Proposal of a set of quantitative criteria for evaluating and classifying urban street flooding spots in Vietnam

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Abstract. Street flooding in urban areas in Vietnam has always been a stress issue despite the municipal government’s investment in renovating and upgrading the drainage system. Until present, in order to evaluate and classify street flooding spots, the authorities have been applying the criteria specified in Document No. 338/BXD-KTQH issued by Ministry of Construction dated March 10, 2003. Despite their certain efficiency and value, the current criteria have not shown how the flooding spots affect traffic and not clarified how to measure or determine the parameters as a basis for flood classification, etc. Therefore, the Ministry of Construction has ordered the research team to develop a set of quantitative criteria for evaluating and classifying the street flooding spots in Vietnam. Accordingly, this paper presents the results of the study in contribution to more effective management of urban infrastructure.

1. Introduction

For decades, Vietnam has been experiencing rapid urbanization in parallel with the need for urban infrastructure development. Under the pressure of urbanization, the ever-increasing occupation of natural surface by concrete and hard pavement results in increase of surface runoff and consequent overloading the drainage systems, negative impact on groundwater resources [1, 2]. Flooding due to rains, high tides, etc. is one of the main causes of traffic congestion; damage and disruption of technical infrastructure works; costly maintenance and repair of drainage systems [3-8]. In addition to increasing investment in drainage infrastructure [9] and application of sustainable drainage solutions [10] such as promoting local storage of storm runoff with hollow structures [11], increasing permeability by using porous materials [12], etc., informing traffic participants of newly arising flooding spots as the later could induce difficult traffic situation. Traffic participants are always in need of the information of how the rain that just happened would affect their planned route in order to make necessary changes; authorities need the information of magnitude and impacts of flooding spots in order to work out proper repair and investment plans for street drainage system.

With the development of modern technology, forecasting and real-time reporting the location and size of street flooding spots has become increasingly popular. However, apart from technology, it is necessary to develop a set of criteria to evaluate and classify flooding spots in a quantitative, simple manner, a set that would be used together with automatic monitoring system in the future.
Up to now, municipal drainage infrastructure management units in Vietnam have been applying the criteria cited from Document No. 338/BXD-KTQH on the Framework program for urban drainage system by the Ministry of Construction dated 10.03.2003 (hereinafter referred to as VB 338) \[13\] to identify and classify flooding spots. These criteria include depth (in cm), area (in m²) of the flooding spots and duration of flood receding (in minute) i.e. the time since the rain stops until the moment the flooding spot drained completely. Based on the monitored data according to the above-mentioned criteria, the flooding spots are classified into four levels: No flooding or water ponding, slightly flooded, moderately flooded and heavily flooded.

It can be seen that these criteria have not considered the impacts of the flooding spots on street capacity and vehicles travel speed. As the result, a spot of average size and depth, although classified as “moderately flooded” could seriously affect or even cause traffic congestion due to that it happens on a small street. On the other hand, inconsistent assessment happens since different municipal drainage infrastructure management units may use different measurement methods when applying these criteria.

To overcome the said limitations, the research team has carried out a study on developing a set of quantitative criteria for identifying and classifying urban street flooding under a project framework of Ministry of Construction [14].

2. Assessment of the current set of criteria

The criteria cited from VB 338 [13] classify urban street flooding spots into the four levels as shown in table 1 below.

| Classification of flooding spots | Criteria | Note |
|---------------------------------|----------|------|
| No flooding                     | Depth of flooding spot: water ponding, depth is less than 10 cm | - | - |
| Slightly flooded               | Area of flooding spot: maximum flooded area of 2,000 m² | The flood is not completely drained within 30 minutes after the rain stops | If the value of one of the 3 criteria exceeds the limit, the level is classified as “Moderately flooded”. |
| Moderately flooded             | Duration of flood receding: the flood is not completely drained within 30 minutes to 120 minutes after the rain stops | - | - |
| Heavily flooded                | Flooded area: over 4,000 m² | The flood is not completely drained within 120 minutes after the rain stops | If the value of one of the 3 criteria is less than the limit, the level is classified as “Moderately flooded”. |

The current set of criteria includes three criteria: flooding depth, flooding area and flooding time. Of these criteria, the flooding area does not really reflect the impact of the flooding spot on street capacity and vehicles travel speed.
traffic. It is notable that if flood spots with the same area happened on the street of different width, it could have much greater impact on the narrower street, since the ratio of the flooded street surface over the street width, and the length of flooding spots – factors directly affecting travel time and street capacity would be significantly greater for narrower street.

