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A Study of Vital Components Essential to Sustain Aquatic Life of River Ganga in Uttarakhand Himalayas and Optimizing Them: A Fuzzy Goal Programming Approach

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Abstract

River Ganga is abode of many flora and fauna species. In Uttarakhand Himalayas it is catering to a huge species of aquatic life and thus creates a vast river water ecosystem. Its main tributaries are also home to many aquatic species and together a huge ecosystem is maintained in Uttarakhand Himalayas. During last couple of decades due to massive increase in human activities in the area like extensive increase in tourism, development of hydro power stations, and direct sewage discharge in the rivers the quality of water has been considerably deteriorated. The vital components necessary for survival of aquatic life are losing their quality and quantity and hence a threat has been posed on aquatic life in the area. This is posing a serious threat to the sustenance of this beautiful ecosystem.

In this paper we are trying to propose a Fuzzy Goal programming model to regulate the flow of water from dams in order to maintain the water quality in River Ganga and its tributaries. The main components considered in the study are temperature, dissolved solids, dissolved oxygen, biochemical oxygen demand, fecal coliform and pH. This model can be very helpful in sustainable development of the area.

Keywords: Optimization, sustainable development, fuzzy goal programming.

Introduction

Apart from being a holy river and a spiritual feeling for millions of Indians; river Ganga is the abode of huge variety of aquatic life also. River Ganga along with its main tributaries Bhagirathi, Alaknanda, Mandakini and Bhilangana forms an extensive aquatic ecosystem. In India pollution of Ganga has been an issue of serious concern for last four decades and many programmes like Ganga action Plan (GAP), Sparsh Ganga, Namami Gange, etc. has been launched and has done remarkable efforts in the monitoring and improving of the quality of water of River Ganga. Now days due to over population, extensive tourism, use of chemical fertilizers and pesticides in hilly farms, throwing untreated sewage and construction waste into these rivers, etc the quality of water of river Ganga has been deteriorated considerably which has created a threat to the aquatic life in the region. The construction of hydro electric power plants, effluences from domestic and commercial sewages directly to the rivers are adding to the pollution of Ganga water.

The vital components necessary for sustaining aquatic life in rivers are temperature; pH, dissolved oxygen (DO), total dissolved solids (TDS), biochemical oxygen demand (BOD) and fecal coli form (FC). There has been a considerable change in these components in last decade which in near future can be a possible threat to the aquatic life prevailing in river Ganga and its tributaries.

Aim of the Study

In this paper we have made a study of the present amount of these components and the standards laid down by CPCB; also we have proposed a Fuzzy Goal Programming (FGP) model to optimize net flow of water in four major tributaries namely Bhagirathi, Alaknanda, Mandakini and Bhilangana along with amount of the above said vital components in order to dilute harmful effluents and wash them away from the concerned ecosystem along with optimizing quantity of vital components essential for sustenance of aquatic life in Ganga water.

Goal Programming

Goal Programming (GP) was first introduced by Charnes and Cooper in the year 1961 and further developed by Lee (1972), Ignizio (1985), Tamiz, et.al. (1998) and Romero (2001). Goal Programming is a fancy name for a very simple idea: the line between objectives and constraints is not completely solid. In particular, when there are a number of objectives, it is normally a good idea to treat some or all of them as constraints instead of objectives.

The only difference between linear programming and goal programming is that goal programming is multi dimensional in nature. Goal programming is the achieving the multiple goal simultaneously. In the linear programming the max/min function is set for only one quantity to control on its optimum value. Goal programming carries many goals related to each other and they have to be achieved. In this the minimum and maximum deviation are also set for the achieving the goal. Goals are arranged in an order according to priority which helps to minimize the deviations between the achievement and aspiration levels.

The oldest form can be expressed as follows:

(GP model)

Minimize $\sum |f_i(X) - g_i|$ subject to

$X \varepsilon F$. F is a feasible set.

Where $f_i(X)$ is the linear function of the i^{th} goal, g_i is the aspiration level of the i^{th} goal.

