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A Fuzzy-Delphi Approach for the Prioritization of Traffic Impact Mitigation Measures under Heavy Rainfall Conditions

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ABSTRACT

The management of traffic issues under heavy rainfall conditions is a subject of high importance to prevent subsequent impacts. In this regard, the adoption of effective tools and actions can potentially assist in controlling the risks during such extreme conditions. On the other hand, actions should reflect technical, environmental, economic, and social criteria in compliance with the sustainability principles. To this end, the Fuzzy-Delphi methodology was conducted to identify the influencing criteria and prioritize them by forming an international panel of 20 experts of various required relevant expertise to classify the relative importance of the identified actions. According to the results achieved, all the proposed actions were deemed important to be considered to manage the traffic under heavy rainfall conditions. The improvement of driving culture and public training were identified as the most important actions which indicate the importance of "driver behaviour" to control the risks under heavy rainfall conditions. The results of the present study can be used by the decision-makers to prevent traffic events and emergency conditions under heavy rainfalls by designing and implementing sustainable measures. More research is also recommended for the practical applications of the results achieved in the present study.

1. INTRODUCTION

Adverse weather conditions have been well demonstrated to affect the frequency and intensity of events such as traffic crashes (Uddin and Huynh, 2017). Driving under such conditions is a highly challenging issue due to the reduction in the visibility of the roads. Also, the lower friction between road surface and tires can bring difficulties for the drivers to control the vehicles (Do et al., 2020). The stormwater runoff can also be considered as another problem created under heavy rainfall conditions (Morales Torres et al., 2015). Such water typically contains various pollutants including air pollutants, causing acidification and eutrophication agents (Koroneos et al., 2008) and the contaminants, which are added when stormwater flows over impervious surfaces. Road flooding by stormwater is also a source of a set of problems by declining the traffic flow. As stated by the European Environment Agency (2010), stormwater flooding is among the most common and disastrous natural phenomena in Europe during rainy seasons. However, the consequences of stormwater on urban activities have not been well studied and managed all over Europe.

Heavy rainfall is fundamentally unavoidable. However, some measures can be adopted to reduce the negative effects of this phenomenon on urban traffic and to increase the safety level under such a situation. In this regard, the implementation of a scientific-based traffic management plan is an essential need. The mentioned plan may require to develop urban infrastructures such as the installation of smart guidance facilities (i.e. traffic lanes), improvement of the rainfall discharge facilities (i.e. drainages), and public awareness about the action they have to take under such conditions, which can potentially reduce the risks under such conditions. However, the adoption of effective traffic management actions should be based on a set of considerations. In this regard, sustainability criteria, including technical, economic, environmental and social parameters, can be considered in the decision-making process in order to select the most effective option among the existing alternatives (Kamali et al., 2019). Sustainability principles have been demonstrated to be of enormous importance in terms of appropriate solutions for various scientific issues. Delphi methodology is considered a beneficial approach for identifying and prioritizing the most important measures based on a consensus achieved among a group of experts. To this end, professional questionnaires are normally prepared and spread among the panel (Kamali et al., 2019). Fuzzy-Delphi is considered a popular methodology among scientists in various fields of study (Kamali, 2020; Okoli and Pawlowski, 2004). The integration of fuzzy theory with multi-criteria decision-making methods such as Delphi can result in a more precise outcome (Ocampo et al., 2018) by clearing out the uncertainties. Fuzzy-Delphi has the potential to aid in making sustainable decisions in various scientific fields (Hsu et al., 2010; Sánchez-Lezama et al., 2014; Tahriri et al., 2014). However, to our best knowledge, there has been no study performed in the literature on the prioritization of traffic management measures, especially under heavy rainfall conditions. In this study, such novel approaches using a Fuzzy-Delphi methodology were employed to find the most sustainable actions to be taken into consideration for the effective management of the traffic issues under heavy rainfall conditions, when preventive measures fail.

2. TRAFFIC MANAGEMENT ALTERNATIVES

There are two main types of factors that can influence traffic flow in urban areas, namely fixed and variable factors. Road condition (e.g. geometric characteristics) and road type (e.g. intersections and roundabouts) are considered as the fixed factors, which can influence traffic performance. However, there are factors such as weather conditions that can influence the traffic situation by speed change, travel time, queue, traffic flow, level of service and number of stop-and-go actions, among others. For instance, in the case of drainage systems (as a fixed factor) it should be stated the stormwater flow limit to canals or local lands preventing road flooding. In such conditions, there are always high levels of risks (e.g. collision) that need to be controlled and managed (Jackson and Sharif, 2016). It has been well documented in the literature that extreme weather conditions can negatively affect traffic parameters.

Table 1 summarizes some findings regarding the impact of weather on the overall traffic performance.

Table 1. A summary of the impacts of the weather (rain, snow, sleet, hail and flooding) on roadways and traffic operations.

