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SUSTAINABLE GROUNDWATER MANAGEMENT MODEL BY THE EXISTENCE OF UNCERTAINTY

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ABSTRACT

In the management of ground water resources, the uncertainty will exist in the parameters of the system and the relationship will intensify the problems associated with water allocation conflicts between the urban, industrial and agricultural interests. Furthermore, the discrepancy and uncertainty which are always associated with groundwater and eventually result in a difficult case to solve. The causes of the presence of uncertainty in groundwater management, among others: (i). Lack of knowledge about the aquifer system, (ii). The characteristics and parameters of the flow and the characteristics of the transportation and (iii) Economic considerations. This paper will focus on the methods and formulations that explicitly combine the uncertainty by using a mathematical model that can help the underground water system management which is beneficial for the supply of clean water that has been contaminated or threatened by chemical pollutants. The main purpose in the stochastic program model in this study is to build a model of groundwater management in an effort to manage the quality and quantity of groundwater so that the objective function of obstacle control can minimize the pumping costs. The results of the research of the non-linear stochastic program model have been built in to a basic framework for the management of groundwater, especially to manage the quantity and quality of groundwater, uncertainty condition (stochastic) is required due to the fluctiating hydraulic and groundwater, while the cost components appeared in this model is to control the excessive groundwater pumping.

Key words: Management Model, Groundwater, Sustainable and Uncertainty

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1. INTRODUCTION

Groundwater is one of the natural resources that is used as water supply for the daily needs of residents, agricultures, industries and others. The need for groundwater needs is certainly in line with the increase in population and development (Tarmizi *et al*., 2016, 2017; Sihombing *et al*., 2017 & Muda *et al*., 2018). It will continue to increase in the future to meet the needs, although the groundwater resources are intrinsically renewable, but the efforts in the utilization of groundwater resources should be through a method in which the groundwater pumping should be as optimal as possible while maintaining the continuity to maintain the balance of the environment. In the implementation of regional autonomy as stipulated in Law No. 32 of 2004, the regions have their autonomy in the management of ground water resources in their regions and are responsible to maintain environmental sustainability. It means that the implementation of groundwater management authority must be based on the principle of management of which source is the *sustainable groundwater resources* which can ensure the *sustainable groundwater development*.

Groundwater is a commodity plays a vital economic role, even in some regions, such role can be classified as a strategic factor (Lubis *et al*., 2017 & Muda *et al*., 2018). However, on the other hand, the overexploitation of groundwater resources has caused some problems result in negative impact on the surrounding environment, among others; land subsidence, reduced quantity of groundwater, degradation in groundwater quality, subsidence and saltwater intrusion into the equifer of groundwater. Complexity, natural characteristics and uncertainty of the ground water resources have led some researchers to propose some models of groundwater management based on uncertainty. Aguado and Remson (1974) have developed a model of water resources utilization from any location, with or without considering certain expenses. The problem in groundwater quality solved by using the "*embedding*" method is by maximizing the waste disposed in an area while maintaining standard-quality of groundwater if the quantity of pumping and recharge have been preset (Willis 1976a and 1976b, Gorelick 1980, and Goerlick and Remson 1982a) and the handling of groundwater quality by maintaining certain *gradient head* (Remson and Gorelick, 1980). Furthermore, Tyson *et al*, 1993; Gu and Dong, 1998, make some changes in the policy regarding water quality, groundwater quantity and further strategy with an integrated approach that requires mathematical modeling as a tool in the management of groundwater quality.

The mathematical model is increasingly used (Deksissa et al, 2004), due to its ability to predict groundwater quality caused by pollution and is more efficient in costs. Furthermore, the complex relationship between the content of pollutants from different sources can be described by a mathematical model. Guang Li et al (2004), suggest that the important part of research on groundwater modelling is related to, and involves the formulation and solution of management problems that have uncertainty associated with both the quality and quantity of groundwater. The proposed mathematical model is a mathematical model used to build the management and to optimize the groundwater management system with the presence of uncertainty combined with a two-stage stochastic program method approach. This optimization can be in the form of a benefit maximization or cost minimization to help the management in analyzing the (operating) costs. Therefore, there is a need of groundwater management to preserve its availability which means that the principles of benefit, balance and sustainability in the management of groundwater in groundwater resources can be sustaniable.

- The problem that can arise as results of uncertainty is on How to build a model that will be able to apply for the sustainable groundwater management in the presence of uncertainty and

- How should the optimal management be on groundwater quantity in order to minimize the objective function of the constraints.

1.1. Research Objectives

- To build a model of groundwater management in the effort of groundwater quantity and quality management by using a stochastic model.
- To build an optimal management model towards the groundwater quantity in order to minimize the objective function of cost control constraints.