On the other hand, some limit value of the current criteria is still unrealistic. For example, for most moto-bikes and small cars, a water depth of 30 cm could flood their exhaust pipes and cause engines to stall, resulting in serious traffic congestion. However, according to current criteria, this value is the upper limit of the "moderately flooded" level. Such classification would hardly be accepted by traffic participants as well as the whole society.

The current criteria are not accompanied by clear and specific guidelines of flooding spots measurement. Therefore management units conducted the measurements in different ways. This leads to inconsistent assessment and classification of flooding spots, which is shown in Table 2:

| Criteria                        | Hanoi Sewerage and Drainage Company | Ho Chi Minh City Urban Drainage Company |
|--------------------------------|-------------------------------------|-----------------------------------------|
| Area of flooding spot          | Measured by conventional measuring tape: |
|                                | \[ S = L \times B \ (m^2) \]          | Measured by conventional measuring tape: |
|                                | \[ S = L \times B \ (m^2) \]          | where:                                  |
|                                | where:                               | L: Length of flooding spots (m)         |
|                                | L: Length of flooding spots (m)       | B: Average width of the flooded street section (m). |
| Depth of flooding spot         | Measure with geodetic mia at the flooding spots, choose the maximum value. | Conduct the measurement at the representative point which has the greatest depth on the flooded street section at \( \frac{1}{4} \) of the traffic direction. |
| Duration of flood              | Defined as the time from the appearance of flooding spots until the water is completely drained. | Defined as the time from the appearance of flooding spots until the water is completely drained. |

The above comparison shows the inconsistency in depth measurement between the two drainage system management companies in the two biggest cities of Vietnam. Selection of points for measuring the flood depth is also crucial. The road surface always has slopes toward the road shoulders on either side (two-slope cross section) or on one side (single-slope cross section) for collecting and draining rainwater runoff. At the same flooding spot, the positions closer to the road shoulders be would have significantly greater values of flooded depth.

Thus, one can see that in the practice, the current set of criteria has some inadequacies in evaluation and classification of urban street flooding spots. Therefore, it is necessary to study and establish a set of quantitative criteria to identify and classify the street flooding spots. The development of a new set of criteria will be carried out based on the survey data on the current status of flooding at typical areas in Hanoi, as well as the analysis of the impact of flooding on the traffic of popular means of transport.

3. Current status of typical flooding spots in Hanoi
Rainy season, a typical weather generally in the North of Vietnam and particularly in Hanoi usually takes place from May to October. During this time, the rains often have high intensity with heavy precipitation in short time, so flooding spots occur often during and after the rains. Therefore, the research team conducted the survey from July to October of 2019 at a number of spots in Hanoi where
flooding frequents, such as: Tran Binh street, Dich Vong Hau street, Tay Son street, Nguyen Chinh street, Hoang Mai street, ...

The measurement methods are applied as follows:

- Rain measurement data is updated from rain gauge stations in the survey locations;
- The length and width of the flooding spots are measured with a laser ruler;
- The depth of the flooding location is measured with a geodetic mia. Measurement location: at the middle of the flooded traffic direction of the streets. The measurement value shown in the table is the rounded average value of measurements at locations along the flooding spots.

The survey results of the frequently flooding spots in rains in Hanoi are presented in table 3 below.

