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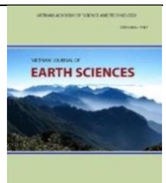

The controlling of paleo-riverbed migration on Arsenic mobilization in groundwater in the Red River Delta, Vietnam

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ABSTRACT

In the Red River Delta, the concentrations of Arsenic in groundwater of alluvial dominated systems are very high, exceeding the WHO's permissible. The correlation between the Arsenic concentrations in groundwater and the age of Holocene sediment as a key controlling groundwater Arsenic concentration in the Red River Delta has been investigated. The evolution of sediments in the Holocene is closely related to paleo-riverbed migration in the past. A combination of methods is implemented including remote sensing, multi-electrode profiling (MEP), gamma-logging, drilling, soil sample and groundwater modeling. The resul has identified the shape, sediment compositions and location of the six paleo-riverbed periods. The age of the paleo-riverbed is determined by drilling, soil sampling and optically stimulated luminescence (OSL) in the laboratory. The oldest sediments is 5.9±0.4 ka BP in Phung Thuong near the mountain, the youngest one is from 0.4÷0.6 ka BP in H-transect near the Red River and the rest of the other is around 3.5 ka BP. The modeling results by using MODFLOW and MT3D show that the dynamics of paleo-riverbeds controlling Arsenic mobilization in groundwater in the Red River Delta. When the river moved to another position, the current river position at that time was filled with younger sediments and became paleo-riverbed formation with reducing conditions, Arsenic content which was adsorbed in the previous stage then released into groundwater. Therefore, Arsenic concentration in groundwater of young Holocene sediments is higher than in older ones which elucidates that paleo-riverbed migration controls on Arsenic mobilization in groundwater in the study area.

Keywords: Paleo-riverbeds; groundwater arsenic pollution; Red River Delta; Dan Phuong - Thach That area; MODFLOW; solute transport model.

1. Introduction

Red River Delta consists of three main geological structures (Mathers & Zalasiewicz, 1999), comprising: alluvial dominated systems, tidal dominated systems and wave-dominated systems (Fig. 1). According to the Arsenic previous researches conducted by (Winkel et al., 2011) and (Larsen et al., 2008), the concentrations of the Arsenic in groundwater of tidal and wave-dominated systems are low. While the concentrations of Arsenic in groundwater of alluvial dominated

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systems are very high, it exceeds the WHO's permissible.

According to Jessen et al., 2008, there is a relationship between the amount of Arsenic and the "missing" of anion SO_4 in groundwater of geological structures were influenced by the tidal and wave impacts. The "missing" of SO_4 increased due to the precipitation of Arsenic in FeS_2. This process also demonstrates the low amount of Arsenic in the groundwater of geological structures influenced by the tidal and wave impacts. For alluvial dominated system, other research has shown the correlation between the Arsenic concentrations in groundwater and the age of Holocene sediment as a key controlling groundwater Arsenic concentration in the Red River delta (Postma et al., 2012). After the maximum transgression period, the formation of Holocene sediment was effected by the river dynamics. Specifically, paleo-riverbed migration plays an important role in the evolution of Holocene aquifer (Nghi et al., 2004).

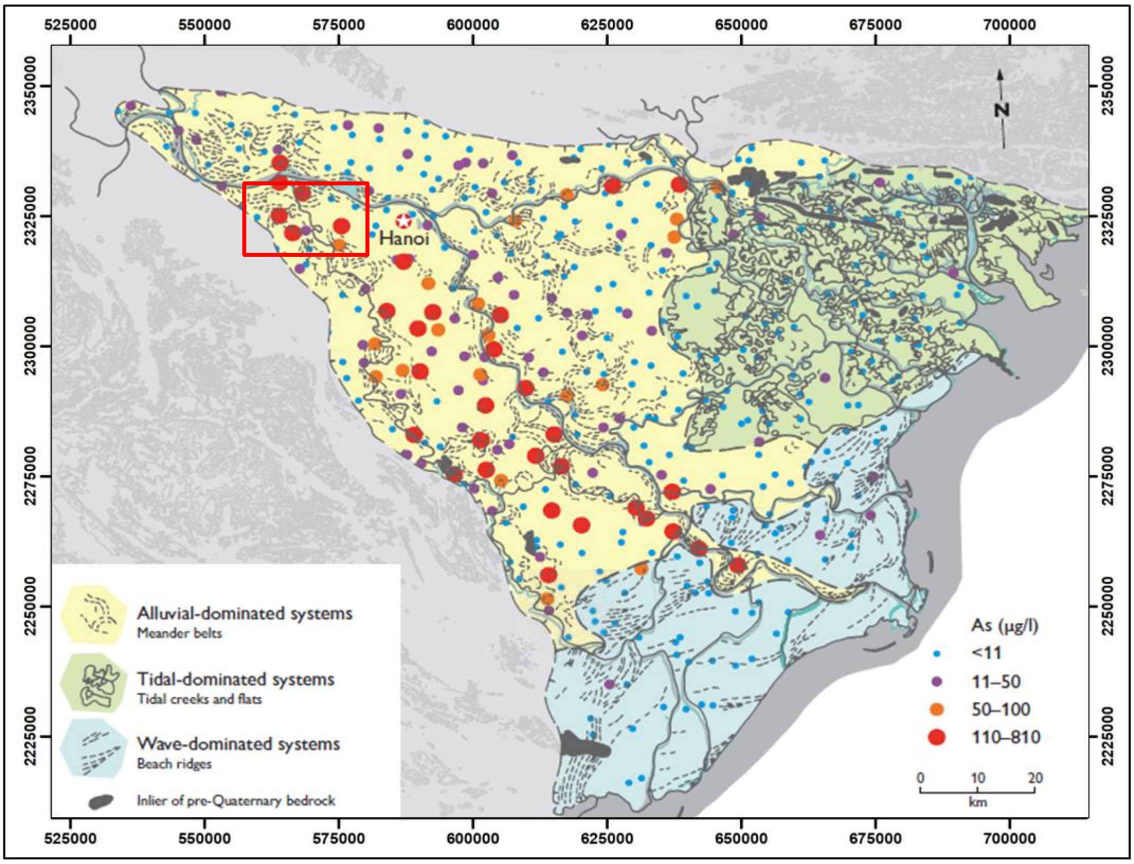

Figure 1. The relationship between geological structure and arsenic concentration in groundwater (Kazmierczak et al., 2016)

