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# Topographic and flow direction model: a case study of Khuan Kreng peat swamp forest, Southern Thailand

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**ABSTRACT**

Floods and droughts are contrasting natural phenomena. The risk of forest fires tends to be increased by the dry and hot conditions of the dry season. A topographic and flow direction model is aimed to be created using Mathematica and ArcGIS programs. The purpose of this model is to assist in water management to prevent forest fires in the Khuan Kreng peat swamp forest located in Nakhon Si Thammarat Province, Southern Thailand. Digital elevation models obtained from the Department of Land Development, representing altitude data of the terrain at a scale of 1:4,000, are utilized in this work. Using cellular automata principles with eight sub-cell flow pathways with a precision of 5×5 meters, identification was carried out. The Universal Transverse Mercator (UTM) coordinate system can store horizontal (X, Y) and vertical (Z) data in one cell, providing information about 2D and 3D topography. Our findings regarding flow direction are comparable to reference values for summer under dry conditions, where water mass is limited. The topographic model data was found to be compatible with data obtained from ArcGIS, Google Maps, and surveys. The ArcGIS flow modeling results are found to be suitable for flood simulation. The proposed method is applicable for regulating water use during droughts and preventing forest fires.



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## 1. INTRODUCTION

The digital elevation model (DEM), also referred to as the digital terrain model, is a crucial prerequisite dataset for many applications, including map generation, three-dimensional geographic information system (GIS), environmental monitoring, and geospatial analysis. Different spatial resolutions and quality have been attained in the literature depending on the acquisition strategy; however, it can be based on survey data [1], [2]. A DEM is commonly represented as a rectangular matrix consisting of floating-point or integer values, which serves as a visual representation of the elevation of the land surface concerning specific reference points [3], [4]. DEM may be used in hydrology to determine the basin border and the direction of flow. Using the Arc Hydro tool in ArcGIS on a DEM effectively extracts the drainage network and basin borders and calculates the amount of freshwater present in the research location [5], [6]. With the improved resolution and accuracy in the spatial modeling of landscapes provided by DEM, and the various terrain variables generated from them, these terrain models have become an important information source for ecological studies. It will produce satisfactory results in the foothills of the natural basin, but there are restrictions on flat land [7]–[9].

The flow direction model indicates the direction of the water's movement, where it accumulates, how the water level changes, and where it receives water. This may be used for a variety of things, including drought control, water management for forestry, and agriculture. The most popular and extensively used approach, the D8 model, may be used to determine the flow direction. The most well-known D8 algorithm is arguably the basic version (how to find eight neighbors) [10]–[12]. The D8 algorithm is widely used on the raster-based dataset to illustrate the correlation and relationship of any particular pixel with its neighboring pixels in the water flow direction model [13], [14]. Each cell in the DEM is assigned a flow direction code based on the steepest downhill path to indicate the direction of flow. Flow dynamics modeling has been intensively investigated in terms of programming the use of cellular automaton rules to simulate flow direction and surface-flow concentration [15]–[17].

Cellular automata are discrete mathematical models used to simulate dynamic systems across diverse fields by dividing space into simple cells with predefined rules. Cellular automata have evolved into a powerful tool for understanding complex phenomena in a wide variety of scientific fields. More recently, in the domains of urban water and urban growth, studies [18]–[20] harnessed cellular automata in studies that exemplify their versatility in solving real-world challenges.

Floods and droughts are two distinct natural occurrences, whereby the possibility of wildfires is often increased in arid and hot conditions typical of the dry season. In case of floods, the Arc Hydro tool in ArcGIS on a DEM effectively extracts the drainage network. The objective of this novel work is to support water management endeavors aimed at averting wildfires in the Khuan Kreng peat swamp forest located in Nakhon Si Thammarat, Southern Thailand. Regulating the water table between +0.30 to +0.50 meters in the early summer period allowed for the maintenance of the water level in the swamp forest for 2–3 months, although it could decline to -0.20 meters in the late summer. Mathematica program was used to create 2D topographic, 3D topographic, and flow direction simulations using a DEM from the Department of Land Development at a scale of 1:4000 in the Khuan Kreng peat swamp forest. The cellular automata (CA) and the D8 algorithm were employed to describe water flow on a DEM surface. Water from a given cell could flow in one of eight output directions relevant to the eight adjacent cells in the framework of CA [21]. The mathematical simplicity in CA description was considered a significant advantage for modeling, rather than using systems of differential equations [22]. This work created based on a series of CA rules using Mathematica to manage the water to prevent forest fires.

