Development of Map of Gridded Basin Flash Flood Potential Index: GBFFPI Map of QuangNam, QuangNgai, DaNang, Hue Provinces

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Abstract—Flash flood is occurred in short time rainfall interval: from 1 hour to 12 hours in small and medium basins. Flash floods typically have two characteristics: large water flow and big flow velocity. Flash flood is occurred at hill valley site (strip of lowland of terrain) in a catchment with large enough distribution area, steep basin slope, and heavy rainfall. The risk of flash floods is determined through Gridded Basin Flash Flood Potential Index (GBFFPI). Flash Flood Potential Index (FFPI) is determined through terrain slope flash flood index, soil erosion flash flood index, land cover flash floods index, land use flash flood index, rainfall flash flood index. Determining GBFFPI, each cell in a map can be considered as outlet of a water accumulation basin. GBFFPI of the cell is determined as basin average value of FFPI of the corresponding water accumulation basin. Based on GIS, a tool is developed to compute GBFFPI using ArcObjects SDK for .NET. The maps of GBFFPI are built in two types: GBFFPI including rainfall flash flood index (real time flash flood warning) or GBFFPI excluding rainfall flash flood index. GBFFPI Tool can be used to determine a high flash flood potential site in a large region as quick as possible. The GBFFPI is improved from conventional FFPI. The advantage of GBFFPI is that GBFFPI is taking into account the basin response (interaction of cells) and determines more true flash flood site (strip of lowland of terrain) while conventional FFPI is taking into account single cell and does not consider the interaction between cells. The GBFFPI Map of QuangNam, QuangNgai, DaNang, Hue is built and exported to Google Earth. The obtained map proves scientific basis of GBFFPI.

Keywords—ArcObjects SDK for .NET, Basin average value of FFPI, Gridded basin flash flood potential index, GBFFPI map.

I. INTRODUCTION

WHEN flash flood is occurred, water flow discharge is much larger than bankfull water discharge, water flow depth is higher than bankfull depth and water flow velocity is very high. The more amount of accumulated water is available, the larger water discharge is. High flow velocity causes from very high geo potential value of accumulating water. Flash flood is occurred when basin rainfall intensity is very high and basin attendant rainfall is large. Flash flooding is one of the many severe weather events that can put life and property in danger. Flash flooding is a serious threat in a mountain region in Vietnam. Greg Smith, the Senior Hydrologist at Colorado Basin Center, developed a Flash Flood Potential Index (FFPI) [1]. The FFPI ranks the flooding

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potential of region and designed to assist operational forecasters in making "Flash flooding warn" or " no flash flooding warn" decision. Some modified FFPI equations was developed [2]. Flash Flood Early Warning System Reference Guide [6] introduce the application of FFPI in flash flood warning system

The above conventional FFPI is to quantitatively describe risk of flash flooding based on static characteristics of cell such as surface slope, land cover, land use and soil type/texture. By indexing a given cells risk of flash flooding, the FFPI allows the user to see which cells are more predisposed to flash flooding than others. The above FFPIs are only taking into account single cell and do not consider the interaction between cells and corresponding basin. In nature, water accumulates and flows from a high position to a low position, so locations with positive platform curvature and locations near to the top of hill are non-flood zone. Conventional method FFPI used a simple overlay operation for 4 layers (surface slope, land cover, land use and soil type/texture), the results flash flood locations on the flash flood map contains many fault flooding locations (cells) with high FFPI but flooding events is never happened [4]. Because fault flooding locations often have steep surface slope (local slope) but water accumulation area of cell is small and the fault flooding locations are not in strip of lowland. Most reported flooding occurred in strip of lowland next to mountain ranges and in lower elevation (comparing to top of mountain) area. The conventional FFPI often indicate many locations with the high response label but in nature, a number of flash flood locations are not much. Using the conventional FFPI, there will be low number of occurrences in the high response labeled area because there are many fault flash flood locations. There was a need to accurately assess the flash flood risk of a cell in a map

II. METHODOLOGY

To improve the conventional FFPI method, a Gridded Basin Flash Flood Index (GBFFPI) is introduced. By taking into hydrological theory of flash flood formation process, GBFFPI characterizes the basin response to flash flood formation, overcomes difficulties in using FFPI, and have some advances comparing to conventional FFPI. Conventional FFPI is computed by weighted overlay operation of the above layers. Obtained FFPI at each cell is computed as weighted average of a cell of the above layers so the FFPI have not been taken into account the flash flood response of neighboring cells. One

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problem is that how to characterize the flash flood response of a cell. A solution is that FFPI of the cell corresponding basin is computed.