2. RESEARCH METHOD

2.1. Research Design

The model building in this research can be divided into two main categories, they are; stochastic program and water quality.

2.2. Stochastic Program Model

The model proposed in this research is a sequential making decision process with the presence of uncertainty in the finite time horizon. Express the time horizon of decision with T = {1,..., |T|}, assumed that the information provided by the stochastic process $\{\xi_t\}_{t=1}^{|T|}$ defined in the probability space (Ξ, F, P). The decision is based on the information available on the current time, that is a set of decisions which have been made and on the outcome of random variable in the previous stage. If the vector of all decisions made from stage 1 to stage t is shown by $\mathbf{x}_t = (x_1 ,..., x_t)$ and the vector of random variable of the results during the same interval is shown by by $\boldsymbol{\xi}_t = (\xi_1,...,\xi_t)$, then, the stochastic program of the whole number (*bilangan cacah*) of multiple stages can be expressed as follow:

$$\text{Min } \{c_1(\xi_1)x_1 + Q_1(x_1)\ W_1x_1 \leq h_1(\xi_1),\ x_1 \in \mathbf{X_1}\},$$

Where :

$$Q_t(x_t) = E_{\xi t+1|\xi t} \min\{c_{t+1}(\xi_{t+1})x_{t+1} + Q_{t+1}(x_{t+1}) :$$
$$T_{t+1}(\xi_{t+1})x_t + W_{t+1}x_{t+1} \leq h_{t+1}(\xi_{t+1}),\ x_{t+1} \in \mathbf{X_{t+1}}\}$$

For t = 1,..., | T | – 1, with $Q_{|T|} \equiv 0$. It is assumed that ξ_1 is known at time t = 1 and $E_{\xi t+1|\xi t}$ expresses the expectation towards the distribution ξ_{t+1} which is required in observation ξ_t For all realizations of ξ and time stage, it is assumed that $T_t(\xi_t)$, W_t ,$c_t(\xi_t)$, $h_t(\xi_t)$ are the rational matrix and vectors with certain dimension. The X_t set expresses a set of decision variables. It needs to assume that the expectation defines Q_t is finite for random x_t policy. In this research, it is assumed that the variable vector ξ has finite support; that is $\Xi = (\xi^1 , ... , \xi^r)$ with a probability p^1,...., p^r. This hypothesis results that uncertainty can be expressed by scenario. A scenario is a realization of random variable ($c(\xi)$, $h(\xi)$, $T(\xi)$) which is related to an elementary event $\xi \in \Xi$.

3. RESULT AND DISCUSSION

3.1. Water Quality Management Model through Gradient Control

One of the conservative model approaches toward the management of the contaminated groundwater is determining the borders of surrounding contaminated areas and ensuring that the contaminated groundwater does not cross the existing borders. The border is also known as catchment curve or interception layer. The point is that by ensuring the hydraulic gradient into the catchment curve, it can reduce the spread of contamination to the uncontaminated areas. Hydraulic gradient is determined by the operation of the pumps and injection wells in the area. The purpose of this approach is to keep/protect the uncontaminated groundwater outside catchment curve and the possibility to treat contaminated water is pumped from this location, to clean up the location. Javandel and Tsang (1986), proposed an analysis methods for the placement and operation of the wells containing the contamination with catchment curves in homogeneous areas. Meanwhile, according to Gorelick (1987), he has also managed to present a method to integrate the information concerning the spatial variability into the problems of catchment curves. As seen in his paper, Gorelick has representatively taken ten examples of hydraulic conductivity and determine the operation planning to minimize the total volume of pumping while maintaining the required gradient to ten cases.

The management of groundwater system is modeled by a response matrix formed from any results of the formulations in the study of groundwater which use more results regarding a review and present the groundwater system with the approach of limited differences in the flow equation model, so that the results of the two models are not directly comparable. In the following section, the formulation for the problems of catchment curves is given for some sample problems to be resolved and is analyzed for its sensitivity, which is conducted on various parameters used in the formulation.

