Bulletin of Pure and Applied Sciences.
Vol.39F, Geology (Geological Science), No.1
January-June 2020: P.47-54

Print version ISSN 0970 4639
Online version ISSN 2320 3234
DOI: 10.5958/2320-3234.2020.00004.9

Original Article

Available online at ww.bpasjournals.com

Modeling Texture of Shale Gas Water Management under Risk Factor

[1]Firoz Ahmad, [2]Ajhar Hussain, [3] Ahmad Yusuf Adhami*

Author's Affiliations:
[1,3]Department of Statistics and Operations Research, Aligarh Muslim University, Aligarh, Uttar Pradesh 202002, India.
[2]Department of Geology, Aligarh Muslim University, Aligarh, Uttar Pradesh 202002, India.

***Corresponding Author: Firoz Ahmad,** Department of Statistics and Operations Research, Aligarh Muslim University, Aligarh, Uttar Pradesh 202002, India.
E-mail:firoz.ahmad02@gmail.com

(Received on 05.02.2020, Accepted on 16.04.2020)

ABSTRACT

Shale gas energy is the most prominent and dominating source of power across the globe. The extraction processes of shale gas from shale-rocks are very complex. In this present study, a multi objective optimization framework has been presented for the overall water management system which includes the allocation of fresh water for hydraulic fracturing and optimal management of produced wastewater with different techniques. The generated wastewater from shale fracking process contains highly toxic chemicals. The optimal control of a massive amount of contaminated water is quite challenging tasks. Therefore on-site treatment plant, underground disposal facility, and treatment plant with its expansion capacity has been designed to overcome the environmental issues. A multi objective trade-off between socio-economic and environment have been established under a set of conflicting constraints. A theoretical, computational study has been presented to show the validity and applicability of proposed multi objective shale gas water management optimization model and solution procedure. The obtained results and conclusions along with the significant contributions have been discussed in the context of shale gas supply chain planning policies over the time horizons.

KEYWORDS: *Intuitionistic fuzzy parameters; Uncertainty modeling; Shale gas water management system.*

INTRODUCTION

Apart from conventional sources of energy, shale gas is the most promising source of natural gas which is located within the shale rocks. Among all, the United States is the second richest country after China, in terms of the abundance of shale gas resources. In the year 2000, only 1% of the United States (U.S) natural gas production was contributed by shale gas energy; by the year 2010 it was more than 20% and according to prediction of the U.S. Government's Energy Information Administration (EIA); it will be more than 46% by 2035, of the United States' natural gas supply from shale gas [6].

The shale gas extraction planning model and optimal strategic implementation inherently depend on various parametric factors that are actively indulged in the decision-making process. The requirement of the tremendous amount of fresh water for hydraulic fracturing (i.e., between 7000 and 40000 m^3 per well) turns into a challenging task. The assessment of different freshwater sources is somehow uneconomic, but the other extrication is possible to fulfill freshwater demand.

In this study more practical aspects is discussed. First, it may not always be possible to have a historical data for which the stochastic technique may be applied and also; due to some hesitation regarding imprecise parameters; the fuzzy number may not be an appropriate representative of uncertain parameters. Hence, the better representation of a hesitation degree under vagueness or impreciseness can be done by using the intuitionistic fuzzy number which considers the degree of belongingness as well as non-belongingness of the element into the possible set.

Second, Zhang et al. [7] only designed the optimization framework for optimal management of waste water throughout the shale gas extraction processes and have not considered the management of freshwater which is also an integrated part of the whole shale gas extraction overtime horizons. Thus, we have unified the above two discussed aspects of this proposed study. The proposed shale gas optimization model also provides an opportunity to adopt the available on-site treatment technology along with the expansion option of the treatment plant which would be beneficial for Pennsylvania because underground disposal facility is scarce and most often wastewater would be supplied to nearby city Ohio.

