Quality Management of Groundwater Resources in Aghala

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Expanded Abstract

Introduction

Water quality refers to the chemical, physical and biological characteristics of water. It is a measure of the condition of water relative to the requirements of one or more biotic species and or to any human need or purpose. It is most frequently used by reference to a set of standards against which compliance can be assessed. The most common standards used to assess water quality are related to health of ecosystems, safety of human contact and drinking water. Some studies have focused only on chlorides alone without considering the nitrates. Reports of harmful effects for human health have been reported only for nitrates. Therefore, reducing nitrates level below the specifications of WHO may yield ‘‘healthy’’ water. On the other hand, high levels of chlorides may render the water undrinkable due to its salinity. In other words, focusing only on chlorides would not solve the problem since people would rather drink non-salty water than water with high level of nitrates which is proved to be dangerous in terms of health. This research considers both nitrates and chlorides using goal programming, which provides a way of striving toward more than one objective function simultaneously. It seeks to establish a specific numeric goal for each of the objectives, and then seeks for a solution that minimizes the weighted sum of deviations of objective functions from their corresponding goals. The purpose of this study is to achieve an optimal combination for drinking water according to the World Health Organization standards and the maximum desirable standard of groundwater in the study area of Aghala using weighted goal programming model.

Goal programming formulation: Assuming that we have (n) wells, the amount of chlorides in the i^{th} well is (CL_i) mg/l and the amount of nitrates is (N_i) mg/l. Moreover, the i^{th} well can discharge the amount of S_i (m^3/ year) at a given operational level. Since the levels of nitrates and chlorides are high in some wells and low in others, it is known that mixing of certain proportions from given wells will help achieve the required objective. It is also assumed that there are (m) reservoirs (destinations) each of which can accommodate a certain amount of water that satisfies the demand of the specific region. Let (D_j) represent the demand required for reservoir (j) and (X_{ij})the amount of water (m^3/year) discharged from well (i) to reservoir (j). The maximum allowable amount of chlorides per liter (WHO standard) is (CL_{max}), while the maximum allowable amount of nitrates according to WHO standards is (N_{max}). Therefore, the writers formulated a goal programming model of optimal water allocation in Aghala region as follows (All the symbols are difided in the first table of the text):

a) Objective function

$$\text{Min} \ \sum_{j=1}^{j=6} p_{jCL} + \sum_{j=1}^{j=6} p_{jN}$$

b) Well capacity constraints

$$\sum_{j \in Ur^{FW} \cup Ar^{FW}} X_{ij} \le S_i, \qquad \forall i \in W$$

c) Reservoirs capacity and demand constraints

$$X_{ij} \ge TD_j^{D^{FAr}} \qquad \forall i \in AR, \ \ \forall j \in D^{FAr}$$

$$X_{ij} \ge TD_j^{D^{FUr}} \qquad \forall i \in Ur, \ \ \forall j \in D^{FUr}$$

d) Balance constraint amoang the nodes

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$$\sum_{i\in Ur^{To:W}} X_{ij} - \sum_{i\in D^{FArFUr}} X_{ij} = 0 \quad \forall j \in Ar^{FUr}$$

$$\sum_{i\in W^{TAr}} X_{ij} - \sum_{i\in D^{FArFW}} X_{ji} = 0, \quad \forall j \in Ar^{FW}$$

$$\sum_{i\in Ur^{FW}} X_{ij} - \sum_{i\in Ar^{FUr} \cup D^{FUr}} X_{ij} = 0 \qquad \forall j \in Ur^{FUrFW}$$

e) Groundwater reservoirs capacity

$$\sum_{i\in W} X_{ij} \le CUr_j^{FW} \quad \forall j \in Ur^{FW}$$

$$\sum_{i\in Ur^{FW}} X_{ij} \le CUr_j^{FUrFW} \quad \forall j \in Ur^{FW}$$

f) Air reservoirs capacity

$$\sum_{i\in W^{TUr}} X_{ij} \le CAr_j^{FW} \quad \forall j \in Ur^{FW}$$

$$\sum_{i\in Ur} X_{ij} \le CAr_j^{FUr} \quad \forall j \in Ar^{FUr})$$

g) Chlorides balance constraints

$$\sum_{i\in W^{ToUr}} X_{ij} CL_i - \sum_{i\in W^{TUr}} X_{ij} CL_{Max} + n_{jCL} - p_{jCL} = 0 \quad \forall j \in Ar^{FW}$$

h) Nitrates balance constraints

$$\sum_{i\in W^{TUr}} X_{ij} N_i - \sum_{i\in W^{TUr}} X_{ij} N_{Max} + n_{jN} - p_{jN} = 0 \qquad \forall j \in Ar^{FW}$$

i) All variables are ≥0.

The set of constraints in Eq. (b) guarantees that the total amount of the discharged water from certain wells does not exceed their capacity. While the constraints in Eq. (c) require that the amount of water supplied to a given reservoir from given wells does not exceed the capacity of that reservoir. Eq. (d) represents balance constraint among the nodes. Eqs. (e) and (f), respectively, represent groundwater and air reservoir capacity in the case study area. Eqs. (g) and (h), respectively, also represent the chlorides and nitrates balance before and after mixing. The assumption in the (chlorides/nitrates) balance constraints is that there are no reactions due to water mixing which may decrease the amounts of both elements under study. Therefore, this assumption, though approximate, guarantees that the levels of nitrates and chlorides can always be equal to or less than the amount determined by World Health Organization (WHO). Moreover, it is assumed that the system experiences no loss of nitrates as shown by preliminary experiments. In other words, the results will always be on the conservative side. Solution of the above model results in obtaining combination of wells and the amounts of water from each well.

Results and Discussion

This research describes a mathematic programming model dealing with achieving an optimum mixture of water from different underground wells, each having different amounts of nitrates and chlorides. The amounts of chlorides and nitrates in each of the wells may be higher or lower than the World Health Organization (WHO) standards. Therefore, the optimum mixture would be the one that meets WHO standard which is 250 mg/l for chlorides and 50 mg/l for nitrates. A goal programming model was developed to identify the combination of wells along with the amounts of water from each well that upon mixing would result in minimizing the deviation of the amounts of chlorides and nitrates from the standards of WHO. Application of the proposed model to the real case example (Aghala region) demonstrates the reliability and flexibility of the model. The most important results of this study showed that according to the WHO standards and the difference elements of each the wells, water withdrawal of the combination of the wells is an appropriate way to allocation of reservoir water. The purpose of this study is to achieve an optimal combination for drinking water according to the WHO standards and the maximum desirable standards of groundwater in the Aghala region using weighted goal programming model. In this region, there are 4 groundwater wells, 6 air reservoir and 2 ground reservoir (to save and transport water to the air reservoir) to supply drinking water for 17 villages. The results of this study also showed that the amount of water withdrawal in the wells in the WHO standard and maximum desirable standard is different. The most water withdrawal in the condition of WHO standards and maximum acceptable standard is belonging to well number 3 and the least withdrawal amount is belonging to well number 1 due to high concentration of nitrate in this well. According to the results in the maximum acceptable standard, there was not water withdrawal of well number 3 because of the high concentration of nitrate in this well. Therefore, according to the WHO standards and the difference elements of each the wells, water withdrawal of the combination of the wells is recommended. Finally, wells with levels of nitrates and chlorides that are highly intolerable can be used for drinking purposes upon mixing.

Keywords: chloride, goal programming, groundwater, nitrate, water quality.