Road characteristics	Impact	Consequence	Ref.
Visibility	Decrease	Decrease in the roadway capacity and increase in the collision risk	(Higgins et al., 2017)
Pavement friction	Decrease	Difficulty in controlling the vehicle and the risk of an accident	(Coleri et al., 2013)
Infrastructure damage such as pavement crack	Increase	Difficulty in controlling the vehicle and accident risk	(Mousa et al., 2019)
Obstruction and submersion	Increase	Reduction in the speeds and increase in the traffic jam	(Blocken et al., 2009)
Stormwater flow	Increase	Decreasing the speed of the vehicles and increase in the relevant safety issues	(Fallah Shorshani et al., 2014)

According to Table 1, heavy rainfall conditions can cause both immediate impact such as the decrease in the road visibility (Fig. 1, a) which can potentially increase the risk of collisions and overflow from the existing drainage system (Fig. 1, c) as well as issues that may occur after some time. A good example in this regard is the failure and crack in the road pavement (Fig. 1, b). Crashes that normally occur during rain, sleet, snow, fog, or under wet pavement conditions are categorized as weather-related events (Pisano et al., 2008). Some measures can be taken to control the traffic load and to prevent safety risks. According to the specialist literature, there are several most important actions to be considered to control the heavy rainfall conditions associated risks, and they are summarized in Table 2.

Fig. 1. The effects of the heavy rainfall on the roads, Ave. Universidade de Aveiro, Aveiro, Portugal: *a). Overflow from the urban drainage with limited capacity in critical rainfall conditions. b). Effects of inefficient drainage on the streets. c). Traffic disturbance and crossing problems caused by the insufficient urban drainage capacity in critical rainfall conditions.*

Table 2. Applicable actions that can influence the emergency management after heavy rainfall.

Alternatives	Identification	Description	Ref.
Design smart traffic light	STL	The existence of smart traffic lights may allow decreasing the traffic load on the lane where rainfall emergencies occur	(Cruz-piris et al., 2018; Souravlias et al., 2016)
Design smart signs	SS	The existence of smart signs to inform about the emergency on the road. The signs can lead the drivers to the local accesses to prevent further pressure on the road	(Gautam et al., 2016; Lira et al., 2016)
Provide local access points	LA	Designing the proper local access points that may allow discharging the traffic load from the main street, affected by traffic emergency caused by rainfall	(Su et al., 2016)
Design proper footbridges	FB	Designing footbridges of adequate capacity	(Oviedo-Trespalacios and Scott-Parker, 2017; Bruno and Corbetta, 2017)
Develop drainage system	DS	Designing drainage systems capable to collect the rainfall, in case of an emergency	(Jiusto and Kenney, 2016; Hussain et al., 2018; Su et al., 2016; Zhou, 2014; Qin et al., 2013)
Road modification to meet the rainfall conditions	RM	The characteristics of the street including the width, slope, should be tailored to become suitable for emergencies. It also includes the elimination of dangerous turns, slipping, etc.	(Asadi et al., 2019; Aron et al., 2015; Cai et al., 2013; Jackson and Sharif, 2016)
Design appropriate lighting systems	LS	Providing adequate light on the road in case of an emergency created by heavy rainfall	(Kastman et. al, 2017)
Public training	PT	The need for public training programs on the management of emergencies created under heavy rainfall	(Berg et al., 2004)
Improvement of the driving culture	DC	Adopting appropriate actions to improve the driving culture considering variables such as sex, age, etc.	(Stringer, 2018; Yates et al., 2017; Su et al., 2016)

Each action to be undertaken should consider traffic parameters such as the number of trips (defined as the number of vehicles that travel at a certain time in a certain direction on one or more lanes of the street) (Hellström and Nordström, 2012), and also the traffic volume, which can be explained as the traffic loaded to the street and the probable manipulations manipulated under emergency created by heavy rainfall (Hu et al., 2018; Jiang et al., 2015).

3. MATERIALS AND METHODS

A critical review was performed to identify the most significant actions that may influence the management of the emergency after heavy rainfall in urban areas. Based on the criteria identified, a fuzzy-Delphi methodology was employed to identify if they are important to be considered for the management of traffic under heavy rainfall conditions.

The method was also utilized to prioritize actions and to demonstrate the relative importance of the actions to be adopted. A questionnaire on the identified actions was prepared. A high-quality expert panel was formed by selecting and inviting experts with high levels of academic education and professional experience in the field of study, from various countries all over the world (Chang et al., 2000; Doyon et al., 1971; Kamali et al., 2019; Yousuf, 2007).

The information related to the experts who participated in this study including the competencies and the area of expertise was provided as supplementary information (see Appendix 1). Experts were asked to express their opinion on the importance of each alternative considering their technical, environmental, economic, and social significance.