[ref. Formulating the multi-segment goal programming, Chin-Nung Liao]

Fuzzy Goal Programming (FGP)

Fuzzy GP is based on fuzzy set theory. Fuzzy sets are used to describe imprecise goals. These goals are usually associated with objective functions and are used to reflect both a weighting (with values from zero to one) and range of goal achievement possibilities. The numerical relationship between the goal of profit and utility in the profit occurrences. The relationship between the weighting and the profit function can be linear or nonlinear. Most importantly, this methodology allows the decision maker who cannot precisely define goals to at least express them using a weighting structure that is not limited. This makes fuzzy programming an idea approach when utility function type goals are to be used in the GP model. Narashiman (1980) had initially proposed FGP by using preference based membership function. Fazlollahtabar et al. [2013] proposed a fuzzy goal programming model for optimizing service industry market by using virtual intelligent agent. Kumar et al. [2004] approached a fuzzy goal programming for vendor selection problem in a supply chain. Mekidiche et al. [2013] approached a weighted additive fuzzy goal programming to 35 aggregate production planning. Yimmee and Phruksaphanrat [2011] proposed fuzzy goal programming for aggregate production and scientists.

A solution set X is found for FGP that contains n fuzzy goals:

$$f_i(X) \gtrsim g_i \ (or\ f_i(X) \lesssim g_i); i = 1, 2, \ldots, n.$$

$$s.t.\ X \in F\ (F\ is\ a\ feasible\ solution)$$

Where

$$f_i(X) \gtrsim (\lesssim) g_i$$

Indicates that the i^{th} fuzzy goal is approximately greater than or equal to (or approximately less than or equal to) the aspiration level g_i.

The FGP has the advantage of allowing for the vague aspirations of decision makers (DMs) which can be qualified using some natural language or vague phenomenon. The membership functions are defined on the interval [0, 1]. So the membership function for the i^{th} goal has a value 1 is the goal is attained and the decision multi criteria is totally satisfied; otherwise the membership function assumes a value between 0 and 1.

Area of Study

The study focuses on the quality of water discharged from 4 tributaries of river Ganga. They are Alaknanda, Bhagirathi, Mandakini and Bhilangana. Our area of study lie in the Uttarakhand hills covering the districts Chamoli, Tehri, Uttarkashi and Pauri. The samples of water are from areas of Tehri stage I, Stage II, Vishnuprayag, Maneri Bhali, Bowla Nandprayag, Srinagar, Koteshwar, Lohari Nagpala, Chinyalisaur, Phatabhyung, Singoli Bhatwari,etc. The main reasons of increase of pollutants in these areas are hydro electric power plants, use of chemical fertilizers and pesticides, throwing untreated sewage waste directly into rivers, throwing construction waste directly into rivers, increasing tourism and population.

Data

Table: 1

This table shows daily average discharges of the four tributaries.

Table:1

S.No.	RIVER	AVERAGE DISCHARGE (m^3/ sec)
1.	Bhagirathi	257.78
2.	Alaknanda	164.79
3.	Mandakini	49.00
4.	Bhilangana	32.88

Table: 2

The average quantity of pollutants prevailing in these rivers taken from different areas is given as:

Table: 2

POLLUTANT	RIVER	QUANTITY
TEMPERATURE: Permissible Level: 4°C to 16°C	BHAGIRATHI	11.52
	ALAKNANDA	10.60
	MANDAKINI	11.90
	BHILANGANA	11.93
DISSOLVED OXYGEN (DO) Minimum permissible concentration = 8.0 mg/l	BHAGIRATHI	8.30
	ALAKNANDA	8.20
	MANDAKINI	8.22
	BHILANGANA	8.95
TOTAL DISSOLVED SOLIDS (TDS). Maximum permissible concentration = 500mg/l	BHAGIRATHI	1006
	ALAKNANDA	1090.80
	MANDAKINI	256.20
	BHILANGANA	298.10
BIOCHEMICAL OXYGEN DEMAND (BOD): Maximum permissible limit= 3.0 mg/l	BHAGIRATHI	2.10
	ALAKNANDA	2.16
	MANDAKINI	1.80
	BHGANAILAN	1.90
FECAL COLIFORM (FC) Maximum permissible concentration = 500 MPN/l	BHAGIRATHI	408
	ALAKNANDA	795
	MANDAKINI	615
	BHILANGANA	345
POTENTIAL OF HYDROGEN (pH): Permissible Range: 6.5-8.5	BHAGIRATHI	7.52
	ALAKNANDA	7.78
	MANDAKINI	7.53
	BHILANGANA	7.44