Red River and Day River run through the study area. The literature review showed that three generations of paleo-riverbeds as follows (i) the late Pleistocene riverbed distributed in the North of the Red River (districts Me Linh, Dong Anh) (ii) the early Holocene riverbed distributed in the Northwest of Hanoi (Thach That), iii) the late

Holocene riverbed that is easy to be seen along Day River (Bao et al., 2014). The concentration of Arsenic in the river water is often low due to the oxygen-rich river water. Therefore, under the high oxidation environment, Arsenic is absorbed into the sedimentary layer at the bottom of the river due to Fe-oxide precipitation. However, as rivers were filled due to time forward, the oxidizing environment was gradually transformed into a reducing type, releasing absorbed Arsenic content in Fe-oxide, resulting in the increase of Arsenic content in groundwater (Smedley and Kinniburgh, 2002) and (Posma et al., 2016; 2017).

The detailed study for analyzing the processes of the paleo-riverbed migration was carried out in Dan Phuong-Thach That area including three north-western districts of Hanoi as follows: Thach That, Phuc Tho and Dan Phuong (the red rectangle in Fig. 1). There are two main aquifers in the study area which are Holocene and Pleistocene. Groundwater in the Holocene aquifer in the study area was revealed to be highly contaminated with Arsenic (Postma et al., 2007; Larsen et al., 2008). Groundwater in the Pleistocene aquifer has also been found to be contaminated with Arsenic at an elevated concentration.

The objective of this study is to understand the evolution of sediments in the Holocene or riverbed dynamics in Dan Phuong-Thach That area which was controlling Arsenic mobilization in groundwater.

2. Methods and materials

In order to understand the evolution of sediments in the Holocene or riverbed dynamics in Dan Phuong-Thach That area, a combination of methods is implemented including remote sensing, multi-electrode profiling (MEP), gamma-logging, drilling, soil sample dating.

2.1. Remote sensing

By using remote sensing classification with the software, eCognition ver. 9.1, as a tool to perform Geographic Object-Based Image Analysis (GEOBIA), Hass & Hoffmann, 2016 have incorporated classification of values of not only spectral but also of the shape and contextual information. This is the key since the structures that need classification to imply a wide range of spectral behavior and thus the classification has to primarily be based on the distinct shape that traces of fluvial activity leaves in the landscape. The classification was performed on a Landsat 7 ETM+ scene from November 2000 recording a low flood situation. The partial results indicate that including the shape index and asymmetry of image objects is crucial to classify these present and historic fluvial structures. To fully comprehend the dynamics that have formed the alluvial plain of the Red River, temporal analysis of Corona and multiple Landsat sensors, have also been established.

Elevations of Red River Delta were derived from the recently released Shuttle Radar Topography Mission (SRTM) 1 Arc-Second data as of Feb 11–22, 2000, with the resolution of 30 m. The total number of Landsat images is 49, in which Landsat TM 1MSS (6 images); Landsat TM 2MSS (1 image); Landsat 5TM (26 images); Landsat 7ETM (12 images); Landsat 8 OLI-TIRS (3 images). In addition to the above image data, topographic maps in 1873 (made by France), the map of the Red River dike system in 1929 (made by France) was also used (Hass & Hoffmann, 2016).

2.2. Geophysical method

There are 2 geophysical methods were applied in this study: Multi-electrode profiling (MEP) and Gamma logging.

Multi-electrode profiling (MEP) is an electrical survey method. By introducing a current to the soil through two current electrodes and measuring the change in potential with two potential electrodes the resistivity of subsurface materials can be estimated. Different sediments have different resistivity values, from which geology can be interpreted. Most minerals in sediments and rocks are isolators (Kearey et al., 2002).

There are totally 4 MEP lines in this study such as BB line (10.5 km length), MEP line (12.7 km length), NL line (10.33 km length) and NT line (16.02 km length) as shown in Fig. 2, respectively. The geophysical line passed through the project's well fields, detailed as - the BB line passed through the well fields at Van Phuc, Xuan Phu, Phuc Hoa, and Cam Yen communes; - the MEP line passed through the well fields at Van Coc, Thuong Coc, Phung Thuong, and Phu Kim communes; - the NL line passed through the well fields at Phuong Dinh commune, and the NT line passed through the well fields at Tan Hoi and Phung communes (Fig. 2).

