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ARSENIC SOLUTE TRANSPORT FROM HOLOCENE TO PLEISTOCENE AQUIFER IN NAM DU WELL FIELD, HANOI

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Abstract

In many of the large Quaternary delta systems in Southeast Asia, groundwater in the shallow Holocene aquifer contains elevated concentrations of arsenic (As). In anoxic sediments, reduction of As bearing Fe-oxides by organic matter oxidization, releases As to the groundwater. Therefore, from 1990s, most of water supply to Hanoi, in Red River delta plain, has been abstracted in the deeper Pleistocene aquifer. There is hydraulic correlation between Holocene and Pleistocene aquifers, especially in the area that close to river, the pumping has generated a leakage of water from the river into the adjacent Holocene aquifer and further into the Pleistocene aquifer. The Nam Du well field is the one of the largest water plants in Hanoi, with a daily pumping of 60.000 m^3. We applied a 3D groundwater flow modeling, coupled with advection, dispersion and reaction solute transport modeling, to simulate the As mobilization in this study area. The results show that sorption isotherm in represent of retardation factor is the one of importance mechanisms controlling As mobilization from Holocene to Pleistocene aquifer. The results also show that retardation factor of Pleistocene aquifer ranges from 2 to 20 and much lower than results of laboratory sorption experiment in sediments which were taken from this area as the state of sorption - desorption at the site may not be reached equilibrium as in the laboratory. In flooding season river water level is raised up enough for gravitational flow and it can be a source of recharge to groundwater. Therefore, a line of injection wells close to river bank which may be constructed as artificial recharge will reduce the As concentration at abstraction wells in coming years.

Keywords: Holocene aquifer; Pleistocene aquifer; Red River delta; Nam Du well

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1. Introduction

Hanoi city is the capital of Vietnam and located in Red River side. Most of water supply for domestic and industrial use comes from well fields located in and around city. More than 80% volume of water supply comes from very productive Pleistocene aquifer (qp: qp1 and qp2) which is underlying less productive Holocene aquifer (qh) and an aquitard layer in between [5]. Consequently, groundwater abstraction has caused some problems in which contamination of qp aquifer by leakage pollutants from qh aquifer is one of the most concern

problems as it threatens to quality of supply water [11].

As is the one of pollutants can be easily move in groundwater under anoxic condition [14]. In many of large Quaternary delta systems like Red River delta plain, the groundwater in the upper qh aquifer contain elevated concentrations of As [1, 3]. In anoxic sediments, the reduction process of As bearing Fe-oxides caused by organic matter oxidization is releasing As in to groundwater [2, 12, 14].

Nam Du well field is located in South East Hanoi, it is one of the largest water plants in Hanoi city with daily pumping up to 60,000m^3 (see Fig. 1). An bank infiltration of Red River water is pumped from 18 abstraction wells in the qp aquifer, located parallel to the river at 500 m with pumping rate from 2,500m^3 to 4,000m^3/ day [11]. In the strip along Red River, there is absent of the aquitard between qh and qp aquifer then water from Red River can infiltrate easily into abstraction wells by moving through qh aquifer. In study area, 16 investigation boreholes were drilled into qh and qp aquifers. In which ND_H6 is the abstraction well, ND_01-11 was drilled close to river bank with different in screen depth and 4 other boreholes were drilled along a flow path of water from river toward to ND_H6 in qp aquifer (see Fig. 1 and 3). As concentration of groundwater from investigation boreholes is quite high, more than 110µg/L in qh aquifer and more than 50µg/L in qp aquifer. Consequently, a question was raised as Is there As solute transport from qh aquifer to qp aquifer under affected of groundwater exploitation in this area and increase As concentration in both qp aquifer and abstraction wells. As solute transport modeling was used to assess mobilization mechanism and effect of several factor to this transport process.