For a given outlet, a polygon averaged value of a factor can be computed by using ArcGIS. Therefore, GBFFPI map can be built by similar way utilizing ArcObjects SDK for .NET. For the given cell, one can determine a water accumulation basin corresponding cell and compute the basin averaged value of a variable. Computing process continues in the same way for other cell.

There are two types of GBFFPI map: a GBFFPI map including rainfall flash flood index for real time flash flood warning or GBFFPI map excluding rainfall flash flood index for plan management. GBFFPI Tool can be used to determine a high flash flood potential site in a large region in detail. The concept in developing the GFFPI is simple. The process involved developing raster (gridded) datasets that represent the type of physiographic characteristics and weather condition that influence the hydrologic response and flash flood potential. For each given dataset of factors that relate to precipitation runoff (Digital Elevation Model (DEM), Land Cover/Use, Soil Type/Texture, Vegetation, Cover/Forest Density and rainfall), a raster layer is developed. A relative flash flood potential index ranging from 1 to 5 was assigned to each data layer based on the layer attributes associated with the hydrologic response. An index value of 1 indicates a minimum flash flood threat and an index of 5 indicates a maximum flash flood threat. Depending on the influence degree of considering factor, a classification scheme was used. The index values are unit-less. These values represent a grid cell's susceptibility to flash flooding relative to neighboring cells. For each cell a corresponding water accumulation basin is determined, then basin average value of potential index of the considering factor is computed as a gridded basin flash flood potential index of the factor.

The gridded basin flash flood potential index for each of the above layers were weighted averaged together to generate a composite gridded basin flash flood potential index.

A. Computation of Gridded Basin Flash Flood Potential Index of Factors

The datasets that can be used to compute GBFFPI are listed as:
1) Digital Elevation Model (DEM) data
2) Land Cover/Use data
3) Soil Type/Texture
4) Vegetation Cover/Forest Density) data
5) Rainfall (Hourly or Haft-hour rainfall series) data

The factors from 1 to 4 are static factors and rainfall is a dynamic factor so Gridded Basin Flash Flood Potential Index is divided in two group static index and dynamic index. So there are GBFFPI without or with taking into account rainfall

Gridded Basin Flash Flood Potential Index of factors is computed by utilizing GIS software in 3 steps

Step 1: Gridded Flash Flood Potential Index (GFFPI) of the given factor is created using a classification scheme based on the influence degree of considering factor to flash flood

Step 2: For each cell Gridded Basin Flash Flood Potential Index (GBFFPI) of the factor is computed as the cell corresponding basin average of the GFFPI

Step 3: Composite GBFFPI is computed as weighted overlaying data layers

Component Gridded Basin Flash Flood Potential Indexes are computed by using raster operations and classification scheme is selected through the knowledge of flash flood formation processes

Using Digital Elevation Model (DEM) raster data, a raster layer of slope of terrain is created. The basin slope is classified according to criteria in Table I. Soil Type is classified according to criteria in Table II. Vegetation Cover is classified according to criteria in Table III. Land cover is classified according to criteria in Table IV.

TABLE I
BASIN SLOPE CLASSIFICATION

Class	Symbol	Basin Slope (degree)	Hydrologic Response
1	BS_1	<12	Very low
2	BS_2	12-25	Low
3	BS_3	25-35	Moderate
4	BS_4	35-45	High
5	BS_5	>45	Very high

TABLE II
SOIL TYPE/TEXTURE CLASSIFICATION

Class	Symbol	Soil type	The risk of erosion
1	ST_1	Fa, Fq, Ha, Hq	Very low
2	ST_2	X, B, Ba	Low
3	ST_3	Fs, Fj, Fe, Fp, Hs, Hj	Moderate
4	ST_4	Fk, Fu, Fv, Fn, K, Rk, Ru, Rv, Rdv, Fl, Hk, Hv	High
5	ST_5	Others	Very high

TABLE III
VEGETATION COVER CLASSIFICATION

Class	Symbol	Vegetation Cover Type	Protection Capacity
1	VCT_1	IIIA3, IIIA2, IIIA1, IIB	Very low
2	VCT_2	Young forest restoration no reserves (Ia), young forest mountains, bamboo forests and plantation forests reserves (closed canopy)	Low
3	VCT_3	Regenerated vacant land and scattered trees (Ic); rocky mountainous; industrial crops (rubber, coffee, tea, ...); fruit tree	Moderate
4	VCT_4	Rocky mountain without forest; grazing land (Ia); land of scrub (IB); new forest plantation (immature), cultivation land	High
5	VCT_5	Agricultural land; other types of forest land without vegetation cover as residential land and dedicated land, land rivers lakes	Very high

A method for criteria using hourly rainfall and cumulative rainfall was promoted by Ministry of Construction, Japan [3]. The method is used for debris flow warning and flash flood warning. The method modified by using the concept of

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cumulative rainfall amount with effectiveness of antecedent precipitation.