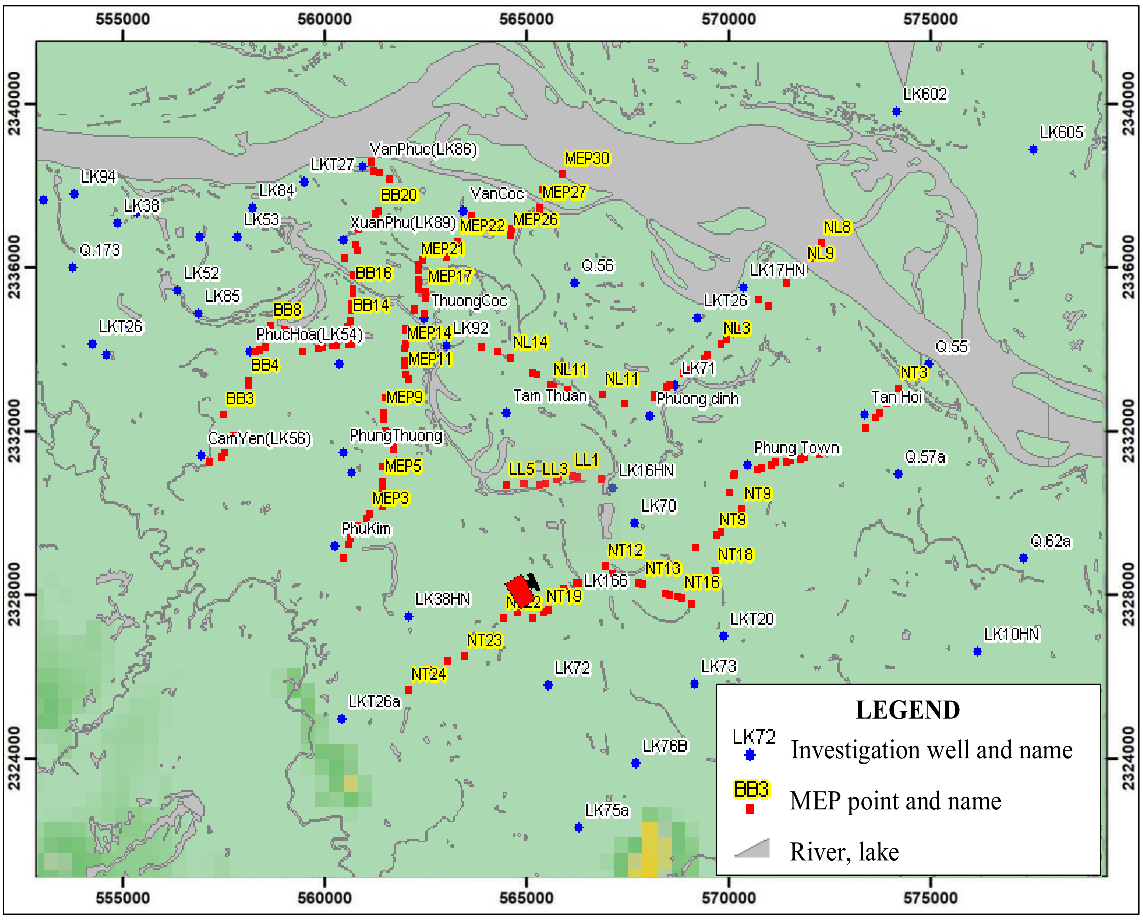

Figure 2. MEP line and investigation wells and national monitoring wells in Dan Phuong-Thach That area

The MEP line also passed through some of the previous investigation wells (Dan, 1995; Lau, 1981; Minh, 1993; Van, 1977). Therefore, the lithological material information of the wells is mainly used to interpret the results of MEP measurements for each line. The results of geological structure interpretation were compared with the results of remote sensing image interpretation. The purpose of geophysical analyzing results was to identify the paleo-river (sand body) in Holocene sediments, due to the sediment deposition period of the paleo-rivers (Fig. 3). The blank in Fig. 3 is a valid measurement result due to barriers (roads, rivers, houses, etc.).

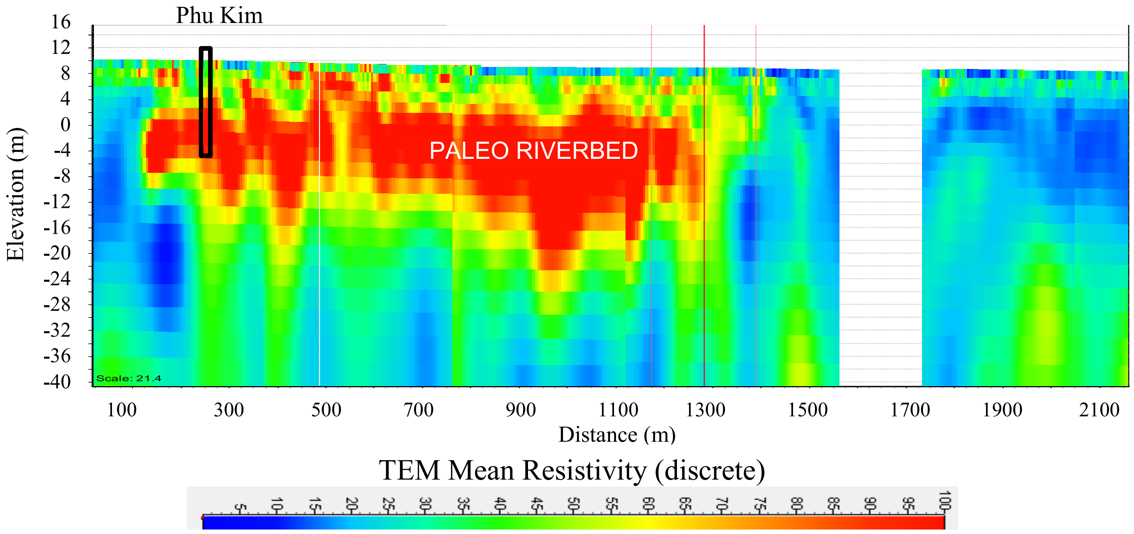

Figure 3. The MEP line, MEP 1-5 interpolated by Geoscene 3D

Gamma-logging is based on the principle that different types of sediments emit different amounts of gamma radiation. The gamma radiation is produced by the decay of radioactive elements that are naturally occurring in the sediment; the elements which contribute the most to the gamma radiation are potassium (^{40}K) from micas, feldspars, and clay minerals, and trace amounts of thorium (^{232}Th) and uranium (^{238}U) (Kearey et al., 2002). Clay by nature has a higher content of these elements than other types of sediments (Nichols, 2009). Thus, by measuring the amount of gamma radiation from sediments at different depths in a well, it is possible to recognize clay horizons. The result of gamma-logging is used to recheck or interpolated geological strata for MEP points. The gamma radiation is measured in API or CPS (counts per second). CPS translates into API in the following conversion: 1 CPS is 1.04-1.19 API. API range for clay minerals is 80-300 while quartz will give an API of zero (Rider & Kennedy). This leads to CPS ranges for clay minerals and quartz of 67-288 and zero, respectively. The total number of Gamma wells measured in this study is 31 wells, including 25 new wells in this period and 5 wells in the previous period (VietAs project, 2004–2012). Figure 4 reveals high amounts of gamma rays corresponds to clay whereas low gamma-ray amount corresponds to sand in communes Xuan Phu and Phuc Hoa.