3.2. Formulation

In this problem, the decision variable is the pumping rate of each well. The objective is to minimize the pumping energy cost reduced by the profit obtained from the water that had been taken. Energy cost is a function of the flow at which water is pumped x (multiplied by) height of groundwater uptake. Energy cost are quadratic, because the uptake is a linear function of the pumping rate. The advantage of pumping is expressed in financial and as a quadratic function of the total amount of the water taken, so that the objective function is quadratic. The model involves two types of constraints. The first constraint related to the pumping speed to the hydraulic head in this area. Furthermore, this constraint is obtained by combining the finite difference approach from the flow equation into the optimization problem. The second constraint defines the catchment curve for each pair of elements towards the catchment curve. This constraint requires that the gradient (head difference) heads to the areas containing groundwater. Both constraints are linear. Uncertainty in the model comes from the difficulty in obtaining the value of hydraulic conductivity which is partially distributed in which each parameter is treated as a realization of the origin areas which is stationary log-normally distributed. Since the top part depends on the value of conductivity, including what value of the pump is selected, the condition of the top which is also uncertain. In this case, the pumping rate is the "here and now" variable. The recourse cost of "wait and See" derived from the outside-headed gradient cost.

3.3. Model Building

According to Anderson and Woesner (1992), model is a tool made by using approach to show the field condition. In mathematical definition, model is an illustration of a system through some analogies, equations, and procedures to illustrate the behavior of a prototype system.

3.4. Groundwater Flow Equation

Groundwater flow has a tendency towards reaching an equilibrium. It can move in laminar or turbulent. In general, the groundwater flow is laminar and is considered a two-dimensional flow. One of the basic equations that are important to solve the problem of groundwater is the continuity equation. This equation is actually a mass viscosity law, which in this case is applied to the observation of a change in water volume. The volume of water that enters and leaves the aquifer element at certain time should be the same. This law or equation in solving the problem of groundwater flow will always be associated with Darcy's law. (Todd, 1995). Darcy's equation (Wagner, 1988), can be used to determine the equation of groundwater flow velocity in a limited area, which can be written as follow:

$$Q_x = -K_x A \frac{\partial h}{\partial x} \tag{3.1}$$

Where :

Q_x = flow velocity (meter^3/second)

K_x = hydraulic conductivity based on direction x (meter/second)

h = head (meter)

A = border section area (meter^2) and

X = length (meter)

The partial-differential of continuity is expressed as follow:

$$\frac{\partial vx}{\partial x} + \frac{\partial vy}{\partial y} + \frac{\partial vy}{\partial z} = 0 \tag{3.2}$$

By combining equation (5.1) and (5.2) by considering the mass equilibrium, it will result the following partial-differential equation for the two-dimensional flow in an anisotropic media:

$$\frac{\partial}{\partial x}\left(K_x b \frac{\partial h}{\partial x}\right) + \frac{\partial}{y}\left(K_y b \frac{\partial h}{\partial x}\right) \pm \delta = 0$$

Where:

x,y = width, length (meter)

b = depth of aquifer (meter)

δ = input/output of water (meter/second)

This equation needs to be discredited by taking the derivative as the difference limit on the finite element. From the Darcy's Law, the flow into elements (*i*,*j*) from element (*i + 1, j*) is given by :

$$-K_x \frac{(h_{i,j} - h_{i+1,j})}{\Delta x} b \Delta y$$

The same equation applies for the flow from elements (*i+1,j*), (*i,j+1*) and (*i,j-1*).

In addition, the flow going out of well is given by:

$W_{i,j}$ = pumping rate from elements *i, j* (meter^2/second)

For the completeness, variable $W_{i,j}$ should be used for each element. If the element is without wells, the value of this variable can be limited by zero. From mass conservation, for each element (i,j), it obtained the equation for height differences for the steady flow as follow:

$$-K_x \frac{(h_{i,j} - h_{i,1-j})}{\Delta x} b\Delta y - K_x \frac{h_{ij} - h_{i,1+j})}{\Delta c} b\Delta y - K_y \frac{(h_{i,j} - h_{i,1-j})}{\Delta x} b\Delta y$$
$$-K_x \frac{h_{ij} - h_{i,1+j})}{\Delta y} b\Delta x = w_{i,j} \tag{3.3}$$

Pay attention that the equation of height difference is liner in h and w. Express N the number of limited elements. Thus, by re-arranging N equation from the form (5.3) it obtained a liner system, which is expressed as:

$$Fh = w - f \tag{3.4}$$

Where:

F = matrix N x N from the head coefficient (from (5.3))

h = N vector of head variable

w = N vector of pumping variable, and

f = N vector N constant (from (5.3))

Since the coefficient is not zero, it is only seen in the adjacent elements, matrix F in (5.4) has a specific structure.

3.5. The Linear-Quadratic Deterministic Programming Formulation

As explained previously that the objective of this problem is minimizing the pumping costs reduced by the benefits obtained from water. Energy costs function for pumping is determined by the pumping rate multiplied by the uptake water level. The benefit is assumed to be quadratic in the total number of pumping.