Triangular fuzzy numbers which are to define the fuzzy spaces are composed of three values as: $\tilde{A}=(a_1, a_2, a_3)$ (Ban and Coroianu, 2012). The membership functions of these values are as described in the following equations (Gani and Assarudeen, 2012).

$$y = m(x) = \begin{cases} 0 & x < a_1 \\ \frac{x-a_1}{a_2-a_1} & a_1 \le x \le a_2 \\ \frac{a_3-x}{a_3-a_2} & a_2 \le x \le a_3 \\ 0 & x > a_3 \end{cases} \quad \text{Eq. 1}$$

Table 1 represents the linguistic variables used in this study and the respective three angular fuzzy numbers. Equation 2 was also used for computing the three angular fuzzy numbers, including L, M, and U, which can be combined according to equation 3, to defuzzify the fuzzy numbers for the ranking of the respective criteria (Hsu et al., 2010).

$$L_j = \operatorname*{Min}_i\{L_{ij}\}, \quad M_j = 1/n \textstyle\sum_{i=1}^{n} M_{ij}, \quad U_j = \operatorname*{Max}_i\{U_{ij}\} \quad \text{Eq. 2}$$

$$df = \frac{1}{4}(L + 2M + U) \quad \text{Eq. 3}$$

The expert scientific panel was asked to assign the importance of the various aspects of sustainability (i.e. technical, environmental, economic, and social) as well as of each action, based on the fuzzy scale presented in Table 3.

The structure of the questionnaire is provided as supplementary information (see Appendix 2). After analyzing responses received from every expert, the results of the first round were extracted and sent to the panel for any further comments, as a second round. The results of the fuzzy-Delphi methodology are finally communicated after reaching consensus among the participating experts. The obtained data were analyzed using SPSS (25.0) and Cronbach's alpha index was calculated to examine the internal consistency of the answers provided by the expert panel (Cronbach, 1951). Coefficients on a range of 0 to 1 were used to determine if a certain degree of response consistency was reached among the experts on the relative importance of the studied alternatives. Values closer to 1, can demonstrate a higher degree of reliability (Trizano-Hermosilla and Alvarado, 2016).

Table 3. Linguistic variables used in this study and their respective fuzzy numbers.

Linguistic variable	**Fuzzy Scale (L, M, U)**	$df = \frac{1}{4}(L+2M+U)$
Extremely high	(0.9, 1.0, 1.0)	0.975
Very high	(0.7, 0.9, 1.0)	0.875
High	(0.5, 0.7, 0.9)	0.7
Fair	(0.3, 0.5, 0.7)	0.5
Low	(0.1, 0.3, 0.5)	0.3
Very low	(0.0, 0.1, 0.3)	0.125
Extremely low	(0.0, 0.0, 0.1)	0.025

If Cronbach's alpha coefficient has a value greater than 0.7, the responses can be considered with the required degree of consensus among the experts (Bland and Altman, 1997). Also, the Kolmogorov-Smirnov (KS) test (which is utilized to test the nonparametric hypothesis) was used to examine and analyze the non-matching responses and further check whether parameters were parametric. The Shapiro-Wilk test was also conducted to find out if the distribution of the data is normal (it should be noted that the sample size was less than 2000) (Razali and Yap, 2011). Also, the Kruskal-Wallis test was used to verify the uniformity of the perceptions of respondents. In case the calculated score is greater than 0.05, the perceptions of the respondents can be considered similar (Theodorsson-Norheim, 1986).

4. RESULTS AND DISCUSSION

4.1. Prioritization of alternatives

In this study, a total of 20 experts from 13 countries from all over the world were invited and participated. The spatial distribution of the experts is indicated in Figure 2. After the first reply to the questionnaire, the relative importance of the main sustainability pillars was calculated based on the opinion given by the participating experts, as indicated in Table 4. Then, the fuzzy weights of the studied alternatives were ranked as presented in Table 5 and Figure 3. The information presented in Table 5 can demonstrate that technical, environmental, and economic considerations to adopt the proper methods for traffic management under heavy rainfall share the same importance (26.3% for each pillar), slightly higher than the social ones (21.2%). It can be interpreted as pointing to the necessity of considering the alternatives that can satisfy all the mentioned criteria to provide a sustainable alternative to deal with heavy rainfall conditions.

Fig. 2. Global distribution of the experts who participated in the study, from 13 countries all over the world.

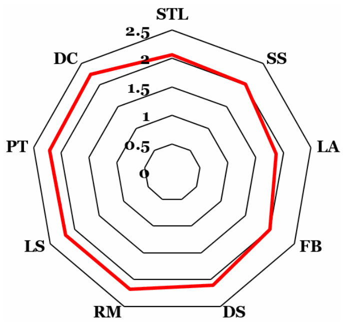

Fig. 3. The relative importance of the studies alternatives for urban traffic management under heavy rainfall conditions: *DC - improvement of driving culture; PT - public training; LS - designing appropriate lighting systems; RM - roads modification to meet rainfall conditions; DS - development of the drainage system; FB - designing proper footbridges; LA - providing local accesses; SS - designing smart signs; STL - designing smart traffic lights.*

According to the defuzzified values (expressed by final weights in Table 5), most of the studied alternatives (except STL, SS and LA) are believed as important to be considered for the traffic management under heavy rainfall conditions by receiving the importance values for sustainability pillars higher than "Fair", when the fuzzy values are converted to linguistic descriptors (Table 3). Hence, decision-makers can utilize the provided alternatives to make the best decisions considering their relative importance, calculated in this study. Among all the analysed alternatives, driving culture (DC) and public training (PT) were evaluated as the most important alternatives among others. This conveys the idea that human behaviour on how to deal with such conditions is of very high significance. Other alternatives including lighting system (LS), modification of the existing roads (RM), application or extending the drainage systems (DS), designing footbridges (FB) categorized as next priorities.