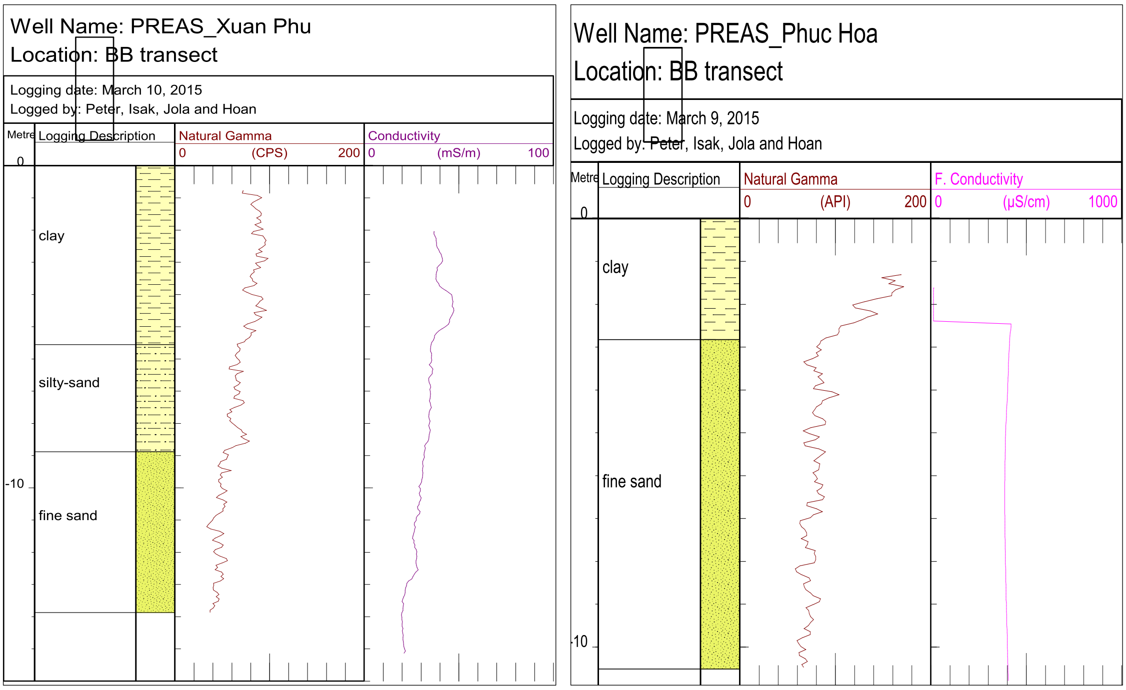

Figure 4. Gamma-ray log and sediments in communes Xuan Phu and Phuc Hoa

2.3. Methods to identify the physical composition and age of sediments

In order to determine the age of each paleo-river bed, it was necessary to take the soil sample. The soil samples were carried out at 23 wells. In order to keep the situation of sediment to be undisturbed after sampling, aquifer sediment sampling was conducted base on the piston corer method-improved from the coring tube method developed by (Kullenberg, 1947). The 3 m long sample tube was cut into 60cm long tubes. The ends of the tubes containing sediment were covered with a dedicated plastic lid, then wrapped with aluminum foil and adhesive tape to avoid the contact of sediment with oxygen air. These sediment samples were remained the situation until being analyzed (by storing in a deep freezer at -20°C and transported to a laboratory in Denmark). The age of sediment samples was identified based on the optically stimulated luminescence (OSL) analyzed by the laboratory of GEUS (Geological Survey of Denmark and Greenland) in Denmark. The method makes use of electrons trapped between the valence and conduction bands in the crystalline structure of certain minerals (most commonly quartz and feldspar). The trapping sites are imperfections of the lattice-impurities or defects. The ionizing radiation produces electron-hole pairs: Electrons are in the conduction band and holes in the valence band. The electrons that have been excited to the conduction band may become entrapped in the electron or hole traps. Under the stimulation of light, the electrons may free themselves from the trap and get into the conduction band. From the conduction band, they may recombine with holes trapped in hole traps. If the center with the hole is a luminescence center (radioactive recombination center) emission of light will occur. The photons are detected using a photomultiplier tube. The signal from the tube is then used to calculate the dose that the material had absorbed (Edward J., 2011).

Based on the sediment analysis results conducted by the OSL method, the age of soil samples was determined over 9,000 years old, belong to the Pleistocene sediments in some locations such as Tan Hoi, Thuong Coc, and Phung and location 5 etc. (Table 1).

Table 1. The geological ages in transects by using OSL method

No	Location	Sampling depth (m)	Geological age (ka)
1	Phuc Hoa (PH)	9.50	2.94±0.17
2		14.70	3.22±0.18
3		26.10	3.40±0.30
4	Xuan Phu (XP)	13.50	1.74±0.13
5	Van Phuc (VP)	14.20	0.55±0.04
6		20.10	0.80±0.10
7		25.50	3.19±0.17
8	Tam Thuan (TT)	20.70	1.72±0.11
9		24.70	4.20±0.20
10	Phuong Dinh (PD)	14.70	3.10±0.20
11		19.10	5.00±0.30
12		23.50	4.10±0.20
13		28.70	3.10±0.60
14	Phung (P)	25.55	7.60±0.40
15		38.15	11.20±0.70
16	Tan Hoi (TH)	9.50	74.00±5.00
17		13.50	72.00±5.00
18		20.60	128.00±11.00
19		27.10	67.00±4.00
20	Location 1 (lc1)	10.10	1.10±0.11
21		14.10	0.61±0.04
22		18.10	3.40±0.20
23		22.10	4.10±0.20
25	Location 5 (lc5)	26.30	40.00±3.00
26		27.60	67.00±5.00
27	Location 6 (lc6)	9.50	3.30±0.30
28	Location 8 (lc8)	10.10	3.40±0.30
29		16.10	5.20±0.40
30		22.10	4.20±0.40
31	LK53	9.50	0.69±0.04
32		10.70	0.72±0.04
33	Thuong Coc	17.10	78.00±6.00
34	H-transect*	10.00	0.46 ± 0.03
35		12.76	0.6 ± 0.07
36	Van Coc*	8.20	0.67±0.06
37	Phu Kim*	8.30	3.5 ± 0.13
38		15.1	3.56 ± 0.12
39	Phung Thuong*	10.7	5.90 ± 0.40