TABLE IV
LAND COVER/USE CLASSIFICATION

Class	Symbol	Land Cover/Use	Infiltration capacity
1	LU_1	Evergreen broadleaf and average closed forest	Very low
2	LU_2	Bamboo, mixed punish forest, new plantations forest, sparse forests, evergreen broadleaf forest	Low
3	LU_3	Farmland	Moderate
4	LU_4	Bare soil and rock	High
5	LU_5	Hard coated area: housing, roads, roofs	Very high

The working rainfall is defined as the sum of the antecedent working rainfall and the accumulative rainfall during a series of rain. Taking into account influence of rainfall on flash flood potential, a Critical Rainfall Gridded Flash Flood Potential Index (RGFFPI) is developed. CRGFFPI is computed based on combination of working rainfall with 1.5 hours haft-life and working rainfall with 72 hours haft-life. There is a good agreement between the changes in the working rainfall (half-life of 1.5 hours) with the changes in surface water storage, as well as between the changes in the working rainfall (half-life of 72 hours) with the changes in surface water storage and groundwater water.

For rainfall series X_i (i=1, 2, N) (mm) with time step τ, working rainfall with T haft-life at time t $R_{w,t}^T$ is determined as:

$$R_{w,t}^T = X_t + \sum_{k=1}^{M} X_{t-k} * (0.5)^{\frac{k*\tau}{T}} \qquad (1)$$

where, $R_{w,t}^T$ is working rainfall with T haft-life at time t, M is a positive integer number large enough so that $(0.5)^{\frac{M*\tau}{T}}$ is larger than 0.0004.

Critical Rainfall Index (CRI) at time t is defined as combination of working rainfall (half-life of 1.5 hours) $R_{w,t}^{1.5}$ and working rainfall (half-life of 72 hours) $R_{w,t}^{72}$

$$CRI_t = R_{w,t}^{1.5} + a * R_{w,t}^{72} - b \qquad (2)$$

where, a, b: are parameters of critical line equation [4], which are determined through observed data of flash flood events and rainfall.

For initial analysis, parameters a, b can take some empirical value [4]. For example a= 0.9 and b depends on rainfall area

$$b = \begin{cases} 206 \text{ for small rainfall area} \\ 287 \text{ for medium rainfall area} \\ 362 \text{ for large rainfall area} \end{cases}$$

where, for small rainfall area: Probabilistic rainfall of 100 years less than 250 mm/day, for medium rainfall area: Probabilistic rainfall of 100 years from 250 to 350 mm/day, for large rainfall area: Probabilistic rainfall of 100 years more than 350 mm/day. Initial value of b in computing CRI can be assigned 206.

Classification of critical rainfall index is based on actual rainfall data and observed flash flood events. Initial Gridded Critical Rainfall Index (GCRI) for a large rainfall area is computed by classifying the critical rainfall index CRI according criteria in Table IV.

TABLE V
CRITICAL RAINFALL CLASSIFICATION FOR FLASH FLOOD

Class	Symbol	CRI	Flash flood influence
1	CRI_1	< -40	Very low
2	CRI_2	-40 to -20	Low
3	CRI_3	-20 to -4	Moderate
4	CRI_4	-4 to 4	High
5	CRI_5	> 4	Very high

Gridded Basin Critical Rainfall Index (GBCRI) is computed as basin average of GCRI. Depending on the type of rainfall data source, calculating GBCRI and development of GBCRI are carrying in different ways. For rainfall raster dataset raster operations are used, for rainfall dataset at meteorological station, GBCRI is computed for each station then GBCRI map is created using weighted overlay operation.

After GFFPI of Surface Slope, Soil Type/Texture, Soil Type/Texture, Vegetation Cover/Forest Density, Land Cover/Use, Critical Rainfall (Hourly or Haft-hour rainfall series) computed, GBFFPI for each factor is calculated. A composite GBFFPI is created using weighted overlay.

B. Gridded Basin Flash Flood Potential Index without Taking into Account Rainfall

Calculation of GBFFPI excluding rainfall according to

$$GBFFPI = \frac{w_1.GBFFPI_{BS} + w_2.GBFFPI_{ST} + w_3.GBFFPI_{VCT} + w_4.GBFFPI_{LU}}{w_1 + w_2 + w_3 + w_4} \qquad (3)$$

where, $GBFFPI_{BS}$, $GBFFPI_{ST}$, $GBFFPI_{VCT}$, $GBFFPI_{LU}$ are Gridded Basin Flash Flood Potential Index of Surface Slope, Soil Type/Texture, Soil Type/Texture, Vegetation Cover/ Forest Density, Land Cover/Use, w_1, w_2, w_3, w_4 are weights.