MODELING AND OPTIMIZATION UNDER UNCERTAINTY

Objective function

Total cost related to freshwater

Minimize $Z_1 = \sum_{s=1}^{S} \sum_{i=0}^{n} \sum_{s=1}^{s} \{EV(c\tilde{a}q_{s,t}) + \text{EV}\ (c\tilde{t}f_{s,i,t})\} FW_{s,i,t}$

Total cost related to wastewater

Minimize $Z_1 = \sum_{i=1}^{I} \sum_{j=1}^{J} \sum_{t=1}^{T} \{EV(c\bar{t}r_{j,t}) + \text{EV}\ (\tilde{c}d_{j,t}) EV(c\tilde{t}w_{i,j,t}) - rr_{j,t}.re_{j,t}\} WW_{i,j,t}$

Capital investment for expansion of treatment plant

$$\text{Minimize} Z_3 = \sum_{\text{j}=1}^{\text{J}} \sum_{\text{m}=1}^{\text{M}} \sum_{t=1}^{T} \{\text{EV}\ (\text{c}\tilde{\text{e}}x_{j,m,t})\} \text{Y}_{\text{j,m,t}}$$

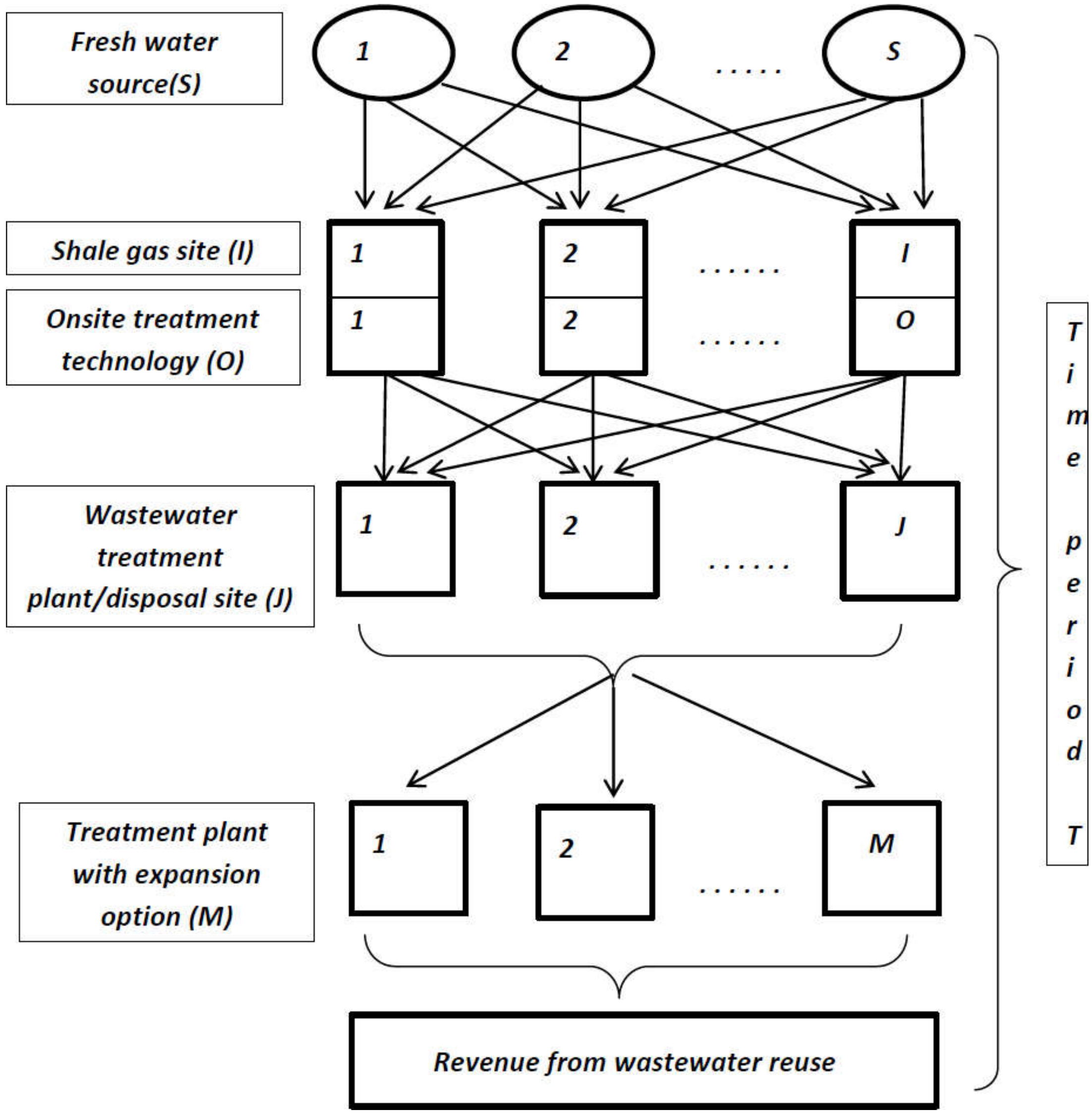

Figure 1: Representation of shale gas integrated water flow optimization network over time.