## 2. METHOD

### 2.1. Case study

The Khuan Kreng peat swamp forest, with a total size of around 357.312 km$^2$, is Thailand's second-largest peat swamp forest. The highest risk areas for forest fires in Khuan Kreng were found in Amphoe Cha Uat and Amphoe Ron Phibun, Nakhon Si Thammarat, between December 2018 and February 2019. The occurrence of El Niño, also referred to as an atypical drought, exacerbated the forest fire conditions in the year 2019 compared to preceding years [23]. In addition to altering the watershed processes that regulate streamflow, soil erosion, nutrient export, and downstream water chemistry, wildfires frequently result in dramatic changes in the structure of forest plants and the conditions of the soil [24], [25]. The smoke produces carbon and other environmental emissions, making it one of the main contributors to extreme weather conditions that have a detrimental effect on production systems [26], [27]. Figure 1(a) depicts the research region in Southern Thailand, Nakhon Si Thammarat Province and Figure 1(b) depicts the Khuan Kreng peat swamp forest, Kreng Subdistrict, Cha-Uat District [28]. It has a 64 square kilometer area. In the ABCD frame, Point A represents 618000 E 882000 N, Point B represents 626000 E 882000 N, Point C represents 626000N E 874000 N, and Point D represents 618000 E 874000 N, which illustrates the UTM grid coordinates of the square ABCD simulation area.

### 2.2. Equipment

The Department of Land Development of the Ministry of Agriculture and Cooperatives (Thailand) provided us with DEM data at a scale of 1:4,000. In raster format ($Filename.img$), which consists of a total of twenty sections and 64 square kilometers divided into 5×5 square meters, or a total of 2,560,000 cells. Programs for the simulation and analysis results were created in ArcGIS 10.6, Google Earth Pro, and Mathematica 12. The simulation and analysis programs are made with the help of Arc Toolkit's Hydrology.

Hardware specifications for a computer include an Intel Core i9 (8-core), 2.3 GHz, Turbo Boost 4.8 GHz, DDR4 2400 MHz - 16 GB SSD PCle 512 GB, and 64.0 GB of installed memory (RAM). The operating system for software is Windows XP Profession. Mathematica software is known as a high-performance, high-level symbol, and numerical program. The functional programming style has also been used in a symbolic Mathematica program with 2D and 3D graphics. DEM can be collated as lists, making the data amenable to manipulation using functional programming algorithms. Functional language scripts are brief and more closely resemble traditional mathematical notation. We may modify circumstances to create a database for water management based on the context of the changing areas, and we can continue to model disaster risk areas near the area's actual conditions.

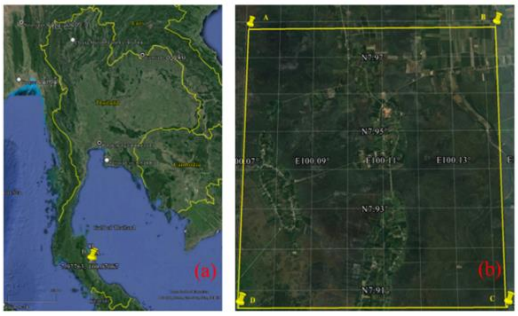



Figure 1. The study area of (a) Nakhon Si Thammarat province in Southern Thailand and (b) Khuan Kreng peat swamp forest