Note: (*) the boreholes of the previous VietAs project (2004-2012)

For Holocene sediments, due to the erosion of younger sediments and the dynamics of paleo-river: the oldest Holocene sediment age over 5.9 ka BP corresponding to paleo-riverbed at the first stage (in Phung Thuong commune). The paleo-riverbed from stage 2 to stage 5 with the sediment ages approximately 3.5 ka BP. The youngest sediment age corresponding to stage 6 was identified by about 0.4–0.6 ka BP (H-Transect).

In accordance with the analysis results combined from remote sensing technology and geophysical measurements, the paleo-riverbed ages were divided into 6 periods: from the oldest of over 5.9 ka BP (stage 1) to the youngest fluctuated around 0.4–0.6 ka BP (stage 6). Other remaining periods (from stage 2 to stage 5) were determined by about 3.5 ka BP. The process of paleo-riverbed dynamics is shown in the area in Fig. 5 and on the cross-section in Fig. 6.

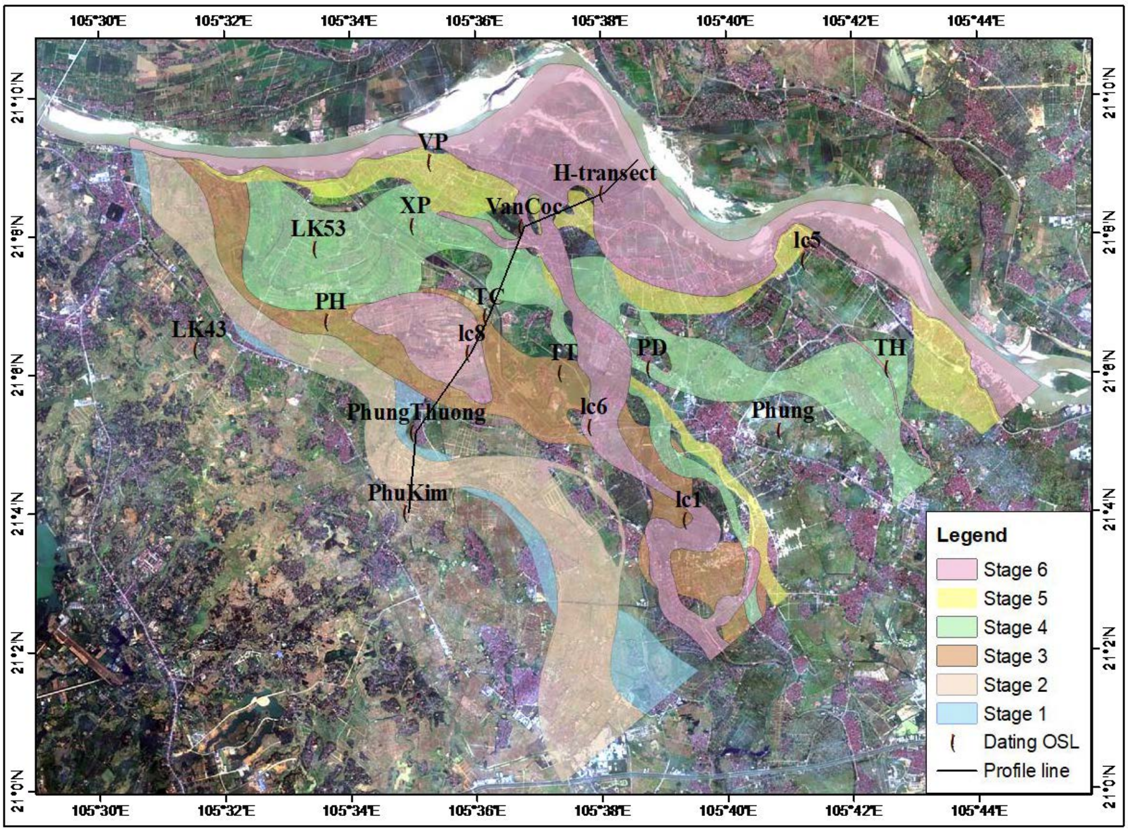

Figure 5. Map of the paleo-riverbed periods from stage 1 (over 5.9 ka BP) to stage 6 (about 0,4÷0,6 ka BP)

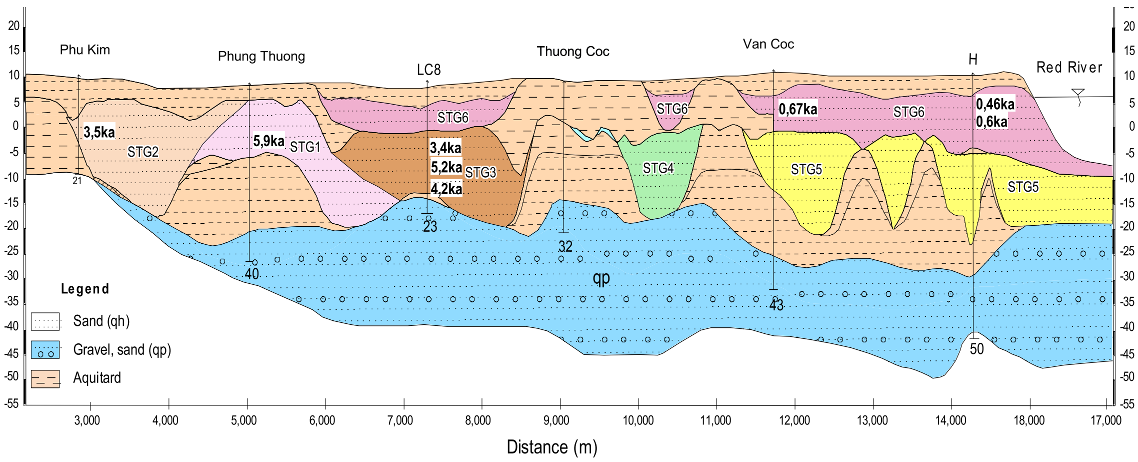

Figure 6. Paleo-riverbed periods along a cross-section which runs perpendicular to the Red River
Note: Stg = stage; ka = thousand years ago

