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TRAN KY

DEVELOPMENT OF AN MATHEMATICAL MODEL ON ACIDIC WATER SPREADING IN THE LONG XUYEN QUADRANGLE AND APPLICATION IN COSIDERATION OF CERTAIN IMPACTS ON THE REGION PRODUCTION

Sector: Water Resources Engineering

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Sciencetific supervisor 1: Prof. Dr. Nguyen Tat Dac

Sciencetific supervisor 2: Assoc. Prof. Dr. Luong Van Thanh

Reviewer 1: ………………………………………………………..

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PUBLICTATIONS OF THE AUTHOR

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FOREWORD

1. The necessity of the doctoral thesis

Acid sulfate soil in the Mekong Delta is estimated about 1.5 million hectares, accounting for 45% of the total land area and mainly distributes in the Dong Thap Muoi (Plains of Reeds), Ca Mau Peninsula, and in the Long Xuyen quadrangle. The alum formation processes are extremely complex, from the biochemical processes in the soil to the hydrological processes etc., and during the dry season, the capillary process causes alum products formed in the soil emerge to the topsoil. When the early rains of the raining season appear, the alum products hydrolyzed, which forms highly acidic water (alum puddles), mix with rainwater and drift into rivers and canals. As a result of the runoff process, generally, or under the Mekong Delta tides, alum-affected water overflows to nearby areas and becomes a negative impact on the environment, daily life, and production.

The author has modeled the alum spreading process on the canal system for the acidic soil area of the Long Xuyen quadrangle based on the study results in the 1980s, including the acid sulfate soil improvement studies, the biochemical process studies, and the studies on the alum diffusion from soil to the canal system, which usually acidize the water sources. The studies in the 1980s were conducted by the “Acid Sulphatic Soil Improvement in the Dong Thap Muoi (the Plains of Reeds)” Project funded by the National Mekong Committee (MRCS).

2. The objectives of the thesis

This study is to fill in the missing equations to develop a mathematical model of the spreading of acidic water in the canal system of Long Xuyen quadrangle at the early stage of the rainy season. This model will be used to see how the spreading of acidic water affects the regional production.

3. The objects and scope of the research

Objects: Water environment: The author focuses on researching certain important parameters in the water environment, i.e. Fe^{3+}, Al^{3+}, SO_4^{2-}, and H^+ in canal water over time and space as well as their impacts on the agro-ecosystem.

Therefore, the thesis content merely analyzes the effects of acidification during the early rainy season when there are the water runoff flows running from fields to the canal system, but not examines the alum formation in the soils.

Soil environment: The thesis focuses on researching and surveying the documents from two sources: (i) topics and projects that have been conducted for the study area and the similar areas in term of the parameters regarding the alum produce, acidity, and toxicities to the aquatic organisms, the data from soil solutions, surface water, and soil profiles; and (ii) surveying and studying data provided by the experts and the colleagues working at the Sub-National Institute of Agricultural Planning and Projection, the Southern Institute of Water Resources Research, and the Southern Institute of Water Resources Planning, which pave the way for the evaluation and calculation documents of this model.

Scope of research: The research is for the Long Xuyen quadrangle. The author focuses on analyzing the alum results and developments in the Ha Giang canal in the the Ha Tien quadrangle subregion of the Long Xuyen quadrangle.

3. The research approaches and methods

Research approaches: The multiple approaches are selected for the study, including: (i) General approach; (ii) Practical approach; and (iii) Integrated approach to information.

Research methods: (i) Mathematical modeling; and (ii) Application of new scientific advances.

4. The new and creative points:

(1) The thesis has determined the acidic water components in the Long Xuyen quadrangle, which consist of aluminum and iron. Thereby, the stoichiometry rules for these components are applied to establish additional mathematical equations for finalizing the system of equations that manifest the spreading of acidic water in rivers and canals in the Long Xuyen quadrangle.

(2) Based on the aforesaid information, we can develop a computer program for 1D acidic water spreading, namely ACID2020, to simulate certain typical parameters of acidic water spreading in rivers and canals in the Long Xuyen quadrangle.

5. Scientific significance: We can model the acidic water spreading in rivers and canals in the Long Xuyen quadrangle and the corresponding computer tool (ACID2020) to calculate the spreading of acidic water, which appears at the beginning of the rainy season.

The computer program, ACID 2020, has been utilized to assess the development of acidity and its spreading quantitatively.

It will serve as a reference basis for further studies tracking the acidic water spreading in rivers and canals.

It will serve as a reference for teaching and training in the water resources (for the Faculty of Water Resources, Ho Chi Minh University of Natural Resources and Environment).

To some extent, the thesis results help come up with certain scientific ways to deal with the effects of extracting and using land resources (regarding the water quality and aquatic organisms) as a basis for managing and exploiting the water resources and the environment protection in the Long Xuyen quadrangle.

6. Practical significance: The findings of this thesis contribute to the assessment and determination of the levels and the spreading of acidty in the water environment of the Long Xuyen quadrangle, as well as to the consideration of impacts on the regional production to catch up with the requirements of the socioeconomic development and the environmental protection.

The results of this thesis will be a reference for the training in the natural resources and environment, as well as enriching knowledge in the research field and the improvement of acidic water quality for the Long Xuyen quadrangle in particular and the Mekong Delta in general.