### 2.3. Method

In the first step, we used the mosaic function on the new raster of ArcGIS to merge every file and transfer DEM from the image to a $file.txt$. We then simulated the region using our method. For the 2D and 3D topographic models, simulation programs were developed based on an analysis of topographic features using DEM data. The simulation proceeds by calculating the altitude (Z) of the digital elevation model (DEM) at the Cartesian coordinates (X, Y) of each grid cell. By simulating the flow direction with cellular automata (CA) rules, we demonstrated how Mathematica defined the color scheme for the D8 rule to represent flow direction. The research process is illustrated in Figure 2, which depicts the flowchart. A small area of the DEM was selected to evaluate the flow direction model, using the Relief Plot function for the 2D topographic simulation. The simulation results for the study area's 2D topography are presented. Flow direction findings, consisting of eight potential directions, were derived from the DEM data. This enabled the development of a program to simulate water flow direction, ultimately identifying the flow from one cell to another.

Our approach utilizes both the D8 algorithm and CA rules to model water flow on a DEM surface using Mathematica. The directional codes for water flow were represented through specific colors and numbers: north (red-64), northeast (yellow-128), east (green-1), southeast (dark green-2), south (turquoise-4), southwest (light blue-8), west (blue-16), and northwest (violet-32). The Mathematica results for flow direction simulation in the study area were compared with ArcGIS, and the total cells accumulated with neighboring cells were calculated. Water accumulation analyses can help determine water paths and watersheds. In recent years, there has been increasing demand for accurate flow direction information for practical applications such as drainage network planning, agricultural activities, and related construction projects [29], [30]. In the flow direction model, the matrix position was checked using the MatrixPlot function, with the study area represented as a 1600×1600 square grid cell, as shown in Figure 3, which illustrates the simulation results in matrix form.

The flow direction in two-dimensional graphics of a 3×3 square grid cells for each direction from the center is implemented in the Mathematica program The raster code of the flow direction was shown in Figure 4(a) RGB color codes and Figure 4(b) RGB colors in decimal. The CA can be viewed as a discrete dynamical system in which space, time, and the states of the system. The space is represented by a regular lattice in one, two, or three dimensions. The states of the cells in the lattice can be updated according to a local rule. In other words, at a given time, the state of a cell depends only on its state and the states of its nearby neighbors at the previous time step. All cells on the lattice are assumed to be updated synchronously in parallel. Therefore, the state of the lattice advances in discrete time steps [31]–[33].