C. Critical Gridded Basin Flash Flood Potential Index Taking into Account Rainfall (CRGBFFPI)

Calculation of Rainfall Gridded Basin Flash Flood Potential Index RGBFFPI (taking into account rainfall) according to

$$RGBFFPI = (GBFFPI^{\alpha_1}.GBCRI^{\alpha_2})^{\frac{1}{\alpha_1+\alpha_2}} \qquad (4)$$

where, GBCRI is Gridded Basin Critical Rainfall Index, α_1, α_2 are Weights (Initial value α_1= 0.5, α_2= 1.5).

D. Gridded Basin Flash Flood Potential Index Tool for Development of GBFFPI Map (GBFFPItool)

A map layer of GBFFPI is a static layer and a map layer of CRGBFFPI is a dynamic layer. Development of the layer of CRGBFFPI depends on the source data type (gridded rainfall data (radar or satellite or outputs of weather numerical model) or observed rainfall data at stations).

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GBFFPI a tool based on VB.NET and ArcObjects SDK for .NET is developed, to compute GBFFPI and to build GBFFPI map. Some operations on raster data and feature data in ArcObjects SDK for .NET are used to GBFFPItool such as RasterConversionOpClass, RasterConditionalOpClass, RasterInterpolationOp, RasterZonalOpClass. RasterReclassOpClass, RasterHydrologyOp, The program interface for developing a GBFFPI is shown in Fig. 1.
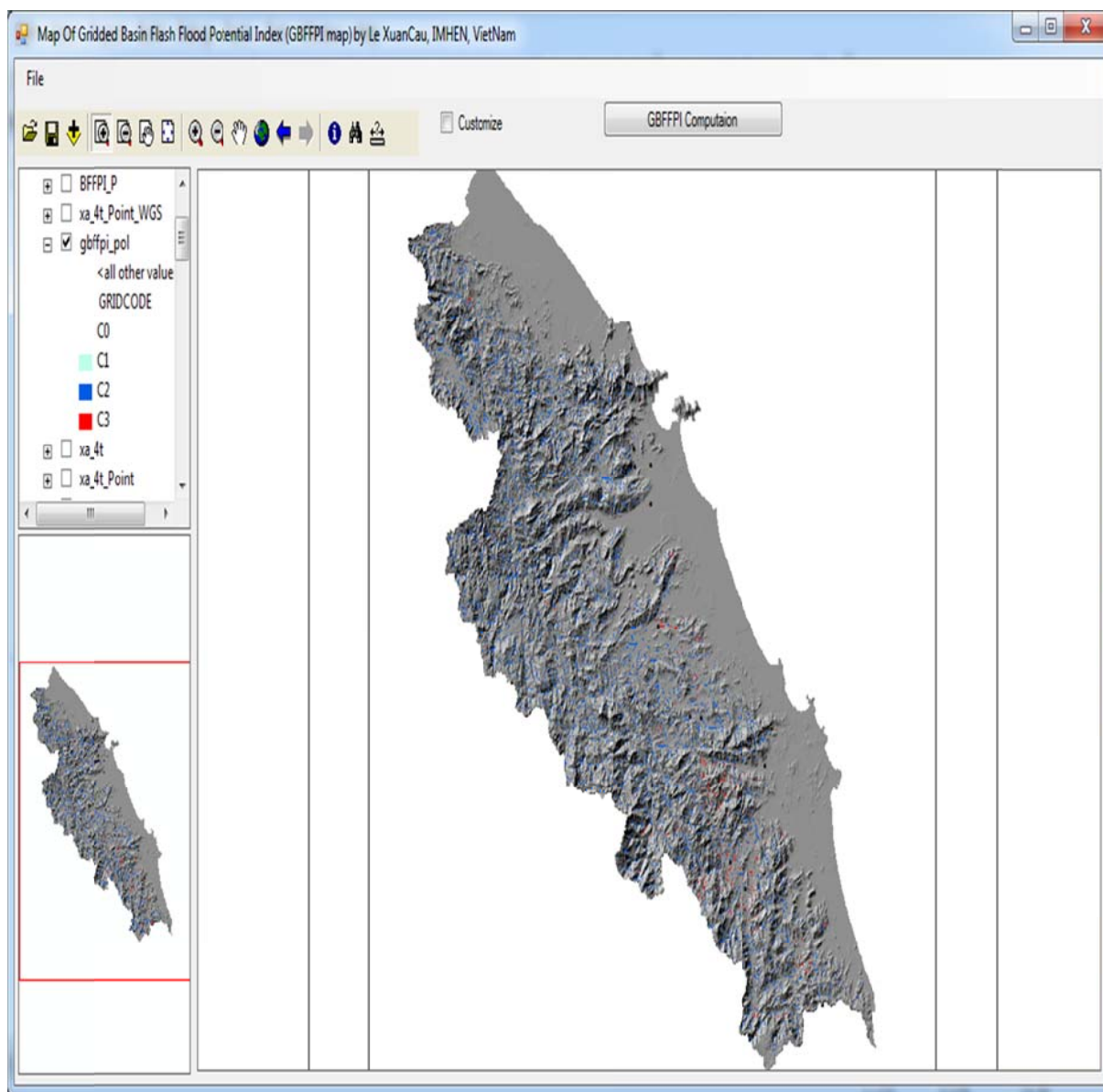
Fig. 1 Program interface for developing a GBFFPI map of QuangNam, QuangNgai, DaNang, Hue Provinces

