OPTIMAL SELECTION OF NUMBER AND LOCATION OF METEO-HYDROLOGICAL MONITORING NETWORKS ON VU GIA - THU BON RIVER BASIN USING GIS

Nguyen Thi Hong[1], Phan Thi Thanh Truc[2], Nguyen Duy Liem[2], Nguyen Kim Loi[2]

[1]Faculty of Geology, Hanoi University of Science, Vietnam National University,
334 Nguyen Trai, Thanh Xuan District, Ha Noi City, Vietnam.
Email: nthong@vnu.edu.vn

[2]Department of Applied Geomatics, Nong Lam University - Ho Chi Minh City,
Linh Trung Wizard, Thu Duc District, Ho Chi Minh City, Vietnam.
Email: nguyenduyliem@hcmuaf.edu.vn

ABSTRACT

Meteorological data play a particularly important role in hydrologic research because the climate and weather of an area exert a profound influence on most hydrologic processes. Meanwhile, hydrological data are critical for performing a range of purposes, including water resources assessment, impacts of climate change and flood forecasting and warning. It can be said that the prevention of disasters caused by floods and droughts would be impossible without rational forecasting technology based on an understanding of the rainfall-runoff phenomenon and statistical analysis of past hydrological data, which cannot be achieved without meteo-hydrological observations. The lack of adequate meteo-hydrological data affects the ability to model, predict and plan for catastrophic events such as floods and droughts which have obvious negative impacts on public health and socio-economic aspects. The accurate estimation of the spatial distribution of meteorological and hydrological parameters requires a dense network of instruments, which entails large installation and operational costs. It is thus necessary to optimize the number and location of meteo-hydrological stations. This paper presents a GIS-based approach to establishing an optimal meteo-hydrological station network on Vu Gia-Thu Bon river basin for developing an up-to-date real time flood warning system. Based on statistical analysis of the annual rainfall total data at 9 existing gauges in the study area from 1980 to 2013, it showed that the error of the existing network was about 7.47%. Considering 9 rain gauges as a standard representative of rainfall over the region, if the error decreases from 7.47% to 5%, the number of additional rain gauges should be 20. For adequate and economical network design, these additional rain gauges were spatially distributed between the different isohyetals after considering the relative distances between rain gauges, their accessibility, personnel required for making observations using multi-layers analysis and spatial interpolation. For hydrological stations, based on consideration existing network with the requirements set out by the flood warning system, the number of stations should be five. In terms of spatial distribution, three stations were distributed across two main tributaries of Vu Gia- Thu Bon river basin, behind the dams for water discharge calibration and the others were located on downstream for water stage calibration. The results of the study provided a scientific approach can be applied to optimizing the meteo-hydrological station network over the river basin.

1. INTRODUCTION

Meteorological data play a particularly important role in hydrologic research because the climate and weather of an area exert a profound influence on most hydrologic processes. Meanwhile, hydrological data are critical for performing a range of purposes, including water resources assessment, impacts of climate change, flood forecasting and warning. It can be said that the prevention of disasters caused by floods and droughts would be impossible without rational forecasting technology based on an understanding of the rainfall-runoff phenomenon and statistical analysis of past hydrological data, which cannot be achieved without meteo-hydrological observations (WMO 2003). The lack of adequate meteo-hydrological data affects the ability to model, predict and plan for catastrophic events such as floods and droughts which have obvious negative impacts on public health and socio-economic aspects. The accurate estimation of the spatial distribution of meteo-hydrological parameters requires a dense network of instruments, which entails large installation and operational costs. It is thus necessary to optimize the number and location of meteo-hydrological stations which gives greater accuracy of meteo-hydrological data estimation with minimum cost.

