British Journal of Applied Science & Technology
17(1): 1-14, 2016, Article no.BJAST.26840
ISSN: 2231-0843, NLM ID: 101664541

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Optimization of Drinking Water Treatment Process by Modeling the Aluminum Sulfate Dose

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Authors' contributions

This work was carried out in collaboration between all authors. Author MF designed the study, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript and managed literature searches. Authors LH and MD managed the analyses of the study and literature searches. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/BJAST/2016/26840
Editor(s):
(1) Abida Farooqi, Department of Environmental Sciences, Quiad-i-Azam University, Pakistan.
(2) Ahmed Fawzy Yousef, Geology Department, Desert Research Center, Egypt.
Reviewers:
(1) Eman N. Ali, Universiti Malaysia Pahang, Malaysia.
(2) Margarita Teutli León, Benemérita Universidad Autónoma de Puebla (BUAP), Mexico.
Complete Peer review History: http://www.sciencedomain.org/review-history/15713

Original Research Article

Received 5th May 2016
Accepted 3rd August 2016
Published 9th August 2016

ABSTRACT

The coagulant optimal dose determination is an issue of particular concern in water treatment processes. Coagulant dosing is correlated to raw water quality related to some parameters (Turbidity, pH, Temperature and Conductivity). The aim of this study is to provide water treatment operators with a tool that enables to predict and sometimes replace the manual method (jar testing). The model is developed on the basis of current process data recorded in water treatment plant located in the middle of Morocco (Meknes). This non linear model is related to turbidity, pH and temperature parameters. Comparison between aluminum doses measured and the alum doses calculated by the elaborated model shows a very interesting result. In fact, modeling can reduce aluminum sulfate consumption by more than 10%. Thus, the model can be applied in determining aluminum doses in the water treatment plant and can be extended to others.

Keywords: Coagulation; turbidity; aluminum sulphate; water treatment.

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1. INTRODUCTION

The demand on water supply is increasing over the last century due to improved lifestyle, industrial development and population growth. This increased demand is facing a paradox to produce treated water with high quality at lower cost. In order to reduce the water cost, it is very important to optimize the operating expenses in the water treatment plant (power, chemicals and operator's expenses) and many measures should be performed in this vision.

Optimization of water treatment plant is not a disciplinary to maximize the treatment objective and minimize the cost of produced water. But it consists on the understanding of the treatment plant functioning and treasure the experience of the operators in dealing with all treatment process related to different aspects.

The treatment of drinking water comprises the coagulation, flocculation, sedimentation, filtration and disinfection of raw water produced by the springs. During the rainfall period, the water's turbidity increases, colloidal particles are removed in the treatment plant by means of a chemical coagulation process: Consisting in the charge destabilization of the suspended particles by adding coagulant. The coagulant used is aluminum sulfate; it is the most widely used coagulant in Morocco as well as many other countries in the drinking water industry. It is mainly used because of its effectiveness, accessibility and low price. As a common practice, aluminum sulfate is applied according to the jar test results. The main difficulty is to determine the optimal dose of aluminum sulfate related to raw water characteristics. Both manual and automatic methods are used to predict optimum coagulant dose [1,2,3]. Automatic method is ensured by streaming current detectors [4,5,6,7]. However, manual method is consisting to determine the quantity of the coagulant to apply experimentally and based on the jar test results. Jar test involves taking a raw water samples and applying different quantities of coagulant to each sample [2]. After a short period of time, each sample is assessed for water quality and the dosage that produces the optimal result used a set point. This operation should be repeated by the operators each time when the quality of raw water changes. The aluminum sulfate is the compound likely to be mathematically modeled and therefore its value can be estimated according to the data available in the treatment plant [8,9,10]. The optimization of using the coagulant is very interesting approach because under dosing of coagulant can lead to poor quality drinking water while too much coagulant leads to many operating problems (less efficient filtration and sedimentation, pH), health problems can increase the cost of treated water [11,12].

Some attempts have been made to model relationships between raw water quality characteristics and the optima coagulant dosage rate [13,14,15,16].

This paper addresses the problem of building model to predict optimal coagulant dose from raw water characteristics (Turbidity level, pH, Temperature, total dissolved solids).

This study was developed in a water treatment plant located in Meknes in the middle of Moroccan Kingdom, whose source is two big springs Bittit (630 l/s) and Ribaa (400 l/s). The quality of water produced by the springs changes according to the rainfall in the region. Sometimes, it can be affected by the snow in the Atlas Mountains. The water treatment plant, as part of other water resources, water to more than 700.000 inhabitants of Meknes city, and it has a nominal capacity of 600 l/s of treated water. Fig. 1 presents a schematic overview of the various operations necessary to treat the water.

Many measurements of variables such as: turbidity level, PH, conductivity, temperature is needed to carry out the jar test in order to determine aluminum sulfate optimal dose. The raw water variables used in this study are presented with the following variation levels as shown in Table 1.

Table 1. Statistical summary of raw water conditions from 01/01/2013 to 31/12/2015 (National Office of Electricity and Drinking Water ONEE, 2015)

Variables	Min	Max
Turbidity: Bittit (NTU)	1.7	669.71
Turbidity: Ribaa (NTU)	1.62	524.03
pH	6.80	7.74
Temperature: (℃)	14	24.70
Conductivity micro s/cm	509	624

In the rainfall period, the turbidity of raw water changes from time to time as shown in Fig. 2, the turbidity of the raw water can increase to reach levels more than 500 NTU.