Descriptions of restrictions considered in the final problem are the following

Restriction 1

The maximum average flow of river Ganga at Devprayag should not exceed 22 x 10^{12} lit. / year or 697.615 m^3/ litre as this is average capacity of the basin and increase in water may cause flood like situation.

Restriction 2

Due to flow of Bhagirathi River.

Restriction 3

Due to average flow of river Alaknanda.

Restriction 4

Due to average flow of river Mandakini.

Restriction 5

Due to average flow of river Bhilangana. (As these rivers have their limitations in amount of water they pour and sometimes due to excessive rain fall they break all the barriers and bring high amount of pollutants with them.)

Restriction 6

Restriction related to variations in temperature of river water during various months.

Restriction 7

Restriction related to maximum amount of dissolved oxygen permitted.

Restriction 8

Restriction related to maximum amount of total dissolved solids permitted.

Restriction 9: Restriction related to maximum amount of BOD permitted

Restriction 10

Restriction related to maximum number of Fecal Coliforms permitted.

Restriction 11

Restriction related to maximum and minimum concentration of hydrogen ions permitted.

Final FGP Mathematical Model

The problem was formulated in FGP model as:

Membership function 1

To maximize the flow of water in river Bhagirathi

$$u_{z1} = \begin{cases} 1 & , z_1 \le 307.78 \\ \dfrac{324.52 - z1}{16.74} & , 307.78 < z_1 < 324.52 \\ 0 & , z_1 \ge 324.52 \end{cases}$$

Membership function 2

To maximize the flow of water in river Alaknanda.

$$u_{z2} = \begin{cases} 1 & , z_2 \le 194.79 \\ \dfrac{210.09 - z_2}{16.74} & , 194.79 < z_2 < 210.09 \\ 0 & , z_2 \ge 210.09 \end{cases}$$

Membership function 3

To maximize the flow of water in river Mandakini.

$$u_{z3} = \begin{cases} 1 & , z_3 \le 65.0 \\ \dfrac{71.27 - z_3}{6.27} & , 65.0 < z_3 < 71.27 \\ 0 & , z_3 \ge 71.27 \end{cases}$$

Membership function 4

To maximize the flow of water in river Bhilangana.

$$u_{z4} = \begin{cases} 1 & , z_4 \le 51.88 \\ \dfrac{65.77 - z_4}{13.89} & , 51.88 < z_4 < 65.77 \\ 0 & , z_4 \ge 65.777 \end{cases}$$

Membership function 5

To minimize the temperature within required range of river Bhagirathi.

$$u_{z5} = \begin{cases} 1 & , z_5 \le 11.52 \\ \dfrac{16 - z_5}{4.48} & , 11.52 < z_5 < 16 \\ 0 & , z_5 \ge 16 \end{cases}$$

Membership function 6

To minimize the temperature within required range of river Alaknanda.

$$u_{z6} = \begin{cases} 1 & , z_6 \le 10.60 \\ \dfrac{16 - z_6}{5.40} & , 10.60 < z_6 < 16 \\ 0 & , z_6 \ge 16 \end{cases}$$

Membership function 7

To minimize the temperature within required range of river Mandakini.

$$u_{z7} = \begin{cases} 1 & , z_7 \le 11.90 \\ \dfrac{16 - z_7}{4.10} & , 11.90 < z_7 < 16 \\ 0 & , z_7 \ge 16 \end{cases}$$

Membership function 8

To minimize the temperature within required range of river Bhilangana.