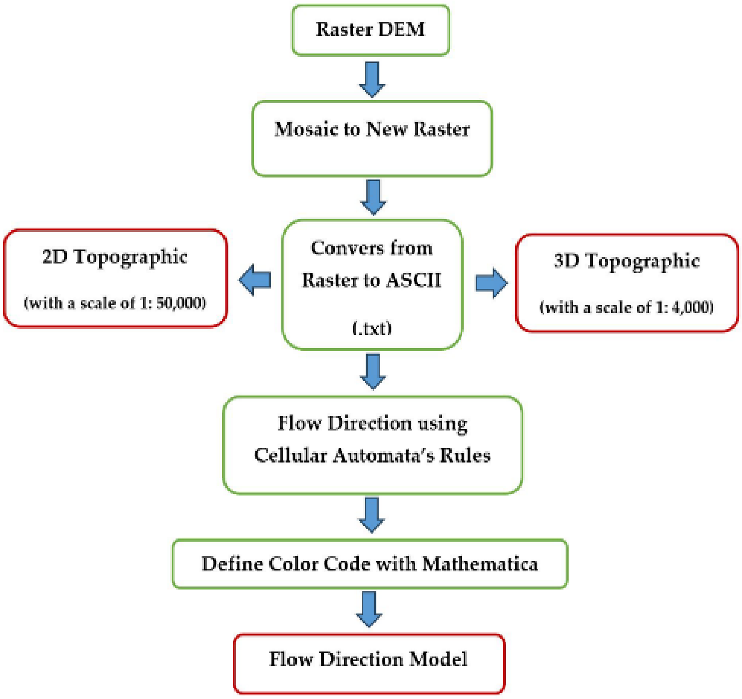



Figure 2. Flowchart of operation in this research

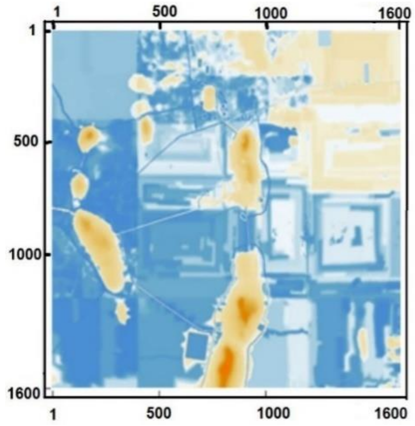



Figure 3. Simulation results of the matrix form

(a)

$$\begin{pmatrix} 32 & 64 & 128 \\ 16 & 0 & 1 \\ 8 & 4 & 2 \end{pmatrix}$$

(b)

Figure 4. The raster code of the flow direction: (a) RGB colors code and (b) RGB colors in decimal

D8 is effective, simple, and precise; therefore, almost all commercial software uses it for the computation of flow direction. The calculation of the cumulative flow of every cell to another cell with a lower slope which is the outlet point of water in the cells with high accumulation values [34]. The Mathematica program displays the elevation value assessment and the flow direction on the DEM. This is achieved by selecting the simulated area as a 6×6 square grid cell for testing the program. The program is composed by adopting CA rules and a D8 algorithm. The CA rules set is applied repeatedly to the DEM lattice involving a Moore function. The flow direction is from each pixel to its steepest downslope neighbor. We also demonstrate the reliability and validity of our programs through testing. The flow direction in all areas is calculated using CA rules, and the simulation results are displayed in both vector and raster formats. The flow direction in all areas is calculated according to the direction code numbers. In the example of DEM data, the simulation results are shown as vectors and raster models, as depicted in Figure 5.

The direction of flow of the central cell will be toward the cell having the lowest Z-value. The flow is accumulated by the input of the flow direction dataset computed before generating a drainage network. In this process, flow cells are identified that contribute to the generation of a drainage network. As the grid cells in boundaries have fewer than eight neighboring grid cells, the flow directions of those grid cells are regarded as having no value by convention. The matrix of flow direction transforms to the raster, is shown in Figure 6.

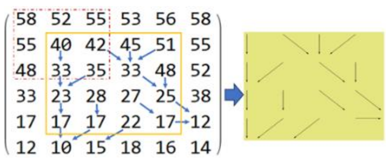



Figure 5. DEM in the matrix transforms to vector code of flow direction

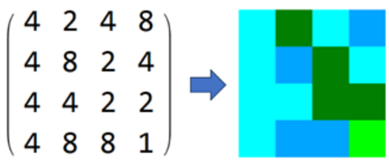



Figure 6. The matrix of flow direction transforms into the raster

## 3. RESULTS AND DISCUSSION

The results of this study demonstrate the effectiveness of using Mathematica and ArcGIS for topographic modeling and water flow simulation in the Khuan Kreng peat swamp forest, particularly in the context of drought conditions and forest fire prevention. The combination of 2D and 3D topographic modeling in Mathematica and flow direction analysis using both Mathematica and ArcGIS provides valuable insights into water management strategies. The research indicates that while the Mathematica-derived flow direction model is more accurate for dry season conditions, the ArcGIS model is better suited for simulating flood scenarios. This dual approach can inform future efforts in water management, especially in designing interventions like underground barriers to maintain soil moisture and prevent wildfires. The study's findings can be applied across various fields such as agriculture, forestry, and disaster management, making it a useful reference for both current applications and future research endeavors.

### 3.1. Topographic

Mathematica is easy to study and learn, and it is a very powerful calculation aid widely used in both education and research. It possesses distinctive features, including the ability to calculate complex equations. The topographic variations regarding elevation in a study area with 2D and 3D topography can be described by DEM using Mathematica. Creating an image with Mathematica software also allows for determining the near and far view. The area can be considered separately for more detailed topographical considerations. We plot the elevation of the study area as a 1600×1600 square grid cell, UTM 618000-628000 N and 874000-882000 E. This involves the case of a 2D topographic using the Relief Plot function. The results of the 2D topographic simulation program in the study area are depicted. The territory of 3 plots of Krajood forest is shown in Figure 7.

