

THE SOFTWARE SUPPORTING SEMI-QUANTITATIVE SOIL CLASSIFICATION OF VIETNAM

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Abstract. Soil classification is essential in mapping soils, land evaluation, and sustainable soil usage. Nowadays, along with the Industrial Revolution 4.0, there is an interest in the development and promotion of information technology in classifying soils. This paper aims to introduce the software supporting soil classification of Vietnam (ICSM) according to the semi-quantitative soil classification system of Vietnam and to apply it to classify the BTGD-06 soil profile as a pilot example. It consists of three main components: (1) Menu and toolbars, (2) Tabs to input data, and (3) suggesting and identifying blocks. It was also applied successfully to classify five soil profiles in Vietnam and illustrated by classifying the soil profile BTGD-06. The results of the trial classification are the same as those published in the Journal of Vietnam soil science about the diagnostic horizons, soil group, soil type, soil subtype, and soil variety. The algorithms used in developing the software can be used to write other quantitative soil classification software worldwide.

Keywords: soil classification, Ferralsols, software, algorithm, Vietnam.

1. Introduction

Almost all countries have their soil classification systems, for example, the soil classification system of Australia [1], Japan [2], China [3], Russia [4], and the USA [5]. Big countries usually have diverse soils; thus, their soil classification systems are vast and complex. The soil classification system of Russia has eight levels, including Trunk, Order, Type, Sub-type, Genus, Species, Variety, and Phase, and has 51 diagnostic horizons. The soil classification system of Japan comprises four levels: Great soil groups, Soil groups, Soil subgroups, and Soil series groups. The system has 10 great soil groups, 27 soil groups, 116 soil subgroups, and 381 soil series groups. The soil taxonomy of the USA includes six levels: 12 orders, 64 suborders, above 300 great groups, above 2.400 subgroups, more than 8,000 families, and more than 19,000 series.

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To simplify and facilitate soil classification, a few countries have applied information technology. It is seen that there are three trends in using information technology for soil classification, including (1) developing Apps running on smartphones, (2) developing software running on computers, and (3) developing websites. According to Kumar et al. (2015), the first trend employed the American Society of testing and Material Classification system to develop Apps for smartphones to classify soils using the particle variable [6]. Soft112 (2016) built Apps called Soil Classification XP 1.3 to support the classification of soils based on soil texture and stickiness. The Apps were usually used by geotechnical engineers [7].

According to the second one, Jacquier et al. (2000) developed software supporting soil classification in Australia called Open DELTA version 1.0 [8]. The software which was fully used for Australia's soil classification system consists of five levels: 14 soil orders, 84 soil suborders, 673 great soil groups, 12439 soil subgroups, and above 1,000,000 soil families. The software was designed as toolbars corresponding to soil classifying levels with an interface that allows classifying a specific soil type. Atajeromavwo et al. (2007) study is a typical one on software development supporting soil classification [9]. They concentrated on soil classification, information storage, access, and export. The relationships in the software were diagramed and designed to aid soil classification storage, access, and export. They addressed operators showing the procedures of soil classification, and information access techniques. Abu-Farsakh et al. (2008) developed the CPT (Cone Penetration Test) soil classification software by programming Visual Basic in an MS-Windows environment. It has been used in geotechnical fields and allowed for the testing of soil penetrability [10]. Khaddour et al. (2020) designed soil classifying tools using Python language in the ArcGIS environment. It allows the classification of soils based on soil texture [11]. The soil texture triangle used in the research is the United States Department of Agriculture triangle, which has 12 classification classes [12]. According to the third trend, a few websites allow the classification of soils based on soil texture. They include the United States Department of Agriculture website and the Centre for Environmental and Agricultural Informatics [13]. In summary, it is evident that the development of software or supporting tools for soil classification has not attracted much interest and is mainly focused on simple soil classification. Regarding the Apps or websites, the classification usually uses one criterion to implement as soil texture, organic matter, or organic carbon (SOC). The software supporting soil classification at the national scale is limited. The Open DELTA software is considered typical software supporting soil classification at a national scale. Each country has its soil classification system. Thus, it is difficult to apply a country's soil classification system support software in another country.

Up to now, the official soil classification system of Vietnam consists of the soil classification table of Vietnam for soil mapping of 1976 at the scale 1:1,000,000, upgraded in 2000 [14]; the one at scale 1:50,000 - 1:100,000; the one at scale 1:5.000 - 1:25.000 [15]. This is a qualitative soil classification system; therefore, it is difficult to transfer it into the international FAO soil classification system. Currently, there is no software supporting soil classification in Vietnam. The semi-quantitative soil classification system of Vietnam upgraded in 2022 comprises 25 main soil groups, 86

soil types, 492 soil subtypes, and soil varieties [16]. It allows favorable international soil information exchange. The procedure of soil classification according to the system has improved, and proven through classifying five different soils in Vietnam [17].

In summary, the soils of Vietnam are diverse and to better classify soils according to the semi-quantitative soil classification system of Vietnam, it is necessary to develop software supporting soil classification. With the advantages of the Industrial Revolution 4.0, strengthening the application of information technology to classify soils in Vietnam is an issue of interest. The study aids in generally introducing the structure of software supporting soil classification of Vietnam (version 1.0), validating the software by trial application for classifying the soil profile BTGD-06 in De Doa village, Dac So Mi commune, Dac Doa district, Gia Lai province, Vietnam.

2. Content

2.1. Materials and Methodology

2.1.1. Materials

As mentioned above, Vietnam's semi-quantitative soil classification system includes 25 main soil groups, 86 soil types, 492 soil subtypes, and soil varieties. The procedure of soil classification is illustrated in Figure 1 and Figure 2. These critical materials are theoretical bases for designing and developing the software.