Table 1: Notations and descriptions

Indices	Descriptions
i	Denotes the number of shale sites
j	Represents the number of disposal site and treatment plants
m	Denotes the available option for the expansion capacity of treatment plant
o	Denotes the on-site treatment technologies
t	Represents the time periods
s	Denotes the source of fresh
Decision variables	
$FW_{s,i,t}$	Amount of fresh water acquired from source s at shale site i in time period t

$WTO_{i,o,t}$	Amountofwastewatertreatedbyon-sitetreatmenttechnologyoatshalesitei in time period t
$WW_{i,j,t}$	Total amount of wastewater generated at shale site i and received by disposal site and treatment plant j in time period t
$WWD_{i,j,t}$	Amount of waste water generated at shale site i and received by disposal site j in time period t
$WWT_{i,j,t}$	Amount of waste water generated at shale site i and received by treatment plant j in time period t
$Y_{j,m,t}$	Binary variable which represents the capacity expansion of disposal site and treatment plant j by expansion option m in time period t
$YO_{i,o}$	Binary variable which represents that on-site technology o is applied at shale site i
Parameters	
lo_o	Recovery factor for treating wastewater of on-site treatment technology o
$fdw_{i,t}$	Fresh water demand at shale site i in time period t
$fca_{s,t}$	Freshwater supply capacity at sources in time period t
rf_o	Ratio of freshwater to wastewater required for blending after treatment of on-site treatment technology o
$wwds_{j,t}$	Capacity for wastewater at disposal site j in time period
$wwtp_{j,,t}$	Capacity for wastewater at treatment plant j in time period t
$wdw_{j,t}$	Total capacity of wastewater at disposal site and treatment plant j in time period t
$eo_{j,m,t}$	Represents increased treatment capacity of wastewater treatment plant j by using available expansion option m in time period t
$caq_{s,t}$	Denotes the unit acquisition cost of freshwater at source s in time period t
$ctf_{s,i,t}$	Denotes the unit transportation cost of freshwater at source s to shale site I in time period t
$ctw_{i,j,t}$	Denotes the unit transportation cost of waste water from shale site I to disposal site and treatment plant j in time period t
$ctr_{j,t}$	Denotes the unit treatment cost of wastewater at treatment plant j in time period t
$cd_{j,t}$	Denotes the unit disposal cost of wastewater at disposal site j in time period t
$re_{j,t}$	Denotes the revenues from wastewater reuse from treatment plant j in time period t
$rr_{j,t}$	Denotes the reuse rate from wastewater treatment plant j in time period t
$cex_{j,m,t}$	Represent investment cost of expanding disposal site and treatment plant j by expansion option m in time period t
ocl_o	Denotes the minimum capacity of on-site treatment of wastewater
ocu_o	Denotes the maximum capacity of on-site treatment of wastewater

Constraints

$$\sum_{s=1}^{S} \mathrm{FW}_{s,i,t} + \sum_{o=1}^{O} \mathrm{lo}_{o}.\mathrm{WTO}_{i,o,t} \geq \mathrm{E}_1^{\mathrm{fdw}_{i,t}} \forall \;\; i,t$$

$$\sum_{i=1}^{I} \mathrm{FW}_{s,i,t} \leq \mathrm{E}_2^{\mathrm{fca}_{s,t}} \forall \;\; s,t$$

$$\sum_{i=1}^{I} \mathrm{WWD}_{i,j,t} \leq \mathrm{E}_2^{\mathrm{wwds}_{j,t}} \forall \;\; j,t$$