The areas represented by A, B, and C are Krajood forests, known as the main source of income for the communities in the area around the Khuan Kreng swamp forest. These areas are related to Google Earth Pro in Figure 1(b) and ArcGIS in Figure 7. In developed countries, forest fires are often caused by natural disasters, while in developing or underdeveloped countries, they are often caused by deliberate forest burning [35], [36]. In the Kreng Sub-district, the Krajood areas are burnt to produce new quality Krajood for basketry. For the case of a 3D topographic representation, we utilized the Listplot3D function. Simulation results of 3D topography with PlotRange set to Full are shown in Figure 8(a), and the region is delineated by a close-up in Figure 8(b), respectively. Geological unit representation, by honoring the functional programming paradigm, allows for the construction of catchment-scale 2D and 3D topographical models using short scripts that can be easily interpreted with limited programming experience. These models, rigorously supporting the data, can be used to determine the thicknesses and volumes of the regions and provide the conceptual framework for further investigations [37]. The Khuan Kreng Mountain is the tallest in the area, with a height of about 100 meters. This corresponds to the results of the ArcGIS program shown in Figure 6, with heights within the range of -2.78 to 110.21 meters in the areas. We can develop the 2D topographic map using ArcGIS, as shown in Figure 9. The predicate is defined by using a sequence of relational and logical operators to delineate the region of interest. The results of the 2D and 3D topographic simulation program in the watershed area of the Khuan Kreng peat swamp forest are relevant to the actual results, and a geographical map in Figure 1 and ArcGIS in Figure 9, along with 3D programming with Mathematica, can be zoomed in at high and low angles, as shown in Figure 8(b). During the field visit, the position calculated by the mathematical program can be analyzed based on the actual area, as depicted in Figure 10. The altitude ranges from approximately -2 to +1 meters. It can be observed from Figure 9 that most of the area is peatland below sea level, comprising low mountains such as Khuan Kreng, Khuan Yao, Khuan Pom, Khuan Sai, Khuan Teen, Khuan Rab, and Khuan Ching, interspersed with low hill areas (Phung Gan). The main thoroughfare within the Khuan Kreng swamp area consists of three large canals. Survey results indicate that the peat may have a depth of approximately 170 centimeters, significantly subsided due to drainage and sunlight-induced subsidence. Peat subsidence is evidenced by the decrease in water level and burns up to 60 centimeters. Since peat material is very dry, it ignites easily.

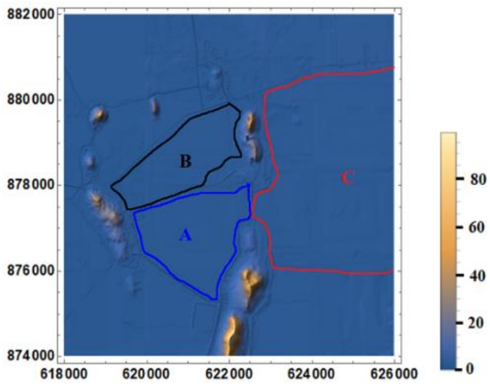
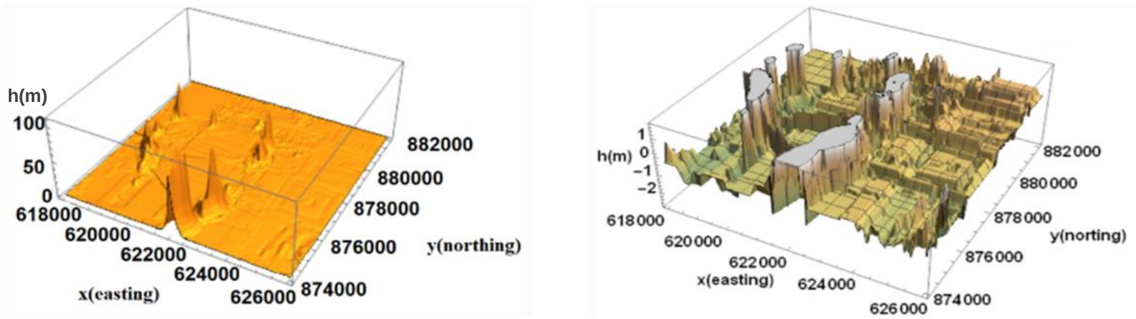