In addition, the findings possibly propose the rational designs of the canal system, aiding in the development of planning options, control solutions, and environmental impact assessments.

Chapter 1: OVERVIEW

1.1. OVERVIEW OF ACID SULFATE SOIL

Acid sulfate soil is defined as soil and material that, as a result of soil formation, generate a quantity of sulfuric acid (H_2SO_4) that causes a significant impact on the soil major properties (L. J. Pons, 1973).

In 1735, Peelman discovered Agrilla Vitrolacea, a mineral that transforms soil into acidic soil. The author assumed that acid sulfate soil appears on Cambrian sedimentary formations in coastal regions. Doyne (1937) also proposed that sulfur (S) in acid sulfate soil is derived from the sea water and that Rhizophora Apiculata Blume is the responsible source of material for acid sulfate soil formation.

According to Le Huy Ba (2003), the origin and formation process of acid sulfate soil have been extensively studied and discussed by numerous authors with various viewpoints.

The scientists who study soil have long studied the use of acid sulfate soils, in developed nations. However, not until 1972, the first conference on the topic did hold in Wageningen University of Netherlands. This conference aimed to standardize research methods, create criteria for evaluating and categorizing acid sulfate soils, and provide information on research findings as well as research and improvement experiences in acid sulfate soils conducted by various nations worldwide. At the fourth World Acid Sulfate Soil Symposium, which was held in Ho Chi Minh city in March 1992 [Selected Papers of the Ho Chi Minh City Symposium on Acid Sulfate Soils, HCM City, Vietnam, March 1992], the number of scientists studying acid sulfate soils worldwide had increased significantly, and a number of equipment and machinery for research in this field had been improved and modernized as well. The national laboratories have basically agreed on the methods of soil analysis (mainly the methods created by the Netherlands, the US, and Belgium) and agreed to choose two standard soil classification systems: the US Taxonomy standard and the FAO-UNESCO standard.

In Vietnam, the management and improvement of acid sulfate soils in the Mekong Delta region have been researched by the domestic scientists since the 1980s.

The chemical change properties of acid sulfate soils are extremely complicated as they depend on the local climate, topography and water regime, as well as the presence of microorganisms of each region. The formation and development of acid sulfate soils is involved in the three primary chemical processes: (i) Pyrite formation, (ii) Oxidation, and (iii) Reduction.

In terms of its properties and nature, acid sulfate soil contains toxic substances (Al^{3+}, Fe^{2+}, Fe^{3+}, $SO4^{2-}$, Cl^{-}...) and the amount of toxic substances found in the aqueous solution, soil, plants, and the human body. The effects of toxic substances derived from the oxidation of acid sulfate soils are diverse, highly variable, and almost irreversible, which significantly affect the growth and productivity in the agricultural production, especially rice, and the reproduction and development of the aquaculture, which need to be addressed with great care on the basis of quantified insights. So far, the multiple valuable lessons learned about the destruction of the ecological balance on acid sulfate soils remain unchanged.

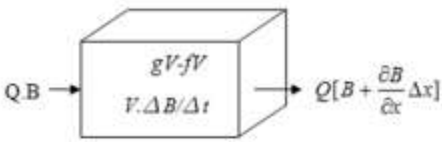
1.2. MODELING THE ACIDIC WATER SPREADING IN THE FLOWS

Because alum is a non-conservative substance and it contains the simultaneous interaction of multiple elements, in terms of biochemistry, the alum diffusion math problem is challenging and attracts less attention. Therefore, this thesis focuses on the initial step of the mathematical model finalization, which involves in creating fundamental equations for the process of alum water spreading in rivers and canals and involves in running various tests and experiments to learn about the rational feasibility of the model. We will go over the remaining steps and try to take advantage of the available results regarding the preservatives.

a) Spreading process:

The spreading substances (e.g.B) obey the Law on Conservation of Mass, which are mathematized by the expression (1) and described by the following figure:

$$Q.B + gV - \left[Q\left(B + \frac{\partial B}{\partial x}\Delta x\right) + fV\right] = \frac{V.\Delta B}{\Delta t} \qquad (1)$$



After some steps, Equation (1) can be transformed into the following form to describe unidirectional (one-dimensional) flows on rivers and canals:

$$\frac{\partial S}{\partial t} + U\frac{\partial S}{\partial x} = E\frac{\partial^2 S}{\partial x^2} - \sigma S + \phi(S_i) \qquad (2)$$

Where S represents the concentration of a single substance and Si represents the concentration of other substances involved in the process. With $\sigma > 0$; E is the dispersion coefficient, and Φ is the function of other unknowns Si based on the particular relationship. Due to the complexity of (2), it is necessary to develop specialized algorithms for the number numerical solutions. In the section hereafter, one of the methods for solving the hyperbolic spreading equation is presented (without second derivative terms).

b) Solution method:

Equation (2) shows that the spreading and dispersing process happen at the same time along a flow with speed U and dispersion coefficient E. The last two terms of (2) represent the generation or loss resulting from the biochemical interactions. For the sake of mathematical simplification, they are broken down into each process using the decomposition method, with the flow-loading process as the dominant one. In the hydrological conditions of the tidal zone, the process of loading along the flow is described by the equation:

$$\frac{\partial S_t}{\partial t} + U\frac{\partial S_t}{\partial x} = 0 \qquad (3)$$

St represents the concentration caused by the loading (transport) process, which plays a crucial role, while other processes function as a time-step correction. The number solution methods (3) frequently encounter the numrerical diffusion phenomenon, which distorts the solution. In order to minimize this numrerical diffusion, the characteristic curve method is used to solve (3).