However, the turbidity level is less than 10 NTU this three last years (2013, 2014 and 2015) for more than 88% of the year. However, in 64% of the year the turbidity is less than 10 NTU for the seven last years as shown in Table 2.

Table 3 gives the max and min value of raw water turbidity by month from 2013 to 2015.

The chemicals used in the water treatment process consume about 50% of total operating expenses of the water treatment. Energy cost is between 10 to 15% related to the total cost in 2013, 2014 and 2015 as shown in the Fig. 3.

In addition, used as coagulant, aluminum sulfate (Alum) consumption is more than 70% of the total chemicals consumption in water treatment plant. Polyelectrolyte (Poly) consumption is less than 10% and the chlorine is between 16 and 26% of total chemicals used in the water treatment plant according to the water quality as shown by Fig. 4.

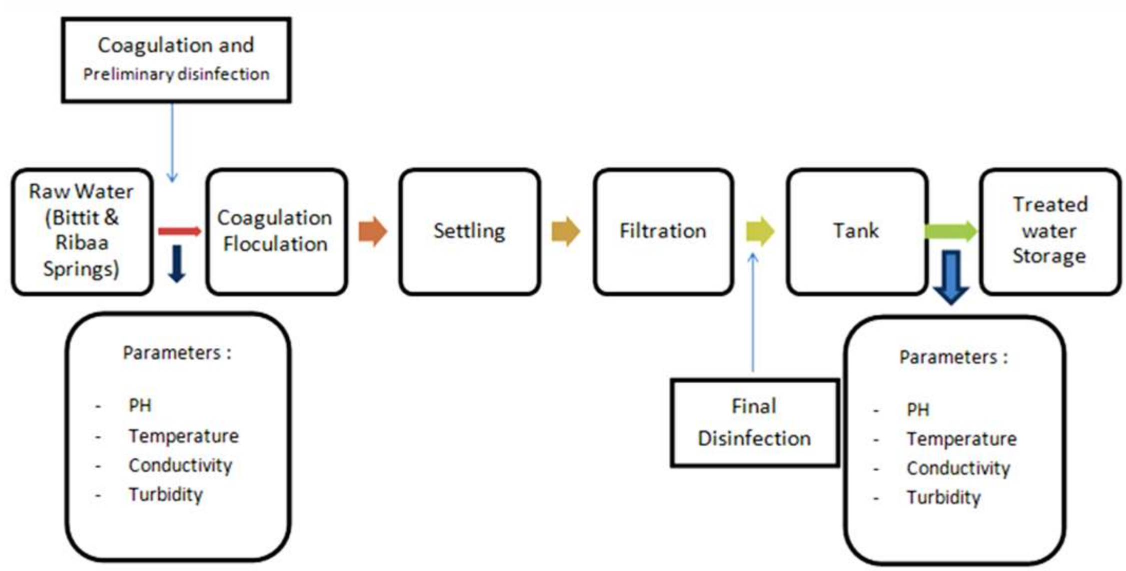

Fig. 1. Simplified synopsis of the water treatment plant

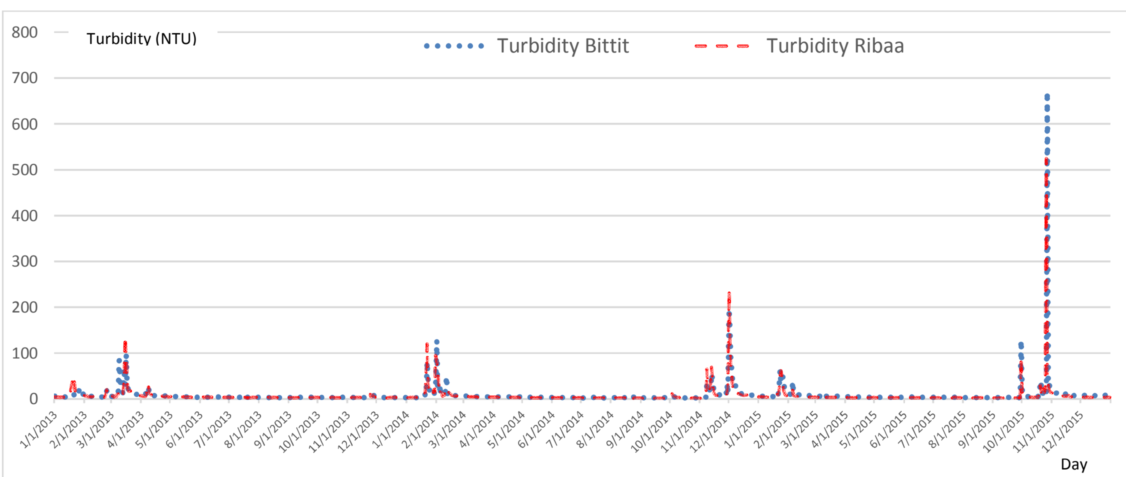

Fig. 2. Statistical data of turbidity level of the spring's water from 01/01/2013 to 31/12/2015 (National Office of Electricity and Drinking Water ONEE, 2015)

Table 2. Turbidity levels distribution from 2009 to 2015 (Number of days per turbidity level)