$$\sum_{i=1}^{I} \mathrm{WWT}_{i,j,t} \leq \mathrm{E}_2^{\mathrm{wwtp}_{j,t}} + \sum_{m=1}^{M} \mathrm{eo}_{j,m,t}.\mathrm{Y}_{j,m,t} \forall \;\; j,t$$

$$\sum_{i=1}^{I} \mathrm{WW}_{i,j,t} \leq \mathrm{E}_2^{\mathrm{wdw}_{j,t}} \forall \;\; j,t$$

$$\sum_{m=1}^{M} \mathrm{eo}_{j,m,t}.\mathrm{Y}_{j,m,t} + \mathrm{E}_1^{\mathrm{wwds}_{j,t}} + \mathrm{E}_1^{\mathrm{wwtp}_{j,t}} \leq \mathrm{E}_2^{\mathrm{wdw}_{j,t}} \forall \;\; j,t$$

$$\sum_{o=1}^{O} \mathrm{rf}_{o}.\mathrm{lo}_{o}.\mathrm{WTO}_{i,o,t} \leq \mathrm{FW}_{s,i,t} \forall \;\; s,i,t$$

$$\sum_{o=1}^{O} \mathrm{ocl}_{o}.\mathrm{YO}_{i,o} \leq \mathrm{WTO}_{i,o,t} \forall \;\; i,t$$

$$\sum_{o=1}^{O} \mathrm{ocu}_{o}.\mathrm{YO}_{i,o} \geq \mathrm{WTO}_{i,o,t} \forall \;\; i,t$$

$$\sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{t=}^{T} WW\,\mathrm{D}_{i,j,t} + \sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{t=}^{T} WW\,\mathrm{T}_{i,j,t} = \sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{t=}^{T} W\,\mathrm{W}_{i,j,t} \forall \;\; i,j,t$$

$$FW_{s,i,t} \geq 0, \qquad FW_{s,i,t} \geq 0 \quad \forall s,i,j,t$$
$$WTO_{i,o,t} \geq 0, WWD_{i,j,t} \geq 0, \quad WWT_{i,j,t} \geq 0 \; \forall i,o,j and t$$
$$0 \leq Y_{j,m,t}, YO_{i,o} \leq 1, \quad Y_{j,m,t} and YO_{i,o} = integer, \quad \forall i,o,j,m and t$$

where $EV(.), E_1^{(.)} and E_2^{(.)}$ are the expected value,lower and upper intervals of triangular intuitionistic fuzzy numbers for all the indices' set respectively

A COMPUTATIONAL STUDY

The integrated framework representative of multi objective shale gas water management optimization model has been presented based on the real-life scenario, hypothetical proposition, data, information and a quick review of the published research article (Lutz et al. [3], Rahm and Riha [4], Rahm et al. [5], Zhang et al. [7], Alawattegama [1]).

Results analyses

The multi objective shale gas water management optimization model was written in AMPL language and solved using solver BARON through NEOS server version 5.0 on-line facility provided by Wisconsin Institutes for Discovery at the University of Wisconsin in Madison for solving optimization problems, see (Drud [2]).

Table 2: Optimal amount of wastewater allocation and treatment plant expansion strategy

	Total amount of Wastewater $WW_{i,j,t}$	Amount of wastewater at disposal site $WWD_{i,j,t}$	Amount of wastewater at treatment plant $WWT_{i,j,t}$	Amount of wastewater for on-site treatment $WTO_{i,o,t}$
1 1 1	6.75	6.75	0	150
1 1 2	17.25	17.25	0	150
1 1 3	13.25	13.25	0	150
1 2 1	645	0	645	200
1 2 2	842.5	0	842.5	200
1 2 3	0	0	0	200
1 3 1	0	0	0	1551.71
1 3 2	0	0	0	2401.65
1 3 3	0	0	0	2701.62
2 1 1	6.75	6.75	0	127.352
2 1 2	17.25	17.25	0	127.352
2 1 3	13.25	13.25	0	127.352
2 2 1	0	0	0	200
2 2 2	0	0	0	6250
2 2 3	0	0	0	200
2 3 1	0	0	0	525.313
2 3 2	0	0	0	4554.66
2 3 3	0	0	0	527.01
3 1 1	6.75	6.75	0	150
3 1 2	17.25	17.25	0	150
3 1 3	13.25	13.25	0	150
3 2 1	0	0	0	200
3 2 2	0	0	0	200
3 2 3	0	0	0	2865.32
3 3 1	137.71	0	137.71	1551.32
3 3 2	675	0	675	2060.51
3 3 3	850	0	850	2208.04
4 1 1	6.75	6.75	0	147.779
4 1 2	17.25	17.25	0	2023.26
4 1 3	13.25	13.25	0	147.779
4 2 1	645	0	645	200
4 2 2	842.5	0	842.5	272.266
4 2 3	937.5	0	937.5	730.788
4 3 1	137.71	0	137.71	751.275
4 3 2	675	0	675	300
4 3 3	850	0	850	300
5 1 1	6.75	6.75	0	150
5 1 2	17.25	17.25	0	150
5 1 3	13.25	13.25	0	150
5 2 1	645	0	645	342.801
5 2 2	842.5	0	842.5	861.73
5 2 3	937.5	0	937.5	861.73
5 3 1	137.71	0	137.71	300
5 3 2	675	0	675	360.539
5 3 3	850	0	850	360.539