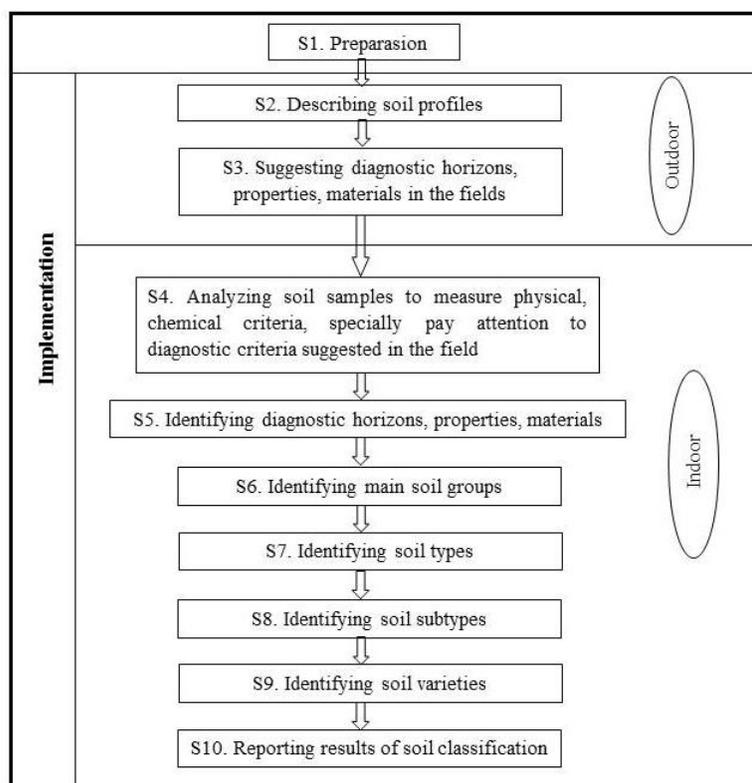


Figure 1. The procedure of soil classification according to the semi-quantitative soil classification of Vietnam [17]

2.1.2. Methodology

The programming language VB.NET based on the Winform platform was combined with ADO.net to make links with the database in MS.Access and was used to develop the software supporting the soil classification of Vietnam. The methodology that was developed to design and program the software includes four main steps: (1) Building a database of parameters for identifying diagnostic horizons, properties, materials, and main soil groups, soil types, soil subtypes, and soil varieties; (2) Calling the database to shape software interfaces with labels describing the parameters' names, text boxes, and combo boxes that allow inputting the parameters' values; (3) Suggesting and identifying diagnostic horizons, properties, and materials; (4) Suggesting and identifying main soil groups, soil types, soil subtypes, soil varieties (Figure 3). This methodology was formed based on the materials mentioned above. The parameters come from the criteria system determining diagnostic horizons, diagnostic properties, diagnostic materials, main soil groups, soil types, soil subtypes, and soil varieties according to the semi-quantitative soil classification system of Vietnam.

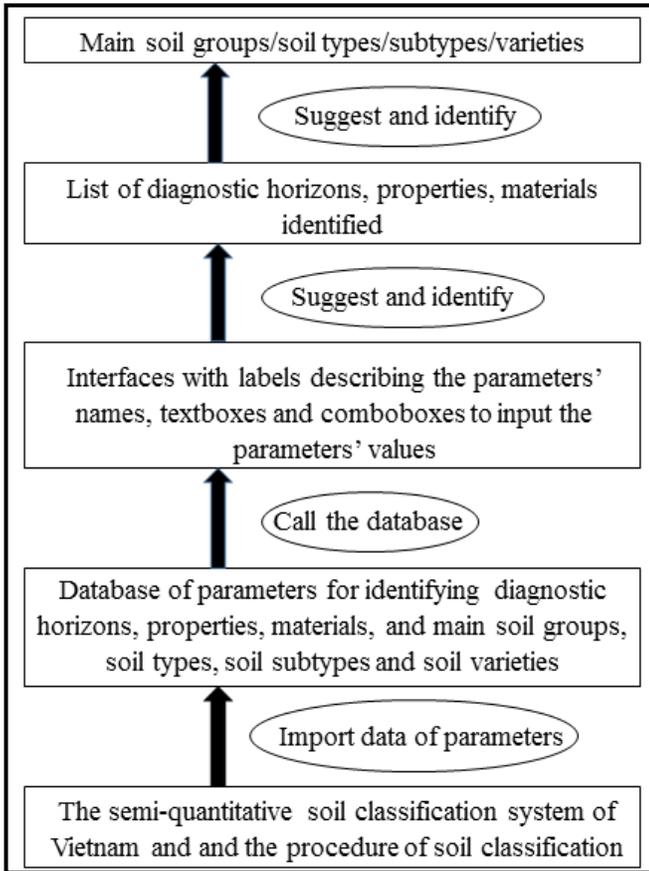


Figure 3. The methodology of design and development of the software

2.2. Algorithm and implementation

The database of parameters determining diagnostic horizons, properties, materials, main soil groups, soil types, soil subtypes, and soil varieties was built into the Access

software. In order to call data from the database of parameters to shape the software interfaces with labels describing the parameters' names, text boxes, and combo boxes that are used to input the parameters' values, the following algorithms were employed:

2.2.1. Input

Algorithms to call data from the database of parameters to shape the software interfaces:

(1) Listing all diagnostic horizons, properties, materials, and main soil groups into list boxes from the database (for example the diagnostic horizon list box named "listA_TangCD")

```
For j As Integer = 0 To dtA_TangCD.Rows.Count - 1
    listA_TangCD.Add(dtA_TangCD.Rows(j).Item("DoiTuongCD"))
Next
```

(2) Clearing available labels showing parameters on panels that determine diagnostic horizons, properties, materials, main soil groups, soil types, soil subtypes, and soil varieties (for example a diagnostic horizon named "TangCD")

```
XtraScrollable_TangCD.Controls.Clear()
```

(3) Considering all records in the related datasheet (for example a diagnostic horizon datasheet named "GridcontrolA_dt") and add controls and their values on a panel (for example labels of diagnostic horizon named myLabel)

```
For i As Integer = 0 To GridcontrolA_dt.Rows.Count - 1
    If GridcontrolA_dt.Rows(i).Item("Bien").ToString() <> "" Then
        Dim myLabel As LabelControl = New LabelControl myLabel.Name = "Lbl" +
            GridcontrolA_dt.Rows(i).Item("ThamSo").ToString()
        myLabel.Text = (i + 1).ToString + ". " +
            GridcontrolA_dt.Rows(i).Item("ThamSo").ToString()
        If myLabel.Text.Length >= 183 Then
            myLabel.Text = Strings.Left(myLabel.Text, 175) + "..."
        End If
        myLabel.ShowToolTips = True
        myLabel.Location = New Point(x + 15, y + 13)
        myLabel.ToolTip = GridcontrolA_dt.Rows(i).Item("ThamSo").ToString()
        XtraScrollable_TangCD.Controls.Add(myLabel)
        Dim myLabel1 As LabelControl = New LabelControl
        myLabel1.Text = (i + 1).ToString
        myLabel1.Location = New Point(x + 1072, y + 13)
        XtraScrollable_TangCD.Controls.Add(myLabel1)
    End If
Next
```