The calculation of the Cronbach's alpha index (α) was also performed using SPSS to identify the consistency-reliability of responses. The obtained coefficient was 0.92. Considering that the values for Cronbach's alpha higher than 0.7 can be acceptable, the results achieved in this study are concluded to be consistent (Bland and Altman, 1997). The outputs of Kolmogorov-Smirnov and Shapiro-Wilk tests were also less than 0.05, indicating that the responses are normalized and non-parametric. The uniformity in the perception of respondents to the questionnaire analyzed by the Kruskal-Wallis test resulted in a value of 0.027 (>0.05) indicating that the respondents' perceptions regarding the importance of the studied alternatives are the same.

Table 4. The relative importance of various sustainability pillars for traffic management under heavy rainfall conditions.

Sustainability Pillar		**Technical**	**Environmental**	**Economic**	**Social**
Relative importance	Calculated weight	0.775	0.775	0.775	0.625
	Normalized weight (%)	26.27	26.27	26.27	21.19

Table 5. Calculated weights of the alternatives regarding the main pillars of sustainability.

Alternative	**Sustainability pillars**				**Final weight**	**Final rank**
	Technical	**Environmental**	**Economic**	**Social**		
STL	0.750	0.500	0.825	0.725	2.06	6
SS	0.750	0.500	0.775	0.725	2.02	7
LA	0.625	0.500	0.700	0.725	1.87	9
FB	0.675	0.700	0.700	0.625	2.00	8
DS	0.725	0.775	0.725	0.600	2.10	5
RM	0.775	0.775	0.700	0.700	2.18	4
LS	0.825	0.600	0.775	0.775	2.19	3
PT	0.750	0.750	0.725	0.775	2.21	2
DC	0.750	0.750	0.775	0.775	2.25	1

5. DISCUSSION

There are several reports in the literature indicating negative effects of heavy rainfall conditions on traffic performance. Table 6 summarizes the main conclusions and remarks of the studies on the negative impact of heavy rainfall on the urban traffic criteria.

The management of urban traffic during heavy rainfall conditions has been considered as one important item in the urban management systems. During heavy rainfall, drivers prefer keeping a low speed and drive more cautiously to reduce the risk of probable accidents (Hussain et al., 2018). When the street capacity decreases as a result of heavy rain, it may result in a long queue. Furthermore, the insufficiency of the existing drainage system may cause the water to be accumulated in lower areas resulting in flood conditions. This will increase travel time and decrease street capacity especially for the vehicles that need fast transportation, namely ambulances. This flooding sometimes maintains from several hours to a few days if the infrastructures are deficient. In such cases, the ponding water needs to be drained by some appropriate facilities such as water pumps or the draining capacity needs to be enhanced, etc. (Youn et al., 2012).

There are some studies available in the literature indicating the adverse effects of heavy rainfall on the traffic parameters such as vehicles' speed (Ahmed and Ghasemzadeh, 2018; Mashros et al., 2014). In addition, there is always a higher risk of collision in such conditions, leading to an emergency situation. The adoption of the most suitable way to deal with the emergencies created under heavy rainfall is a complicated task that necessitates considering various parameters in compliance with sustainable management of urban traffic under such conditions. In such a case, it is vital to have a better understanding of the possible alternatives to manage traffic under heavy rainfall conditions. There is no doubt that the most effective actions are those selected according to the sustainability criteria, including technical, environmental, economic and social (Kamali, 2020). The integration of sustainability criteria with analytical methods for the screening and prioritization of the available alternatives can result in proposing the optimum solutions suitable to control the traffic-related risks with minimum costs and environmental impacts and with a high degree of social acceptability. The Fuzzy-Delphi methodology, as an effective method that is based on the knowledge and experience of experts in the field, has been widely applied to make effective decisions to deal with a wide range of problems in various disciplines (Chang et al., 2000; Jahanshahi et al., 2019; Kamali et al., 2015; Kamali et al., 2019; Nemati et al., 2020; Sánchez-Lezama et al., 2014). There are some reports in the literature on the management of traffic adverse effects such as noise (Ruiz-Padillo et al., 2016) using multi-criteria decision making approaches. However, there is no published report for the prioritization of the alternative measures to be adopted for the management of the emergency that occur under heavy rainfall conditions. In this regard, various parameters are believed to affect the management of the emergencies created under heavy rainfall leading to emergency conditions. Among the most important factors, technical considerations, managerial arrangements, and cultural attributes of the residents can be considered for the effective management of traffic crises after heavy rainfall.