The GBFFPItool lets user select features in a layer or records in a table by building a query. The GBFFPItool is actually creating a SQL query by attribute. A user can query the villages or districts that have the given flash flood potential class. Query results will be shown by a table or flash objects on the GBFFPI map

III. CASE STUDY: GBFFPI MAP OF QUANG NAM, QUANG NGAI, DA NANG, HUE PROVINCES

QuangNam, QuangNgai, DaNang, Hue are provinces in the South Central Coast region of Vietnam. QuangNam comprises flat land along the coast and increasingly high elevations towards the west, with the highest elevations along the border to Laos and Kon Tum Province. The highest peak is NgocLinh Mountain at 2598m. There are no hills or mountains near the coast. More than half of QuangNam's area is covered by forests, making it one of the more forested provinces in Vietnam. 111900ha of land are used for agriculture, mostly in the east of the province. The ThuBon River system covers most of the province (except for the south-east), making it one of the largest river systems in central Vietnam. QuangNgai's topography is dominated by a large plain along the coast and in the center of the province and by mountains and hills.

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Lowlands extend further inland along TraKhuc River. The province's highest peak is at 1630 m in the west of the province near the border to QuangNam. The coastline is relatively straight in most of the south and central part of the province. The province's largest river is the TraKhuc. Other important rivers are the TraBong in the north and the Ve River in the south of the province. The LySon islands belong to QuangNgai. Da Nang and Hue topography is dominated by the steep Annamite mountain range to the north and northwest, featuring peaks ranging from 700 to 1,500 meters in height, and low-lying coastal plains with some salting to the south and east, with several white sand beaches along the coast. QuangNam, QuangNgai, DaNang, Hue are susceptible to damage from typhoons that cross into the South China Sea. Flood and landfall are damaging and destroying homes, downing trees and power lines.
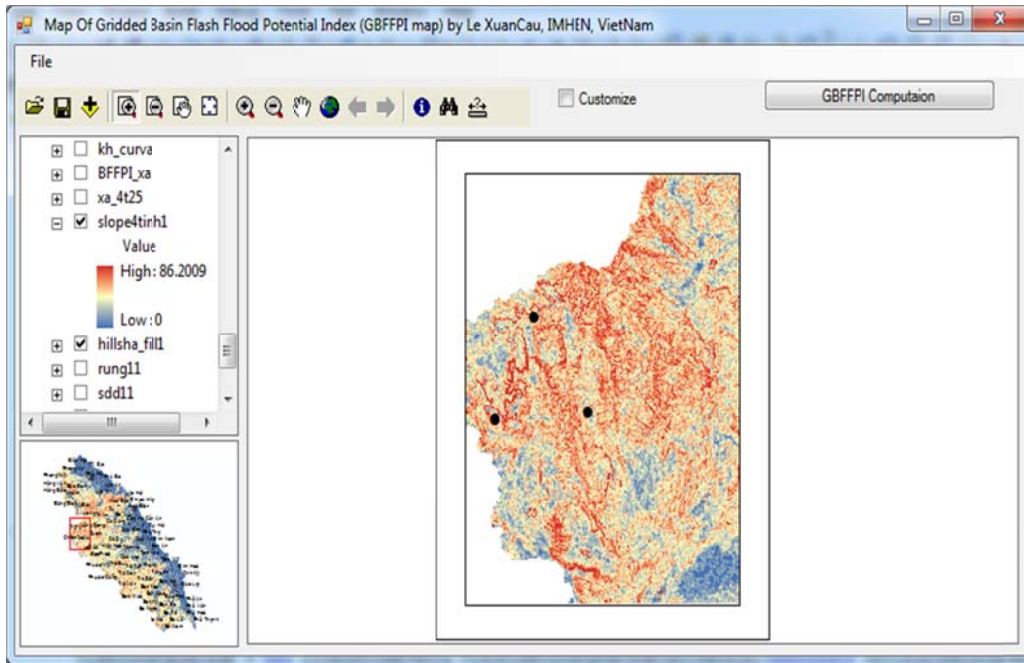
Fig. 2 Terrain Slope FFPI map