2.2.2. Output

** Algorithms to show lists of suggested and identified outputs of diagnostic horizons, properties, and materials*

(4) Removing the diagnostic objects from the list

If BienTong = 0 Then

 MessageBox.Show("KHÔNG phải là "" + DoiTuongCD + """, "Thông báo",
 MessageBoxButtons.OK, MessageBoxIcon.Error)

For i As Int16 = 0 To ListBoxABC.ItemCount - 1

 If ListBoxABC.Items(i).ToString = DoiTuongCD Then

 ListBoxABC.Items.RemoveAt(i)

 Exit For

End If

Next

(5) Adding the matching objects into the list (for instance, the diagnostic object is DoiTuongCD)

ElseIf BienTong >= 1 And BienTong Mod 100 <> 0 Then

 MessageBox.Show("Khắc định là "" + DoiTuongCD + """, "Thông báo",
 MessageBoxButtons.OK, MessageBoxIcon.Asterisk)

For i As Int16 = 0 To ListBoxABC.ItemCount - 1

 If ListBoxABC.Items(i).ToString = DoiTuongCD Then

 ListBoxABC.Items.RemoveAt(i)

 Exit For

End If

Next

 ListBoxABC.Items.Add(DoiTuongCD)

(6) Warning “Not enough data to conclude”

Else

 MessageBox.Show("Không đủ dữ liệu để kết luận có phải là " + vbNewLine + "" +
 DoiTuongCD + "" + " hay không", "Thông báo", MessageBoxButtons.OK,
 MessageBoxIcon.Question)

End If

** Algorithms to suggest the main soil groups*

(7) Considering all records in the datasheet and suggesting main soil groups

For j As Int16 = 0 To ListBoxControlD.ItemCount - 1

 If ListBoxControlD_UuTien.Items(i) = ListBoxControlD.Items(j) Then

 Dim theIndex As Int16 =

 ListBoxControlD.Items.IndexOf(ListBoxControlD.Items(j))

 If i = ListBoxControlD_UuTien.ItemCount Then

 ChoPhepChayListboxSelectedIndexChanged = 1

 End If

```
        ListBoxControlD.SetSelected(theIndex, True)
    End If
Next
    * Algorithms to identify main soil groups/soil type/soil subtype/varieties
    (8) Repeating the algorithms from (2) to (3) for objects consisting of the main soil groups, soil types, soil subtypes, and soil varieties.
    (9) Confirming and showing “This is not the soil group/soil type/soil subtype/variety it has been considering”
    If BienTong = 0 Then
        MessageBox.Show("KHÔNG phải là "" + DoiTuongCD + """, "Thông báo",
            MessageBoxButtons.OK, MessageBoxIcon.Error)
        XtraTabPage_EDonViDat.PageEnabled = False
        XtraTabPage_FDVDphu.PageEnabled = False
        XtraTabPage_GchungDat.PageEnabled = False
        KetLuanD = False
    (10) Confirming and showing “This is the soil group/soil type/soil subtype/variety it has been considering”
    ElseIf BienTong >= 1 And BienTong Mod 100 <> 0 Then
        MessageBox.Show("Khẳng định là "" + DoiTuongCD + """, "Thông báo",
            MessageBoxButtons.OK, MessageBoxIcon.Asterisk)
        ListBoxControlD.UnselectAll()
        ListBoxControlD.SetSelected(ListBoxControlD.Items.IndexOf(DoiTuongCD),
            True)
        XtraTabPage_EDonViDat.PageEnabled = True
        KetLuanD = True
    (11) Warning “Not enough data to conclude”
    Else
        MessageBox.Show("Không đủ dữ liệu để kết luận có phải là " + vbNewLine +
            "" + DoiTuongCD + "" + " hay không", "Thông báo",
            MessageBoxButtons.OK, MessageBoxIcon.Question)
        ListBoxControlE.Items.Clear()
        ListBoxControlF.Items.Clear()
        XtraTabPage_EDonViDat.PageEnabled = False
        XtraTabPage_FDVDphu.PageEnabled = False
        XtraTabPage_GchungDat.PageEnabled = False
        KetLuanD = False
    End If
End Sub
```

End If

KhoiTao_ListboxE()

Besides the main statements mentioned above, the statements New OleDbDataAdapter, System.IO.File.Copy, and Update were applied to build buttons on the toolbar such as Open available project, New project, and Save project.

2.3. Results

2.3.1. Structure and interface of the software

The software structure was designed in Figure 4. It is a database and modules to suggest and identify diagnostic horizons, properties, materials, main soil groups, soil types, subtypes, and varieties. The database allows experts to suggest them. Parameters from diagnostic criteria on horizons, properties, materials, and main soil groups, soil types, subtypes, and varieties are imported to make a database.

Generally, the software includes three main components: (1) Menu and toolbars, (2) Tabs to input data (inputs), and (3) suggesting and identifying blocks (outputs) (Figure 5). The menu and toolbars are at the top with the buttons as Open available project, New project, Save project, export data, manual. The input part is located at the center of the software interface. It is organized based on tabs according to seven modules: (1) Module for suggesting and identifying diagnostic horizons, (2) Module for suggesting and identifying diagnostic properties, (3) Module for suggesting and identifying diagnostic materials, (4) Module for suggesting and identifying soil groups, (5) Module for suggesting and identifying soil types, (6) Module for suggesting and identifying soil subtypes, (7) Module for suggesting and identifying soil varieties. The input data are stored in each database file. Four tabs, including the tab for suggesting and identifying diagnostic horizons, the tab for suggesting and identifying diagnostic properties, the tab for suggesting and identifying diagnostic materials, and the one for suggesting and identifying soil groups, are enabled as starting the software. The information and supplementary documents related to the software are shown below:

Hardware requirements: CPU Core I3, RAM 4GB, monitoring card 1GB; Program language: VB.NET based on the Winform platform was combined with ADO.net to make links with the database in MS.Access;

Software required: Operating system Windows (Windows 7 or higher), Net framework 4.0 or higher. It requires Windows number formats under the international system (the dot “.” means decimal); Program size: 89,5 Mb;

The source codes are available for download at the link: https://drive.google.com/drive/folders/1_sI2NQy6NgKGGgx_WAJMWxGEZL9ZiVIP?usp=share_link.

Supplementary data to this article can be found online at: https://drive.google.com/drive/folders/13Ctb2Q6DK4Ga12dc2qvAsNylCWGEx2nq?usp=share_link: to download the software (free).

Research data on this article can be found online at: https://drive.google.com/drive/folders/1V8Fbkf1CS5PaeVp_k3w2cUuqKOGnLmK_?usp=share_link: to download the database file run test 13 soil profiles, of which five were mentioned in the paper.