$$u_{z8} = \begin{cases} 1 & , z_8 \le 11.93 \\ \dfrac{16 - z_8}{4.07} & , 11.93 < z_8 < 16 \\ 0 & , z_8 \ge 16 \end{cases}$$

Membership function 9

To maximize amount of DO in river Bhagirathi.

$$u_{z9} = \begin{cases} 0 & , z_9 \ge 8.0 \\ \dfrac{z_9 - 8.0}{0.30} & , 8.0 < z_9 < 8.3 \\ 1 & , z_9 \ge 8.3 \end{cases}$$

Membership function 10

To maximize amount of DO in river Alaknanda.

$$u_{z10} = \begin{cases} 0 & , z_{10} \ge 8.0 \\ \dfrac{z_{10} - 8.0}{0.20} & , 8.0 < z_{10} < 8.2 \\ 1 & , z_{10} \ge 8.2 \end{cases}$$

Membership function 11

To maximize amount of DO in river Mandakini.

$$u_{z11} = \begin{cases} 0 & , z_{11} \ge 8.0 \\ \dfrac{z_{11} - 8.0}{0.22} & , 8.0 < z_{11} < 8.22 \\ 1 & , z_{11} \ge 8.22 \end{cases}$$

Membership function 12

To maximize amount of DO in river Bhilangana.

$$u_{z12} = \begin{cases} 0 & , z_{12} \ge 8.95 \\ \dfrac{z_{12} - 8.0}{0.95} & , 8.0 < z_{12} < 8.95 \\ 1 & , z_{12} \ge 8.95 \end{cases}$$

Membership function 13

To minimize amount of TDS in river Bhagirathi.

$$u_{z16} = \begin{cases} 1 & , z_{16} \le 298.1 \\ \dfrac{500 - z_{16}}{201.9} & , 201.9 < z_{16} < 500 \\ 0 & , z_{16} \ge 500 \end{cases}$$

Membership function 14

To minimize amount of TDS in river Alaknanda.

$$u_{z14} = \begin{cases} 1 & , z_{14} \le 500 \\ \dfrac{1090.8 - z_{14}}{590.8} & , 500 < z_{14} < 1090.8 \\ 0 & , z_{14} \ge 1090.8 \end{cases}$$

Membership function 15

To minimize amount of TDS in river Mandakini.

$$u_{z15} = \begin{cases} 1 & , z_{15} \le 256.2 \\ \dfrac{500 - z_{15}}{243.8} & , 256.2 < z_{15} < 500 \\ 0 & , z_{15} \ge 500 \end{cases}$$

Membership function 16

To minimize amount of TDS in river Bhilangana.

$$u_{z18} = \begin{cases} 1 & , z_{18} \le 2.16 \\ \dfrac{3 - z_{17}}{0.84} & , 2.16 < z_{18} < 3 \\ 0 & , z_{18} \ge 3 \end{cases}$$

Membership function 17

To minimize amount of BOD in river Bhagirathi.

$$u_{z17} = \begin{cases} 1 & , z_{17} \le 2.1 \\ \dfrac{3 - z_{17}}{0.9} & , 2.1 < z_{17} < 3 \\ 0 & , z_{17} \ge 3 \end{cases}$$

Membership function 18

To minimize amount of BOD in river Alaknanda.

$$u_{z18} = \begin{cases} 1 & , z_{18} \le 2.16 \\ \dfrac{3 - z_{18}}{0.84} & , 2.16 < z_{18} < 3 \\ 0 & , z_{18} \ge 3 \end{cases}$$

Membership function 19

To minimize amount of BOD in river Mandakini.

$$u_{z19} = \begin{cases} 1 & , z_{19} \le 1.8 \\ \dfrac{3 - z_{19}}{1.2} & , 1.8 < z_{19} < 3 \\ 0 & , z_{19} \ge 3 \end{cases}$$

Membership function 20

To minimize amount of BOD in river Bhilangana.

$$u_{z20} = \begin{cases} 1 & , z_{20} \le 1.9 \\ \dfrac{3 - z_{20}}{1.1} & , 1.9 < z_{20} < 3 \\ 0 & , z_{20} \ge 3 \end{cases}$$