Figure 7. 2D topographic using Mathematica




(a) (b)

Figure 8. Simulation results of (a) 3D topographic and (b) 3D topographic by a close-up

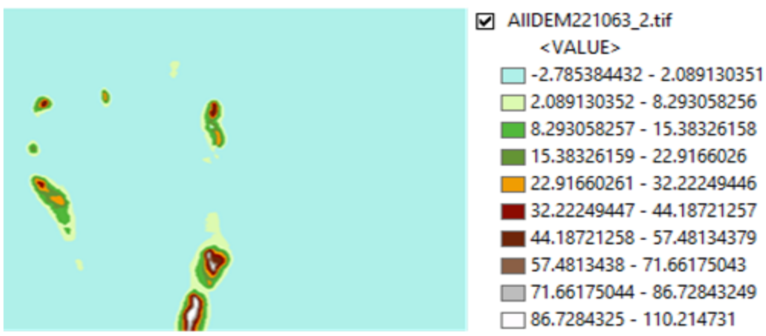



Figure 9. 2D topographic using ArcGIS

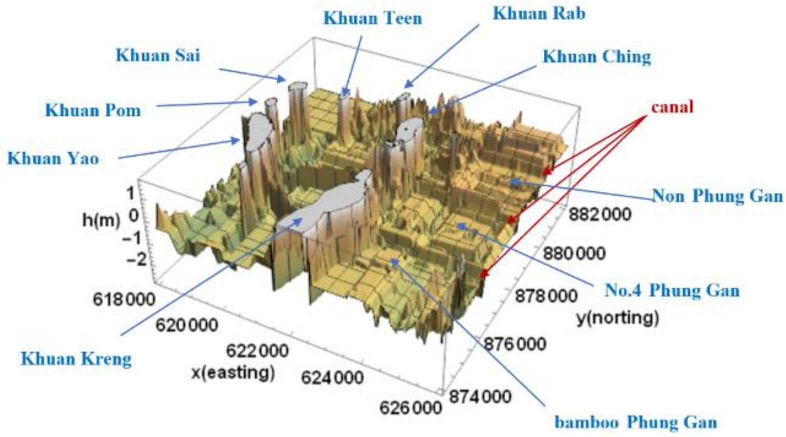



Figure 10. 3D topographic in Khuan Kreng peat swamp forest

### 3.2. Flow direction

An example flow direction program when inputting a file size of 1600×1600 cells. The mathematics and scripting steps provide insights into the exactness and limitations of the models and the application of the algorithms is demonstrated by constructing a flow direction model. The following steps are used to compute the flow direction as follows:

```
data1 = Import["D:\\DataDem_Kreng \\rastert_162.txt", "Table"];
data2 = Drop[data1, {1, 6}];
data = Reverse[data2];

Moore[func_, lat_] := MapThread[func, Map[RotateRight[lat, #] &,
{{0, 0}, {1, 0}, {0, -1}, {-1, 0},{0, 1}, {1, -1}, {-1, -1}, {-1, 1}, {1, 1}}], 2];

update[x_, n_, e_, s_, w_, ne_, se_, sw_, nw_] :=
 If[Min[n, e, s, w, ne, se, sw, nw] == n, 64,
  If[Min[n, e, s, w, ne, se, sw, nw] == e, 1,
   If[Min[n, e, s, w, ne, se, sw, nw] == s, 4,
    If[Min[n, e, s, w, ne, se, sw, nw] == w, 16,
     If[Min[n, e, s, w, ne, se, sw, nw] == ne, 128,
      If[Min[n, e, s, w, ne, se, sw, nw] == se, 2,
       If[Min[n, e, s, w, ne, se, sw, nw] == sw, 8,
        If[Min[n, e, s, w, ne, se, sw, nw] == nw, 32]]]]]]]]

flow direction = Moore[update, data];
Flow = Take[flowdirection, {2, 1599}, {2, 1599}];
Graphics[Raster[Flow, ColorFunction -> (Switch[#, 32,
        RGBColor[0.8, 0, 1], 64,
        RGBColor[1, 0.2, 0], 128,
        RGBColor[0.9, 1, 0], 16,
        RGBColor[0, 0, 1], 1,
        RGBColor[0, 1, 0], 8,
        RGBColor[0, 0.65, 1], 4,
        RGBColor[0, 1, 1], 2,
        RGBColor[0, 0.5, 0]] &)]]
```