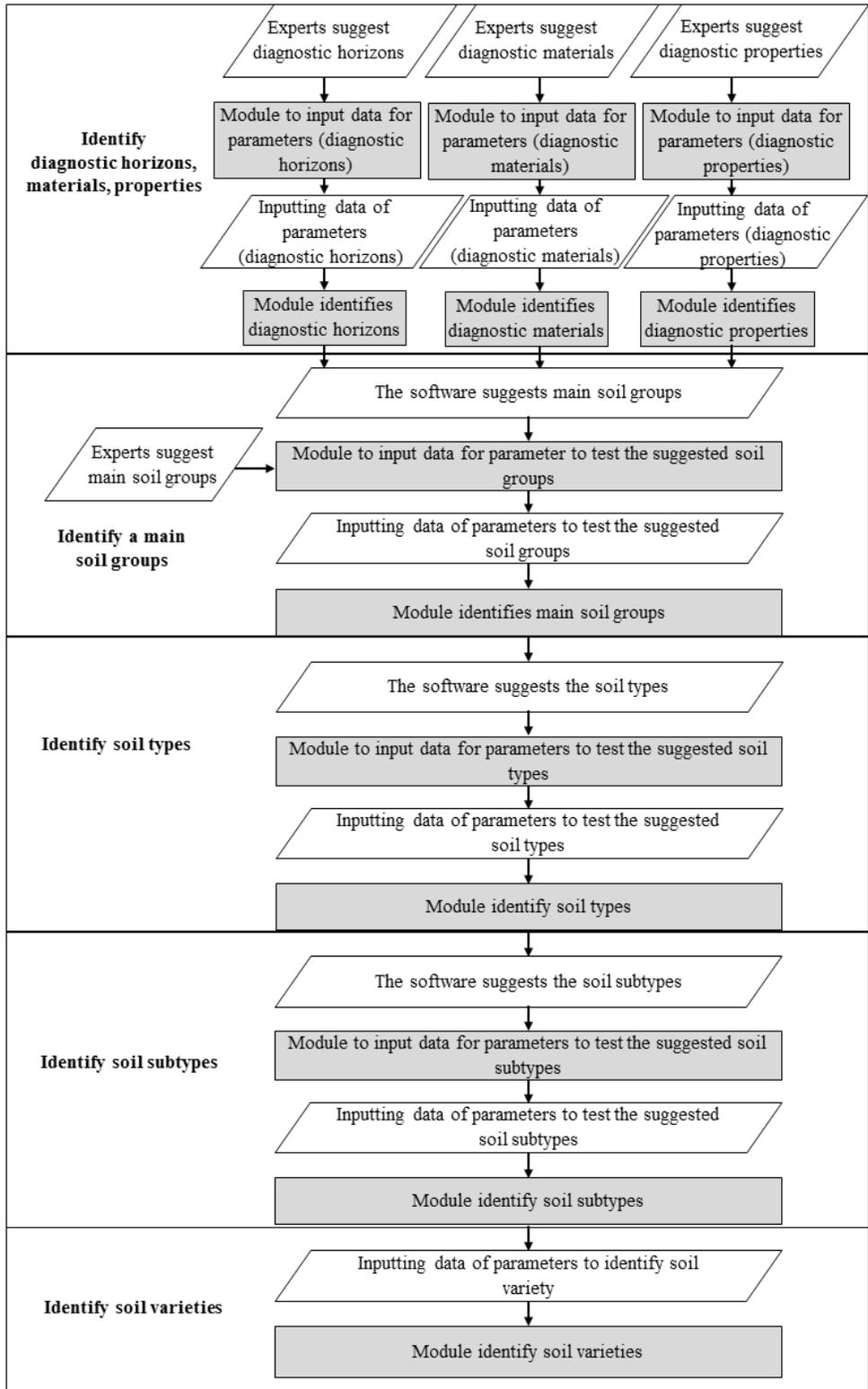


Figure 4. The structure of the software ICSM

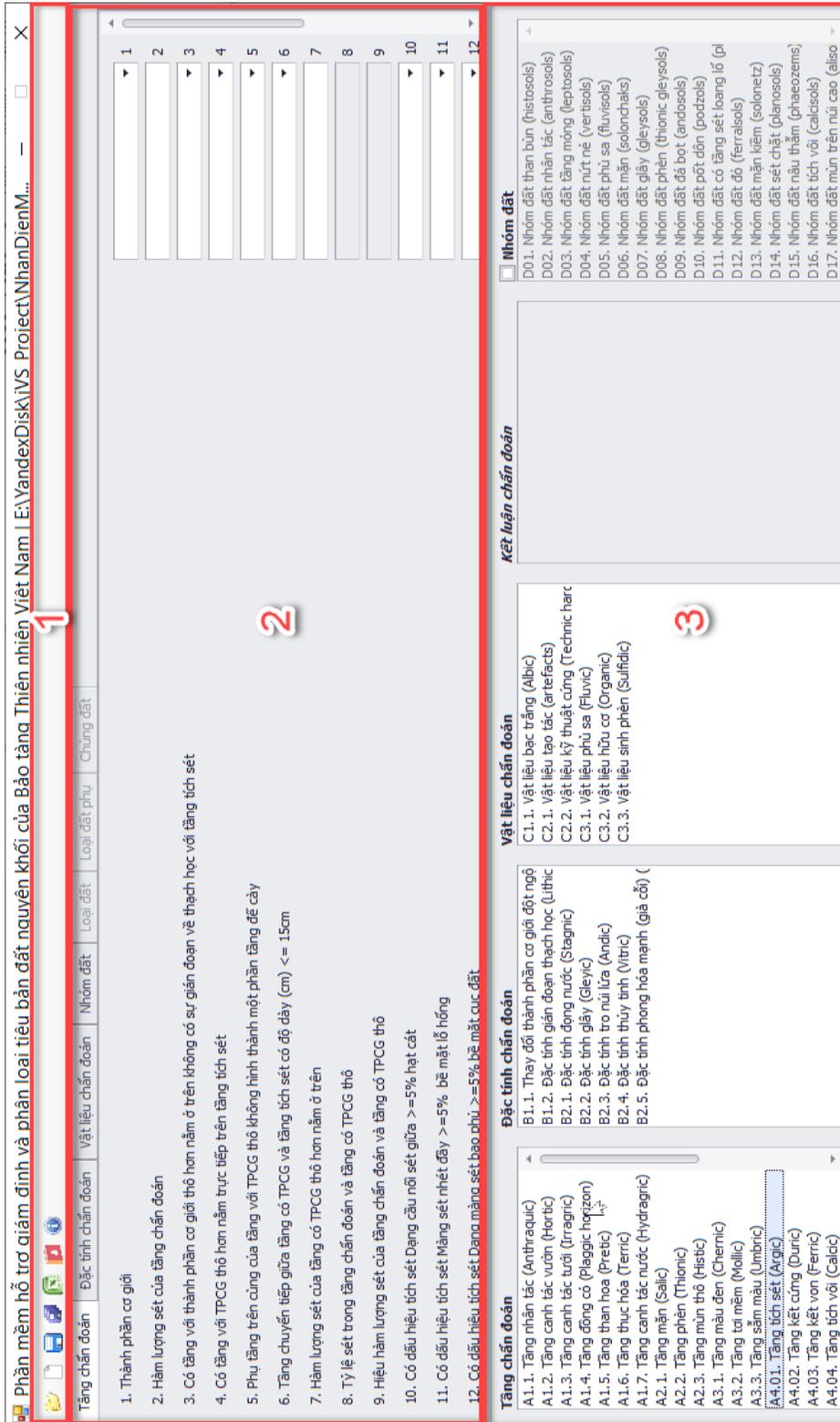


Figure 5. The main interface of the software

2.3.2. Results of trial application

The software ICSM was tested successfully for five different soil profiles in Vietnam. They are the soils in Vietnam's plain, coastal, highland, and mountainous regions [17]. However, the authors only illustrate the supporting ability of the software to classify soil through the classification of soil profile called BTGD-06 in the paper.

*** Information on soil profile BTGD-06**

Sign of soil profile: BTGD-06;

Location: De Doa village, Dac So Mi commune, Dac Doa district, Gia Lai province;

Coordinates: 14°09'33''N, 108°09'38''E; Elevation: 721 m; Slope: 3 – 8°;

Landform: Gentle plateau; Vegetation: Secondary forest; Date: 16/09/2020;

Surveyors: Nguyen Thanh Tuan, Ho Quang Duc, Lai Quang Trung, Le Anh Tuan.

The morphology of the soil profile is in Table 1.

The primary identification in the field showed three expected diagnostic horizons consisting of the mollic horizon, Cumbria horizon, and ferric horizon, and two expected diagnostic properties: andic property and vitric property in the soil profile.

Table 1. Description of the soil profile BTGD-06

| Soil depth | | Description |
|------------|------------|--|
| Sign | Depth (cm) | |
| Ah | 0 - 30 | Dusky red with Hue 2.5YR 3/2 (moist), Hue 10R 3/3(dry); slightly moist; clay; granular structure; slightly sticky; mixing few roots with the diameter 0.1 - 3 cm; there is a little litter on the soil surface; a few termite, wormholes; mixing few charcoals with diameter 0.5 cm; horizon boundaries are clear according to soil color and root mixing level. |
| Bw1 | 30 - 60 | Dark reddish brown with Hue 2.5YR 3/4 (moist), Hue 5YR 3/4 (dry); slightly moist; clay; coarser granular structure; slightly sticky; mixing a few roots with the diameter 0.1 – 0.5 cm; a few termite, wormholes with diameter 0.1 – 20 cm; mixing a few charcoals and nodules with diameter 0.1 cm; horizon boundaries are clear according to soil color and root mixing level. |
| Bw2 | 60 - 110 | Dark red with Hue 2.5YR 3/6 (moist), Hue 5YR 3/4 (dry); slightly moist; clay; sticky, coarser granular structure at the horizon; scattering small roots with diameter 0.1 - 1 cm; scattering nodules manganese with diameter 0.5 – 1 cm; horizon boundaries are gradual according to soil color and root mixing level. |