Membership function 21

To minimize amount of FC in river Bhaghirathi.

$$u_{z21} = \begin{cases} 1 & , z_{21} \le 408 \\ \dfrac{500 - z_{21}}{92} & , 408 < z_{21} < 500 \\ 0 & , z_{21} \ge 500 \end{cases}$$

Membership function 22

To minimize amount of FC in river Alaknanda.

$$u_{z22} = \begin{cases} 1 & , z_{22} \le 500 \\ \dfrac{795 - z_{22}}{295} & , 500 < z_{22} < 795 \\ 0 & , z_{22} \ge 795 \end{cases}$$

Membership function 23

To minimize amount of FC in river Mandakini.

$$u_{z23} = \begin{cases} 1 & , z_{23} \le 500 \\ \dfrac{615 - z_{23}}{115} & , 500 < z_{23} < 615 \\ 0 & , z_{23} \ge 615 \end{cases}$$

Membership function 24

To minimize amount of FC in river Bhilangana.

$$u_{z24} = \begin{cases} 1 & , z_{24} \le 345 \\ \dfrac{500 - z_{24}}{155} & , 345 < z_{24} < 500 \\ 0 & , z_{24} \ge 500 \end{cases}$$

Membership function 25

To minimize the pH within required range of river Bhagirathi.

$$u_{z28} = \begin{cases} 0 & , z_{28} \le 6.5 \\ \dfrac{z_{28} - 6.5}{0.94} & , 6.5 < z_{28} < 7.44 \\ \dfrac{8.5 - z_{28}}{1.06} & , 7.44 < z_{28} < 8.5 \\ 0 & , z_{28} \ge 8.5 \end{cases}$$

Membership function 26

To minimize the pH within required range of river Alaknanda.

$$u_{z26} = \begin{cases} 0 & , z_{26} \le 6.5 \\ \dfrac{z_{26} - 6.5}{1.28} & , 6.5 < z_{26} < 7.78 \\ \dfrac{8.5 - z_{26}}{0.72} & , 7.78 < z_{26} < 8.5 \\ 0 & , z_{26} \ge 8.5 \end{cases}$$

Membership function 27

To minimize the pH within required range of river Mandakini.

$$u_{z27} = \begin{cases} 0 & , z_{27} \le 6.5 \\ \dfrac{z_{27} - 6.5}{1.03} & , 6.5 < z_{27} < 7.53 \\ \dfrac{8.5 - z_{27}}{0.97} & , 7.53 < z_{27} < 8.5 \\ 0 & , z_{27} \ge 8.5 \end{cases}$$

Membership function 28

To minimize the pH within required range of river Bhilangana.

$$u_{z28} = \begin{cases} 0 & , z_{28} \le 6.5 \\ \dfrac{z_{28} - 6.5}{0.94} & , 6.5 < z_{28} < 7.44 \\ \dfrac{8.5 - z_{28}}{1.06} & , 7.44 < z_{28} < 8.5 \\ 0 & , z_{28} \ge 8.5 \end{cases}$$

Results of FGP Model

Table 3

S. No.	River	Optimized Discharge
1.	Bhagirathi	318.045 m^3/ sec.
2.	Alaknanda	198.898 m^3/ sec.
3.	Mandakini	68.969 m^3/ sec.
4.	Bhilangana	55.563 m^3/ sec.

Table 4

S.No.	Component	Optimized Quantity	Result
1.	Temperature	5.0^{o} C	ACHIEVED
2.	Dissolved Oxygen	9.9 mg/ lit.	ACHIEVED
3.	Total Dissolved Solids	494 mg/ lit.	ACHIEVED
4.	Biochemical Oxygen Demand	0.54 mg/ lit.	ACHIEVED
5.	Fecal Coliform	239.96 MPN/ lit.	ACHIEVED
6.	pH	7.67	ACHIEVED

Results & Conclusion

The FGP model formulated here was solved using LINGO 13.0. The above table reveals that the goals assigned to the model are achieved considerably.

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