So, this objective can be written as:

$$\text{Min } Bw\,(s-h) - \alpha\,(e\,w)^2$$

where :

B = coefficient of cost per day for pumping (IDR/meter^3/meter Of height) x 86.400 seconds/day

T = time (second)

h = depth from the surface to the floor of aquifer (meter)

w = coefficient of benefit for water (IDR/[meter^3/second]^2)

e = N vector of unit

One of the requirements in this model is the gradient head. It can be written in :

$$h^{in} - h^{out} \leq 0$$

where

h^{in} = expressing head into the catchment curve, and

h^{out} = denoting head suitable to the outside of the catchment curve

If ℓ = number of points in which the gradient is calculated (control point), then h^{in} and h^{out} are the vectors in ℓ size**.** The pumping rate should be limited non-negatively and less than the maximum value w. So, the deterministic liner quadratic program (if the value of hydraulic conductivity (K_x, K_y) is known) is given by:

$$\min Bw\,(s-h) - \alpha\, w^2 \tag{3.5}$$

with a constraint :

$$Fh = w - f$$

$$h^{in} - h^{out} \leq 0$$

$$0 \leq w \leq w^{maks}$$

3.6. Model with the Existence of Uncertainty

In this problem, the main source of uncertainty is the hydraulic conductivity (*K*). Uncertainty in this value is often treated as a stationary, correlated, log-normally distributed, and random condition. By using this model, we can specify the combination of probability distributions for the value of K at each point. In the model of finite difference, the attention point taken is the middle point of each element. Then, it is assumed that the value in the middle part represents the entire element. In order to use this stochastic optimization method, it is necessary to obtain a discrete value for the conductivity which shows the combination of probability distribution. One of the methods used by Eiger and Shamir (1987) included the value discretization at any point in several levels and then look at all of these level combinations on a random variable. This approach is not feasible in the catchment curve, related to the value of K, and range in the value. For example, although theoretically the log-normally distributed variables can be ranging from 0 to + ∞, if the value of K is limited to 5, the probability value will be 10^{-2}, 10^{-3}, 10^{-4}, 10^{-5} and 10^{-6}. The result of random variable for the catchment curve problem requires K value for every 110 elements. So that, with 5 possible values for one element, the number of results possible for this area is $5^{110} = 7.7 \times 10^{76}$, which is too big to build. In addition, since the conductivity is correlated, it is not clear on how to calculate probability from every result. Determination of realization and random parameter used opportunity fitering method. For each realization, these variables correlate spatially in three dimensions according to the stationary exponential correlation function:

$$C(\varsigma) = \sigma^2 \exp\left[-\left\{\left(\frac{\varsigma_1}{\lambda_1}\right)^2 + \left(\frac{\varsigma_2}{\lambda_2}\right)^2 + \left(\frac{\varsigma_3}{\lambda_3}\right)^2\right\}^{1/2}\right]$$

Where :

C(Ç) = stationary anisotropic covariance for the points separated by Vektor *Ç*

σ^2 = random field variance

i = separation throughout the dimension i (i = 1,2,3) and

Λi = correlation scale throughouth the dimension i (i = 1,2,3)

Filtering programs, which resulted in a single realization of the hydraulic conductivity is repeated by using a random number generated as an initial value for the next section. Each process results in collective-free-probability distributed independent samples, assumed that each sample showed the existing results. Although this optimization problem requires K value along the two-dimensional field, this program is used to generate three dimensions of values in order to avoid numerical problems with the program. One of the additional steps is required to use the conductivity value in the specific differentiation equation. For certain elements, the conductivity is generated by the turning band program which is a proportional constant which has an effect of correct flow for the gradient that passes through the elements. In this equation, it requires the conductivity which is able to provide the correct flow between the middle of the two elements. So, it is necessary to find a series of effective conductivity between two elements. The general approach is used with a harmonic average:

$$K_{\text{eff}} = \frac{2(K_i K_j)}{K_i + K_i}. \tag{3.6}$$

This equation is derived as follows. It is assumed that each element is homogeneous so that the flow from node i to node j will pass through two different layers.

