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IDENTIFICATION AND INTERPRETATION OF WATER QUALITY OF YAMUNA RIVER IN DELHI SEGMENT EMPLOYING FUZZY APPROACH

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ABSTRACT. Yamuna, the sub-basin of the river Ganga is regarded as one of the most sacred river of Northern India. Despite of such an esteem status, multiplying population and enlarging industrial and agricultural activities Yamuna is struggling to survive. The Yamuna is the most polluted in its Delhi stretch. Delhi is alone guilty for 76% of the total pollution burden and is the major contributor to this stressful and disturbing condition of the river. The present study deals with identification and interpretation of quality of water of Yamuna river in Delhi segment employing Fuzzy approach. The results of the study affirms that before entering Delhi river water has average water quality which gets adversely deteriorated after leaving Delhi. There is urgency for an immediate action to thoroughly examine existing schemes and do the needful amendments wherever required to rescue the ailing river.

1. INTRODUCTION

The Yamuna, originates from the Yamuna glacier at a height of 6387m, is the longest tributary of the river Ganga in India. Streching over 1376 km the Yamuna transverses through several states of India (U.P., Uttaranchal, Haryana, H.P. and Delhi) prior to its merging with the river Ganga at Triveni Sangam in Allahabad [1]. Like river Ganga, the Yamuna is hailed as a sacred river in Hindu

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mythology. With an estimated 60 million people directly or indirectly relying on the river, the holy river is known as the lifeline of Northern India. However, over the past few decades there has been witnessed drastic change in the water quality (WQ) of river Yamuna. In spite of such significant prominence the river is struggling for its survival due to pollution load through extensive urbanization, immense increase in population and immeasurable anthropogenic activities.

Today the revival of the river and to safeguard its quality has been the major challenge in front of environmental researchers. Various enduring endeavours by Water authorities and Government of India have been evoked for rejuvenation of the river Yamuna. The primitive effort in this direction was initiated in 1993 as Yamuna Action Plan (YAP)-I, a joint venture between Government of India and Japan and this plan strike its end in 2003. The phase II of YAP begun in 2003 as the key project under the National River Conservation Plan by government to cover U.P. and Haryana along with Delhi. This phase primarily focuses on the reduction of drastic pollution of the river Yamuna due to pollution load and massive industrialization by raising the capacity of Sewage Treatment Plants (STP's). The project was still progressing with an added phase to clean river from the pollution. Despite of various efforts under phase I and II of YAP the river water quality is still disappointing and desired up gradation of water quality is still waited. This is due to a large gap between the number of available and number of needed STP's, improper estimation of STP's location, low efficiencies of STP's of Delhi and inadequacy of fresh water. Further the ministry of Environment has approved YAP phase-III project for Delhi with an approximated cost of Rs. 1656 crores with collaboration with Japan International Cooperation Agency. YAP phase-III has Delhi Jal Board as its implementing agency and primarily incorporates up gradation of existing STP's. In addition to YAP many other projects are still progressing and many are in pipeline for river's revival and development.

Monitoring and assessing the WQ is acknowledged as one of the primary step headed for recognizing the reasons behind water pollution and formulating new potent policies and amending existing ones. Various studies have been performed to map WQ status of Yamuna [2–4]. Moreover, various studies acknowledged that water quality modelling of rivers utilizing Artificial Intelligence techniques yields better results in comparison to numerical modelling [5–7]. Application of neural network tools in assessing water quality of rivers was demonstrated by [8–13]. Besides this to deal with uncertainties and vagueness in environmental problems, Fuzzy approach [14], [15] have been used. Fuzzy based methods have been well manifested in many studies in predicting and forecasting ground and surface water quality [16–22].

In the present study a well accepted Multi- Criterion Decision Making (MCDM) method is used to predict the WQ of river Yamuna at Delhi segment. A total of four locations are used as sampling sites and critical water quality parameters are recorded at these sites. A WQ model is proposed to estimate the WQ at this segment.