According to the results of this study the importance of the heavy rainfall management criteria can be classified as follows:

a). Human factors related to the driving culture are the most important parameters to manage the emergency conditions under heavy rainfall. There have been some studies already performed in the literature on the importance of driving culture and human factors on various variables of urban traffic such as the effects of human behaviour on urban traffic intensity and congestion risk (Lizbetin and Bartuska, 2017). There are few studies available in the literature on the effects of the driving culture on the intensity of risks under heavy rainfall conditions. For instance, Ahmed and Ghasemzadeh (2018) simulated the behaviour of the drivers under heavy rainfall conditions. They concluded that skilled drivers almost kept their high speed compared to the other group, causing the increase in the accidents during the laboratory tests. They indicated that only 21% of the drivers have good performance during heavy rainfall. This is probably the reason why the experts concluded that this parameter is of utmost importance for traffic management under heavy rainfall conditions. Hence, the implementation of proper plans to improve driving culture would be extremely meaningful in these situations. Such plans need to focus on not using automatic vehicle control devices, such as cruise control, the importance of slowing down, avoiding driving through flooded areas, etc. Also, public training, which has received the second importance among the studied actions, is recommended to be considered seriously by the decision-makers. Some studies have also emphasized the importance of public training on how to deal with such emergency conditions to prevent subsequent adverse impact (Rong et al., 2011).

b). Designing appropriate lighting systems was also identified as another significant action to be taken to deal with emergency conditions under heavy rainfall. The intensity of light is normally decreased under heavy rainfall, especially during night time (Mukhlas et al., 2016), which can limit the ability of drivers to respond and can increase the likelihood of accidents (Mukhlas et al., 2016).

c). Technical actions such as modifications of the existing drainage systems, designing new systems with optimal capacities and the implementation of appropriate footbridges were also designated as the next priorities among the studied alternatives. It can be interpreted as a recommendation for the assessment of the effectiveness of HFRMs before the implementation of more expensive solutions. Also, risk assessments can aid to identify the extent of the technical corrections required. Some of the studied alternatives, however, can bring economic benefits. For instance, the design of appropriate drainage systems can provide water resources to be used according to the load of pollution in the collected stormwater. Such systems are vital city infrastructures to collect and convey stormwater to prevent water accumulation on the street pavement (Chocat et al., 2007). Despite the rapid urban development over the previous decade, it remains a significant challenge to design effective urban drainage systems to deal with the subsequent effects of heavy rainfall. According to the existing literature, the amount of stormwater that cannot be collected by the existing drainage systems can cause urban flow and issues such as traffic interruption, as well as associated economic issues. Furthermore, the runoff can wash the pollutants and transfer them into underground water bodies. Hence, there is an increasing need to control and manage the conditions after heavy rainfall events (Huong and Pathirana, 2013). Rangari et al. (2018) have introduced a stormwater management model (SWMM) that was developed to analyze the efficiency of the drainage network and allows for the assessment of the effect of green stormwater controls. The model has been simulated for one real storm event that was designed for the intense storm for a 2-year return period and 1-hour duration. Frequency analysis is performed by using best-fitted distribution; for instance, the frequency values are used for the development of intensity-duration-frequency curves. Asghar and Garg (2018) have carried out the urban stormwater modelling with SWMM using a hybrid modelling technique including ArcGIS and SWMM. The results have indicated that there is a significant threat of node flooding especially in the case of extreme rainfall events.

d). Providing local access was also identified as important for the management of the traffic under heavy rainfall conditions, although of less significance compared to other so far discussed alternatives. This can be because the provision of local access can bring some difficulties sometimes and it is highly dependent on the urban infrastructures and the availability of the local access. In addition, designing the locations of local access, can reduce congestion intensity and pressure on the main road, but still other actions may be required to prevent the attributed risks, mainly related to the human factors.

e). Other actions were brought into discussion, such as the implementation of smart traffic lights (Al-qutwani and Wang, 2019; Aleko and Djahel, 2020; Cruz-piris et al., 2018) as well as smart signs (Xu et al., 2019) to inform the drivers about the emergencies that may happen under extreme environmental conditions such as heavy rainfall. However, such alternatives received the least degree of importance among all the studied alternatives in the present research. In addition, there are no studies available in the literature on the pure effects of the implementation of such methods to reduce the risks that exist under heavy rainfall conditions, which can be the subject of future studies in this regard. Regarding the applicability of the results of the present study, it is worth mentioning that climate change has aggravated environmental conditions such as heavy rainfall. This can lead to huge safety and economic issues, especially in those regions of the world prone to more extreme weather conditions. For instance, in the case of England and Wales, it has been estimated that the damage of urban flooding is of about £270 million annually (Sayers et al., 2014).