If i' = j' is the border between two elements and

q_{ij} = flow from node *i* to node *j'*

$q_{i,i'}$ = flow from node *i* to *i'* and
$q_{j',j}$ = flow from node *j'* to *j*
since there is no intervention

$$q_{ij} = q_{i,i'} = q_{j',j} \tag{3.7}$$

from the finite difference approach to the Darcy's equation:

$$q_{ij} = \mathrm{K_{eff}}\,\frac{\mathrm{hi - hj}}{\Delta \mathrm{X}}\mathrm{A} \tag{3.8}$$

$$q_{ij} = \mathrm{K_{eff}}\,\frac{\mathrm{hi - hj}}{\Delta \mathrm{X}/2}\mathrm{A}$$

$$q_{1,1} = \mathrm{K_1}\,\frac{\mathrm{hi - hj}}{\Delta \mathrm{X}/2}\mathrm{A}$$

(Clearly, $h_{i'} = h_{j'}$)

By substituting the equation (5.8) to (5.7) and completing the value K_{eff}, it obtained:

$$K_{eff} = \frac{\Delta x}{\frac{\Delta x/2}{K_i} + \frac{\Delta x/2}{K_j}}$$

By eliminating Δx, it obtained equation (5.6)

4. QUADRATIC STOCHASTIC PROGRAM MODELLING

If $\omega = 1,...\Omega$ shows the result of a set of hydraulic conductivity (K) values on the area, then for every K value obtained different $F\omega$ matrix. By seeing the second row of the equation (5.5), it is clearly that for certain value of decision variable w, for every result of w, it obtained the different top part and different constant in vector f, so that h and f are should be replaced by h_ω and f_ω. By calculating the violation v_ω from the constraint of gradient opportunity, and the penalization results in the quadratic linear stochastic program as follow :

$$\min \mathrm{E}\{ \mathrm{Bw}\,(\mathrm{s}-\mathrm{h_w}) + \mathrm{ep}\,(\mathrm{v_w}) - \alpha\,(\mathrm{e\ w})^2\} \tag{3.9}$$

with a constraint :

$$F_\omega h_\omega = w - f_\omega$$

$$V_\omega = h_\omega^{\ n} - h_\omega^{\ out}$$

$$0 \le w \le w^{\ maks}$$

Where :

V_ω expressing the vector of violation 1 in every part of catchement curve.
$\rho\ (v_\omega)$ expressing the penalty for violation V_ω

The form of objective function is the minimization of price expectation. The model still contains random parameter ω. In order to solve it, the stochastic program model is transformed into an equivalent deterministic mode. In this problem, head is a liner function for the pumping rate h_ω which can be solved in ω, as follow:

$$h_\omega = F_\omega^{-1}\,[w-f_\omega] \tag{3.10}$$

substituting (5.10) into (5.9) will obtain the following model without any variable, if:

$$\min \mathrm{E}\{\mathrm{B}_\omega(\mathrm{s} - \mathrm{F}_\omega^{-1}[w - \mathrm{f}_\omega \mathrm{l}] + \rho\,(\mathrm{v}_\omega) - \alpha\,\mathrm{w})^2\}$$

With a constraint

$V_\omega = G_\omega(W f_\omega)$

$0 \leq w \leq w^{maka}$

where Gw = $[F_\omega^{-1}]^{1n} - [F_\omega^{-1}]^{out}$ (3.11)

(Notation: violation is only related to certain head, which are h_ω^{in} and h_ω^{out} . So that, in order to calculate mistake in (5.11), it only requires certain row from F_ω^{-1}, expressed as $[F_\omega^{-1}]$in and $[F_\omega^{-1}]^{in}$. If there is N element and gradient calculation in point 1, F_ω^{-1} has a size of N x N and $[F_\omega^{-1}]^{in}$ and $[F_\omega^{-1}]^{out}$ is l x N)

If every realization of direction parameter ω occurred with probability π_ω, the form of expectation E{ . }, can be written as:

$$\sum_\omega n_\omega \left(Bw(s - F_\omega^1[w - f_\omega]) + p(v_\omega)\right) - \alpha \ w^2$$

Thus, model (5.9) can be written into an equivalent deterministic model as

$$\sum_\omega n_\omega \left(Bw(s - F_\omega^1[w - f_\omega]) + p(v_\omega)\right) - \alpha \ w^2$$

With a constraint

$V\omega = G\omega (w - f\omega)$

$0 \leq w \leq w$

Now, the form of optimization model is a quadratic optimization program with the objective function as a quadratic function and linear constraints function. The decision variable in this model is the pumping rate w and it can be viewed as the dependent variable. Thus this model can be solved by quadratic programming method.

5. MANAGEMENT OF GROUNDWATER QUALITY THROUGH GRADIENT AND CONCENTRATION CONTROL

In the previous section, it has been examined for the problems regarding the management of the groundwater contamination area. There are a number of additional groundwater quality management issues which must be addressed. It includes on how to manage the flow entering and surrounding the contaminated area, so that it will sustainably able to supply groundwater that can be utilized for a number of existing wells. This problem is the same as the problem in the previous section, that the decision variable still includes pumping and recharging speed for the existing wells. The main difficulty, in this case, is also to consider the heterogeneity of the soil. This problem is also modeled by using review. The cost of this process will greatly depend not only on the head resulted from the pumping plan voters but also on the concentration resulted from this plan. For example, if it needs to manage the pumping rate in the supplying and controlling wells in order to maintain the groundwater quality in the supplying wells, it should meet the applicable standards. By controlling the pumping rate, it can control the water and rate of the contaminant, so that it is able to:

- Divert the contamination around the supplying wells, or
- Eliminate and manage the contaminated water before reaching the supplying wells.