2. Materials and Methods

The present analysis is an effort to estimate the change in WQ of the river Yamuna in passing through Delhi. Withn this analysis an efficient Fuzzy Inference (FI) rule-based method named 'Mamdani Method' has been employed which involves three basic steps described as follows:

Step 1. Fuzzification: This step involves fuzzification of crisp (non-fuzzy) input values. The fuzzifier converts the crisp input values to imprecise fuzzy values along with a degree of association to it whose value generally varies from 0 to 1. This is done through application of a convenient membership function (MF). Fuzzy Inference tool box of MATLAB provides us with various MF,s viz. trapezoidal, general bell shaped, triangular, logistic, Gaussian, sigmoidal, pseudo-exponential. In this study, trapezoidal membership function is chosen.

Step 2. Inferencing: This step involves the construction of FI rules which are linguistic in nature and are of the form If-Then statements. These rules are formed by experts or decision makers depending upon the nature and type of input parameters and the expected outputs. The fuzzified inputs (received from step 1) along with their MF's are then fired with these rules to generate a fuzzified output for each rule.

Step 3. Defuzzification: The purpose of this step is to convert the fuzzy output (received from step 2) into a non-fuzzy (scalar) value with a given set of fuzzy rules and with their corresponding MF's. The 'centroid of gravity' is used as Defuzzification method in this study.

2.1. **Study Area.** In this study, the stretch of Yamuna passing through Delhi is considered. The stretch starts at 1.5 km upstream of Palla and leaves Delhi at Jaitpur following the Okhla Bridge. This stretch comprises only 2% of total length of river and contribute for about 76% of entire pollution load of the river. The study covers most polluted 22 km stretch of Yamuna river from Wazirabad barrage to Okhla barrage. Water quality parameters are recorded at four sampling sites Wazirabad, Nizamuddin, Okhla Bridge (Inlet of Agra Canal), Okhla A/M of Shahdara drain.

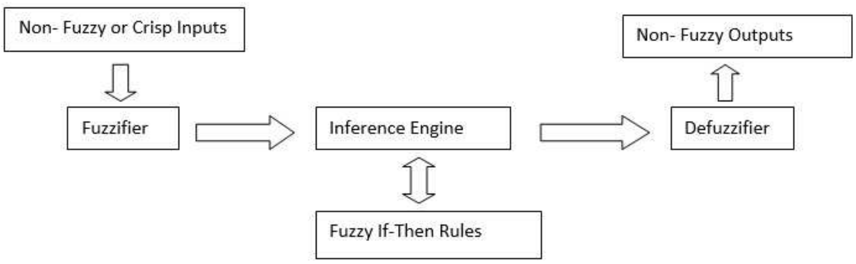

Figure 1. Stepwise representation of Fuzzy Inference System

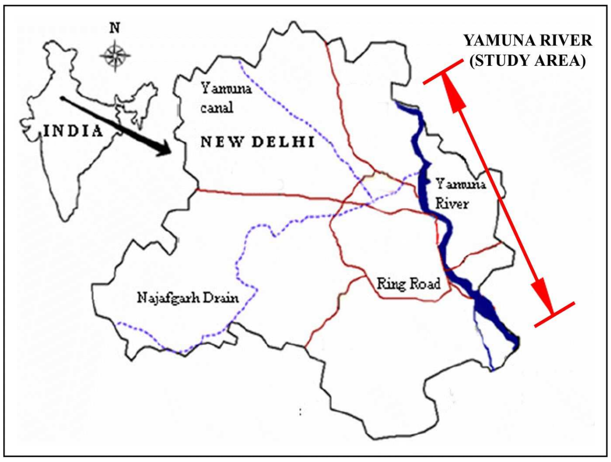

Figure 2. Location map of the study area

2.2. **Critical WQ parameters considered in this analysis.** The WQ at mentioned above four sampling sites is established in terms of its physio-chemical parameters. The critical WQ parameters considered for this study are pH, Dissolved Oxygen (DO) and Total Coli form (TC). The data values of these parameters are taken from CPCB (2016).