The results of the present study can provide enough elements to make sustainable decisions to mitigate the impacts of heavy rainfall conditions on the traffic parameters. The prioritization of criteria can be helpful for decision-makers to adopt the appropriate measures considering the available infrastructures to manage traffic flow efficiency.

According to the results achieved, the application of sustainable drainage systems can be highly effective to control such extreme conditions. It has been indicated in the very recent literature that smart drainage systems can be an ideal alternative to deal with such conditions. However, there is a limited number of reports in the literature to investigate the applicability of smart drainage systems to manage heavy downpours. Keung et al. (2019) concluded that the real-time urban drainage monitoring by IoT Sensors (Fig. 4) is highly efficient to prevent the reduction in speed and delay in urban transportation, which is in line with the results obtained in the present study.

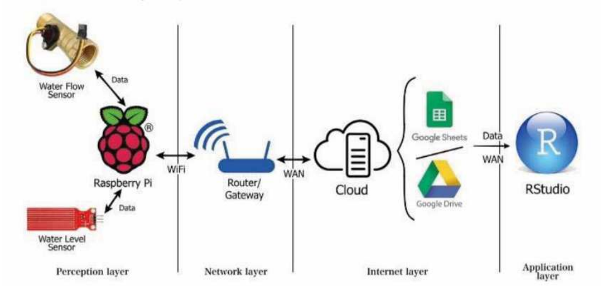

Fig. 4. An IOT strategy for the urban smart drainage systems *(Keung et al., 2019)*.

Also worth mentioning is that most of the countries suffering from heavy rainfall conditions, especially under climate change conditions, are the least capable to invest in drainage systems (Maksimović et al., 2009). Hence, the design of the smart management system should satisfy the economic considerations to provide sustainable solutions, especially for developing countries.

Table 6. A summary of the main findings and remarks of the papers published in the literature on urban traffic and management under heavy rainfall.

Subject of the study	Conclusions/ Remarks	References
Effects of torrential rain on traffic performance criteria.	Some roads are seriously affected and form local clusters under torrential rain.	(Guo et al., 2018)
Impacts of heavy rainfall on urban road network.	Rainfall normally bring severe adverse effects on the road traffic. Rainy conditions affect the macroscopic fundamental diagram (MFD) parameters such as: the decline in production, accumulation and weighted speed-at-capacity, weighted jam density and weighted free-flow speed (9.9%, 4.9%, 4%, 9.6% and 1.5%, respectively).	(Xu et al., 2013)
Effects of high-intensity storms on urban traffic	Heavy rainfall conditions resulted in floods with significant adverse effects on Athens transportation network.	(Mitsakis et al., 2014)
Model the number of accidents occurred during heavy rainfall	The severity of the accidents that occurred during heavy rainfall is correlated with some factors such as road properties, human factors and rain intensity.	(Lee et al., 2018)
Likelihood for accidents to occur under heavy rainfall conditions	Incorporating the real-time traffic and weather data from urban road arterials was performed indicating a high likelihood for accidents under heavy rainfall conditions.	(Theofilatos, 2017)
Study traffic indicators, accidents and rain	Significant relationship between rainfall conditions and road events such as crashes and safety events were identified, near the city of Marseille, in the south of France.	(Aron et al., 2015)

6. CONCLUSION

To design an effective urban management system to deal with the emergencies occurring under heavy rainfall, there is initially a need for identification and prioritization of the alternatives that may influence the effective management of such conditions. In this study, firstly, a multi-criteria decision making (MCDM) approach was implemented to identify the most sustainable alternatives to deal with traffic issues under heavy rainfall conditions. Some 20 experts from 13 countries participated in this study for evaluating the relative importance of the 9 main alternatives extracted through literature review.

The results indicated that, first, most of the proposed measured are important when looking for effective actions to deal with traffic management under heavy rainfall conditions. Among the studied alternatives, those related to the human factors, including the driving culture, public training and providing appropriate lighting systems, are of the highest importance. When considering technical approaches, sustainability criteria dictate to adopt low-cost and highly efficient actions with environmental and social positive impacts. In this regard, designing drainage systems, which can collect the excess water when required, coupled with storage and infiltration systems, providing treatment to reduce the pollutant load, can be proposed as examples of appropriate technical alternatives. This research also calls for more studies on the implementation of the alternatives ranked in this study and to explore their effectiveness in real environmental conditions.