Chapter 2: THE ACIDIC WATER SPREADING MODEL IN RIVERS AND CANALS

2.1. PHYLOSOPHY FOR ALGORITHM EQUATIONS THAT MODEL THE ACIDICIC WATER SPREADING PROCESS IN RIVERS AND CANALS

Measuring unit: In chemistry, the typical unit used for monitoring chemical concentrations is “Mol”, which is the molecular weight in grams and is an important quantitative concept as each Mol consists of the same number of molecules. However, in practice or in the laboratory, mg/L (or g/L), upon each specific case, is also used to measure the concentrations. Thus, it is necessary to convert the calculations into the same unit.

- *Determind aluminum equilibrium and iron equilibrium in the Dong Thap Muoi and the Long Xuyen quadrangle:*

According to Nguyen Thanh Tin, 1990, the Jurbanite aluminum equilibrium in Tan Thanh and Dong Thap Muoi areas is as follows:

$$AlOHSO_4 + H^+ \rightleftharpoons Al^{3+} + SO_4^{2-} + H_2O \qquad (4)$$

In Water environnent: $H^+ + OH^- \Leftrightarrow H_2O$

$\Rightarrow$ pH = pSu + pAl +d

This equilibrium is also found in the alum water in the Long Xuyen quadrilateral, but according to Dang Trung Thuan (2005), the sulfide minerals are also found typical in the Long Xuyen quadrilateral.

When pyrite is weathered, its final product is iron oxide, which is a difficully dissolving and accumulating compound and has brown color and this product is also popular in the Long Xuyen quadrilateral.

The oxidation of FeS_2 pyrite to iron oxide can be found in a series of reactions or equal to the following equilibrium reaction:

$$Fe^{2+}S_2^{-} + 15O_2 + 14H_2O \rightleftharpoons 4Fe^{3+}(OH)_3 + 16H^+ + 8S^{6+}O_4^{2-} \qquad (5)$$

These balanced equations are used to model the mathematical relationships in the alum water diffusion.

The following equation can be established to describe the acidic water:

$$H.Su\frac{dAl}{dt} + H.Al\frac{dSu}{dt} - Al.Su\frac{dH}{dt} = 0 \qquad (6)$$

$$pH = pSu + pAl + d \qquad (7)$$

Where d is a constant and Al, H, SO4/Su are the instantaneous concentrations of aluminum, hydrogen, and sulphate at x, y, z, t.

For the Long Xuyen quadrangle: The studies also detected the Jurbanite aluminum equilibrium and the Jarosite iron equilibrium (the linear correlation of pH, Al and SO4 or pH, Fe and SO4).

Similar to (7), for the iron mineral equilibrium, we have the following equation to calculate the pH:

$$pH = \alpha pSu + \beta pFe + m \qquad (8)$$

Where *m*, *α*, *β* are the constants and *Al*, *H*, *SO4/Su* are the instantaneous concentrations of iron, hydrogen, and sulphate at x, y, z and t.

For the time derivatives of aluminum, hydrogen, sulphate or iron, we must comply with the biochemical equilibrium laws, in addition to the compliance with the Law of Substance Mass Conservation. Thus, establishing and solving diffusion mathematic problems is much more difficult and complex than establishing and solving single-conservative substance diffusion math problems, for example a saltwater diffusion mathematic problem. Although existing in different patterns of complexity, they all have a common diffusion equation, so that a common method can be applicable to numerically solve these equations. The below is a brief introduction of the applicable method to the Jurbanite aluminum equilibrium (6) (7):

$$AlOHSO_4 + H^+ \rightleftharpoons Al^{3+} + SO_4^{2-} + H_2O \qquad (9)$$

2.2. ACIDIC WATER SPREADING IN RIVERS AND CANALS

For a system of numerous rivers and canals, their branches will connect each other at confluence and disjunction points (also known as nodal points/notes). In this case, if the aluminum concentrations at the notes are given, the math problem will be solved for each single river tributary. Therefore, the diffusion mathematic problem must be considered within a canal system. By applying the characteristic line method, when a water current directly flows to confluences, the concentrations at the cross-sections close to the confluences can be calculated by solving a pure load equation, and the diffusion term is assumed to be given (or evaluated) in the previous class of time. Thus, when water flows run towards confluences at different tributaries, without the same concentrations required (like the available models), the unique condition we must follow is the conservation of substance at the confluences in order that the total amount of substance entering the confluences is equal to the total amount of substance leaving the confluences, from which we will have the following condition for the concentrations of substances at confluences (or distributaries).

$$S_N = \frac{\sum_i Q_i^V S_i}{\sum_j Q_j^R} \quad ; \quad \sum_i Q_i^V = \sum_j Q_j^R \qquad (10)$$

Where S_N consists of the concentrations at the cross-sections flowing out of the confluences; S_i, Q_i^v are the concentrations and water flows at the cross-sections close to confluences of branches which flow into the confluences (of course the inflow or outflow depends on the time); and Q_j^R are the water flows at the the cross-sections close to confluences of the outflow branches. Once the assumed concentration values at the confluences are given, we can combine them with the boundary conditions to solve the mathematic problem for each river tributary.