The optimisation of meteo-hydrological monitoring networks and particularly those devoted to rainfall monitoring networks, have been received much attention from researchers, with various approaches mentioned in scientific papers. One of the earliest attempts at stream gauge network design was conducted by Langbein (1954) who concluded that a network should be established from a firm group of base stations to serve as fixed points for the time sampling factor, and a group of secondary stations to be operated for relatively short periods on numerous stream in order to provide geographic sampling. Panigrahy & Mani (2000) used Cv method, key station method, spatial correlation method and Entropy method to determine the adequate number of raingauge stations and their suitable location for Pagladiya basin. Based on this study, it has been found that additional station are required in certain parts of the basin while in other parts some redundant stations have been identified. Nermin & A Unal (2006) have conducted a research to evaluation and selection of streamgage network on Kizilirmak basin, Turkey using Entropy methods. The results showed that Entropy methods provided reliable results in evaluating the performance of existing streamgage network. Barca *et al.* (2008) used geostatistics and probabilistic techniques (simulated annealing) combined with GIS instruments to estimate the optimum location of fifty new stations on existing rainfall monitoring network in the Apulia region, South Italy. Meanwhile, in Vietnam, the location of meteo-hydrological stations is determined primarily based on the regulations of the Ministry of Natural Resources and Environment. Until now, there has been no research relating to optimizing meteo-hydrological monitoring networks.

The Vu Gia – Thu Bon river basin is a huge basin in the Central part of Vietnam with a total area over 8.000 km^2 (see Figure 1). The basin covers major parts of Quang Nam province and Da Nang city, as well as a small part of Kon Tum province. Topographically, the basin is characterized by a complex mix of mountains, hills, plains and coastal zones with the average slope of 25.5%. Originating on the eastern side of the Truong Son mountain range, its upstream is short and steep with a narrow riverbed, steep riverbanks and many cascades. In the middle part, the riverbed is rather wide and shallow. In the downstream, the riverbanks become low which allows water overflows into fields and villages during the flood season. The climate of Vu Gia- Thu Bon basin has two distinguished seasons: the wet season from September to December, and the dry season from January to August with average temperature of 25.4°C and average annual rainfall varies from 2,500mm to 3,000mm. Due to the influence of topography, hydromorphology, climate, floods often occur on the basin every year, causing widespread loss of life and damage to property, infrastructure. Because of the rapidly moving flood water, flood forecasting has faced many challenges, which requires monitoring and updating meteo-hydrological data data continuously with high reliability.

Therefore, the purpose of this study is to establish an optimal meteo-hydrological station network on Vu Gia - Thu Bon river basin for developing an up-to-date real time flood warning system. The methodology proposed in this paper integrates geostatistical theory with optimisation methods based on GIS analysis tools.

2. METHODOLOGY

The proposed methodology consists of two steps. In the first step, it is necessary to define an optimum number and suitable locations of meteo-hydrological stations. The second step, a field trip was conducted to choosing specific location for installing meteo-hydrological stations.