### Table 3. Dimensions of flooding spots

| No | Survey location (street name) | Length of flooding spot (m) | Average width of flooding spot (m) | Flooding area ($m^2$) | Precipitation Depth of flooding spot | Duration of flood receding (*) |
|----|--------------------------------|----------------------------|-----------------------------------|-----------------------|------------------------------------|-----------------------------|
|    |                                |                            |                                   |                       | Highest (mm) | Lowest (mm) | Highest (cm) | Lowest (cm) | (minutes) |
| 1  | Tran Binh                      | 500                        | 4.0                               | 2,000                 | 155.6 (1)   | 44.9 (4)   | 70              | 20            | 1440       |
| 2  | Dich Vong                      | 200                        | 3.0                               | 600                   | 155.6 (1)   | 23.2 (5)   | 20              | 10            | 60         |
| 3  | Tran T Tong                    | 500                        | 5.0                               | 2,500                 | 155.6 (1)   | 23.2 (5)   | 70              | 20            | 1440       |
| 4  | Duy Tan                        | 300                        | 2.5                               | 750                   | 155.6 (1)   | 22.5 (3)   | 50              | 30            | 180        |
| 5  | Dg Van Ngu                     | 150                        | 4.0 - 5.0                         | 600 - 750             | 176.6 (1)   | 56.0 (4)   | 20              | 10            | 30         |
| 6  | Tay Son                        | 270                        | 8.0                               | 2,160                 | 176.6 (1)   | 63.8 (5)   | 30              | 10            | 30         |
| 7  | Van Ho 3                       | 50                         | 3.0 - 4.0                         | 150-200               | 188.8 (1)   | 43.0 (3)   | 20              | 0             | 180        |
| 8  | Ng Chinh                       | 300                        | 4.0 - 5.5                         | 1,200-1,650           | 155.6 (1)   | 61.6 (5)   | 100             | 20            | 720        |
| 9  | Tan Mai                        | 400                        | 3.0 - 4.0                         | 1,200-1,600           | 155.6 (1)   | 109.5 (4)  | 20              | 15            | 10         |
| 10 | Tam Trinh                      | 200                        | 8.0                               | 1,600                 | 155.6 (1)   | 68.8 (5)   | 50              | 20            | 45         |
| 11 | Dinh Cong                      | 70                         | 4.0 - 5.0                         | 2.80 - 3.50           | 155.6 (1)   | 115.5 (4)  | 30              | 20            | 15         |
| 12 | Giap Bat                       | 100                        | 5.0 - 5.5                         | 500-550              | 155.6 (1)   | 66.2 (5)   | 50              | 20            | 180        |
| 13 | Dai Tu                         | 100                        | 6.0                               | 600                   | 155.6 (1)   | 98.3 (2)   | 50              | 30            | 30         |
| 14 | Hoang Mai                      | 200                        | 5.0                               | 1,000                 | 155.6 (1)   | 93.3 (2)   | 80              | 30            | 180        |
| 15 | Hong Xa                        | 200                        | 2.0 - 3.0                         | 400-600              | 176.6 (1)   | 66.6 (5)   | 50              | 20            | 60         |
| 16 | Phuc Xa                        | 100                        | 2.5 - 3.0                         | 250 - 300            | 156.6 (1)   | 61.6 (5)   | 30              | 10            | 60         |
| 17 | Doi Can                        | 50                         | 1.5 - 2.5                         | 75 - 125             | 156.6 (1)   | 55.3 (5)   | 20              | 0             | 180        |
| 18 | Ngoc Khanh                     | 100                        | 1.5 - 2.0                         | 150-200              | 156.6 (1)   | 61.5 (5)   | 30              | 5             | 20         |
| 19 | Nguyen Trai                    | 300                        | 4.0 - 5.0                         | 1,200-1,500          | 156.6 (1)   | 61.5 (5)   | 20              | 10            | 10         |
| 20 | Phg Khoang                     | 100                        | 4.0 - 4.5                         | 400 - 450            | 188.8 (1)   | 61.6 (5)   | 50              | 10            | 100        |

Note:

1: The survey on July 23, 2019;  2: The survey on July 31, 2019;
3: The survey on August 3, 2019;  4: The survey on August 28, 2019;
5: The survey on September 19, 2019

(*) Durations of flood receding are shown for the heaviest rain
It can be seen from the table, during small rains, the flooding depth at the survey spots fluctuated mainly in the range of 10 – 20 cm. At this level, most vehicles can move still despite their decreased speed. In medium and heavy rains, the flooding depth increased significantly, ranging from 30 cm to 70 cm, especially in some spots soared up to 100 cm. At such great flooding depth, most popular vehicles such as small cars, motorbikes would not be able to travel as their exhaust pipes would be flooded.

Regarding the dimensions of the flooding spots, although being flooded with moderate area, the streets such as Giap Bat, Hoang Mai, Hong Ha could still cause many difficulties to traffic participants due to their narrow width.