	Number of days					Total
Year	**Turbidity less or equal than 5 NTU**	**Turbidity more than 5 and less or equal than 10 NTU**	**Turbidity more than 10 and less or equal than 20 NTU**	**Turbidity more than 20 and less or equal than 40 NTU**	**Turbidity more than 40 NTU**	
2009	147	60	101	34	23	365
2010	0	0	113	148	104	365
2011	0	132	144	59	30	365
2012	301	38	17	5	5	366
2013	260	74	23	8	0	365
2014	247	62	32	20	4	365
2015	184	132	34	10	5	365
For the three last years (2013, 2014 and 2015):						
Total	691	268	89	38	9	**1095**
Aggregated data	691	**959**	1048	1086	1095	
Percentage	63%	24%	8%	3%	1%	
Percentage of Aggregated data	63%	**88%**	96%	99%	100%	
For the seven last years (from 2009 to 2015):						
Total	**1139**	**498**	**464**	**284**	**171**	**2556**
Aggregated data	1139	**1637**	2101	2385	2556	
Percentage	**45%**	**19%**	**18%**	**11%**	**7%**	
Percentage of Aggregated data	**45%**	**64%**	**82%**	**93%**	**100%**	

Table 3. Statistical data of turbidity min and max (NTU) measured in 2013, 2014 and 2015 per month (National Office of Electricity and Drinking Water ONEE, 2015)

Year : 2013 / Turbidity (NTU)				
Month	**Bittit spring**		**Ribaa spring**	
	Min	**Max**	**Min**	**Max**
January	3,70	18,95	10,00	50,00
February	4,50	19,00	3,95	20,65
March	4,95	98,40	4,50	136,66
April	6,40	21,95	4,90	32,77
May	3,93	6,30	3,80	5,30
June	3,72	4,40	3,34	4,89
July	3,30	4,33	2,92	3,62
August	3,00	3,80	2,70	3,46
September	3,10	4,64	2,68	4,15
October	2,90	3,99	2,46	3,62
November	2,70	7,44	2,90	10,00
December	3,07	4,23	2,60	3,95
Year : 2014				
Month	**Bittit spring**		**Ribaa spring**	
	Min	**Max**	**Min**	**Max**
January	3,06	81,69	3,00	120,66
February	6,48	128,00	5,93	78,90
March	4,86	6,91	3,90	5,65
April	4,30	4,90	3,30	4,19
May	3,17	4,77	2,48	3,37
June	3,00	3,86	2,60	2,87
July	2,36	4,50	2,16	2,49
August	1,74	4,20	1,88	2,28
September	1,80	3,50	1,64	1,90
October	1,89	4,20	1,67	11,64
November	1,80	55,50	1,68	69,29
December	6,57	197,50	5,06	235,89
Year : 2015				
Month	**Bittit spring**		**Ribaa spring**	
	Min	**Max**	**Min**	**Max**
January	5,09	63,10	3,96	61,59
February	6,33	38,52	3,98	19,45
March	4,97	6,27	3,26	4,64
April	3,65	5,60	2,80	3,76
May	3,50	5,23	2,68	3,06
June	3,40	4,52	2,61	3,19
July	2,80	4,75	2,40	3,60
August	2,60	3,26	2,45	2,74
September	2,70	128,45	2,35	86,63
October	4,35	669,71	3,22	524,03
November	6,76	17,18	3,99	13,19
December	7,18	9,54	3,42	4,02

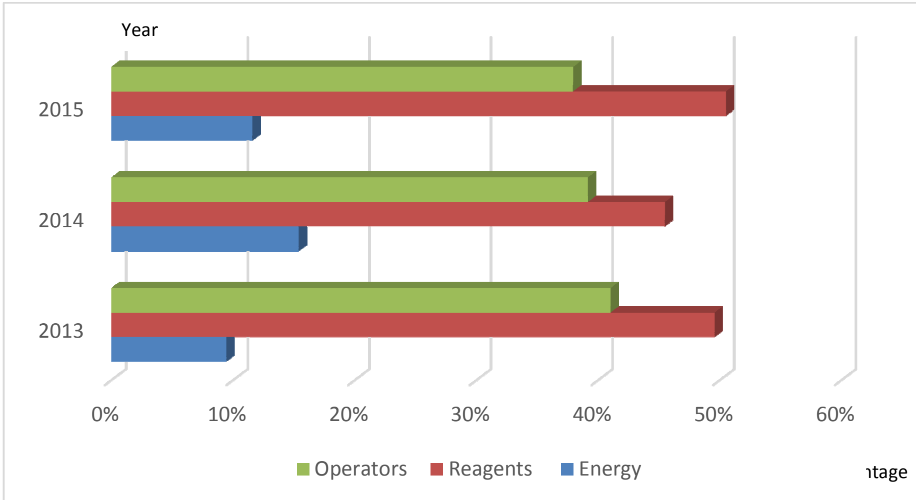

Fig. 3. Operations expenses of the water treatment plant in 2013, 2014 and 2015 (National Office of Electricity and Drinking Water ONEE, 2015)