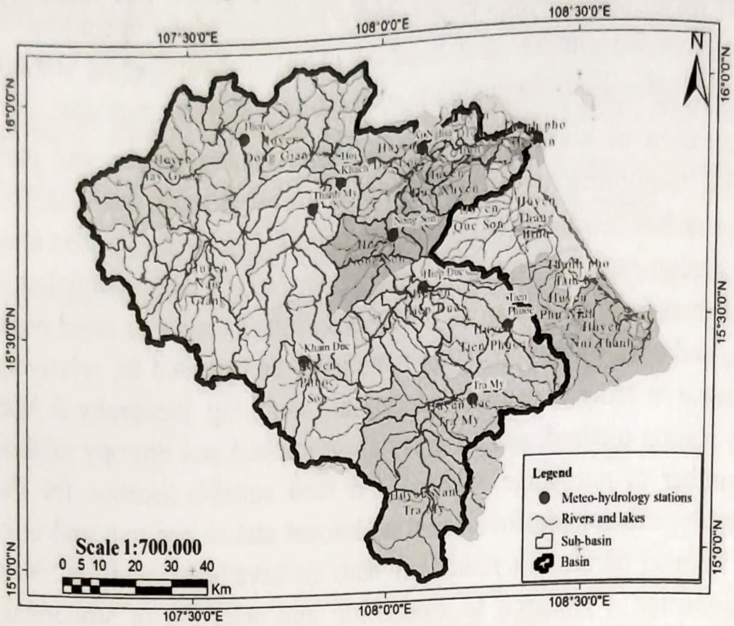

Figure1. Location of Vu Gia – Thu Bon river basin

2.1 Optimum meteorology network design

Precipitation is one of the most important inputs in hydrological modeling and forecasting. In a rainfall–runoff model, precise estimation of areal precipitation is essential for more accurate runoff simulations, as the representative precipitation is used in determining surface hydrological processes. Rain-gauge stations provide the basic means of estimating precipitation at a point, over a region or catchment. However, geographical or economic issues often limit the gauge density and location. In fact, rainfall intensity is the most important variable in runoff and erosion impact prediction. More generally, rainfall network accuracy depends on precipitation variability as well as on the network size and design. Due to the limited of economy, rain-gauge stations can not be installed for all locations in the catchment. Therefore, optimum selection of the rainfall gauges means optimizing the number and location of rainfall gauges which gives greater accuracy of areal rainfall estimation with minimum cost.

In the research design rain-gauges network for Pagladiya basin, Panigrahy & Mani (2000) recommended the rain-gauge density as follow (Table).

Table 1. Rain-gauge network based on type of area

Area	Rain-gauge density
Plains	1 in 520 km^2
Elevated regions	1 in 260-390 km^2
Hilly and very heavy	1 in 130 km^2

(Source: Panigrahy & Mani 2000)

The aim of the optimum rain-gauge network is to obtain all quantitative data averages and extremes that define the statistical distribution of the meteo-hydrorological elements, with sufficient accuracy for the practical purposes. When the mean areal depth of rainfall is calculated by the simple arithmetic average, the optimum number of rain-gauge stations to be established in a given basin is given (Mazdoor *et al.* 1994).

$$N = \left(\frac{Cv}{p}\right)^2 \quad (1)$$

Where N: optimum number of rain-gauge stations to be established in the basin

C_v: Coefficient of variation of the rainfall of the existing rain-gauge stations (say, n)

p: desired degree of percentage error in the estimate of the average depth of rainfall over the basin.

The number of additional rain-gauge stations N should be distributed in the different zones (caused by isohyets) in proportion to their areas, i.e., depending upon the spatial distribution of the existing rain-gauge stations and the variability of the rainfall over the basin.

According to WMO (2008) and Vietnam's standard, suitable locations to set up rain-gauge station should be chose as follow:

- The site should be well away from trees, buildings, walls or other obstructions. The distance of any such obstacle (including fencing) from the rain-gauge should not be less than twice the height of the object above the rim of the gauge, and preferably four times the height.

- Outdoor instruments should be installed on a level piece of ground where there should be no steeply sloping ground in the vicinity and the site should not be in a hollow and. The instruments should be set up above the ground about 1,50m. If these conditions are not met, the observations may show peculiarities of entirely local significance;

- The instruments should be installed away from lakes, ponds and river at least 100m and the instruments do not effected in flooding condition.

- Location of gauges must be located near the roads and urban areas, so that easily to set up instrument and get record data (should be located on buffer zones about 100m).

- Location of gauges must be located near BTS station areas to receive and transfer data information.

- At the irrigation management office or project management office should be set up a rain-gauge station.

2.2 Optimum hydrology network design

The collection of stream flow data that are both accurate and representative of a region's water resources is essential. Surface water gauging stations are the monitoring tools used to measure the rate of flow of water in streams and rivers. The goal of a hydrologic (stream flow) monitoring network is to be able to address all of these concerns by obtaining timely, quantitative and comparable information, and develop an integrated, comprehensive, and effective monitoring network that provides coverage across all watersheds where flow data is required. WMO emphasized the importance of establishing an optimum network, where the interpolation between values at different stations should make it possible to determine the characteristics of the basic hydro-meteorological elements at any point within a country.

The density of stream flow station is important to collect stream flow and discharge data on a catchment. Therefore, the selection of location for stations are very important to adapt the demand of data and financial for setting these stations. WMO (2010) recommended the density of a stream flow network based on type of area as follow (Table).