Fig. 3 Slope GBFFPI map

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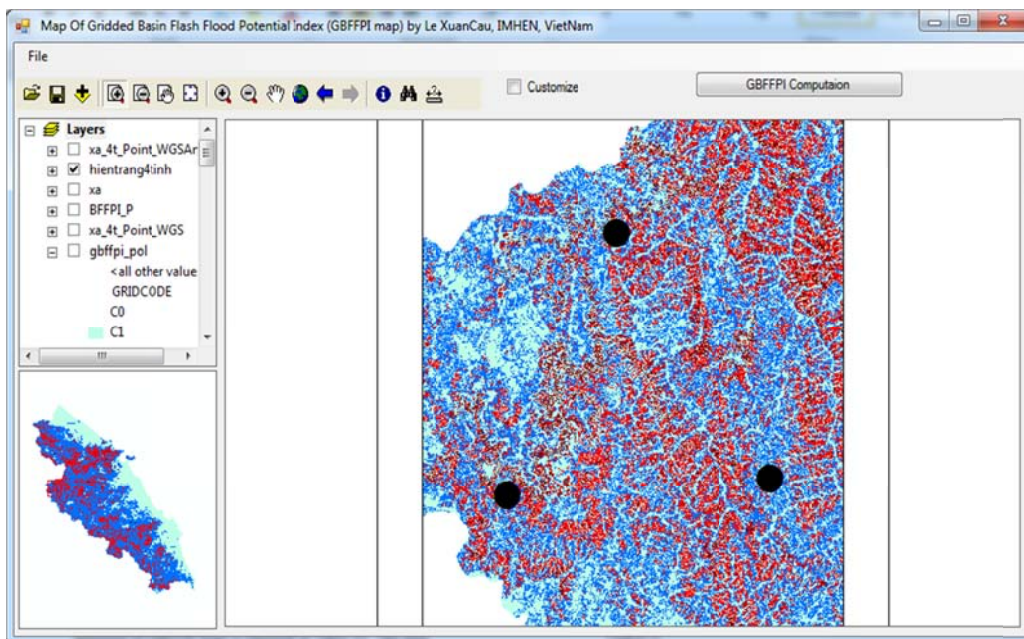
The GBFFPI Map of QuangNam, QuangNgai, DaNang, Hue provinces is built and exported to Google Earth.

The datasets of for QuangNam, QuangNgai, DaNang, Hue provinces is collected and provided by [5]

a. Digital Elevation Model (DEM) data (cell size 25 x 25)
b. Land Cover/Use data
c. Soil Type/Texture data
d. Vegetation Cover/Forest Density) data

Some observed flash flood events are shown in Fig. 1. The observed flash flood sites are marked by dark circle. They are in strip of lowland next to mountain ranges and in lower elevation (comparing to top of mountain) area.