2.4. 2D groundwater modeling method

The influence of the paleo-riverbed dynamics on the concentration of Arsenic in groundwater is illustrated by 2D groundwater models. The selected cross-section was run through the development stages of the paleo-riverbed, from Phu Kim to Phung Thuong, Thuong Coc, Van Coc and H transect. This cross-section is typical of alluvial dominated systems (Fig. 7). In order to understand the process of Arsenic mobilization in groundwater, 2 groundwater models were set up by Visual MODFLOW code: Flow groundwater model by FLOW package and consequently set up solute transport model by MT3D package.

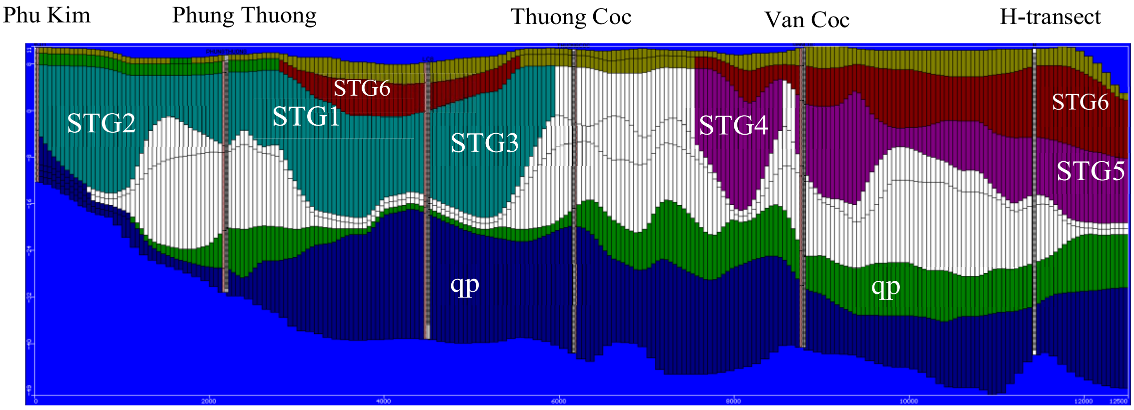

Figure 7. Design grid and 2D geological structure in MODFLOW

Design grid

The cross-section length is 12.5 km, divided into 1 row, 250 columns and 7 layers. Grid size is 100 × 100 m.

Aquifer and aquitard layers

The total number of layers in MODFLOW model includes the following 7 layers:

- Layer 1: Ground surface aquitard;
- Layer 2: Holocene aquifer in stage 6 and aquitard;
- Layer 3: Holocene aquifer from stage 2 to stage 5 and aquitard;
- Layer 4 and layer 5: Holocene aquitard and Pleistocene aquitard;
- Layer 6 and layer 7: Pleistocene aquifer (sand on the top and gravel, pebble at the bottom).

The simulation time is from 6 ka BP so the geological structure model is divided into 3 models corresponding to 6 paleo-riverbed periods.

- 1st geological structure model: from top of layer 3 to bottom of layer 7;
- 2nd geological structure model: from top of layer 2 to bottom of layer 7;
- 3rd geological structure model: all 7 layers.

Groundwater flow model

Boundary conditions: Recharge boundary (Neumann boundary) Recharge rate, so-called the infiltration value, is calculated for the top layer based on rainfall and evapotranspiration. The recharge rate is calculated similarly for the Red River Delta (Dongmei, 2011; Luu, 2016) (Table 2):

Table 2. The amount of groundwater recharge in the period from 6,000 years to present

Time (ka BP)	10	6	5	4	3	2	1	0
Recharge (mm)	30	30	80	90	60	80	70	70

No flow boundary (Q=0): This is the type II boundary condition used for the left boundary of the model where the aquifer and aquitard reach bedrock. The underlying bedrocks are considered to be no-flow boundaries. In addition, during the simulation, the northern of the Red River outside the study area was also simulated by this Neumann condition by assigning an "inactive cell" in the model.

General Head Boundary (Cauchy boundary): It is used to assign the paleo-rivers from the first stage to the present stage with the assumption that this aquifer is not in direct relationship with the river but through the river bed materials. The conductance of the paleo-river stages has not been studied in detail, but the current period can be based on the results of cluster pumping test near the Red River with (D) = 218m (Giang, 2018) (Nhien, 2004) and grid size in the model (LxW) was by 100 × 100 m, hydraulic conductivity (K) of the aquifer is determined by pumping test near the Red River is from 20 to 40 m/day (Giang, 2018). The conductance value (C) is calculated using the following formula: C = (LxW)*K/D is from 917 to 1500 m^2/day.

The initial time and stress period for the model:

The selection of initial time (t = 0) and a time step of each stage based on the age of paleo-riverbed sediment which were determined by the OSL method.

Stage 1-2: from 10 ka to 5.9 ka;

Stage 3: from 5.9 ka to 3.4 ka;

Stage 4: from 3.4 ka to 2 ka;

Stage 5: from 2 ka to 1 ka;

Stage 6: from 1 ka to 0.6 ka.

With respect to the above-mentioned stages (1-6), there were 2 constraints varying vertically (geological evolution models) and horizontally (boundary conditions). For example, stage 1 to stage 5 uses the 1st geological evolution model, stage 6 corresponds to the 2nd geological evolution model and stage 6 corresponds to the 3rd geological evolution model.