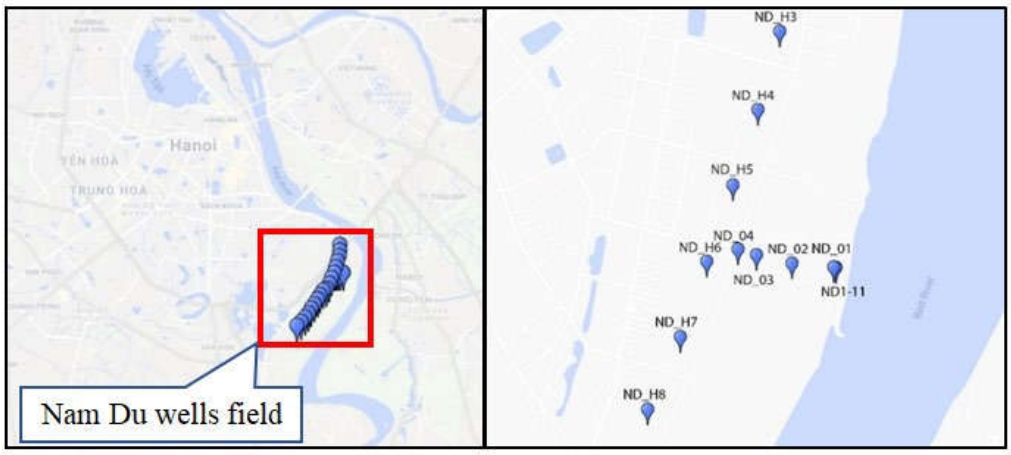


Figure 1: A map of the inner Hanoi city and the Nam Du study area

2. Geology and hydrogeology setting

2.1. Geology

The geological formations in Nam Du area are mainly of Quaternary and Pliocene age. In general, most of the formations have the thickness increases from NW to SE of Red River Delta. The formation is discontinuing and absent in strip along of Red River [10].

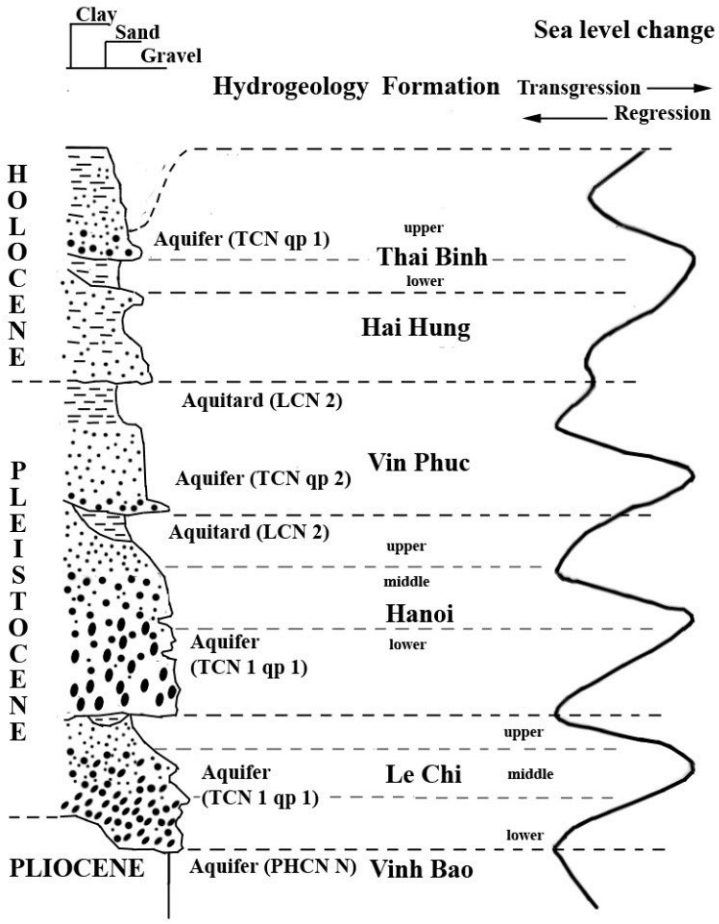


Figure 2: A Geological cross section presents s formation names in correlation withsea level change, aquifers, materials and time periods [4, 6, 10].