| BC | 110 - 130 | Reddish brown with Hue 10YR 3/4 (moist), Hue 2.5YR 4/4 (dry); slightly moist; clay; sticky; granular structure; no effervescence. |

*** Analyzed results of soil samples of the profile BTGD-06**

The analyzed results of 28 criteria for four soil samples collected according to four horizons are shown in Table 2. The criteria include soil moisture, texture, bulk density, pH, organic carbon, CEC, base saturation, exchange acidity, electric conductivity, Cl^- , SO_4^{2-} , available phosphate, and active iron were analyzed by using the Vietnam standard (TCVN); Water-dispersible clay, $CaCO_3$, and free iron were analyzed following the procedure of Soils and Fertilizers Research Institute (Vietnam) [20]. The mineralogical analysis of particle sizes of 0.05 – 0.2 mm was done according to the procedure of Mehba and Jackson (1960) [21].

Table 2. Analyzed results of soil samples according to soil horizons in the profile BTGD-06

| SD (cm) | BD (g/cm ³) | Porosity (%) | CF(%) | Particle fraction (%) | | | | WDC (%) | SM (%) |
|------------|----------------------------|-----------------|-------|-----------------------|-------|-------|-----------|------------|-----------|
| | | | | Sand | Silt | Clay | Fine clay | | |
| 0-30 | 0.73 | 73.24 | 0.78 | 28.91 | 14.39 | 56.70 | 27.82 | 48.50 | 22.68 |
| 30-60 | 0.99 | 63.25 | 0.59 | 15.33 | 11.42 | 73.25 | 37.95 | 65.35 | 57.25 |
| 60-110 | 1.17 | 57.85 | 5.72 | 14.26 | 17.03 | 68.71 | 38.57 | 57.80 | 31.02 |
| 110-125 | 1.19 | 57.38 | 0.71 | 19.02 | 21.43 | 59.55 | 38.44 | 54.00 | 29.35 |

SD: soil depth; BD: bulk density; CF: coarse fragments; WDC: Water-dispersible clay;

SM: soil moisture

| SD (cm) | pH _{H2O} | OC (%) | P ₂ O ₅ (%) | Avail. P ₂ O ₅ (mg/kg) | Ca ²⁺ | Mg ²⁺ | K ⁺ | Na ⁺ | Al ³⁺ | CEC _{soil} |
|------------|-------------------|-----------|--------------------------------------|--|------------------|------------------|----------------|-----------------|------------------|---------------------|
| | | | | | (meq/ 100g soil) | | | | | |
| 0-30 | 4.52 | 4.31 | 0.259 | 0.971 | 1.15 | 0.71 | 0.475 | 0.01 | 0.711 | 13.83 |
| 30-60 | 4.94 | 2.15 | 0.123 | 0.511 | 2.21 | 0.26 | 0.006 | 0.23 | 0.117 | 6.11 |
| 60-110 | 5.48 | 0.71 | 0.149 | 0.456 | 1.24 | 0.21 | 0.096 | 0.00 | 0.048 | 3.52 |
| 110-125 | 5.71 | 0.71 | 0.132 | 0.536 | 0.67 | 0.07 | 0.075 | 0.04 | 0.046 | 3.16 |