2.3. **Data Normalization.** Since different parameters measured for analysis have different units and hence it is necessary that all of them must be assessed on same scale. To ensure viable analysis of each of the measured parameter at every sampling site, normalization of data values is imperative. This can be achieved through linear normalization process of the real measured data values of these values with standard data values. If Vo is the observed value of the studied parameter, V_{max}, V_{min} are respectively maximum and minimum values, V_S is the standard value, then the normalized value of the parameter is given by

$$V_N = \frac{V_o - V_{min}}{minV_s - V_{min}}\ ;\ for\ V_o \leq V_s$$
$$V_N = 1;\ for\ V_o \in [\min V_s, \max V_s]$$
$$V_N = \frac{V_{max} - V_o}{V_{max} - \ maxV_s}\ \ otherwise$$

For illustration Table (i) to (iv) shows normalised values at the four sampling sites

Table (i) Yamuna at Wazirabad

Parameters	Vmin	Vmax	Vo (mean value)	min Vs	max Vs	V_N
pH	7.2	8	7.6	6.5	8.5	1
DO (mg/l)	5.1	13.5	9.3	6	10	1
TC(MPN/100ml)	490	54000	27245	400	1000	0.505

Table (ii) Yamuna at Nizamuddin

Parameters	Vmin	Vmax	Vo (mean value)	min Vs	max Vs	V_N
pH	7.1	7.9	7.5	6.5	8.5	1
DO (mg/l)	0.4	2.6	1.5	6	10	0.196
TC(MPN/100ml)	24000	9200000	4612000	400	1000	0.499

Table (iii) Yamuna at Okhla Bridge (Inlet of Agra Canal)

Parameters	Vmin	Vmax	Vo (mean value)	min Vs	max Vs	V_N
pH	7.1	7.8	7.45	6.5	8.5	1
DO (mg/l)	0.4	1.8	1.1	6	10	0.125
TC(MPN/100ml)	24000	9200000	4612000	400	1000	0.499

Table (iv) Yamuna at Okhla A/M of Shahdara drain

Parameters	Vmin	Vmax	Vo (mean value)	min Vs	max Vs	V_N
pH	7.0	7.9	7.45	6.5	8.5	1
DO (mg/l)	0.1	1.6	0.85	6	10	0.127
TC(MPN/100ml)	230000	160000000	80115000	400	1000	0.499

3. Fuzzy Inference Rules

The relativity amongst input and output variables is interpreted and expressed through If-Then rules which are then connected through utilizing a fuzzy operator (AND or OR) . In this study the three inputs pH, DO and TC each having three MF's (Bad, Acceptable, Good)) are analysed at each of the sampling sites to get the final output having five MF's (very bad, bad, acceptable, good, very good)) as WQ. So, the fuzzy system has 27(3*3*3) rules. Few rules composed in this study are listed in table.

Table (v) -Few of the FI rules formed in MATLAB

WQ parameters	pH	DO	TC	Output
FuzzyOperator	IF	AND	AND	THEN
Rule 1	G	B	B	VB
Rule 2	G	B	A	B
Rule 3	G	B	G	B
Rule 4	G	A	B	B
Rule 5	G	A	A	A
Rule 6	G	A	G	A
Rule 7	G	G	B	B
Rule 8	G	G	A	A
Rule 9	G	G	G	VG

4. Simulation outcomes and analysis

The model recommended in this study for WQ interpretation was justified using MATLAB simulation studies. The Fuzzy inference system tool of MATLAB is applied to measure the WQ of river Yamuna at Delhi stretch. Table (vi) represents the WQ at each four of the sampling sites.

Table (vi)

Sampling site & Average score	
Yamuna at Wazirabad	0.5
Yamuna at Nizammudin	0.347
Yamuna at Okhla bridge(inlet of Agra canal)	0.305
Yamuna at Okhla A/M of Shahdara drain	0.307

The values of the table proclaim highly precarious and hazardous status of the Yamuna river at this stretch. Important findings of the model are

1. DO level in the river diminish notably significantly after Wazirabad barrage and endure low level in rest of the studied river stretch.
2. At Nizamuddin and Okhla level of TC were found to be quite high and ranged between 24000-160000000 MPN/100ml.
3. Solely pH was parameter that meets recommended standards at all of the studied sites

5. Conclusion

The model developed in this study asserted the woeful condition of the river Yamuna after entering Delhi which is primarily due to a huge gap between sewage generation and existing STP's capacities. There is an immediate need of critical analysis of areas to look for improvement and come out with a viable management schmes primarily focussing on maximizing efficiencies of existing STP's , reducing the gap between sewage generation and treatment and pollution control. Moreover, this study provides a fuzzy based model which is flexible and provides a tool for water authorities to assess water quality in systems involving complexities and uncertainties.

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