2.2. Hydrogeology

The hydrogeological composition of Nam Du area has been well established [8]. There are 6 major hydrogeological units could be distinguished [9]:

- Aquifer in Holocene sediments (qh)

- Aquiclude in Pleistocene - Holocene sediments

- Aquifers in upper Pleistocene sediments (qp2)

- Aquiclude in middle-upper Pleistocene sediments

- Aquifer in lower-upper Pleistocene sediments (qp1)

- Water bearing formations in Neogene sediments

3. Arsenic solute transport model: setup, results and discussion

3.1. Conceptual model

Conceptual model in Nam Du area was based on hydrogeology setting and described as water from Red River infiltrate through river bed, qh aquifer, qp aquifer and finally pumps out by abstraction well ND_H6. During flowing process inside qh aquifer, water brought As is released from qh aquifer [12, 16]. When water move through qp aquifer, part of As was absorbed by sediments, other part continued to move up to abstraction well as presented in Fig. 3

3.2. Groundwater flow model

Groundwater flow model was constructed based on the Red River

delta groundwater flow model by using MODFLOW code. The model consisted of 5 layers from top to down: cover layer, qh aquifer, discontinues aquitard, qp aquifer and bed rock. Domain discretization is 50 × 50 m with 96 rows and 102 columns. Data set of topologies, hydrogeology, hydrogeological parameter, meteorology data and pumping, etc.… got from previous investigation in the area and 16 investigation boreholes [9, 10]. Boundary conditions was set to simulate interaction between groundwater and Red River and outside modeling domain. Model simulation period was setup from 31 Dec 1994 to 31 Dec 2014 with 240 timesteps. Every timestep is equal a month.

Nam Du model was calibrated under both steady state and transient condition. Modeled groundwater levels were compared to observed groundwater level data at many monitoring wells. The RMS error is around 1m and modeled groundwater level is quite match with observed data.