Flow model parameters

Hydraulic conductivity of the layers on the cross-section is based on the results of slug-test experiments at test sites by Solinst's self-recording device with both Holocene and Pleistocene aquifers and calculated on software Aquifer Test by Hvorslev method. The summary of the slug test results is shown in the following Table 3.

Specific yield and specific storage is determined based on the data of the previous hydrogeological survey boreholes (Long, 2019), in which specific yield (S) in the range of 0.08÷0.18 and specific storage (S_s) in the range of 0.0001÷0.00022.

Table 3. Hydraulic conductivity was determined by slug test in Dan Phuong-Thach That area

No	Transect	Number of tested wells	Aquifer	Stage of paleo-riverbed	Lithology	Hydraulic conductivity (m/day)
1	Phu Kim	7	qh	STG2	sand	14.48
2	Phung Thuong	4	qh	STG1	sand	39.30
		4	qp		sand	7.61
3	Thuong Coc	5	qp		sand	15.07
4	Van Coc	2	qh	STG6	sand	15.50
		7	qh	STG5	sand	33.35
		1	qp		Pebble, gravel	213.00
5	LC8	1	qp		Pebble, gravel	138.00

Solute transport model (MT3D)

Solute transport model parameters:

Longitudinal dispersivity (α_L) and effective porosity were determined based on the results of pumping test and tracer tests in Thuong Cat area with tracing distance 12m and α_L= 0.44 m (Giang, 2018). In the study area, the grid size is 100 m, so the longitudinal dispersivity is equivalent to 3.7m, horizontal dispersivity α_H = 0.1αL and vertical dispersivity α_V = 0.01aL. Effective porosity (n_e) is also determined as n_e = 0.23.

Diffusive coefficient of Arsenic (D*) in groundwater is D* = 2×10–9 m^2/s (Long, 2019). However, in the Holocene and Pleistocene aquifers the diffusion process is not significant compared to convection process because of the high flow velocity in aquifers. Other way, diffusion process is significant for aquitard layers where the flow velocity is small and almost stagnant (Long, 2019).

For adsorption process, the model used the Langmuir non-linear two-component adsorption model. Adsorption parameters are $Ks^{As(III)}$ = 1500 L/mol and s_{tot} = 8.4 µmol/g (Long, 2019).

Concentration boundary conditions:

- Recharge concentration: Suppose Arsenic-free in rainfall and evapotranspiration, and thus recharge concentration is assigned to 0mg/l.

- Initial concentration (C0): Depending on the stage, the initial concentration is assigned by the result of the previous stage model.

Adsorption mechanism and desorption mechanism: Arsenic concentration is adsorbed in Holocene sediment is large, an average of about 10 mg/kg of sediment (Long, 2019). In the model, the adsorption process is simulated on the Langmuir nonlinear component equation with parameters of adsorption for the equation shown in Table 4. For the desorption process, it will be stimulated by the initial boundary conditions for the next stage base on the initial concentration at the H field near the current river position (under the same conditions), where the Arsenic concentration in groundwater is high (0.3–0.4mg/l).

Table 4. Summary of Arsenic transport parameters in the study cross-section

D^* (m^2/s)	α_L (m)	α_H (m)	α_V (m)	n_e	$K_s^{As(III)}$(L/mol)	s_{tot} (µmol/g)
2×10^{-9}	3.7	0.37	0.037	0.23	1500	8.4

3. Results

The results of the flow model and solute transport model show that in the past, the groundwater hydraulic system takes a leading role in the Arsenic mobilization in groundwater.

In the flow model, the prevailing flow direction in the paleo-riverbed sections is from groundwater flowing into the river in the direction from Phu Kim to H-transect (Fig. 8). The velocity is very small from 0.07÷ 0.01m/day where the velocity in the early stages is often greater than that in later stages due to relief and consequently gradient of hydraulic system (such as Phu Kim and Phung Thuong).

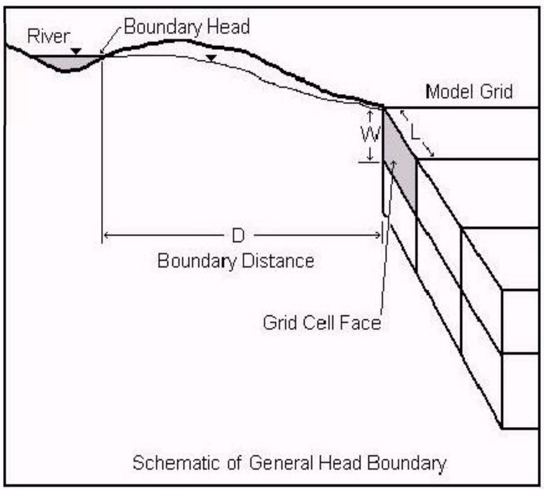

Figure 8. General Head boundary in the model

River water is an oxygen-rich environment, so Arsenic content is adsorbed in the bottom sediments of the current river. When the river moved to another position, the current river position was filled with younger sediments and became paleo-riverbed formation with reducing conditions. Arsenic which was adsorbed in the previous stage then released into groundwater and moved to the current river location. The processes keep repeating until the present stage. Arsenic concentration in groundwater at the present stage is shown in Fig. 9. The simulation results of Arsenic concentration in groundwater at the current stage are compared to the analysed Arsenic concentration in groundwater (Khue, 2012; Long, 2019; Postma et al., 2012) is shown in Fig. 9.