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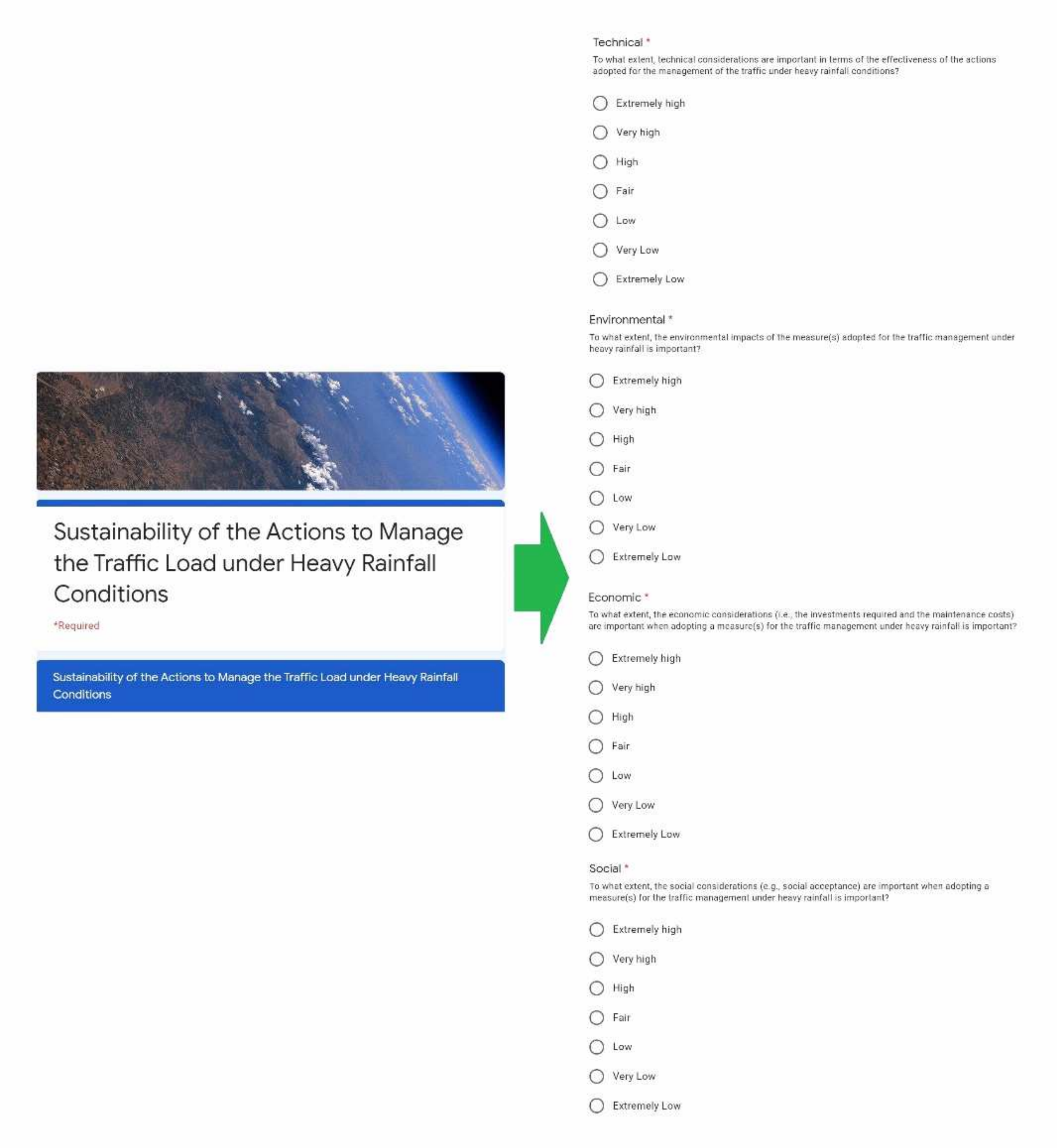
APPENDIX 1. Information on experts who participated in the study, including competencies and expertise

Affiliation	Position	Expertise
Kalindi College/ India	Assistant Professor	Disaster Management, Resource Management and Sustainable Development
Khazar University/ Azerbaijan	Lecturer	Structural Engineering
Rey Juan Carlos Madrid University/ Spain	Professor	Statistics and Operational Research
Ilorin University/ Nigeria	Researcher	Environmental Pollution Control
Aveiro University/ Portugal	Researcher	Materials for Road Construction
The national Research Council/ USA	Researcher	Environment Engineering
North Carolina State University/ USA	Professor	Colloidal Chemistry Affecting Dewatering
Aveiro University/ Portugal	Researcher	Traffic management
KU Leuven/ Belgium	Assistant Professor	Environment Engineering
Applied Science Private University/ Jordan	Researcher	Urban Planning and Environmental Policy
Federal University of Technology, Akure/ Nigeria	Lecturer	Ecotourism Management
Galati University/ Romania	Professor	Engineering and Management Development
Porto University/ Portugal	Researcher	IT Engineering
Khazar University/ Azerbaijan	Assistant Professor	Structural Engineering
Khazar University/ Azerbaijan	Lecturer	Water Structural Engineering
Aveiro University/ Portugal	Assistant Professor	Traffic Engineering
Western University/ USA	Lecturer	Water Engineering
Aveiro University/ Portugal	Researcher	Traffic Engineering
Teknologi Malaysia University/ Malaysia	Researcher	Hydraulics and Hydrology
Seoul National University/ South Korea	Professor	Water Resources Engineering

APPENDIX 2. Structure of the questionnaire

A-1) Relative importance of the various sustainability pillars for the adoption of the appropriate tools/actions for the traffic management under heavy rainfall conditions.