The purpose is to meet the standards given, so that the minimum costs that include the pumping cost in all wells and disposals or water handling costs in the controlling wells, it can also involve the benefits of the pumped water, if necessary. The reviewing cost includes the cost for water treatment at supplying wells if it does not meet the standards given and the cost of pumping management is too high. Here, it can formulate the difference equation to relate the pumping rate towards concentration. Then, the finite difference equation can be developed as a constraint in stochastic program, as well as to the finite difference equation for contamination issues. However, after the concentration equation is inserted, the optimization problem will not meet the form of stochastic programming method developed in this paper, so that the stochastic optimization problem is not realized for a realistic size. In the next section, the formulation of this problem as a quadratic stochastic program (with the quadratic purpose and quadratic limitation) is proposed. Then. it will be shown why this problem is not in accordance with the method developed in this paper. In the last section, the problem solving method will be proposed.

5.1. Modelling with the Existence of Pollutant Concentration

It is assumed that the main processes of setting the pollutant flux transportation are advection and dispersion. Advection is the movement of contaminants transported throughout the flowing water. The equation for advection is:

$$P_a = Qc = c(-K_x \frac{\delta h}{\delta x} A)$$

Where :

P_a = pollutant flux related to advection (miligram./second)

c = concentration (miligram/.meter^3)

Q = water discharge (meter^3/second)

K_x = hydraulic conductivity in direction x (meter/second)

h = head (meter)

A = section area from the border (meter^2) and

x = length (meter)

Note: contaminant concentration through this discussion is assumed in milligram per cubic meter of water. Dispersion is the movement of pollutants due to molecular diffusion and mechanical mixing during advection. Mechanical mixing results in the reduction of contaminant due to the different microscopic path taken by the water and contaminant molecules. Fick's first law specifies that the dispersion in the border is proportional to the concentration difference on the border or :

$$P_d = -D_x \eta \frac{\partial c}{\partial x} A$$

Where :

P_d = pollutant flux related to dispersion (miligram/meter^2/second)

η = soil porosity (-) and

D_x = dispersion coefficient in direction x (meter^2/second)

By combining this equation with mass equilibrium will result in partial differential equation for the two-dimensional contaminant flux in anisotropic media:

$$\frac{\partial}{\partial x}\left(D_x\eta b\frac{\partial c}{\partial x}\right)+\frac{\partial}{\partial x}\left(cK_x b\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(D_y\eta b\frac{\partial c}{\partial y}\right)+\frac{\partial}{\partial y}\left(cK_y b\frac{\partial h}{\partial y}\right)\pm\delta c=0$$

Where:

x,y = width, length (meter)

b = depth of aquifer (meter), and

δ = input/output point from water (meter/second)

In order to implement this equation into the optimization, this equation is discreted with regard of the derivative form as the limit of the difference taken on the finite elements. The flux occurs across the element limit, so that it requires the concentration value in the discreted equation in the limit. The concentration in the limit of the elements is approached as the average concentration. As well as the substance flux in the box, the mass of contaminant enters the element (i,j) from element (i + 1, j) from the advection in the rate:

$$-K_x\frac{(h_{i,j}-h_{i+1,j})}{\Delta x}b\,\Delta y\quad\frac{(c_{i+1,j}+c_{i,j})}{2}$$

The same equation applies for the advection flux from the elements *(i-1,j), (i,j+1) and (i,j-1).*

The mass enters the box (i,j) from the wells with a rate ; $-W_{ij}C_{ij}$

Where :

$W_{i,j}$ = pumping rate from elements *i, j (*meter^2/second)