Certainly, to solve the diffusion problem, there must be “velocity field U” along a water flow. For water flow mathematic problems, multiple types of software are being used, but for the river/canal problems, DHI's Mike11 is widely applicable. However, as mentioned above, for the convenience and initiative, in this study the author will use the DELTA software of Prof. Dr. Nguyen Tat Dac, which has been applied to multiple water projects in the Mekong Delta in Vietnam.

2.3. ACIDIC WATER SPREADING IN FIELD PLOTS

Giving the assumption that the acidic water in each field plots is evenly dissolved, the equilibrium equations in each field plots will become simple as shown below.

Assuming that *V* is the total volume of each field plots (in practice, if field plots is too large, we can divide it into smaller ones); *C* is the concentration of acidity producing substance in that field plot; *Cs* is the concentration of acidity generation substance in circulating flows (inflow and outflow) between a canal and field plots at the flow rate of Qs; and the rainfall on the field is denoted by *Qr*, *Qe* featuring the evaporation flow. With such notation, the equilibrium equation that balances the volume of water in field plots will be as follows (11):

$$\frac{dV}{dt} = Q_s + Q_r - Q_e \qquad (11)$$

And the equilibrium equation for the acidic substance in field plots will be (12):

$$\frac{d(V.C)}{dt} = Qs.Cs + F(Cg) \qquad (12)$$

Where *F(Cg)* is the total quantity of acidity -producing substance from the ground with *Cg* concentrations, or from different sources.

Determining the *Cg* by the model will be very complicated and difficult. So, the purpose of the study is to consider the spreading process on canals, to make it simple, in the thesis, it is proposed to use the method of calculating *Cg* by the following formula (13):

$$Cg = \sum_i C_{oi} \cdot e^{-a_0(t-t0)} \qquad (13)$$

Where C_{oi} is the initial concentration of acidity at the beginning of the rainy season on a field surface (lake) at point ***i***; a0 is a constant that depends on a number of factors, this constant is determined from the measurement data. By the difference, equation (13) is changed to the following (14):

$$V.C = V'.(C' + \alpha 1.Cg) + Qs.Cs.\ t \qquad (14)$$

In which *Al* is the characteristic constant for the partial dissolution process in the field plots at the time *t. V'* and *C'* is the water volume and the concentration of Al producing substance in the field plots at the previous time; *Cs* is the concentration of alum-producing substance in the canal if water flows backwards from the canal into the field plots and equals to the concentration of alum-producing substance *C'* in the field plots in the opposite case (note that in a intertidal zone, water may flow from the field plots to the canal at low tide and flows from the canal into the field plots at high tide). Thus, once the flow characteristics from hydraulic calculations are clarified, it is easy to calculate the concentration of Al producing substance C in the field plots via formula (14).

2.4. ACID2020 PROGRAM

Based on the algorithm briefly described above, a computer program, named **ACID2020,** has been written to test the diffusion of alum water for the Long Xuyen quadrilateral. This software uses the Digital Visual Fortran language and runs on 64bit operating system. ACID2020 simulating the spread of aluminum (or iron) in acidic water in rivers and canals (mainly at the beginning of the rainy season) was completed in March 2020. It consists of a section for calculating algorithm-based river-canal hydraulics and the codes of DELTA software. The block diagram of ACID2000 program is described in **Figure 1**.

The aluminum cocentration calculation section composes of subroutines for calculating aluminum Al^{+3}, sulphate SO_4 or iron Fe.

The algorithms for these subroutines are based on the algorithms described above in this thesis. These subroutines are made by the author and under the guidance of Prof. Dr. Nguyen Tat Dac.

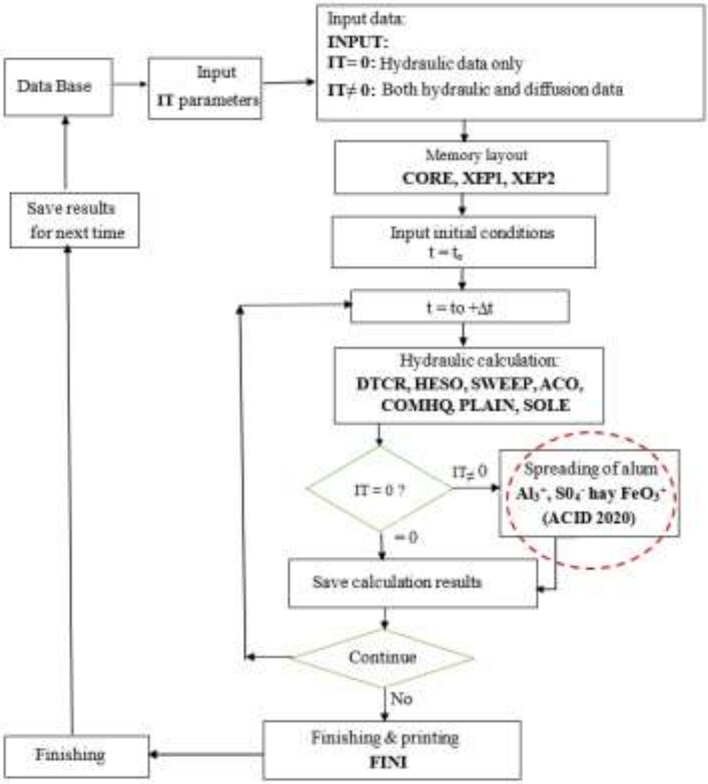


Figure 1: The working diagram of the acidic water calculation program of ACID2020, coupled with the hydraulic calculation program of DELTA.