SD: soil depth

| SD(cm) | CEC _{clay} | EA | Cl ⁻ | SO ₄ ²⁻ | EC (mS/cm) | CaCO ₃ | Free Fe | Active Fe | Free Al | Active Al | BS |
|---------|---------------------|------|-----------------|-------------------------------|---------------|-------------------|---------|-----------|---------|-----------|-------|
| | (meq/100g) | | (%) | | | % | | | | | |
| 0-30 | 16.41 | 1.80 | 1.69 | 0.241 | 0.16 | 3.50 | 0.127 | 0.0023 | 0.081 | 0.082 | 16.93 |
| 30-60 | 12.48 | 0.46 | 0.93 | 0.444 | 0.05 | 0.50 | 0.127 | 0.0011 | 0.040 | 0.057 | 44.22 |
| 60-110 | 7.35 | 0.12 | 0.94 | 0.307 | 0.19 | 3.60 | 0.206 | 0.0023 | 0.050 | 0.039 | 43.97 |
| 110-125 | 9.27 | 0.06 | 0.89 | 0.310 | 0.04 | 3.60 | 0.098 | 0.0010 | 0.017 | 0.028 | 26.91 |

SD: soil depth; EA: exchangeable acidity

| SD (cm) | Mineral composition (%) | | | | | | |
|----------|-------------------------|-----------|----------|----------|----------|--------|----------|
| | Quartz | Kaolinite | Gibbsite | Hematite | Goethite | Anatas | Ilmenite |
| 30 – 60 | 40 | 28 | 24 | ~1 | ~1 | 3 | 2 |
| 60 – 110 | 33 | 31 | 28 | 1 | 2 | 3 | 2 |

*** Results of soil classification of the profile BTGD-06**

The results of the BTGD-06 soil profile classification are shown by steps applied using the ICSM software as shown below:

Step 1: Identifying diagnostic horizons

As mentioned above, there are three expected diagnostic horizons: mollic horizon, umbric horizon, and ferralic horizon. The software indicated that there are two diagnostic horizons: (1) umbric horizon and ferralic horizon. Table 3, Table 4, and Table 5 are the identified outputs of these horizons in the form of tables. The first column of the tables is parameters to determine horizons; the second is values of these parameters of soil horizons coming from the profile; and the last is the preferred values of these parameters to determine diagnostic horizons.

Step 2: Identifying diagnostic properties

The software figured out that the profile has no Andic and Vitric diagnostic properties. Thus it has no diagnostic properties (Figure 6).

Table 3. Outputs exported from results of identification for a mollic horizon

| Parameters of the surface horizon | Horizon values | Reference values |
|--|-----------------------|-------------------------|
| Good soil structure that is not massive and hard when dry | True | True/False |
| SOC (%) | 4.31 | ≥ 0.6 |
| Munsell color: value ≤ 3 (moist), and ≤ 5 (dry), and chroma ≤ 3 (moist) | True | True/False |
| A parent material is present, and its color with a value ≤ 4 (moist) | False | True/False |
| A base saturation (BS) (%) | 16.93 | ≥ 50 |
| Directly overlying continuous rock, technic hard material, or petroplinthic horizon | False | True/False |
| A thickness (cm) | 30 | ≥ 10 cm |

Table 4. Outputs exported from results of identification for an Umbria horizon

| Parameters of the surface horizon | Horizon values | Reference values |
|--|-----------------------|-------------------------|
| Good soil structure that is not massive and hard when dry | True | True/False |
| SOC (%) | 4.31 | ≥ 0.6 |
| Munsell color: value ≤ 3 (moist), and ≤ 5 (dry), and chroma ≤ 3 (moist) | True | True/False |
| A parent material is present, and its color with a value ≤ 4 (moist) | False | True/False |
| A base saturation (BS) (%) | 16.93 | < 50 |
| Directly overlying continuous rock, technic hard material, or petroplinthic horizon | False | True/False |
| A thickness (cm) | 30 | ≥ 10 cm |

Table 5. Outputs exported from results of identification for a ferralic horizon

| Parameters of the subsurface horizon | Horizon values | Reference values |
|--|-----------------------|-------------------------|
| A texture class | Clay | Sandy loam or finer |
| Coarse fragments, concretions/nodules < 80% (by volume) | True | True/False |
| CEC (meq/100 g clay) | 12.48 | < 16 |
| A sum of exchangeable bases + exchangeable aluminum (meq/100 g clay) | 11.08 | < 12 |
| SOC (%) | 2.15 | ≥ 1,4 |
| Weatherable minerals belonging to the 0.05 – 0.2 mm fraction. | 0 | < 10 |
| No andic properties | True | True/False |
| No vitric properties | True | True/False |
| A thickness (cm) | 30 | ≥ 30 cm |

Step 3: Identifying diagnostic materials

There were no diagnostic materials expected in the field; thus it was not necessary to test step 3.

Step 4: Identifying main soil groups

After moving to step 4, the software suggested two soil groups related to the umbric horizon and one soil group related to the ferralic horizon. The two soil groups are the acid sulfate soil group (Thionic Gleysols) and the gleyic soil group (Gleysols). The last is the red soil group (Ferralsols). Consequently, the software identified that the soil profile BTGD-06 is the red soil group (Ferralsols). Table 6 shows the detailed data of parameters to identify and classify the red soil group (Ferralsols) exported from the software.

Step 2 mentioned that the soil profile BTGD-06 has the umbric horizon. Hence, the software outputs show that it is red-brown soil rich in humus (Umbrihumic Ferralsols).