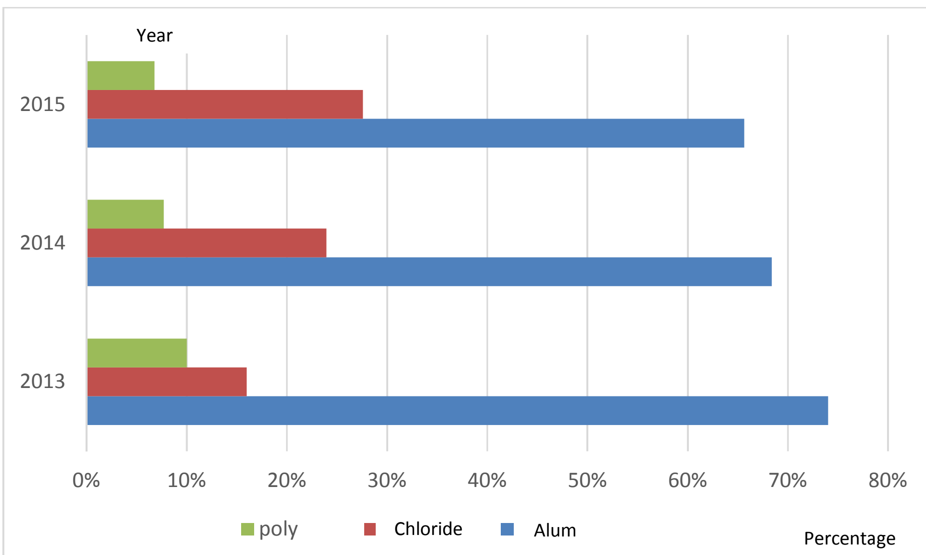

Fig. 4. Percentage of chemicals expenses consumed by the water treatment plant in 2013, 2014 and 2015 (National Office of Electricity and Drinking Water ONEE, 2015)

2. METHODOLOGY

Prediction of optimal coagulant dose from raw water characteristics is a nonlinear regression problem. The identification aims at modeling and parameter estimation. It consists of constructing a mathematical model that can describe the behavior "-Input-output" of the system [17]. The problem is to determine the model parameters from input and output data. The analysis of experimental data for different periods of the year in the water treatment plant allow obtain mathematical models describing the changes in dose of Alum based on the input parameters of the raw water using Statgraphics software.

The developed model will be based on the data available in the plant from 01/06/2014 to 31/12/2015 (495 data). The data validation, processing and modeling of the coagulant dosage rate are the main steps to construct the model as presented by Fig. 5.

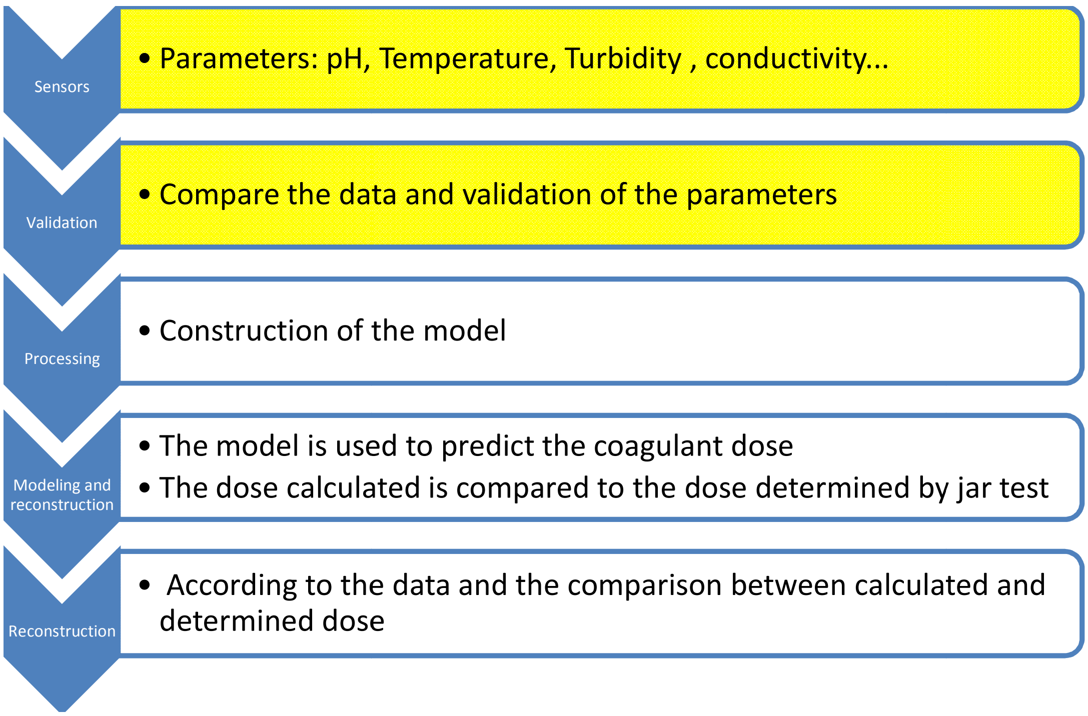

Fig. 5. Structure of the model for the prediction of the coagulant dosage rate

According to the data recorded in the water treatment plant, many models are identified and analyzed using Statgraphics software which indicates the relationship between the Aluminum doses measured and calculated by different models. Only eleven models from the simplest to a complex one are exanimated regarding to the output (aluminum sulfate dose calculated).

After elaboration of models, they are compared each one to the other. Two statistical tests are performed on models in order to choose the model fitted with the observed data. First, an ANOVA test is performed on models to determine if there is a significant difference between models and observed data. Finally, the Euclidian distance method is applied to models in order to choose the more representative of the observed data.

3. RESULTS AND DISCUSSION

For this study, two groups of turbidity are identified:

- Group 1: less turbid raw water (turbidity <=10 NTU).
- Group 2: turbid raw water (turbidity> 10 NTU and <= 20 NTU).