Using the above datasets, GBFFPI can be used to compute with GBFFPITool. Component GBFFPI layer can be represented more detail than conventional FFPI layer. For example, variance of flash flood respond in Slope GBFFPI layer (Fig. 2) is more distinguished than in conventional Terrain Slope FFPI layer (Fig. 3).
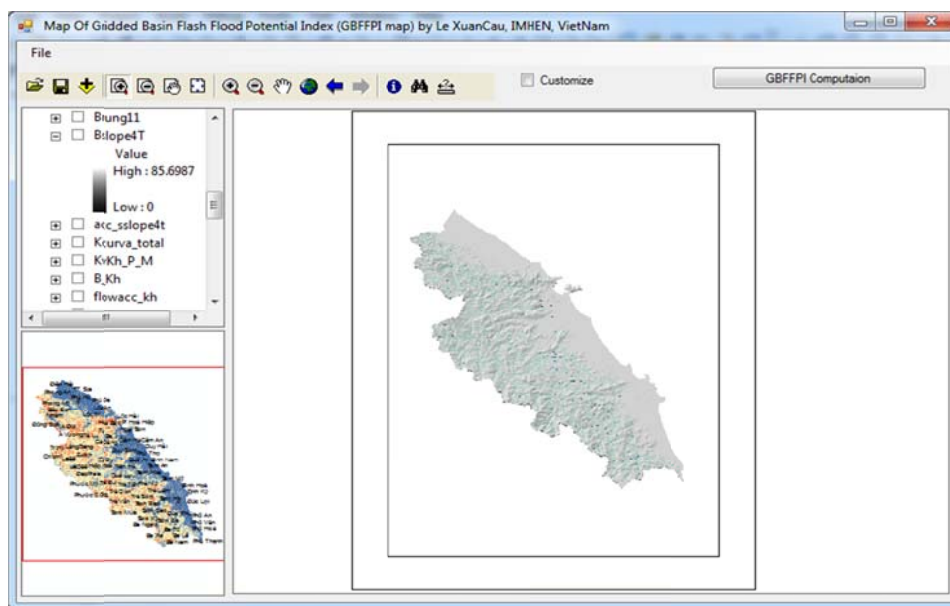
Fig. 4 GBFFPI map of QuangNam, QuangNgai, DaNang, Hue Provinces in GBFFPItool
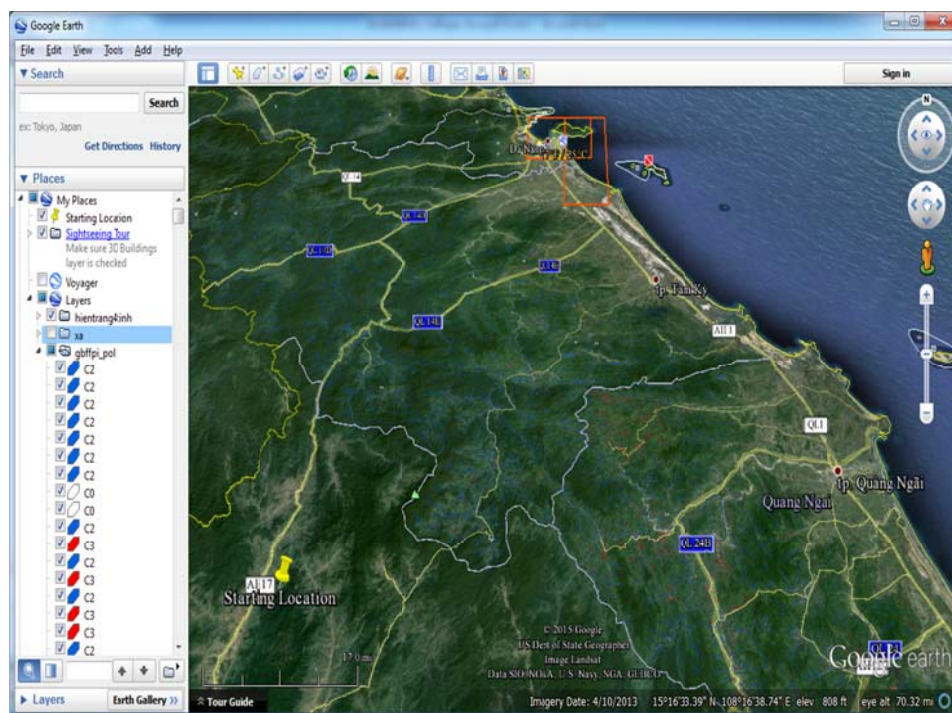
Fig. 5 GBFFPI map of QuangNam, QuangNgai, DaNang, Hue Provinces in Google Earth

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TABLE VI
ATTRIBUTE OF GBFFPI MAP

Classes	Number Of Cells	Area in %
C1	9048268	26.1
C2	21026893	60.7
C3	4567257	13.2

Attribute of GBFFPI map is reported in Table VI. The area of the highest GBFFPI (C3) occupied 13.2% and the area of GBFFPI (C3) is the largest. There is no area for C4 and C5. In nature frequency of flash flood event is small because the chance of occurrence coinciding heavy rainfall location and the high flash flood potential location is small.

The result GBFFPI map for the study region is shown in Fig. 4. The GBFFPI map is exported to Google Earth shown in Fig. 5.