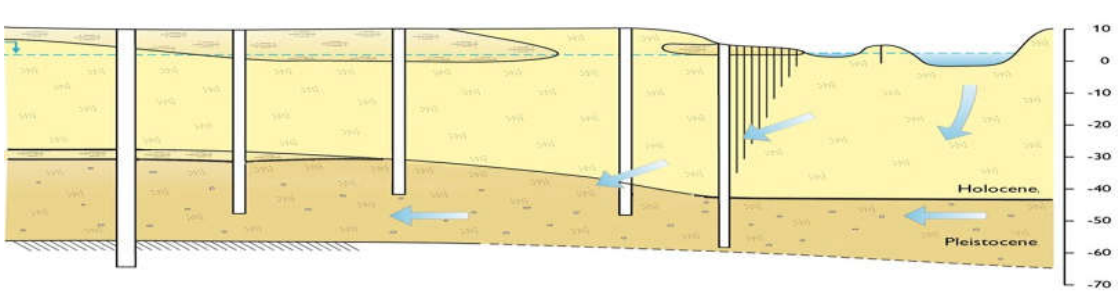


Figure 3: Conceptual model of Nam Du area

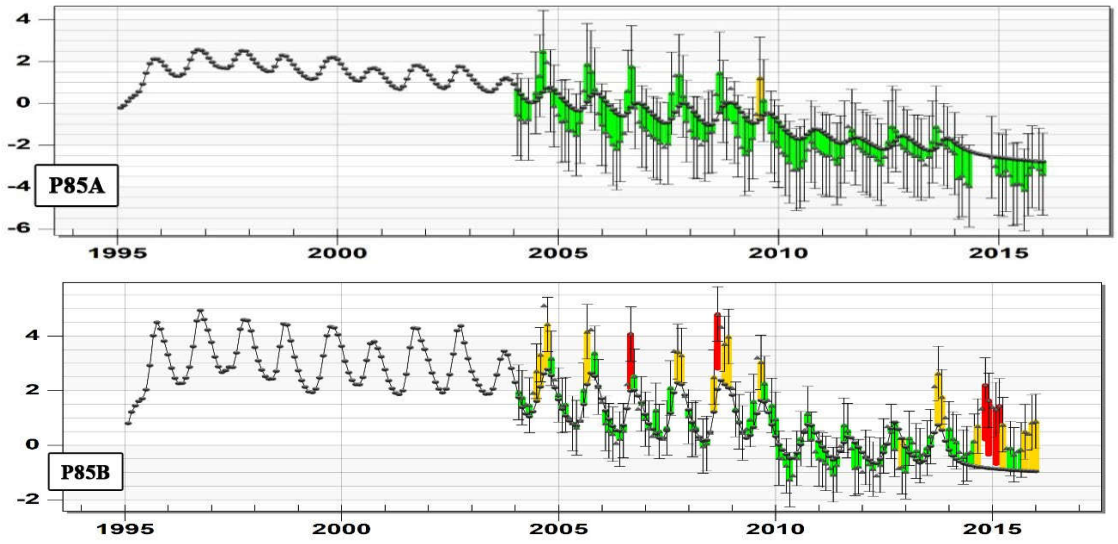


Figure 4: Comparison between modeled and observed groundwater level at monitoring wells P85 A and B. Black dots with error bar are observed ground water level. Green is best modeled matched, yellow is moderate matched, red is poor modeled matched

3.3. Arsenic solute transport model

As solute transport model in Nam Du was constructed based on above mentioned flow model. Grid of transport modeling was refined to increase resolution. Cell size of the area around investigation cross-section was reducing to 6 × 6m. Layers of flow mode was also in which qh aquifer split off 12 new layers and qp aquifer split off 6 new layers.

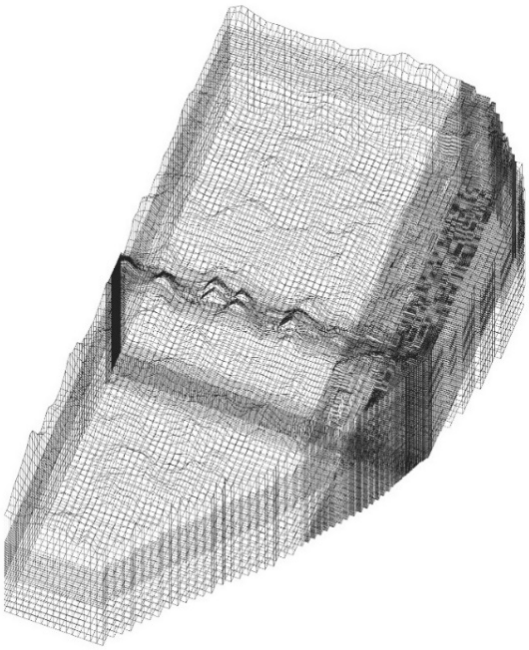


Figure 5: Refined high-resolution grid of Nam Du model

Concentration boundaries: Red River was set to constant concentration boundary with As concentration = 0.2µg/L, qh aquifer was set to constant concentration boundary which is equal to As concentration in groundwater sample at investigation boreholes in May 2010. Other positions were set using interpolation method. Chemical reaction parameter was setup as assumption of Langmuir sorption isotherm for results of sediment sorption laboratory experiment (Thi Hoa Mai, Postma et al. 2014). Value of Langmuir sorption isotherm is $K_s^{As(III)}$ = 1500L/mol and s_{tot} = 8.4µmol/g (R = 62 -1 69). Initial concentration was setup for both qh and qp aquifer based on data set of As concentration at investigation boreholes in May 2010. Transport parameters were added as same as previous study of solute transport in Hanoi area [7].