ACID2020 includes the main program: MAIN, to start the program, and the subroutines to organize memory, read data, calculate and print. A number of subroutines (time, date, CPU time...) are taken from the **DFLIB** library. The programming is quite complicated, so within the framework of the thesis, Prof. Dr. Nguyen Tat Dac and the author of the thesis desire to give the codes of the aluminum cocentration calculation and sulphate calculation for readers to refer to. To have an executable program (.exe), the Fortran compilers are used for the interpretation, and input data files are arranged. The names of the input data files are listed in the file named **"Fvao.txt"**, ACID2020.exe program will search for files listed in Fvao.txt to seek data and then perform the calculations.

Chapter 3: ACID2020 FOR SIMULATING ACIDIC WATER SPREADING IN HA GIANG CANAL

3.1. COMPUTERIZED DIAGRAMATIZATION

This computered schematization covers 1061 cross-sections (or calculation points), 424 river branches, 233 confluence nodes, and 05 hydraulic boundaries which are the water levels of Chau Doc, Vam Nao, Can Tho, Rach Gia and Ha Tien. The rain stations are in Chau Doc, Long Xuyen, Rach Gia, and Ha Tien. The works are Tha La and Tra Su rubber dams (replaced by concrete dams) and 23 salt water sluices along the coast.

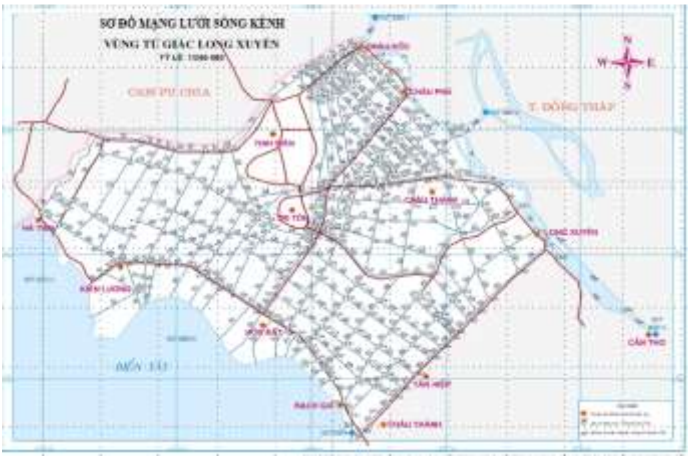


Figure 2: The river and canal network established for the Long Xuyen quadrilateral

Input data: The topographic records was mostly measured until 2011, with some supplements which are recently upgraded. The hydrological records were obtained in 2016.

Simulation time: given the consideration of the aluminum impact at the beginning of the rainy season, the focus should be on exploiting the records of May to June 2016 (the simulation time can reach September); **Emission source:** the emission source comes from the acidic water in field plots covering **an area of 10ha in Ha Giang canal** which supposedly spreads out into the canal (When it rains, the hydrolyzed rainwater will wash away the acidic water in the soil into the canal, causing the acidic phenomenon). At the hydraulic and marine boundaries (Chau Doc, Vam Nao, Long Xuyen, Rach Gia, Ha Tien and the sluice gates to the sea), water is free from acidity (the pH is above 6). The initial aluminum and sulphate figures in the fields correspond to **pH=2.9**. When spreading to the canal after a period of time, the pH will gradually increase under the impingement of rains and tidal currents (the simulations of aluminum variations over time are found in the figures below). **The calculation time step:** Δt = 900s (15 minutes).

3.2. CALCULATION RESULTS

<u>The pH in May:</u>

Changes over time: At the early stage of the rainy season in May, the water levels in the majority of the regional canals are lower than the field surface levels, making it easy for the rainwater overflowing aluminum from fields into canals. Generally, the rainwater flows run along the axial canals to the West Sea.

After early the heavy rains of the season, the rainwater washes away aluminum on the surface of the fields into the inner-field canals, while the water levels in the inner-field canals are quite shallow, in many canal sections water seems running dry, and somewhere the canal beds are dry and cracked. The silty puddles here are the in-situ aluminum ones, which are dissolved and washed away by the rainwater runoff and then accumulate into regional canals. This aluminum-contaminating water infiltrates into axial canals then infield canals around the Ha Tien quadrangle, forming an aluminum den in the Ha Tien quadrangle. The water in the canals starts to become more acidity in May. The acidic water spreading becomes fast in the region, when the contour line at the time has the pH of 2.99 ÷ 5.03 covering most of the North of the Ha Giang canal, then the pH ≤4 contour line in the Ha Giang canal reaches to neighboring canals (like theTra Pho canal, Quoc Phong canal, in-field canals and direct to the Nong Truong canal), the acidic water is finally pushed towards the West Sea.