We considered turbidity (Turb), PH (PH), temperature (Temp) as explanatory variables of the dose of Aluminum sulfate (ASD) variable behavior (dependent variable). After the validation and processing the available data, eleven models are built as presented in Table 4.

3.1 Turbidity <= 10 NTU

- ANOVA test: The Table 4 gives the results of the ANOVA test, there is no significant difference between the observed data and the calculated data of different models except the model 2.
- The Euclidian distance test: The Euclidian distance is calculated between the model i and the data observed (Vobs). The results are exposed in Table 5:

Fig. 6 shows that, except the model 2, others are much fitted to the measured values trend and can explain the evolution of the consumption of the aluminum sulfate in the water treatment plant. Moreover, the model 5 is much fitted to the measured values of the Alum doses as shown by Fig. 7.

Table 4. Models used to predict the aluminum sulfate dose for turbidity less than 10 NTU

Model ID	Model	Variance	Mean squares between groups	Mean squares within group	F	F critic
M1	ASD = a+ b*Turb^2	0,411683761	2,8836E-05	1,135265673	2,54002E-05	3,850888022
M2	ASD = a* Turb	11,18087015	370,0752732	6,519858869	56,76123988	3,850888022
M3	ASD = a + B* PH+c*PH^2+d* Turb^2	0,459349673	0,000346606	1,159098629	0,000299031	3,850888022
M4	ASD = a*PH+b*PH^2+c*Turb^2	0,41235782	0,000271781	1,135602703	0,000239327	3,850888022
M5	ASD = a + b * PH+c * Temp + d * Turb + e * Temp^2 +f * Temp *PH+ g *Temp * Turb + h*PH^2 + i *PH* Turb + j* Turb^2 + k* Temp *PH* Turb	0,598009211	0,003622458	1,228428398	0,002948856	3,850888022
M6	ASD = a +b * Turb +c *PH	0,398624611	0,000260786	1,128736098	0,000231042	3,850888022
M7	ASD = a* Turb + b * PH	0,404036521	0,001562999	1,131442053	0,001381422	3,850888022
M8	ASD = a + b * Turb	0,398033322	3,48569E-05	1,128440454	3,08895E-05	3,850888022
M9	ASD = a* Temp + b* Turb + c* PH	0,451748045	0,0017627	1,155297815	0,001525754	3,850888022
M10	ASD = a+ b*PH + c*Temp + d* Turb	0,443782468	0,00010845	1,151315027	9,41964E-05	3,850888022
M11	ASD = b * PH+c * Temp + d * Turb + e * Temp^2 +f * Temp *PH+ g *Temp * Turb + h*PH^2 + i *PH* Turb + j* Turb^2 + k* Temp *PH* Turb	0,511660954	0,001235877	1,18525427	0,00104271	3,850888022

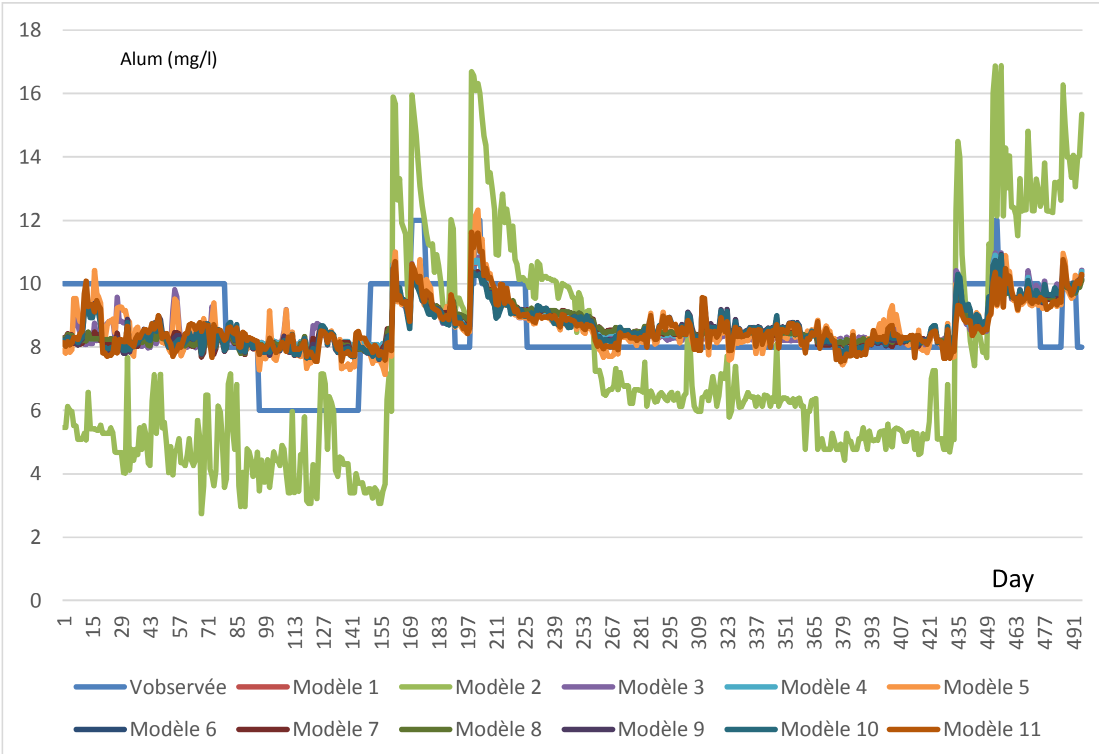

Fig. 6. Simulation of aluminum sulfate dose (mg/l) by different models and dose measured for turbidity less than 10 NTU