Sustainability of the Actions to Manage the Traffic Load under Heavy Rainfall Conditions

*Required

Sustainability of the Actions to Manage the Traffic Load under Heavy Rainfall Conditions

Technical *

To what extent, technical considerations are important in terms of the effectiveness of the actions adopted for the management of the traffic under heavy rainfall conditions?

- Extremely high
- Very high
- High
- Fair
- Low
- Very Low
- Extremely Low

Environmental *

To what extent, the environmental impacts of the measure(s) adopted for the traffic management under heavy rainfall is important?

- Extremely high
- Very high
- High
- Fair
- Low
- Very Low
- Extremely Low

Economic *

To what extent, the economic considerations (i.e., the investments required and the maintenance costs) are important when adopting a measure(s) for the traffic management under heavy rainfall is important?

- Extremely high
- Very high
- High
- Fair
- Low
- Very Low
- Extremely Low

Social *

To what extent, the social considerations (e.g., social acceptance) are important when adopting a measure(s) for the traffic management under heavy rainfall is important?

- Extremely high
- Very high
- High
- Fair
- Low
- Very Low
- Extremely Low

A-2) Relative importance of the tools/actions proposed in this study for the traffic management under heavy rainfall conditions .

A-2-1) Technical considerations

Technical Considerations

What are the degree of Technical advantages of the following actions for the management of the traffic under heavy rainfall conditions? *

A description of each action has been attached to this email.

	Extremely High	Very High	High	Fair	Low	Very Low	Extremely Low
Implementation of Smart Traffic Lights	○	○	○	○	○	○	○
Implementation of Smart Signs	○	○	○	○	○	○	○
Development of Local Accesses	○	○	○	○	○	○	○
Designing Proper Footbridges	○	○	○	○	○	○	○
Development of Efficient Drainage Systems	○	○	○	○	○	○	○
Modification of the Existing Roads to Meet the Rainfalls Conditions	○	○	○	○	○	○	○
Designing the Appropriate Lighting Systems	○	○	○	○	○	○	○
Public Training	○	○	○	○	○	○	○
Improvement of the Driving Culture	○	○	○	○	○	○	○

A-2-2) Environmental considerations

Environmental Considerations

What are the degree of Environmental advantages of the following actions for the management of the traffic under heavy rainfall conditions? *

	Extremely High	Very High	High	Fair	Low	Very Low	Extremely Low
Implementation of Smart Traffic Lights	○	○	○	○	○	○	○
Implementation of Smart Signs	○	○	○	○	○	○	○
Development of Local Accesses	○	○	○	○	○	○	○
Designing Proper Footbridges	○	○	○	○	○	○	○
Development of Efficient Drainage Systems	○	○	○	○	○	○	○
Modification of the Existing Roads to Meet the Rainfalls Conditions	○	○	○	○	○	○	○
Designing the Appropriate Lighting Systems	○	○	○	○	○	○	○
Public Training	○	○	○	○	○	○	○
Improvement of the Driving Culture	○	○	○	○	○	○	○

A-2-3) Cost-effectiveness

Economic Considerations

What are the degree of cost effectiveness of the following actions for the management of the traffic under heavy rainfall conditions? *

	Extremely High	Very High	High	Fair	Low	Very Low	Extremely Low
Implementation of Smart Traffic Lights	○	○	○	○	○	○	○
Implementation of Smart Signs	○	○	○	○	○	○	○
Development of Local Accesses	○	○	○	○	○	○	○
Designing Proper Footbridges	○	○	○	○	○	○	○
Development of Efficient Drainage Systems	○	○	○	○	○	○	○
Modification of the Existing Roads to Meet the Rainfalls Conditions	○	○	○	○	○	○	○
Designing the Appropriate Lighting Systems	○	○	○	○	○	○	○
Public Training	○	○	○	○	○	○	○
Improvement of the Driving Culture	○	○	○	○	○	○	○

A-2-4) Social considerations

Social Considerations

What are the degree of Social Impacts (for instance in terms of social acceptance) of the following actions for the management of the traffic under heavy rainfall conditions? *

	Extremely High	Very High	High	Fair	Low	Very Low	Extremely Low
Implementation of Smart Traffic Lights	○	○	○	○	○	○	○
Implementation of Smart Signs	○	○	○	○	○	○	○
Development of Local Accesses	○	○	○	○	○	○	○
Designing Proper Footbridges	○	○	○	○	○	○	○
Development of Efficient Drainage Systems	○	○	○	○	○	○	○
Modification of the Existing Roads to Meet the Rainfalls Conditions	○	○	○	○	○	○	○
Designing the Appropriate Lighting Systems	○	○	○	○	○	○	○
Public Training	○	○	○	○	○	○	○
Improvement of the Driving Culture	○	○	○	○	○	○	○