Spatial changes: The acidity accumulating and spreading along the contour line with pH = 2.86÷5.50 travels from the upstream of the Ha Giang canal and tends to flow along it towards the Ha Tien quadrangle canals into the West Sea. In addition, the acidic water now flows towards the Tra Pho canal, Quoc Phong canal and infield canals, merge with the amount of inherent aluminum in these canals to continuously travel to neighboring inland canals. The cause of sourness is the blame of the acidic ions in the soil which are dissolved by rainwater and make the water in the fields sour, then flow down the canals, making the canal water sour too.

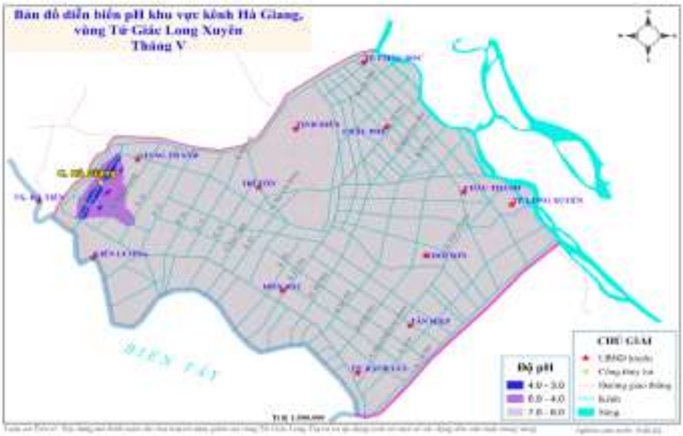


Figure 3: The acidic water map in May

<u>The pH in May</u>: From the first of May to the middle of May, the pH ranges from 2.86 ÷ 3.87 at cross-section 28 and from 2.86 ÷ 4.62 at cross-sections 29A & 30A. These two sections are the upstream and downstream of the Ha Giang sluices which spread in smaller area, however, the pH ≥5.0 diffuses relatively large to the two shores, left and right of Giang canal through small infield canals towards the Giang Thanh River and Nong Truong canals. At cross-section 34 at the time from the first of May to the middle of May, the pH ranges from 4.98 ÷ 5.03. Cross-section 34 of the Nong Truong canal in this region is located far from the alum source of the Ha Giang canal and is only affected by the rainwater washing away the amount of inherent alum in the region, but thank to many small infield canals, aluminum is diluted by water and the pH is 4.98÷5.03, bigger than in the Ha Giang canal.

The reason is that the rainwater washes off the aluminum on the field surface and washes off the condense acid sulfate soil in the Ha Giang canal area to spread acidic water to the surrounding. This becomes the condense epicenter of acidity at the time, the acidic water color is rusty red or blue-black, and the pH stays at the lowest levels, 2.99 ÷ 3.00. This phenomenon appearance is because it happens in a low-lying area which is heavily affected by acid sulfate soil, where rainwater and aluminum water accumulate in place, while the alluvial water from the Hau River does not come to dilute it.

The aforesaid analysis shows that the pH will increase in the Ha Giang canal (in May). The pH increase or decrease depends on the rain-situation and the discharge of acidic water in the region. The first rains of the season drift aluminum-producing products from the field surface, which have been hydrolyzed to become aluminum puddles (or from dry aquaculture ponds, depleted canals, low-lying fields, which are the in-situ alum puddles). Assuming that when it rains, water will follow the alum deposits on field surface and run from fields to small canals and ponds. When the water levels in canals, ponds/fields rise high enough, water will overflow into the lower canals and the canals around and contaminate the drinking water or the production water of the surrounding areas (the chart of alum variations is provided in Figure 3).

The pH in June:

Changes over time: from the second half of May to June, due to the regional rains and discharge of acidic water, water in the canals become severely acidic. The acidic water area with pH ≥6.0 spreads widely in June and lasts till July of the year (depending on whether the annual flood comes early or late, big or small). The contour line of pH=6.0 starting with a small area near the canal upstream and downstream of the Ha Giang sluice then spreads out along surrounding small canals. However, thanks to a larger and larger amount of rain water in the area at the time, which begins to flush into regional canals, the alum water here is slowly diluted. The pH

≥ 6.0 spreads along theTra Pho canal, Quoc Phong canals and in-field canals that are intersecting with the Ha Giang canal branches in two directions: towards the end of Ha Giang canal which intersects with the Rach Gia - Ha Tien canal, and towards Nong Truong canals. Finally, acidic water is gradually led to the West Sea (the aluminum variations are found in Figure 4). The main discharge direction is along the Ha Giang canal towards Rach Gia - Ha Tien canals and then emptying into the West Sea. The intra-field canals to be affected with aluminum water because of the Hau river tides and the acidic water will move and spread out at the low tides.

In June: From the first of June to the middle of June, the pH usually fluctuates from 6.01 ÷ 6.12 at cross-section 28 and from 6.02 ÷ 6.15 at cross-sections 29A & 30A. This is the small spreading area from the upstream and downstream of the Ha Giang culvert. However, the pH ≥6.0 spreads relatively largely to both left and right banks of Ha the Giang canal towards the Giang Thanh River and the Nong Truong canal. At cross-section 34, from the first of June to the middle of June, the pH ranges from 6.57 ÷ 6.75. At cross-section 34 (the Nong Truong canal), because this region is high in intra-field canals, the alum spreading reduces regardless of an in-situ amount of alum existence, but due to the additional rainfall for the region that has diluted alum, in the majority of the area, the pH> 6.0 significantly increase compared to that of in the Ha Giang canal.