4. Evaluating the influence of the flooding depth on the motorized vehicle operation

To evaluate the influence of flooding on street capacity of the popular vehicles, the research team conducted a survey on the height above the ground of the exhaust pipes of various motorbikes and cars. Results are shown in table 4 below.

| No. | Types (motorcycle) | Height of exhaust pipe (cm) | No. | Types (car) | Height of exhaust pipe (cm) |
|-----|--------------------|-----------------------------|-----|-------------|-----------------------------|
| 1   | Honda Dream        | 20                          | 1   | Honda Jazz  | 27                          |
| 2   | Honda Wave RS      | 35                          | 2   | Honda City  | 26                          |
| 3   | Honda Wave RSX     | 40                          | 3   | Honda Civic | 31                          |
| 4   | Honda Wave 110     | 35                          | 4   | Toyota Altis| 30                          |
| 5   | Honda SH Mode      | 33                          | 5   | Toyota Yaris| 28                          |
| 6   | Honda Vision       | 30                          | 6   | Toyota Vios | 30                          |
| 7   | Honda Air Blade    | 40                          | 8   | Hyundai Sonata| 37                         |
| 9   | Brixton            | 35                          | 8   | Honda Accord | 27                         |
| 10  | Yamaha Sirius      | 35                          | 9   | Honda Accord | 27                         |
| 11  | Yamaha Janus       | 37                          | 9   | Honda CRV   | 24                          |
| 12  | Yamaha Jupiter     | 35                          | 10  | Toyota Inova| 28                          |
| 13  | Yamaha Grande      | 25                          | 11  | Toyota Fortuner| 27                      |
| 14  | Piaggio Zip        | 30                          | 12  | Mazda CX5   | 35                          |

The results show that among moto-bikes, Honda Dream – one of the most popular models in Vietnam has the lowest height of the exhaust pipe of 20cm. The height of exhaust pipes of the other kinds of motorbikes is from 25cm and above. The height of the exhaust pipes of the popular cars is in the same range.

5. Proposal of a set of quantitative criteria for flooding spots classification

As mentioned above, criteria for identification and classification of street flooding spots should meet the following requirements:
to reflect the typical parameters of the flooding spots in space, time and level of impact on traffic;

- can be determined quantitatively and objectively.

Based on the analysis and the conducted surveys results, the criteria are selected as follows:

- **Depth of flooding spot**, which directly affects the vehicle speed, street capacity and traffic congestion. If streets are heavily flooded, traffic will be interrupted.
- **Length of flooding spot**, which directly affects the travel time, traffic congestion risk.
- **Carri[de] way occupied ratio**, which affects number of effective lanes and traffic capacity. If there is less than one travelled lane, traffic will be interrupted.
- **Duration of flood receding**, which indicates the time the flooding spot will affect traffic still after the rain stops.

Based on the measured values of the four above mentioned criteria, the level of flooding at a location is classified into 5 levels: No flooded / Spot of water gathering; Slightly flooded; Moderately flooded; Heavily flooded; and Severely flooded. The values of limits dividing levels are proposed as shown in table 5 below:

**Table 5. Criteria and limits for determining and classification of magnitude of flooded spots**

| Classification          | Depth of flooding spot, \(H\) (cm) | Length of flooding spot, \(L\) (m) | Carri[de] way occupied ratio (%) | Duration of flood receding, \(T\) (min.) | Impacts on traffic                                                                 |
|-------------------------|-------------------------------------|-----------------------------------|----------------------------------|----------------------------------------|-------------------------------------------------------------------------------------|
| No flooded / Spot of water gathering | \(<10\)                            | -                                 | \(<25\)%                         | -                                      | Vehicles neither encounter obstruction, nor difficulties in traveling. The traffic capacity is hardly reduced. |
| Slightly flooded        | \(10 \div 15\)                      | 200                               | \(25\% \div 50\%)               | 30                                    | Vehicles encounter some obstruction or difficulties in traveling and must slow down slightly. The traffic capacity is reduced. *If the value of one of the 4 criteria exceeds the limit, the level is classified as “Moderately flooded”.* |
| Moderately flooded      | \(15 \div 20\)                      | \(200 \div 500\)                  | \(>50\%\)                        | \(30 \div 120\)                       | Vehicles encounter obstruction or difficulties in traveling, must slow down considerably. The traffic capacity is significantly reduced. Some interrupted commuting is observed. *If the value of one of the 4 criteria exceeds the limit, the level is classified as “Heavily flooded”.* |
| Heavily flooded         | \(20 \div 30\)                      | \(500 \div 1.000\)                | \(>50\%)                         | \(120 \div 360\)                     | Vehicles encounter lots of obstruction or difficulties and even interruptions in traveling. The traffic capacity is heavily reduced. *If the value of one of the 4 criteria exceeds the limit, the level is...” |
Classification

| Classification       | Depth of flooding spot, H (cm) | Length of flooding spot, L (m) | Carriage way occupied ratio (%) | Duration of flood receding, T (min.) | Impacts on traffic                                      |
|----------------------|---------------------------------|---------------------------------|---------------------------------|-------------------------------------|-------------------------------------------------------|
| Severely flooded     | >30                             | >1.000                          | >50%                            | > 360                               | Majority of vehicles encounter interruptions in traveling. The traffic is mostly congested. |

*Note: The level of flooding is evaluated for each of traffic direction*

To ensure consistency when applying these criteria, the method for determining the value of each criterion is proposed as shown in table 6.