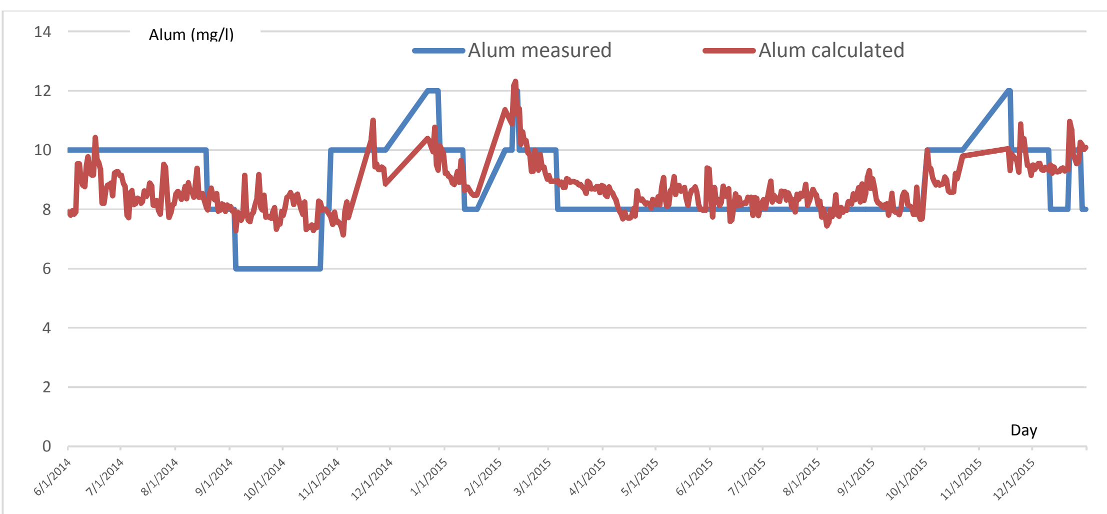

Fig. 7. Simulation of aluminum sulfate dose (mg/l) by different model 5 and dose measured for turbidity less than 10 NTU

3.2 Turbidity> 10 NTU and <=20 NTU

- ANOVA test: Table 6 gives the results of the ANOVA test, there is no significant difference between the observed data and the calculated data of different models except the models 2 and 7.
- The Euclidian distance test: The Euclidian distance is calculated between the model i

and the data observed (Vobs). The results are exposed in Table 7.

Fig. 8 shows that the models are much fitted to the measured values of the aluminum sulfate consumption except the model 2.

Table 5. The Euclidian distance calculated per models, turbidity less than 10 NTU

Vobs/ Mi	Somme (Y obs - Y Mi)^2
Vobs - M1	714,718
Vobs - M2	5096,723
Vobs - M3	691,737
Vobs - M4	714,571
Vobs - M5	617,589
Vobs - M6	721,019
Vobs - M7	721,807
Vobs - M8	721,496
Vobs - M9	699,537
Vobs - M10	698,825
Vobs - M11	663,757

Fig. 9 shows the results of the calculated dose of the aluminum sulfate using the model 5. It is clear that the calculated dose is fitted to the measured dose.

According to Euclidian distance test, for both levels of turbidity (less than 10 NTU and between 10 and 20 NTU), model 5 is the most representative of observed data and it can be selected to predict the dose of the aluminum sulfate in the water treatment plant.

Constructed model is used to predict the aluminum sulfate dose each hour in the water treatment plant. The parameters used in the model are continually changing. Thus, the Alum dose is changing from hour to other as shown in Figs. 10 and 11.

Aluminum sulfate dose can be estimated according to data available in the treatment plant. Figs. 10-11 show that calculated dose of the aluminum sulfate is near of measured dose using jar test. Then, operator can use this model to control and monitor the aluminum sulfate dose in the water treatment plant. Also, the monitoring of the aluminum sulfate injection is possible by using this kind of model.

The coagulant consumption optimization is possible and model can continually calculate the aluminum sulfate dose and this dose is predicted according to the change in the parameters of raw water. Instead to use a measured dose by jar test for twenty four hours minimum. In the other hand, this approach is very interesting in improving the water quality because under dosing of coagulant can lead to poor quality drinking water while too much coagulant leads to many operating problems (less efficient filtration and sedimentation, pH), healthy problems and can increase the cost of treated water.