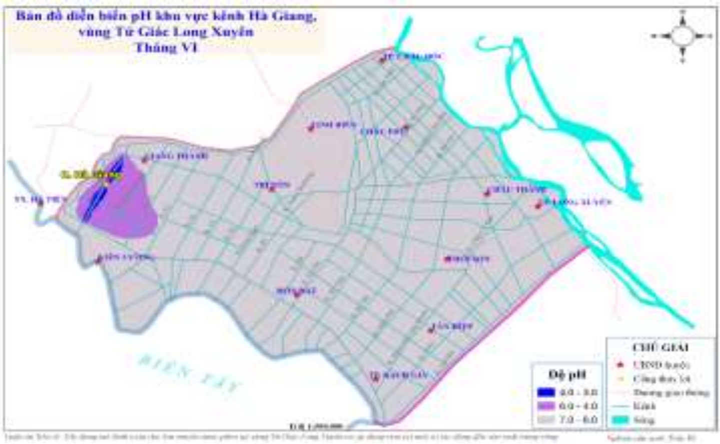


Figure 4: The map of aluminum variations in June

Spatial changes:

In June, the spread of aluminum water in the canal heavily depends on the rainfall situation of the region and the discharge of acidic water in each area. The water in the canals starts to be sour from the second half of May. Because the water level of the Ha Giang canal is higher than the surrounding canals, the acidic area with pH ≥ 6 develops widely in the service area of the Ha Giang canal in the Kien Giang province and in the land of the Giang Thanh district and the Ha Tien city, then gradually decreases following the increase of rains, because the amount of the supplement rainwater for the region will gradually dilute and narrow the acid water area towards the Rach Gia - Ha Tien canal and then empty it to the West Sea. The sour center occurs on the land of the Ha Tien quadrangle due to the poor drainage conditions here which comes from 2 main problems: lack of water to push out acid water and lack of drainage outlets.

It can be said that in June, when heavy rains start, there will be an additional amount of rain water that dilutes the acidic ions and causes the pH to gradually increase. In most of Ha Tien quadrangle at this time the pH = 6.0 is not high, mainly in Ha Giang canal, the pH ≥ 6.75 spreads to the region around the Ha Giang canal with a fairly large coverage, then this amount of alum water emerges from the beginning to the end of the canal axis and to other canals like the Tra Pho canal, Quoc Phong canals, in-field canals, and towards the Rach Gia–Long Xuyen canal. The sour decrease mainly directs along the Ha Giang axis canals to the West Sea.

Here, aluminum water is gray or mossy and contains significant alluvial particles, with a relatively high pH of 6.01 ÷ 6.75. The reason is that there is rain and alluvial water flowing through the Hau River at the time that dilutes aluminum ions which makes alluvial particles in the water precipitate. The water here is both slightly diluted with inherent aluminum and contaminated with "foreign" alum from the upstream of the canal.

At cross section 34, from the first of June to the middle of June, the pH fluctuates at 6.57 ÷ 6.75, which is present in the Nong Truong canal because the spreading to this location was far from the calculated aluminum source, thus the aluminum water in infield canals where the spreading stream passes is affected by rainwater and in-situ water as well as water coming from the Vinh Te canal which dilutes the pH.

The direction of the alum flows in the Long Xuyen quadrilateral deriving from the field surface in the rainy season (in-place showering rains and overflowing runoff) and flowing into infield canals continues flowing into the main canal axis and into tthe Rach Gia - Ha Tien canal and then drains to the West Sea through the saline estuaries as described above.

The correlation of pH, water level and time: Compared with the Dong Thap Muoi region, the water regime in the Long Xuyen quadrangle differs in terms of flood regime, rain regime, quality of aluminum water and aluminum washing capacity. Regarding the rainfall regime: In the Long Xuyen quadrangle, there is the concentration of heavy rainfall. The statistics for many years show that the total rainfall is about 2,100 ÷ 2,200 mm, the biggest is in the rainy season, which accounts for 90 ÷ 93% of the total rainfall of a whole year.

Figure 5: The variations in the pH and water levels over time, at cross-section 96 (branch 30) in May

The highest annual rainfall in Rach Gia is 2,136 mm, Ha Tien is 1,995 mm, the Tan Hiep is 1,841 mm, the Long Xuyen is 1,599 mm, and Chau Doc is 1,254 mm, etc. The average rainy days per year is quite high, the Rach Gia has 159 days, the Tan Hiep has 131 days, the Long Xuyen has 120 days, and the Chau Doc has 107 days.

About 80% of the total rainfall appears in the rainy season. Rains start early (April) and last until December. The arrival of rains is very quick (because it is near the sea). With such the rainy regime, it is favorable for the aluminum washing at the beginning of the crop and convinient for the arrangement of the seasonal crop.

Based on the calculations on the pH variation charts over time (in May & June) and the pH variation charts upon the water levels (in May, June), we can see that in May, when rains start, the pH increases gradually from approximately 3 ÷ 5 (within 10-15 days in May) to June. When it rains a lot and the water levels highly increase, the said ions are diluted by the increasing water, causing the pH to increase gradually and reach the value from 6.01 upwards in June.