Table 2. Stream flow density

Area	Stream flow density
Coastal	1 station per 2.750 km^2
Mountainous	1 station per 1.000 km^2
Hilly	1 station per 1.875 km^2
Plains	1 station per 1.875 km^2
Small island (area < $500km^2$)	1 station per 1.985 km^2
Polar, arid	1 station per 20.000 km^2

(Source: WMO2010)

Hydrologic stations are those established to determine the basic stream flow characteristics of the region. The general location of gauging station is dependent on the specific purpose of the stream flow record. The selection of gauging-station site becomes complicated, however, when the station is to be one of a network of stations whose records are required for study of the general hydrology of a region. Regional flood frequency studies are used for the design of dam spillways, bridges. In that situation, attention to hydrologic principles is required in selecting the general locations of the individual stations in the network to ensure that optimum information is obtained for the money spent in data collection. Sơn & Phượng (2003) and WMO (2010) have recommend some criteria satisfies the following criteria:

- The general course of the stream is straight for about 10 times the stream width, upstream and downstream from the gauge site if the control is a river reach (channel control). If the control is a section control, the downstream conditions must be such that the control is not drowned. The water entering a section control should have low velocity.

- The gauge site is far enough upstream from the confluence with another stream or from tidal effect to avoid any variable influence the other stream or the tide may have on the stage at the gauge site

- The total flow is confined to one channel at all stages and no flow bypasses the site as subsurface flow.

- The stream-bed is not subject to scour and fill and is relatively free of aquatic vegetation Banks are permanent, high enough to contain floods, and are free of brush.

- A pool is present upstream from the control at extremely low stages to ensure a recording of stage at extremely low flow, and to avoid high velocities at the stream ward end of stage recorder intakes, transducers, or manometer orifice during periods of high flow. The sensitivity of the control should be such that any significant change in discharge shall result in a measurable change in stage.

After the general locations has been chosen, the next step is chose station based on the function of station. For example, the general location for reservoirs management will be allocated along the river between the dams and first tributary. Criteria for choosing stream flow station and water level station follow the Vietnam's standard and WMO's criteria (Table 3).

Table 3. Water level and stream flow station location

Type of station	Criteria
Water level station	Section of river relatively straight Stream-bed relatively stable, water surface without sudden changes (expansion or contraction) Avoid confluence, bends, lakes and storage areas
Stream flow station	Section of river must be narrow and straight, L ≥ 3Btb (L: river length, Btb: water surface in average level condition) Velocity > 0.15 m/s Channel depth > 0.3 m River bank must be stable, without confluence or the place where the stream split apart and less affected by human activities.

(Source:Bộ Khoa học và Công nghệ 2009, Bộ Tài nguyên và Môi trường 2012, WMO 2010)

3. RESULTS

3.1 Meteorological network

According to investigating, Vu Gia – Thu Bon basin have 9 stations: Thanh My, Hoi Khach, Ai Nghia, Hiep Duc, Nong Son, Tra My, Kham Duc, Tien Phuoc, Hien. With the range of annual rain-fall record (from 1980 to 2013), it showed that the error of the existing network was about 7.47%. If the error decreases from 7.47% to 5%, the number of additional rain gauges should be 20.

For adequate and economical network design, these additional rain gauges were spatially distributed between the different isohyetals after considering the relative distances between rain gauges, their accessibility, personnel required for making observations using multi-layers analysis and spatial interpolation. This method divides the study area covered by the point input features into proximal rainfall zones, each zones contains only a single rain gauge station. Applying Thiessen interpolation method for study area, the result showed that Vu Gia – Thu Bon basin have 9 difference rainfall zones with different areas.

The number of stations for each rainfall zone will be added based on the weight of rainfall zone area. Nine zones of rainfall areas with name Thanh My, Hoi Khach, Ai Nghia, Hiep Duc, Nong Son, Tra My, Kham Duc, Tien Phuoc, Hien have the number of stations should be add are 1, 1, 1, 1, 2, 2, 3, 4, 5 respectively.

When number station for rainfall zones have been added, maps such as transportation, hydrography, winds direction and sub-basin are used for define suitable location on GIS environment. After finish the final step, the study achieve a map show suitable place to set up meteorology station and the optimum number of station should be set up for each range of rainfall areas.