Mass enters from the element *(i+1,j)* since the dispersion is in the rate of:

$$-D_x\eta\frac{(c_{i,j}-c_{i+1,j})}{\Delta x}b\,\Delta y$$

The same equation applies for the dispersion flux from the elements *(i-1,j*), (,*j+1*) and *(i,j-1*). From the mass conservation, for ever element (*i,j*) the finite difference equation is obtained for the contaminant flux in a constant condition:

$$-D_x\eta\frac{(c_{i,j}-c_{i+1,j})}{\Delta x}b\,\Delta y-D_x\eta\frac{(c_{i,j}-c_{i-1,j})}{\Delta x}b\,\Delta y-D_y\eta\frac{(c_{i,j}-c_{i,j+1})}{\Delta y}b\,\Delta x$$

$$-D_y\eta\frac{(c_{i,j}-c_{i,j-1})}{\Delta y}b\,\Delta x-K_x\frac{(h_{i,j}-h_{i+1,j})}{\Delta x}b\,\Delta y\quad\frac{(c_{i+1,j}+c_{i,j})}{2}$$

$$-K_x\frac{(h_{i,j}-h_{i-1,j})}{\Delta x}b\,\Delta y.\quad\frac{(c_{i-1,j}+c_{i,j})}{2}\quad-K_x\frac{(h_{i,j}-h_{i,j+1})}{\Delta x}b\,\Delta y.\quad\frac{(c_{i,j+1}+c_{i,j})}{2}$$

$$-K_x\frac{(h_{i,j}-h_{i,j-1})}{\Delta x}b\,\Delta y.\quad\frac{(c_{i,j-1}+c_{i,j})}{2}=w_{i,j}c_{i,j}$$

This equation has a liner rate for concentration variable and quadratic rate that includes head multiplied by concentration and pumping rate multiplied by concentration. For this model management problem, it inserts the opportunity constraint into pollutant concentration in the supplying wells, as follow :

$$\rho\{\,wi\sum c_{ij\leq}c_{ij}^{\ maks}\}\geq\alpha_i\ \forall i$$

Gradient constraint is not explicitly involved in this problem, but it is necessary to ensure that the location is not decomposed or inundated with water, so that it is important to involve constraint.

$$0\leq h_{i,j}\leq h_{ij}^{maks}\ \forall i,\ \forall j$$

The form of deterministic objective function is still minimizing the costs including pumping energy cost reduced by benefits derived from the pumped water or

$$\min Bw\,(s - h) - \alpha\, w^2$$

where :

B = daily cost coefficient for pumping (IDR/meter^3/meter of height) x 864.000 second/day.

s = depth from surface to the floor of aquifer (meter)

α = coefficient of benefit for water (IDR/meter^3) ^{2})

It can also involve the in the repair cost, which will be associated with the concentration of contaminants in the water and the total amount of treated water. Head and concentration variables are associated with pumping rate through the finite difference equation in the optimization. The flow equation can be written in the form of matrix as follow :

$$Fh = w - f$$

Where :

F = matrix N x N from the coefficient of head

h = N vector of head variable

w = N vector for pumping variable

f = N vector of constant

Each of these flow equations contains its own matrix, which associates the head with concentration variables.

Expressing :

$g^D_{i,j}$ = N vector of coefficients (including dispersion parameter)

$g_{i,j}$ = N vector of constant, and

$G_{i,j}$ = matrix N x N which associates the main with concentration

Then, for every element (i,j) there is a flow equation in the following form:

$$-c\, g^D_{i,j} - h\, G_{i,j} c - g_{i,j} = w_{i,j}\, C_{i,j}$$

Now, the model of opportunity constraint optimization can be written as:

$$Bw\,(s - h) - \alpha\, w^2,$$

with a constraint;

$$F\,h = w - f$$

$$-c\, g^D_{i,j} - h\, G_{i,j} c - g_{i,j} = w_{i,j}\, C_{i,j} \forall i, \forall j$$

$$\rho\{ wi \sum c_{ij \leq} c_{i\,j}^{\ maks} \} \geq \alpha_i \ \forall i$$

$$0 \leq h \leq h^{maks}$$

$$0 \leq w \leq w^{maks}$$

The form of optimization with the opportunity constraint is changed by still in regard to the conductivity – *k*, as the uncertain parameter, thus it is inserted in the objective function for price component as a result of violations of head and conductivity. Thus, there is a model of:

$$\text{Min } \pi_{w} \left(B_\omega \left(S\, h_\omega \right) + \rho_1 \left(v^h_\omega \right) + \rho_2 \left(v^c_\omega \right) - \alpha\, w^2 \right)$$