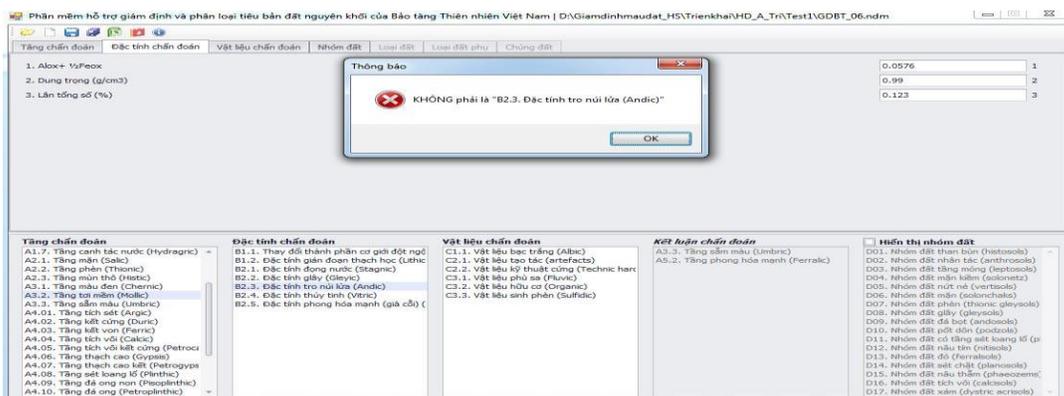
Step 6: Identifying soil subtype

The soil profile BTGD-06 has no argic horizon. Furthermore, the results mentioned above of soil sample analyses show that the sum of exchangeable bases and acidity of soil layer 25 – 100 cm is 4.06 meq/100g clay. The software pointed out that this soil is red-brown soil rich in humus and poor bases (Vetic Umbrihumic Ferrasols).

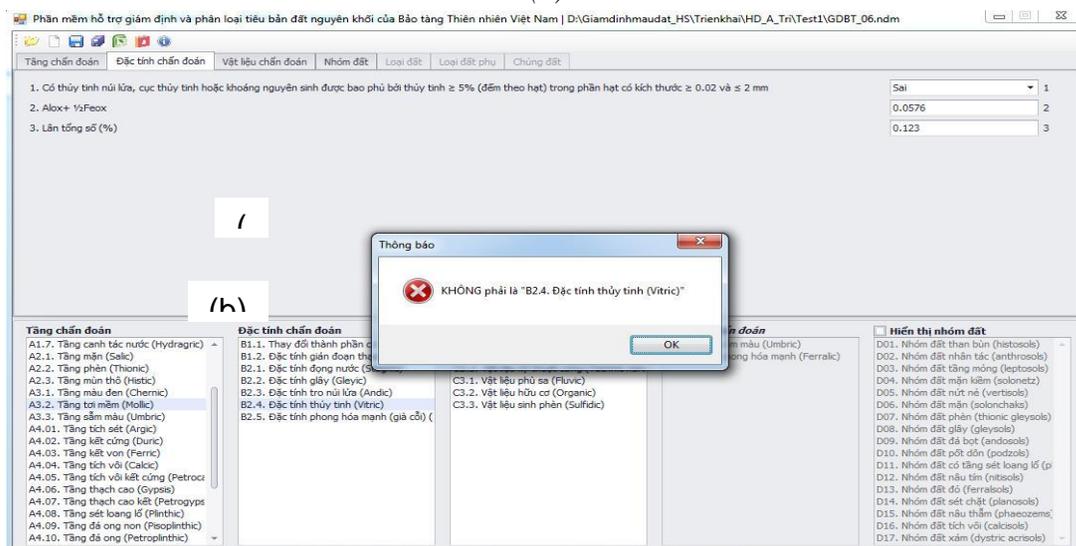
Step 7: Identifying soil varieties

The particle-size class below 0.02 mm in the soil surface layer is 71.09%, and the outputs of software identified that it is the red-brown soil rich in humus and poor bases, clay (Vetic Umbrihumic Ferrasols, (Clayic)).

The software supporting semi-quantitative soil classification of Vietnam



(a)



(b)

Figure 6. The output of testing the Andic property (a) and Vitric property (b)

Table 6. Outputs exported from results of identification for the red soil group (Ferralsols)

| Parameters of the soil profile | Horizon values extracted from a soil profile | Reference values |
|---|--|------------------|
| A ferralitic horizon | True | True/False |
| The soil depth where the ferralitic horizon starts (cm) | 30 | 0 < and ≤ 150 |
| No argic horizon above the ferralitic horizon | True | True/False |

2.4. Discussion

The software ICSM is only a supporting tool to classify soils according to the semi-quantitative soil classification of Vietnam. It makes soil classification faster and more

objective while possibly reducing mistakes as several criteria/parameters make it useful for making reports. Expert knowledge still plays a critical role and has a determinant effect during the procedure of soil classification. It is crucial for diagnosing in the field. This expert knowledge enhances the reliability of the soil classification results. Good experts on soil classification and sheets supporting the determination of diagnostic horizons, properties, and materials prepared in the field are crucial. Besides, the analysis of physical, and chemical criteria supporting soil classification should be done according to the analytical procedures addressed in the semi-quantitative soil classification of Vietnam 2021 [16]. Therefore, it is necessary to carry out the steps of testing the software for the soil profile BTGD-06 based on soil description in the field and results of soil sample analysis carried out in a laboratory.

It is difficult for us to estimate or compare the effectiveness of ICSM software with others such as Open DELTA because each software supports soil classification according to its system. It is impossible to apply the ICSM software to classify soils for other countries where the semi-quantitative soil classification of Vietnam is not accepted and used. However, the logic and methodology used to develop the ICSM software is an important basis for other countries to build their software for soil classification, or even develop software supporting the FAO (2014) international soil classification system. This is the reason why the ICSM software has a Vietnamese language interface.

Just like other software, the ICSM software requires continuous upgrading for soil classification in Vietnam. It is necessary to continue conducting research related to the semi-quantitative soil classification system of Vietnam to get it upgraded while also holding workshops to get new ideas toward officializing the system and the software ICSM.

The semi quantitative soil classification system of Vietnam is an opening system. Therefore, it can be updated according to new records on soil classification in Vietnam. However, the software is a closed system. Hence it is limited in terms of the number of diagnostic horizons, properties, materials, and the number of main soil groups, soil types, soil subtypes, and soil varieties, which have been programmed into it. The same limitations are encountered in the Open DELTA software.

Despite the few evident limitations, the ICSM software is the first one in Vietnam and may be the second one to be deployed on a national scale after the Open DELTA software of Australia. It runs independently on Windows 7 or higher. It was used to successfully classify five different soil profiles in Vietnam [17], as seen in classifying the BTGD-06 soil profile. The results from the classification of soil profile BTGD-06 using the software are the same as the ones published in the Journal of Vietnam Soil Science, volume 63/2021 [22]. The BTGD-06 soil profile has two diagnostic horizons (the umbric horizon and ferralic horizon), belonging to the red soil group (Ferralsols), soil type: the red-brown soil rich in humus (Umbric Ferralsols), soil subtype: the red-brown soil rich in humus and poor bases (Vetic Umbric Ferralsols), soil varieties: the red-brown soil rich in humus and poor bases, clay (Vetic Umbric Ferralsols, (Clayic)). The outputs can be exported in an Excel file to support the writing of reports.