The next step is field trip to consider the topographic conditions such as: urban areas, plants and BTS stations to set up stations and establish network. Locations for station is flat area, area without obstacle and near the transportation. Through field trip survey, meteorological will be set up normally in People's Committee yard, this convenience for manage and collect data. Detail location of meteorological station show in Figure .

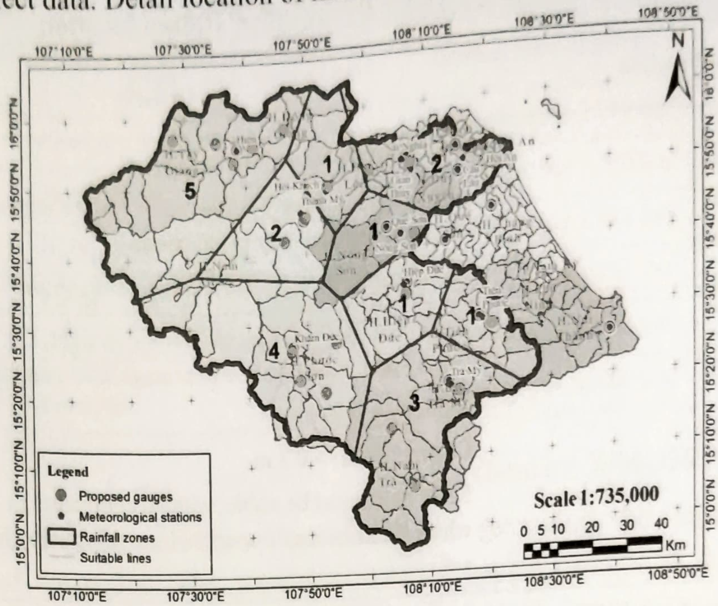

Figure 2. Meteorological stations network on Vu Gia – Thu Bon river basin

3.2 Hydrological network

The optimum number of hydrological stations for Vu Gia – Thu Bon river basin should be 5 stations. According to hydrological station criteria, there have 2 continuous steps need to conduct: the first is choosing the branch of main channel and the second is choosing a section of channel following the function of station. As the same periods like meteorological network, after finished field trip survey, the result showed that 5 hydrological station will be set up on two branches channel are Vu Gia river and Thu Bon river (Figure).

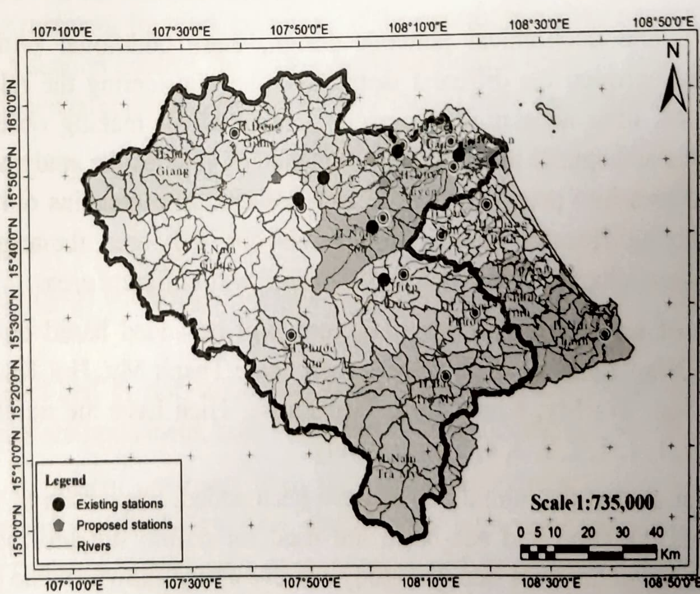

Figure 3. Hydrological stations location on Vu Gia – Thu Bon river basin

4. CONCLUSIONS

The findings of this research proved that integrated GIS on optimizing meteo-hydrological network is scientific establishment for solving optimum problem. New meteo-hydrological network can provide near-real time updates in an online setting; and to automatically e-mail flood-risk alerts based on specified hydrological thresholds. The use of such integrated flood-warning systems can rapidly disseminate information to local inhabitants and agencies; and can provide advance warning of necessary flood preparations, thereby potentially mitigating the effects of flooding within local communities.

5. ACKNOWLEDGEMENTS

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