Flow direction simulation results derived from the Mathematica program are related to the actual results when surveyed in the summer. The pour point is the boundary cell with the lowest elevation for the contributing area of a sink. If the sink were filled with water, this is the point where water would pour out. To calculate the flow direction, delineate the watershed, and extract the drainage network, several software systems have been developed based on different depression-filling algorithms. Employing methods such as the Hydrology module in ArcView of ArcGIS [38], [39]. Flow direction used cellular automata and D8. We determine the water flow condition with the Moore function and update DEM data. Simulation results of the flow direction shown by graphics raster flow in Figure 11. It shows the flow direction analysis with Mathematica without the fill function suitable for low water conditions. The rectangular channel line (ditch) corresponds to the summer survey. The aforementioned canal was excavated to serve as a route for villagers to collect Krajood. The forest fire, geological, and flow direction models of the Khuan Kreng peat swamp forest using Mathematica aim to understand the geography and water flow conditions in the dry season within the forest fire-prone areas for water management. The flow direction using ArcGIS begins with the Fill function to fill and remove peaks. The Fill utility, embedded in Arc Hydro tools, is efficient in filling sinks using the nearest neighbor interpolation technique. The high density of sinks in DEM requires more processing time for sink removal, as shown in Figure 12 representation of sinks and pits.