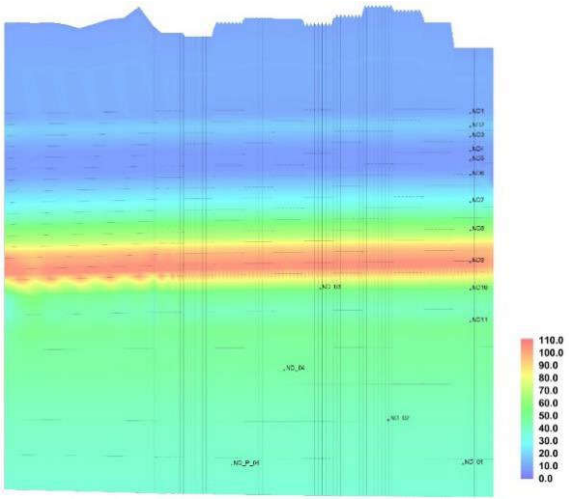
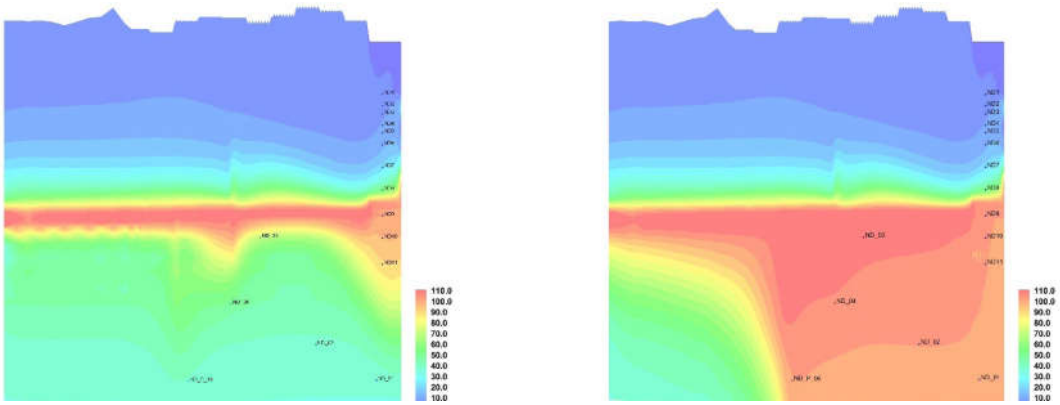


Figure 6: Initial As concentration at investigation cross-section

As solute transport model was run with period from May 2010 to 31 Dec 2014. There are several alternative assumptions were used in order to assessment the effect of sorption - desorption process and retardation factor using liner sorption isotherm. Observed As concentration of investigation boreholes used to compare with modeled As concentration (see Fig. 7; Fig. 8; Fig. 9)



a) With Langmuir sorption isotherm *b) Without Langmuir sorption isotherm*

Figure 7: Results along cross-section at 31 Dec 2013 for 2 alternative assumptions

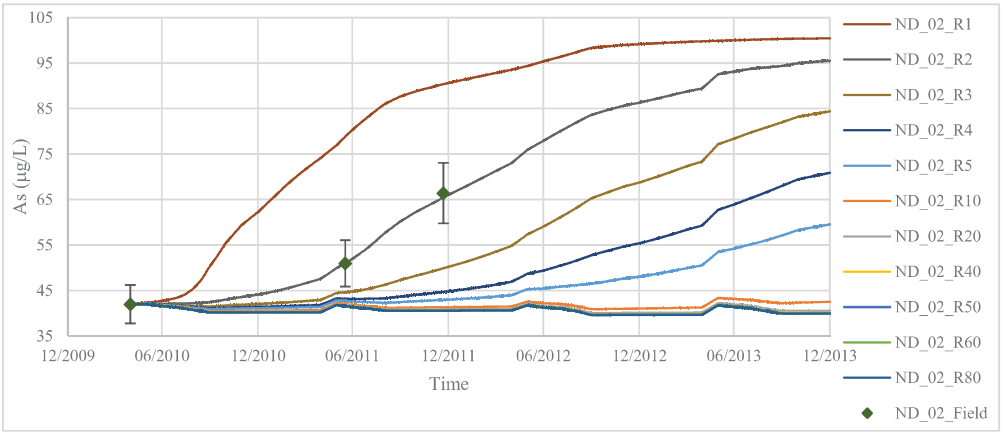


Figure 8: As concentration vs time in borehole ND_02 in depth -52m and 140m far from river bank. Colored lines presented modeled As concentration with different retardation factors. Green dots presented observed As concentration from investigation borehole