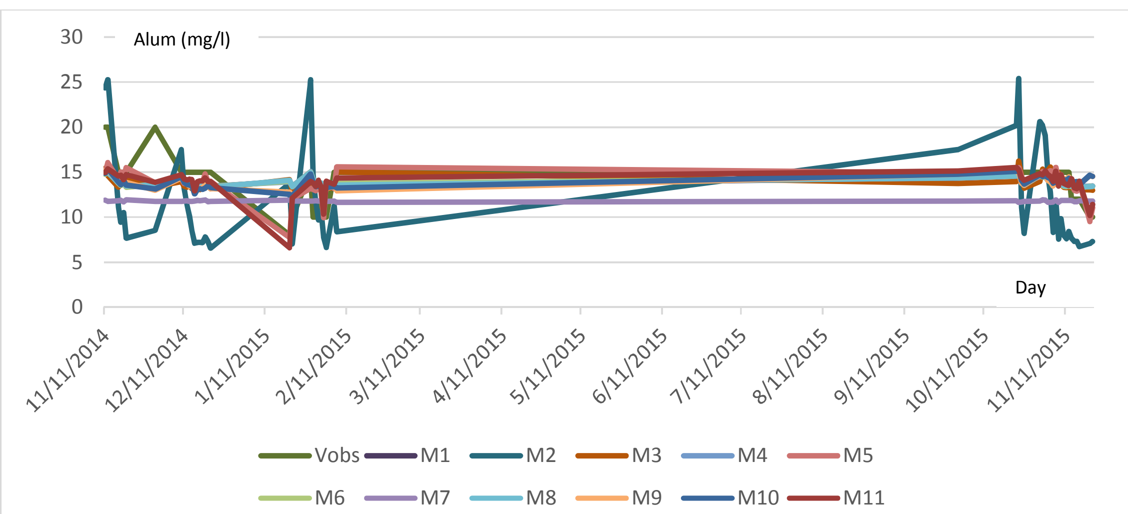

Fig. 8. Simulation of aluminum sulfate dose (mg/l) by different models and dose measured for turbidity between 10 and 20 NTU

Table 6. Models used to predict the aluminum sulfate dose for turbidity between 10 and 20 NTU

Model ID	Model	Variance	Mean squares between groups	Mean squares within group	F	F critic
M1	ASD = a+ b*Turb^2	0,234749871	2,122644009	3,264689885	0,650182432	3,932437831
M2	ASD = a* Turb	29,96359016	180,9770354	18,12911003	9,98267621	3,932437831
M3	ASD = a + B* PH+c*PH^2+d* Turb^2	0,651787305	1,911098825	3,473208602	0,550240151	3,932437831
M4	ASD = a*PH+b*PH^2+c*Turb^2	0,243033647	2,065336707	3,268831773	0,631827164	3,932437831
M5	ASD = a + b * PH+c * Temp + d * Turb + e * Temp^2 +f * Temp *PH+ g *Temp * Turb + h*PH^2 + i *PH* Turb + j* Turb^2 + k* Temp *PH* Turb	2,328561881	2,430658689	4,31159589	0,56374919	3,932437831
M6	ASD = a +b * Turb +c *PH	0,244220963	2,061881321	3,269425431	0,630655559	3,932437831
M7	ASD = a* Turb + b * PH	0,005194236	142,5703974	3,149912067	45,26170712	3,932437831
M8	ASD = a + b * Turb	0,235017994	2,122833224	3,264823946	0,650213689	3,932437831
M9	ASD = a* Temp + b* Turb + c* PH	0,503452321	2,171104533	3,39904111	0,638740299	3,932437831
M10	ASD = a+ b*PH + c*Temp + d* Turb	0,507533169	2,02223202	3,401081534	0,594584987	3,932437831
M11	ASD = b * PH+c * Temp + d * Turb + e * Temp^2 +f * Temp *PH+ g *Temp * Turb + h*PH^2 + i *PH* Turb + j* Turb^2 + k* Temp *PH* Turb	2,139660069	2,006669248	4,217144984	0,475835964	3,932437831

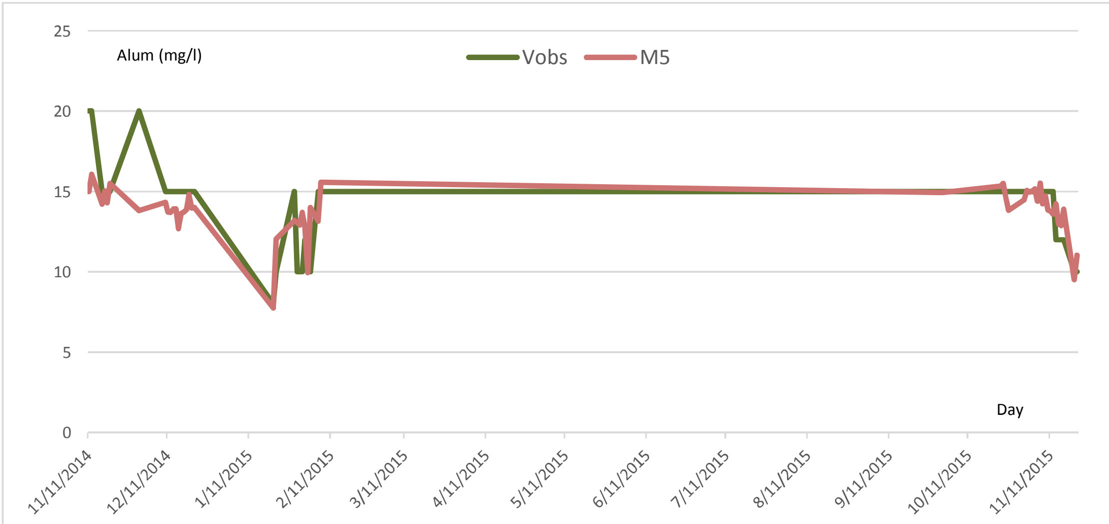

Fig. 9. Simulation of aluminum sulfate dose (mg/l) by the model 5 and dose measured for turbidity between 10 and 20 NTU