With a constraint

$$F_\omega\, h_\omega = W - f_\omega$$

$$c\, g^D_{i,j} - h_\omega\, Gc_\omega - g_{i,j\omega} = w_{i,j}\, C_{i,j\,\omega} \ \forall i, \forall j$$

$$v^h_\omega = h_\omega - h^{maks} \ \forall_\omega$$

$$vc_\omega = c_\omega - c^{\ maks} \ \forall_\omega$$

$$h_\omega \geq 0,\ C_\omega \geq 0 \ \forall_\omega$$

$$0 \leq w \leq w^{maks}$$

In order to use the model as a management tool, a discrete realization should be built to characterize the continuous distribution. For a problem with a small number of random variables, in which each variable can be presented by a small number of complete distribution values that can be presented by forming a realization for each combination of random results. However, since the number of random variables and variations in this problem is computationally infeasible to form a complete set of realizations that characterize the distribution, also, if the establishment of a complete set of realizations can be conducted, the problem in the results of optimization have a very large dimensions. Therefore, the Monte Carlo approach is used in order to obtain a sample from this distribution. The number of variables in this problem is reduced by exploring the fact that the value h_w is determined from the flow constraint after the value ω_i. Matrix - F_w is positive-definite, so, $h_w = F^{-1}_w\,(w - f)$. This substitution into the model obtain a form of

$$\text{Min } \pi_{\omega} \left(B_\omega \left(S - F_\omega^{-1}(w - f) \right) + \rho_1 \left(V^h_\omega \right) + \rho_2 \left(V^{-c}_w \right) \right) - \square\, w^2 \quad (3.12)$$

With a constraint

$$V^h_\omega = G_\omega\,(w - f) \qquad (3.13)$$

$$c\, g^D_{i,j} - F_\omega^{-1}(w - f)\, C - g_{i,j} = w_{i,j}\, C_{i,j\,\omega} \ \forall i, \forall j \qquad (3.14)$$

$$V^c_w = c_\omega - c^{\ maks} \ \forall_\omega \qquad (3.15)$$

where

$$G_\omega = [F_\omega^{-1}]^{msh} - [F_\omega^{-1}]^{luar}$$

(Note, in order to calculate violation $\mathbf{V}^h_\omega$, it only requires a certain row from matrix F_ω^{-1}, expressed as $[F_\omega^{-1}]^{msh}$ dan $[F_\omega^{-1}]^{luar}$.

5.2. Managerial Description

As mentioned earlier that, theoretically, the maximum groundwater uptake is actually difficult to implement due to the uncertain characteristic of groundwater. Some constraints which will affect the acquisition of groundwater uptake include engineering, environmental and economic constraints, including minimizing the operating costs (Lubis *et al.*, 2016; Muda *et al.*, 2016; Sirojuzilam *et al.*, 2016). Therefore, the managerial description of the stochastic model helps to complete it using the optimization method approach. This method works by the principle of optimizing the objective function towards the constraints faced. The optimization can be in the form of benefit maximization or costs minimization, as follows, in the objective function of Equation (3.13), the first factor expresses about minimizing the pumping rate (economic constraints). It shows the importance of controlling the groundwater pumping. The following factor ρ_1 (V^h_ω) from equation (3.12), is a violation against the hydraulic head. The purpose of this factor is to make the hydraulic head within a range of specification value of the hydraulic head. The following factor from equation (3.12), which is ρ_2 (V^c_w), expresses about the violation on groundwater quality (environmental constraint). It means that the model can control the groundwater quality or pollutant concentration in the aquifer is still in the preset and sustainable range. The well-pumped water can also be used for other purposes (if any). The advantage of this side-use is expressed by factor □w^2. The model included in equations (3.12) and (3.15) is the model containing uncertainty, so that it can be assured that the pumping plan will be resulted in: $h_\omega^{msh} - h_\omega^{luar} \leq 0$

Therefore, it defines a formulation expresses how many plans violated for every realization ω (technical constraint). This formulation is expressed in equation (3.12). similarly, for the pollutant concentration, equation (3.15) formulates on how much the violation can occur towards the pollutant concentration, so that it can still meet the standard quality. Equation (3.14) is the equation of flow in which the pollutan concentration variable is included. The model expressed in equation (3.12) until equation (3.15) is the model of quadratic stochastic program in the variable pumping rate w and pollutant concentration c. The quadratic form arises in the objective function and equation of flow in the control. The optimization problems faced have a very big scale which result in difficulties in using the standard optimization method. Theoretically, the optimization problems with a large number of variables can be reduced by using a dual form. Once the dual form built, the Langrange function is taken from the dual model. However, such a process is too technical, especially when it is associated with the environmental programs. Therefore, the overcome on this difficulty is solved in a simulation by firstly determining a value for pumping variable, so that the pollutant concentration variable will be concerned.

6. CONCLUSIONS

Based on the analysis and discussion from the study of stochastic model towards groundwater, the conclusions are as follows:

1. The stochastic program model focuses on the method and formulation combining the uncertainty explicitly, both for the quantity and quality of groundwater.

2. The stochastic program model built helps the management for controlling the quality of groundwater, both for prevention and management, through optimization approach by optimizing the *objective function* on the constraints, such as minimizing operating costs.

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