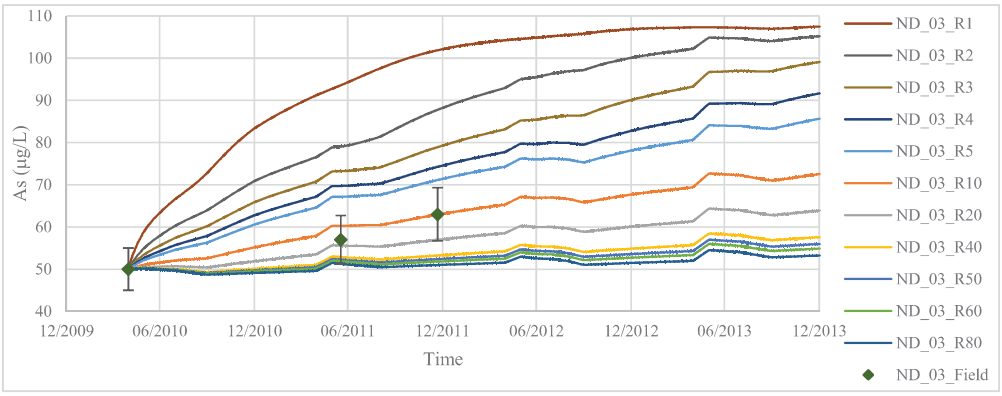


Figure 9: As concentration over time in borehole ND_03 in depth -30m and 250m far from river bank. Colored lines presented modeled As concentration with different retardation factors. Green dots presented observed As concentration from investigation borehole

The results of As solute transport model show that there are huge differences between assumptions with and without Langmuir sorption isotherm (see fig. 7). A comparison of these results with observed As concentration also shows that retardation factor is different with laboratory experiment (see Fig. 8 and 9). Based on these results we found that retardation factor varies in range from 2 to 20. This retardation factor from modeling results also is far difference from laboratory experiment R = 62 - 169. This result implies that the state of sorption - desorption at the site may not be reached equilibrium as in the laboratory and is quite similar to other study in Van Phuc area [16] and in Bangladesh [13].

3.3. Arsenic remediation by artificial recharge

As concentration at abstraction well ND - H6 computed from As solute transport model shows that without sorption As concentration could reach ~20µg/L/year. In order to reduce As concentration of abstraction wells, 2 scenarios of artificial recharge as injection wells that uses river water as water recharge source was proposed. We think that in flooding season river water level is raised up enough for gravitational flow. In scenario 1, a line of injection wells will be placed close to river bank and scenario 2, a line of injection wells will be placed far from river bank (see Fig. 10). Distance between the line of abstraction wells and a line of injection

wells is 150m and retardation factor was chosen as R = 10. Injection wells start pumping water without As at the end of 2011. Results of As concentration was extracted and show as below:

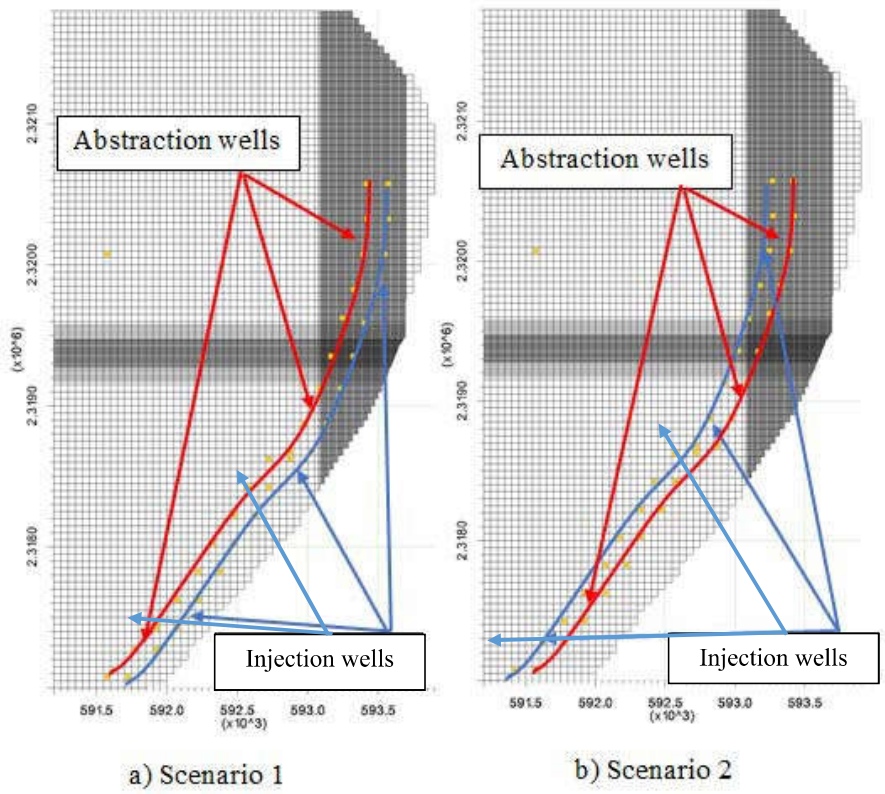


Figure 10: Location of a line of injection wells; a) Scenario 1: a line injection wells will be placed close to river bank and b) Scenario2: a line of injection wells will be placed far from river bank

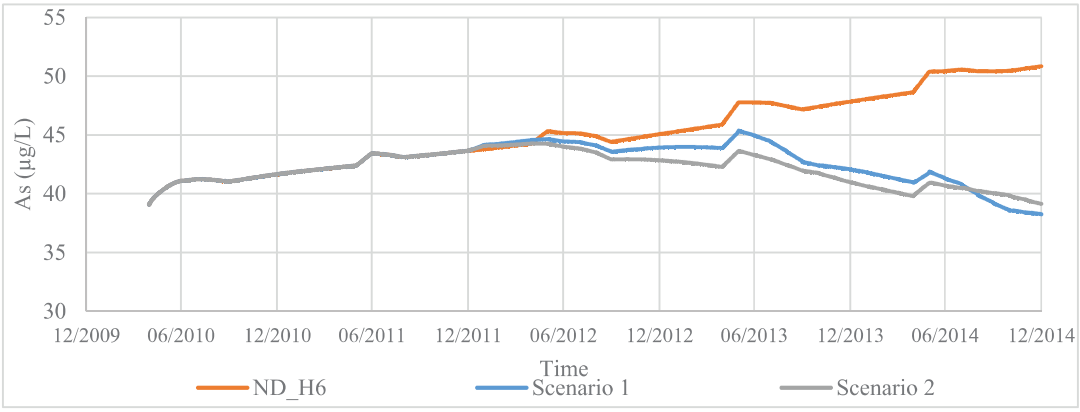


Figure 11: Predicted As concentration results of scenarios with and without artificial recharge

The results show that As concentration of artificial recharge scenarios decrease over time with the rate of 4 - 5µg/L/year. Scenarios 2 result is slightly better than the results of scenarios.

4. Conclusions and recommendations

As solute transport model shows that different results of As concentration with and without sorption process (R = 1 and R = 69 - 162). The comparison between modeled results to observed data shows that retardation factor is quite low (ranging

from 2 to 20). This retardation factor from model also is far difference from laboratory experiment that of 62 to 169. This result implies that the state of sorption - desorption at the site may not be reached equilibrium as in the laboratory and is quite similar to other study in Van Phuc area [16] and in Bangladesh [13]. In flooding season river water level is raised up enough for gravitational flow and it can be a source of recharge to groundwater. Therefore, a line of injection wells close to river bank which may be constructed as artificial recharge will reduce the As concentration at abstraction wells in coming years.

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