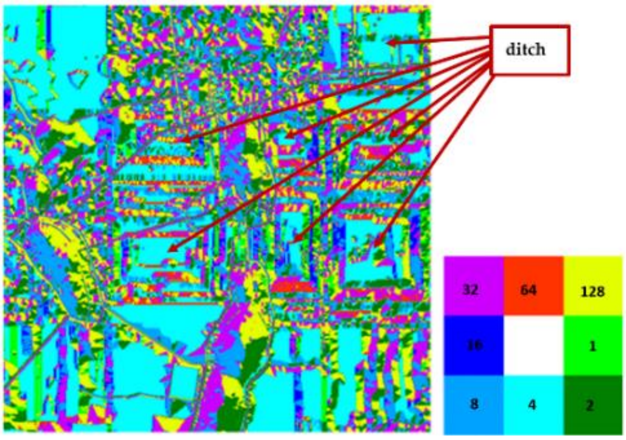



Figure 11. Flow direction in Khuan Kreng peat swamp forest by Mathematica

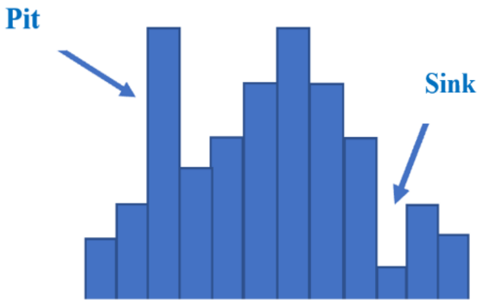



Figure 12. Representation of sinks and pits

To remove peaks, the Minus tool can be applied to the input surface raster, identifying cells where no adjacent cells are higher. This tool locates and fills sinks and peaks in an elevation surface raster to eliminate small imperfections in the data. The function iteratively fills in sinks until all are resolved within the specified Z Limit. The flow direction in the Khuan Kreng peat swamp forest by ArcGIS is illustrated in Figure 13. It was observed that the simulation using the Mathematica program yielded results more consistent with water flow during the dry season compared to using ArcGIS. In contrast, the flow modeling results from ArcGIS align more closely with flood simulations or rainy-season scenarios. The absence of a regulatory framework for managing water volume in the Khuan Kreng swamp forest highlights the role of an external drainage network, which manages water storage during the arid season and water disposal during the rainy season. Water from the peat is drained into dug ponds near the main canal flowing through the forest reserve. To address these issues, the Royal Irrigation Department has proposed constructing land embankments and water towers to maintain safe water levels, ideally between 30 to 50 centimeters. This would prevent the water level in the swamp from falling below -20 centimeters above sea level during the dry season, as the water level decreases by 1 centimeter daily.

The interpretation of landscape morphology and geomorphometric modeling, including surface texture and sediment connectivity, benefits significantly from flow-directional roughness analysis. This research serves as a knowledge base for various applications, such as drought relief, wildfire prevention, and water management planning. Mathematica's symbolic programs offer a simple yet effective approach for simulating 2D and 3D topographies using DEM linked to Google Earth Pro and ArcGIS. These models establish a conceptual foundation for future studies while providing practical insights into the geography of the Khuan Kreng swamp forest. Compared to high-level numerical methods alone, this advancement offers more realistic results. This work creates a valuable database for applications in water management, agriculture, forestry, and disaster mitigation, including flood and drought remedies. The Mathematica-based flow direction model proves more suitable for dry-season water conditions, as it can simulate flow direction without relying on the fill method. Meanwhile, the ArcGIS flow modeling results are better suited for flood simulations.

The study reveals that Mathematica's model effectively simulates water flow during the dry season, making it useful for managing water levels and reducing fire risks in peatland areas like the Khuan Kreng peat swamp forest, where high peat flammability poses significant fire hazards. Conversely, ArcGIS excels in flood simulation, highlighting the need for appropriate tools for various environmental conditions. By integrating these models, we can develop comprehensive strategies for managing both excess water and water scarcity. The findings stress the importance of customized water management approaches that consider seasonal and terrain variations and suggest future research could enhance these models with real-time data to further address water flow and fire risk challenges.

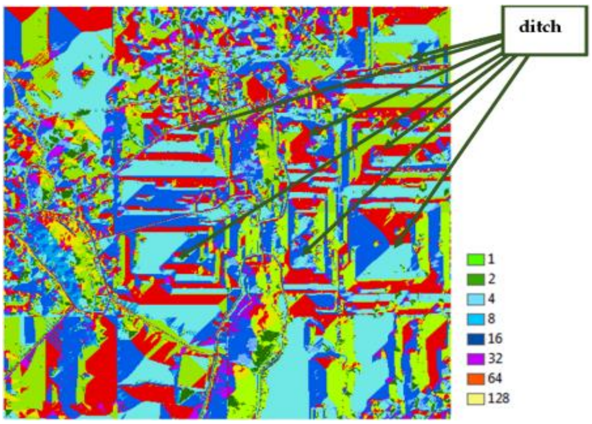



Figure 13. The flow direction in Khuan Kreng peat swamp forest by ArcGIS

## 4. CONCLUSION

The methodology for establishing water flow direction involved creating a topographic model validated against data from ArcGIS, Google Maps, and field surveys, ensuring alignment with standard values observed during summer seasons with scarce water availability. This approach proved effective for managing water consumption during minimal rainfall periods and mitigating forest fire risks by accurately modeling terrain and water movement. While the customized model was ideal for drought conditions, the standard ArcGIS-derived water flow model was better suited for simulating flood scenarios. The comprehensive data and models developed serve as valuable resources across various fields including water management planning, agriculture, forestry, and drought mitigation strategies. Future enhancements involve incorporating precise real-time canal data from ongoing surveys and implementing strategies like constructing underground barriers at drainage points to maintain consistent soil moisture levels and further prevent the spread of wildfires.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