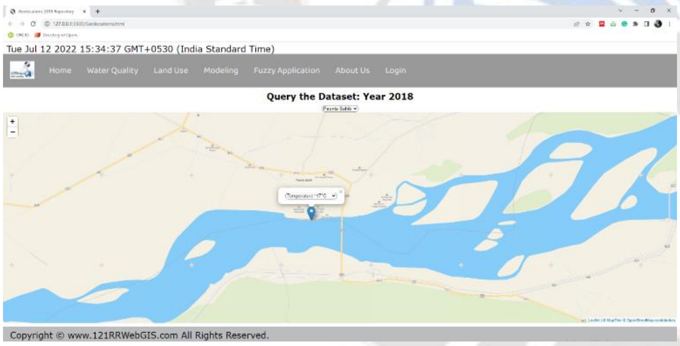

Figure 4. The Geolocations page displays the Temperature value at the Paonta Sahib Site for 2018.

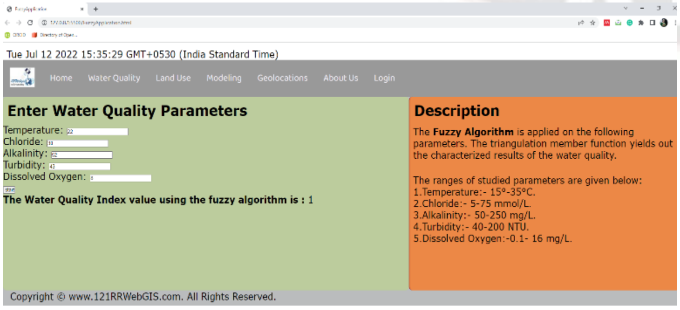

Figure 5. The application of the Fuzzy Algorithm for the calculation of the Water Quality Index. The value stands for best water quality.

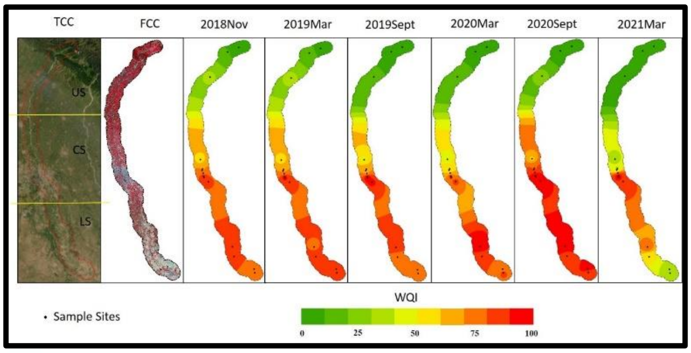

Figure 6. Water Quality Index Maps of the study area divided into 3 sections: Upper Section (US), Central Section (CS), and Lower Section (LS) from November 2018 to March 2021 with the True Color Composite (TCC), the False Color Composite (FCC) and the Sample Sites.

V. Discussion And Conclusion

Based on references such as those [30, 31, 32] a detailed analysis of worldwide Water Quality Analysis has been carried out. The core of WQI is the conversion of quantitative variable data into an ordinal, qualitative, and rigorous output based on one scale factor, as described by [31]. Moreover, deteriorating water quality can be calculated more accurately using fewer variables rather than a complex set of interdependent variables. It is either expert opinion or standard guidelines that apply to the weighting of the variables that affect the final WQI. It includes weighted arithmetic averages, geometric averages, harmonic squares, and weighted and unweighted harmonic squares, as well as aggregation methods based on logarithmic functions grounded on the Fuzzy Algorithm [33, 34, 35, 36]. When variable values were closer to the min-max range observed, arithmetic or geometric averages had the disadvantage of incorporating extreme values. For better accuracy, the Fuzzy Algorithm introduces conditional operators for creating membership functions that range from 0 to 1.

According to [32] WQI models consist of four stages: parameter selection; generation of sub-indices; calculation of parametric weights, and aggregation of sub-indices. The critical analysis of 30 WQI models available today determined that seven of them are prime models that have contributed to the development of surface water quality analysis worldwide. Water quality guidelines, assessment protocols, and data availability determined by waterbody type, usage, regional and local guidelines, and assessment protocols [37,38, 39,40] are the determining factors for the implementation of such models. Furthermore, the first WQI was developed in the 1960s through a set of 10 parameters [33] and later modified by Brown with the National Sanitation Foundation (NSF) to use 142 water quality parameters. According to [30], the NSF WQI and the Canadian Council of Ministers of the Environment Water Quality Index (CCMEWQI) are regularly used in the scientific community. With the CCME and BCWQI models, high efficiency can be achieved with low parameter values. Due to the eclipsing effect of the NSFQI, parameters that are not within the range are masked. The 121RRwebgis overcomes these drawbacks. Keeping in mind the recent technological trends, Geovisualization web applications that incorporate stringent programming concepts, Fuzzy Algorithm applications, and artificial intelligence present ample opportunities for developing water quality indexes, generating research opportunities in the future. This work supports the integration of the Water Quality Index calculated using a Fuzzy Algorithm through the Geovisualizer while providing easy surface water monitoring and assessment.

Numerous algorithms use in situ data to accurately predict water quality. However, they tend to diverge for the complex waters. With integration with JavaScript for a complete platform design, the Fuzzy Algorithm outperforms other types of logic and has been explored less. Temperature, Chloride, Alkalinity, Turbidity, and Dissolved Oxygen variables were thoroughly analyzed, and their significance to the Fuzzy Algorithm was weighed accordingly. [41-44] The fuzzification and design of Triangular Member Functions enabled the creation of the finest input and output spaces, further controlling the universe of discourse. To generate a result using the Center of Gravity technique, the Triangular Member Functions were incorporated into logical conditional statements by using JavaScript competencies to minimize implication and maximize aggregation. End-users, decision-makers, spatial analysts, policymakers, etc. can use this web-based application to analyze the integration of a Fuzzy Algorithm into a programming language to generate results for comparative analysis.

The section above the Paonta Sahib in the vicinity of Tons and Giri represents an interfluve with those rivers, as described by [45]. A strong profile is noted when the braided channel ratio falls between 1.09–3.44, and sinuosity falls between 1–1.33. The landscape is dominated by valley interfluves and Himalayan bedrock. Among the features noted were an unconfined floodplain boundary, mid-channel bars, and sidebars, as well as an alluvial valley setting. Conditions such as these impact the transportation of contaminants in the water body, which in turn affects the quality of the water in general. An integrated impact rather than a single parameter can be attributed to impacting water quality with complex waters, as determined by the study. A summation of anthropogenic activities, industrial units, agricultural activities, and climatic influences over seasonal river flow is shown through the work to be a cause of the variation in water quality in different zones.

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