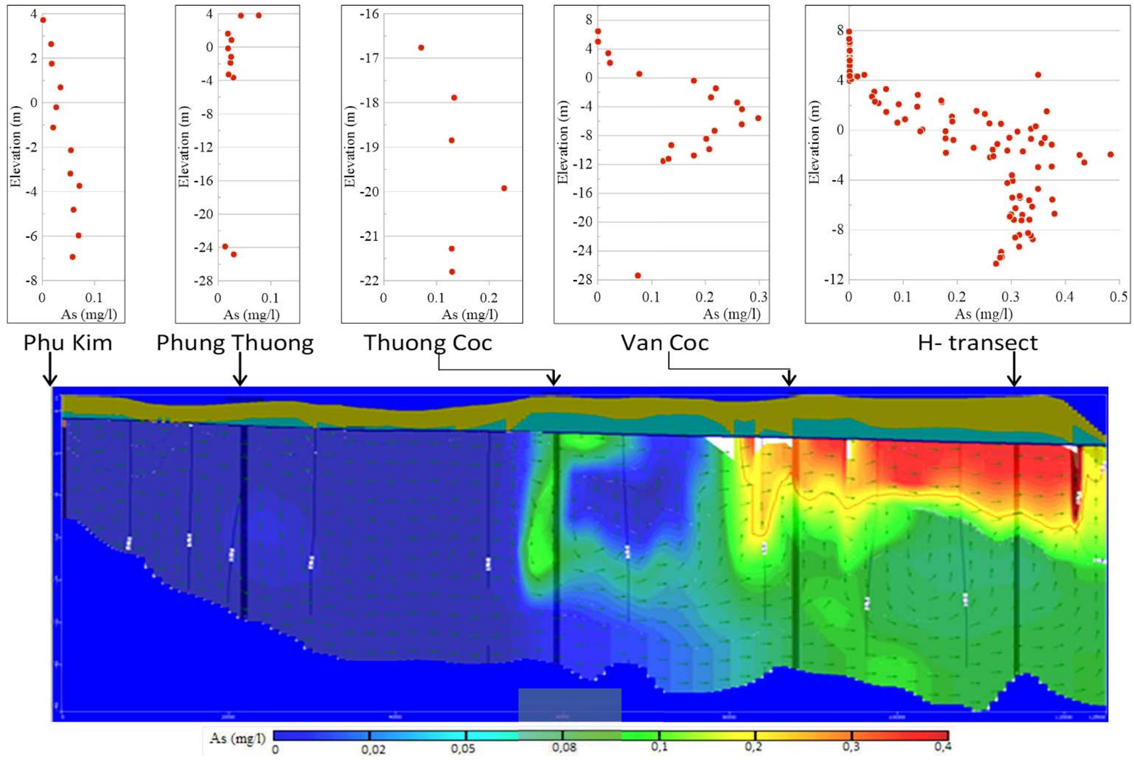

Figure 9. The comparison between the analyzed Arsenic concentration and modeled Arsenic concentration on the cross-section

4. Discussions

Red River Delta consists of three main geological structures (Mather, 1999), comprising alluvial dominated systems, tidal dominated systems, and wave-dominated systems. According to the previous researches conducted by Winkle (2011) and Larsen (2012), in the area surrounding by the south of the Red River and Day River, the concentrations of Arsenic in groundwater of alluvial dominated systems are very high, exceeds the acceptable threshold published by WHO. In the area of Dan Phuong-Thach That, Hanoi, the Arsenic concentration in Holocene aquifers is very high reaches to 7 µmol/l in H-transect, Dan Phuong district (Postma, 2012). The distribution of Arsenic in this aquifer, as well as the mechanism of Arsenic release and movement, are studied in detail in VietAs project, 2004-2012 (Postma, 2007, Flemming, 2008, Soren, 2008, etc.). Other researches have shown the interrelationship between the concentration of Arsenic in groundwater and the age of Holocene formation in the Red River Delta, and it has also emphasized the age of aquifer sediments is a key determinant of groundwater Arsenic concentration (Postma, 2012).

After the maximum transgression period, the formation of Holocene sediment was impacted by the river. Specifically, the paleo-riverbed migration was acting the great significance to the evolution of Holocene aquifer (Tran Nghi, 2004). For the purpose of clarifying the controlling of paleo-riverbed migration, a combination of methods is implemented including remote sensing method, multi-electrode profiling, gamma-logging, drilling method, and soil sample. Regarding the factors affecting the mechanism of Arsenic mobilization, the obtained results from the simulation groundwater flow system from 5.9 ka BP up to the present time by using the MODFLOW flow model and the MT3D groundwater solute transport have shown that the paleo-riverbed affected the hydraulic system of groundwater flow. The simulation results of Arsenic concentration in groundwater at the current stage (phase 7) which are compared to the analysed Arsenic concentration in groundwater (Khue, 2012; Long, 2019; Postma et al., 2012) is shown in Fig. 9 seem to fit very well. The most area of higher Arsenic concentration at the cross-section (Fig. 9) distributes in the younger sediment which is the later riverbed stages as well (Fig. 8). Nevertheless, the area between Phung Thuong and Thuong Cat (Fig. 9) seems different from lower Arsenic concentration. Back to Fig. 8, the distribution of STG6 in this area is thin and shallow so that the reducing environment is week as well.

In this study, the process of sediment erosion has not been considered. Moreover, MT3D model is a three-dimensional model with complicated boundaries. To reduce the uncertainty of the modeling results, the next step for future study should be considered.

5. Conclusions

The results of remote sensing researches combined with geophysical methods, hydrogeological sampling, and gamma logging in wells implied that the dynamics of paleo-river beds in the study area could be divided into 6 stages in about 5.9 ka BP.

The younger sediments were located mainly in the Southwest while the older sediments were distributed in the Northeast of the study area show that paleo-riverbed has been moving from the left to the right. The last period (stage 6) consisted of the youngest sediments in a range from 0.4 to 0.6 ka BP while the rest were determined around 3,5 ka BP (from stage 2 to stage 5) and the oldest one was more than 5.9 ka BP years (stage 1).

Regarding the factors affecting the mechanism of Arsenic mobilization, the obtained results from the simulation groundwater flow system from 5.9 ka BP up to the present time by using MODFLOW flow model and by using MT3D the groundwater solute transport have shown that the controlling of paleo-riverbed migration on Arsenic mobilization in groundwater in the study area.

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