Increased treatment plant	**Expansion option**	**Time period**		
capacity (eo)	**(m)**	**t=1**	**t=2**	**t=3**
Treatment plant 1	1	600	-	600
Treatment plant 1	2	750	-	750
Treatment plant 1	3	850	-	850
Treatment plant 2	1	550	550	-
Treatment plant 2	2	650	-	-
Treatment plant 2	3	800	-	-

Table 3: Optimal amount of freshwater and value of objective functions.

	Amount of freshwater $FW_{s,i,t}$
1 1 1	700
1 1 2	1125
1 1 3	1275
1 2 1	186.765
1 2 2	1125
1 2 3	187.613
1 3 1	700
1 3 2	654.419
1 3 3	528.153
1 4 1	300.48
1 4 2	131.542
1 4 3	131.542
1 5 1	74.1
1 5 2	212.553
1 5 3	212.553
Optimal objective values	
Minimum Z_1	525126
Minimum Z_2	4025940
Minimum Z_3	5548.97

The proposed shale gas optimization model also provides an opportunity to adopt the available on-site treatment technology along with the option of expanding the treatment plant, which would be beneficial for Pennsylvania due to less opportunity for underground disposal facilities.

In Pennsylvania, underground disposal facilities are very scarce and most often wastewater is shipped to nearby cities in Ohio. The solution results have shown a similar situation of Pennsylvania, and less sewage has been allocated to a different underground disposal facility.

CONCLUSIONS

The significant contributions of the proposed multi objective shale gas water management system have been summarized as follows:

- The proposed study considers the overall shale gas water management system which is capable to reveal real scenarios without affecting the environmental issues.
- Uncertainty among the value of parameters ensures the system costs reliability of each component (costs related to freshwater and wastewater) more realistically. The crisp version of uncertain parameters have been determined in terms of expected interval and expected values.

- The multi objective shale gas project planning model has been implemented with the possible dataset and analyzed the obtained optimal results.

REFERENCES

1. S.K. Alawattegama, (2013). Survey of well water contamination in a rural southwestern Pennsylvania community with unconventional shale gas drilling. PhD thesis, Duquesne University.
2. S. Drud, (1994). Conopt—a large-scale grg code .ORSA Journal on computing, 6(2):207–216.
3. D. Lutz, A. N. Lewis, and M. W. Doyle, (2013) Generation, transport, and disposal of wastewater associated with Marcellus shale gas development. Water Resources Research, 49(2):647–656.
4. G. Rahm and S. J. Riha, (2013). Toward strategic management of shale gas development: Regional, collective impacts on water resources. Environmental Science & Policy, 17:12–23.
5. B. G. Rahm, J. T. Bates, L. R. Bertoia, A. E. Galford, D. A. Yoxtheimer, and S. J. Riha, (2013). Wastewater management and marcellus shale gas development: Trends, drivers, and planning implications. Journal of environmental management, 120:105–113.
6. P. Stevens, (2012). The shale gas revolution: developments and changes. Chatham House London.
7. X. Zhang, A.Y. Sun, and I.J. Duncan, (2016). Shale gas wastewater management under uncertainty. Journal of environmental management, 165:188–198.