**Table 6. Methods for determining the value of each criterion**

| Criterion                | Determining methods                                                                 | Measuring technique                                                                 |
|--------------------------|-------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------|
| Depth of flooding spot   | - The depth of flooding spot is determined at the time of the highest water (usually at the end of the rain).  
                           | - Conduct the measurement at the representative point which has the greatest depth on the flooded road section (avoid potholes, manholes and abnormal locations): at the middle of the traffic direction if the road surface is double-sloped; at ¼ of the traffic direction if the road is single-sloped. | Measure directly at no less than 03 points and choose the maximum value.            |
| Length of flooding spot  | Measure the length of flooding spot along the street                                  | Measure the flooded length along street curb                                        |
| Carriage way occupied ratio | The ratio between the width of the flooded section and width of the street.         | Measure the width of flooded section in each direction of the street and calculate the ratio to the width of each street direction. |
| Duration of flood receding | The time for flood to recede, it is the time since rain stops until the flooding depth reaches 10 cm. | Time directly at the flooding spot, watching the water depth |

Thus, the set of proposed criteria is different from the current set of criteria as follows:

- Number of criteria: the criterion Area of flooding spot is omitted, and 2 new criteria are added: Length of flooding spot and Carriage way occupied ratio;
- Classification levels: level “Severely flooded” is proposed in addition;
- Limit values: the upper limit of the level “Moderately flooded” is reduced from 30 cm (as of current criteria) to 20 cm.

To further clarify the difference between the proposed and current set of criteria, the research team has applied the proposed set of criteria to classify flooding spots for cases as shown in the following tables 7 and 8.
Table 7. Classification of flooded spots in accordance with the current set of criteria

| No | Street  | Flooding area (m²) | Depth of flooding spot (cm) | Duration of flood receding (min) | Classification | Impacts on traffic                                      |
|----|---------|--------------------|----------------------------|-------------------------------|----------------|--------------------------------------------------------|
| 1  | Tay Son | 2,160              | 30                         | 30                            | Moderately flooded | Vehicles encounter lots difficulties in traveling. Many car and bikes stalled. |
| 2  | Hong Ha | 3,240              | 50                         | 60                            | Moderately flooded | Vehicles could not travel.                             |
| 3  | Nguyen Trai | 1.600             | 20                         | 10                            | Moderately flooded | Vehicles moved slowly, some moved very slowly.         |

Table 8. Classification of flooded spots in accordance with the proposed set of criteria

| No | Street    | Depth of flooding spot (cm) | Length of flooding spot (m) | Duration of flood receding (min) | Carriidge way occupied ratio (%) | Classification | Impacts on traffic                                      |
|----|-----------|-----------------------------|-----------------------------|-------------------------------|---------------------------------|----------------|--------------------------------------------------------|
| 1  | Tay Son   | 30                          | 320                         | 30                            | 100                             | Heavily flooded | Vehicles encounter lots difficulties in traveling. Many car and bikes stalled. |
| 2  | Hong Ha   | 50                          | 270                         | 60                            | 100                             | Heavily flooded | Vehicles could not travel.                             |
| 3  | Nguyen Trai | 20                           | 200                         | 10                            | 50 – 60                          | Moderately flooded | Vehicles moved slowly, some moved very slowly.         |

The above data demonstrated that, as far as the current criteria are applied, all three spots of flood are classified as "Medium Flood", meanwhile the vehicles at two spots of Tay Son and Hong Ha streets faced lots of difficulties or even were not able to travel. The proposed set of criteria addresses the problem of mismatch between the classified level and the actual traffic situation, classifying the two above mentioned spots as "Heavy flooded".

6. Conclusion
The proposed set of criteria is developed based on inheriting some contents of the current set of criteria [13] in combination with actual survey results, with reference to international experience and expert analysis. With a clear measurement method, the set of criteria emphasizes that classification of flooding spots needs to be connected to the traffic situation on streets. Therefore, this set of criteria can be applied in practice, helping to effectively inform traffic participants about the situation of street flooding. This set of criteria can also assist relevant authorities to make appropriate decisions in the management of urban traffic and drainage infrastructure.

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