Figure 6: The changes in the pH and water levels over time, at cross-section 96 (branch 30) in June

Sulphate value: Most of the sulphate values in the water in this region is lower than the standard, QCVN 39:2011/BTNMT (600mg/l) for irrigation water and the SO_4^{2-} is calculated from 0.49 mg/l ÷ 82.40 mg/l. Particularly at cross-sections 29A&30A, the sulphate much more exceeds QCVN 39:2011/BTNMT, showing that the water source in these locations is contaminated with salt.

Total iron value: The total iron value in 2016 ranged from 0.25 1.35mg/l, except 02 cross-sections (28 & 32) which tended to be higher than other cross-sections and tended to increase at the beginning of the rainy season because the alum was washed from the field surface to the water source that caused the iron increase.

3.3. MEASURES PROPOSED TO IMPROVE ALUMINUM-AFFECTED SOILS

The following solutions are proposed to minimize pollution and alum affection:

Use fresh water supplied from irrigation works to wash aluminum:

The simulations of alum variations in April and May show that the alum source increases the pH and diffuses aluminum along the Ha Giang canal, and after rains, the aluminum dilution and the water runoff increases the pH in June. The improvement of the water quality affected by the aluminum contamination in April & May for Long Xuyen quadrangle can be accomplished by operating a cluster of irrigation works along the West Coast, with 30 one-direction sluices. For the study region – the Ha Giang canal, we can work on the Dam Chich dam, Ha Giang sluice and Than Nong sluicinum to improve the water quality.

Take advantage of tides to wash aluminum and trap aluminum: The scientific basis of the water method to trap aluminum is to retain a layer of water on the field surface. The effect of the water layer on the fields is dissolving and reducing the aluminum concentration on the field surface and in the topsoil, and at the same time, we can make use of the vertical infiltration to bring toxins in the soil layers down to the aquifer. The acid sulfate soil to be flooded will cause the toxins here change in good favor for the plantation and make the pH in the soil rise.

Manage and control the aluminum-producing source due to soil excavation and backfilling…

CONCLUSIONS AND RECOMMENDATIONS

- **Conclusions:**

This doctoral thesis utilizes the simulation model and collected data to come up with a systematic way to study the spread of aluminum water from the fields to the canal system. The most important parts of the thesis research results can be summed up as follows:

- Contribute to the identification of the origin, pattern of aluminum formation and causes of alum, physicochemical and physical properties of acid sulfate soil, the rules of variation and spread of major toxins on acid sulfate soils in the Long Xuyen quadrilateral.

- Contribute to the identification of the chemical balance in acidic water in the Long Xuyen quadrilateral which are Jurbanite and Jarosite etc. and establish a mathematical model to simulate the spread of acidic water on canals, rivers and fields.

- Initially develop a calculation module in the Delta model (one-dimensional hydrodynamics - ACID2020 computer program) to calculate some typical parameters for aluminum water in the river/canal system of the Long Xuyen quadrilateral.

ACID2020 computer program developed is an instrument for the computerization of the spreading of aluminum (or iron) water in rivers and canals (mainly at the beginning of the rainy season). This version is completed in March 2020. It includes the subroutines for calculating aluminum Al^{+3}, sulphate SO_4, or iron Fe based on the algorithms and the codes of DELTA software developed by Prof. Dr. Nguyen Tat Dac who is the author of these subroutines, with the association of the author under the guidance of Prof. Dr. Nguyen Tat Dac.

- Based on the calculations of ACID2020 program, the thesis has provided reasonable solutions to renovate, utilize and manage soil and water on acid sulfate soils in the Long Xuyen quadrangle in line with the strategic agricultural economic development and the sustainable environmental protection.

- The model's calculated results discovers the quite qualitative reasonability, after comparing with the experimental results of previous studies. It can be used as a scientific base for successive research works on land use and soil improvements, which effectively helps to wash aluminum for the areas of heavily acidic soils.

- The results of the thesis will be a reference document for the managers who will be considering and proposing socio-economic development goals and land-use planning as well as the water resource managers in the acid sulfate soils of the Long Xuyen quadrangle.

Summary: The study results help to determine the rule of dispersion of the main toxins on acid sulfate soils in the Long Xuyen quadrilateral and the toxic effects on the agro-ecosystem. On the other hand, the aluminum water stoichiometry, Jurbanite and Jarosite, and ACID2020 computer program have been finalized, which are the instruments to calculate the spreading of aluminum (or iron) water in rivers and canals (mainly at the beginning of the rainy season).

Recommendations:

The research results have initially brought the right track to approach the mathematic problem in solving the aluminum spreading for the Long Xuyen quadrangle and proposed solutions to manage and develop the potential of acid sulfate soils in the Mekong Delta. However, in order to solve the sustainable planning and development mathematic problems in this land, further researches and developments are of necessity as follows:

(1) Research to map soil physicochemical parameters for different acid sulfate soils in the Mekong Delta for the sustainable development planning;

(2) Apply to study technical solutions to the water drainage and management problem on acid sulfate soils;

(3) Research to expand the linkage model between the soil substance transfer problem and the non-conservative substance transfer problem in the canal networks;

(4) Research to develop a management process of construction work system and agricultural solutions to restrain the re-pollution on acid sulfate soils./.