3. Conclusions

The ICSM software has a friendly interface and is easy to use. It has seven modules: (1) Identifying diagnostic horizons, (2) Identifying diagnostic properties, (3) Identifying diagnostic horizons, (4) Identifying the main soil groups, (5) Identifying the soil types, (6) Identifying the soil subtypes, (7) Identifying the soil varieties, and runs independently on Windows 7 or higher. The software supports fast, convenient, and objective soil classification according to Vietnam's semi-quantitative soil classification system. It was applied successfully for five different soils in Vietnam as evidenced by the classification of the soil profile BTGD-06. The soil profile belongs to the red soil group (Ferralsols), soil type: the red-brown soil rich in humus (Umbrihumic Ferralsols), soil subtype: the red-brown soil rich in humus and poor bases (Vetic Umbrihumic Ferrasols), soil varieties: the red-brown soil rich in humus and poor bases, clay (Vetic Umbrihumic Ferrasols, (Clayic)). The results are tallied with the previously published findings. Other countries in the world that use quantitative soil classification systems can employ the logic, methodology, and programming statements that were used to develop the software to build their software. Although the software is in the initial stages of use, it is necessary to deploy it widely to classify soils in Vietnam and also improve it. The system may further be programmed as an online soil classification system of Vietnam.

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REFERENCES

- [1] Commonwealth Scientific and Industrial Research Organisation (CSIRO), 2017. *The Australia Soil Classification*. http://www.clw.csiro.au/aclep/asc_re_on_line/soiusing.htm (accessed 6 August 2017).
- [2] Hiroshi, O., Yuji, M., Kazunori, K., Toshiaki, O., Yusuke, T., 2015. Review “Outline of the Comprehensive Soil Classification System of Japan - First Approximation”. *Japan Agricultural Research Quarterly*, 49 (3), pp. 217-226.
- [3] Huang J., Ebach M.C., Triantafilis J., 2017. Cladistic analysis of Chinese Soil Taxonomy. *Geoderma Regional*, 10, pp. 11-20.
- [4] Shishov, L.L., Tonkonogov, V.D., Gerasimova, M.I., Lebedeva, I.I., 2005. New Classification System of Russian Soils. *Eurasian Soil Science*, 38, pp. 35-43.
- [5] United States Department of Agriculture (USDA), 1999. *Soil Taxonomy: A Basic System of Soil Classification for Making and Interpreting Soil Surveys. Agriculture Handbook Number, 436* (Second edition).
- [6] Kumar, R., Dutta, R.K., Dutta, K., 2015. Mobile App using ASTM System of Soil Classification. *CPUH-Research Journal*, 1(2), pp. 49-53.
- [7] Soft112, 2016. *Soil Classification XP*. <https://soil-classification-xp.soft112.com/> (accessed 22 August 2022).

- [8] Jacquier, D.W., McKenzie, N.J., Brown, K.L., Isbell, R.F., Paine, T.A., 2000. *Interactive Key to the Australian Soil Classification Version 1.0*. CSIRO Publishing, 25 p.
- [9] Atajeromavwo, J.E., Tibi, E.U., Ugboh, O., 2007. Computer-Aided Design for Soil Classification Relational Database and Retrieval Techniques. *Indian Agricultural Research Journals*. 1(2), pp. 141-159. DOI: 10.4314/afrev.v1i2.41005.
- [10] Abu-Farsakh, M.Y., Zhang, Z., Tumay, M., Morvant, M., 2008. *Development of MS-Windows CPT Soil Classification Software*. Louisiana State University. <https://www.ltrc.lsu.edu/pdf/2008/08-0780.PDF> (accessed 24 December 2022).
- [11] Khaddour, R.H., Abdulrahman, A., Alasaad, A.M., 2020. Design a soil classification tool using Python in ArcGIS. *American Journal of Innovative Research and Applied Sciences*. www.american-jiras.com (accessed 24 December 2022).
- [12] Natural Resources Conservation Service Soils (NRCSS), 2022. *Soil Texture Calculator*. https://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/survey/?cid=nrcs142p2_054167 (accessed 20 December 2022).
- [13] Centre for Environmental & Agricultural Informatics, 2022. *Tools and utilities*. <https://www.landis.org.uk/services/tools.html> (accessed 20 December 2022).
- [14] Vietnam Soil Science Society (ASSS), 2000. *Vietnam Soils*. Agricultural Publisher, Hanoi, 411p (in Vietnamese).
- [15] Ministry of Science and Technology of Vietnam (MOST), 2012. *Procedure for investigating soil mapping at medium and large scale* (TCVN 9487:2012). Ministry of Science and Technology of Vietnam (in Vietnamese).
- [16] Tuan, N.T., Duc, H.Q., Bat, L.T., Tuan, L.A., Chien, N.Q., Trung, L.Q., Kyenze, S.K., Chi, T.T., 2022. Upgrading the Vietnam semi-quantitative soil classification system. *Vietnam Journal of Earth Sciences*. 1-19. <https://doi.org/10.15625/2615-9783/17245>.
- [17] Nguyen Thanh Tuan, 2021. Researching soil classification systems of Vietnam and soil identification of soil monoliths. *Report, Vietnam Academy of Science and Technology*, 352 p (in Vietnamese).
- [18] FAO, 2015. World reference base for soil resources 2014: International soil classification system for naming soils and creating legends for soil maps 3rd edition. *Food and Agriculture Organization of the United Nations*, Rome, Italy.
- [19] Georges, S., 2003. *Evolution of tropical soil science: past and future*. Workshop, Brussels.
- [20] Soils and Fertilizers Research Institute (SFRI), 1998. *Analysis handbook for soils, water, fertilizers, and crops*. Ministry of Agriculture and Rural Development (in Vietnamese).
- [21] Mehba, O.P., and Jackson, M.L., 1960. *Iron oxide removal from soils and clays by a dithionite-citrate system buffered with sodium bicarbonate*. Department of Soils, University of Wisconsin, Madison, Wisconsin.
- [22] Nguyen Thanh Tuan, Ho Quang Duc, Le Thai Bat, Le Anh Tuan, Ngo Quang Du, Lai Quang Trung, Tran Thuy Chi, 2021. Experimentally identifying a soil monolith for the Vietnam National Museum of Nature. *Journal of Vietnam Soil Science*. 63/2021, pp. 16-21 (in Vietnamese).