The obtained map proves scientific basis of GBFFPI. The GBFFPI map of QuangNam, QuangNgai, DaNang, Hue provinces consist of flash flood free regions and 3 classes that ranges from C1 to C3. However, flash flood events are observed in study region so rainfall must be the most important factor in flash flood formation.
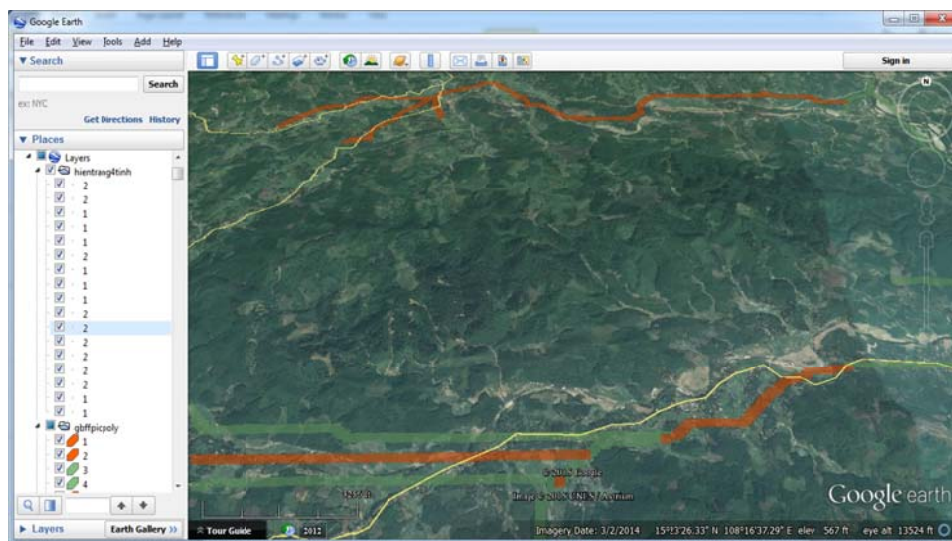
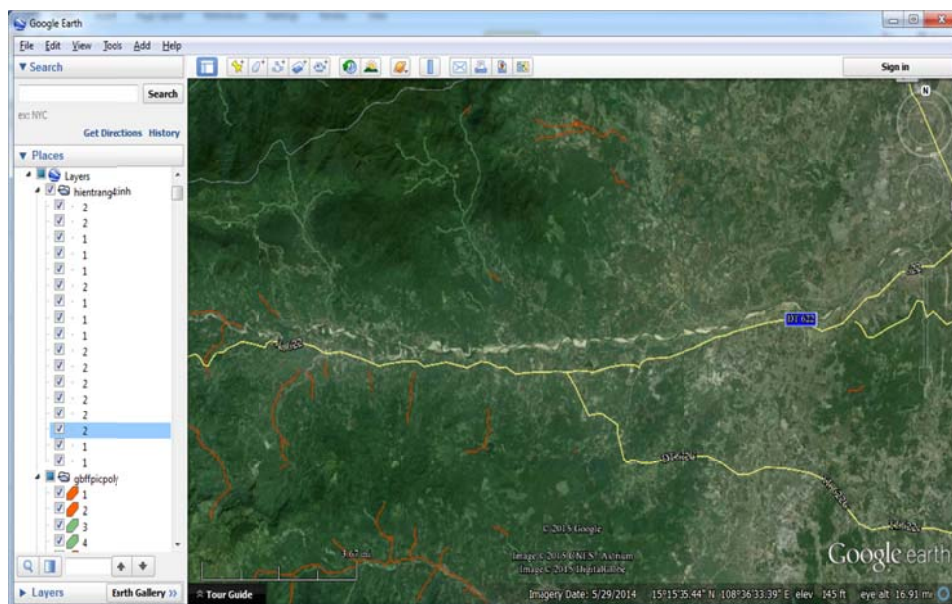Fig. 6 Example for moderate flash flood potential sites (C3) (red color)

Fig. 7 Example for moderate flash flood potential sites (C3) (red color)

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Fig. 8 Example for querying moderate flash flood potential sites (C3)

The map in Fig. 1 indicates that flash flood potential sites are lying in the strip of lowland and there is no flash food in regions near sea coast and in plain regions. Using Google Earth, GBFFPI map allow users to investigate high flash flood potential sites in more detail. It is very useful for users. Figs. 6 and. 7 show that high flash flood potential sites C3 (marked with red color) is reasonable. Analyzing the obtained high flash flood potential sites by considering physiographic characteristics at the sites one can see that obtained results are reasonable. The obtained high flash flood potential sites proved the above method of development of GBFFPI map and GBFFPItool. GBFFPI map of QuangNam, QuangNgai, DaNang, Hue provinces can be viewed in details in Google Earth or downloaded at GBFFPI map [7].

There are some conclusions analyzing the obtained GBFFPI map of four provinces:

a) Flash flood zone in GBFFPI map is always lied in strip of lowland, high flash flood potential sites are lying in a reasonable position (the map has no fault flash flood potential sites)

b) Observed flash flood events occurred in the regions that have high flash flood potential. A position of observed flash flood event depends on rainfall characteristics. Rainfall plays very important role in flash flood formation.

For example, as a query result Fig. 8 represents the villages that have the flash flood moderate potential class (C3).

For flash flood early warning a map of Rainfall Gridded Basin Flash Flood Potential Index (RGBFFPI map) need to be developed by using ArcObjects for .NET

IV. CONCLUSION

The scientific basic of development of Gridded Basin Flash Flood Potential Index (GBFFPI) and Rainfall Gridded Basin Flash Flood Potential Index (RGBFFPI) is discussed. GBFFPI is improved the conventional FFPI. Flash flood zone in GBFFPI map is always laid in strip of lowland. It excludes the fault Flash flood zone in conventional FFPI map. Rainfall Gridded Basin Flash Flood Potential Index (RGBFFPI) is a combination of GBFFPI and Critical Rainfall Index (CRI). RGBFFPI map allows allocating the true flash flood potential zone and is very useful for flash flood potential zone warning.

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