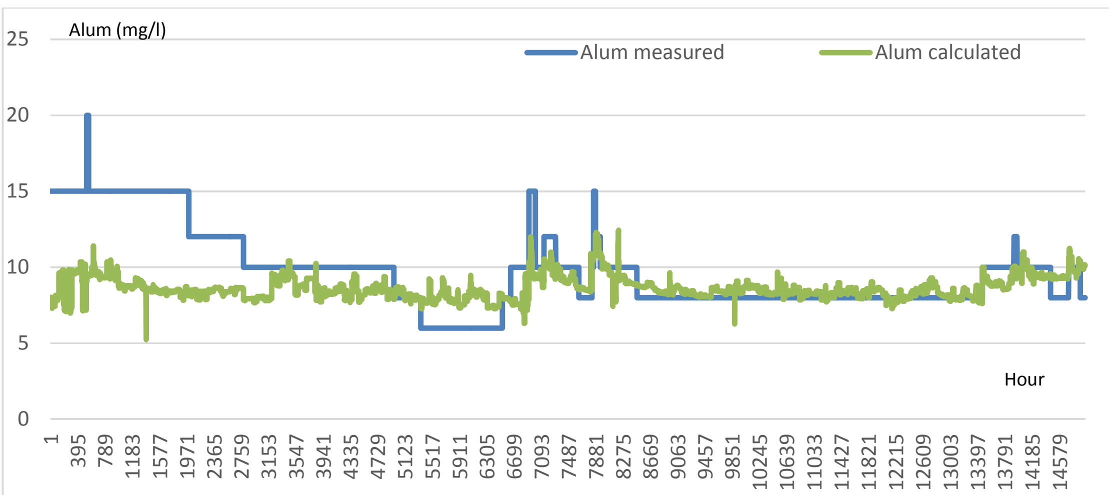

Fig. 10. Comparison between the observed aluminum sulfate dose (Alum measured) and the calculated dose (Alum calculated M5) by using the model 5 per hour for turbidity less than 10 NTU

Table 7. The Euclidian distance calculated per models, turbidity between 10 and 20 NTU

Vobs/ Mi	Somme (Y obs - Y Mi)^2
Vobs - M1	298,372
Vobs - M2	1734,448
Vobs - M3	279,321
Vobs - M4	298,020
Vobs - M5	177,806
Vobs - M6	299,416
Vobs - M7	613,245
Vobs - M8	299,856
Vobs - M9	288,519
Vobs - M10	286,634
Vobs - M11	194,085

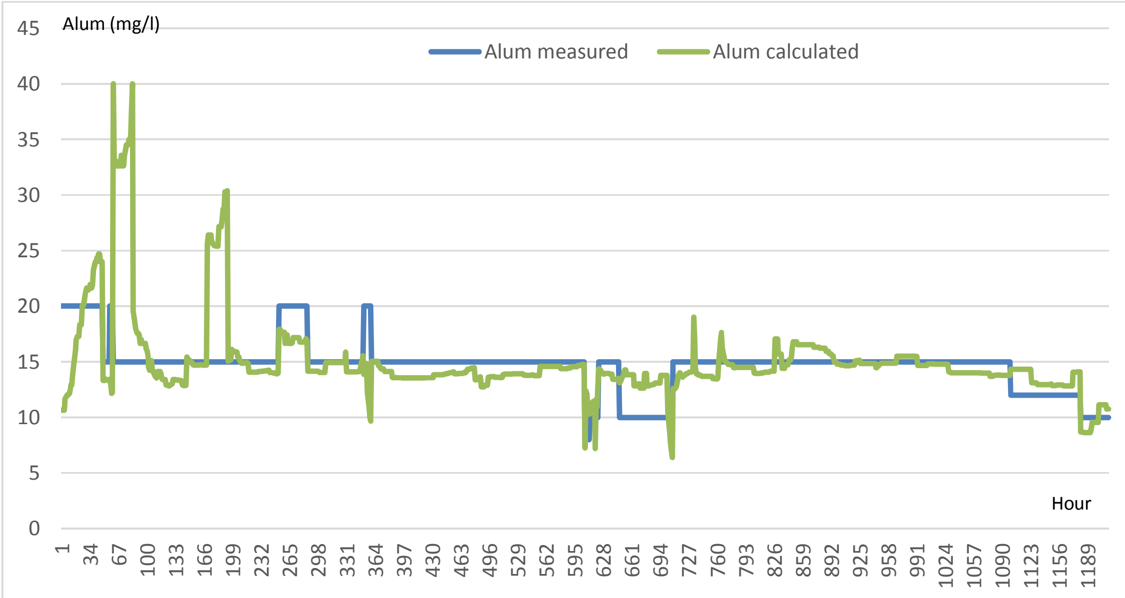

Fig. 11. Comparison between the observed dose of the aluminum sulfate (Alum measured) and the calculated dose (Alum calculated M5) by using the model 5 per hour for turbidity between 10 and 20 NTU

4. CONCLUSIONS

In the aim of improving the water quality and reducing many operating problems. This paper has presented some preliminary results concerning the challenging task of controlling coagulant dosing rate at water treatment plant using non linear model. The model is related to turbidity, pH and temperature parameters. The aim of the model is to provide water treatment operators with a tool that enables prediction of aluminum sulfate dose using the data recorded in the plant. Application of the model can reduce the aluminum sulfate consumption by more than 10% in the water treatment plant. However, the larger and more updated data base is, the more performant the model is.

DISCLAIMER

This manuscript was accepted to be presented in the conference.

Conference name: "ICAWR 2016: 18th International Conference on Advances in Water Resources"

Conference link is "http://waset.org/pdf/books/?id=45249&pageNumber=1602"

Date February 25-26, 2016 Dubai, UAE

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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