A participatory approach for identification of micro flood zones in poorly developed urban areas

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Abstract:

The lack of observation technologies and the information records in developing countries restrict the applicability of advanced approaches for identification of flood zones and setting-up flood risk mitigation plans. Greater challenge is encountered in urban and areas where the natural hydrological conditions are altered. The current paper proposes an approach that utilizes the globally available data for the essential hydrological analysis. The approach integrates the spatial-analysis and hydrological modeling approaches with a set of sequential iterative field/desk activities that confine and filter the flood zones and identify the associated risks. The proposed approach involves a systematic system for classification of the zones prone to flood according to the present status and the foreseen flood-risks. The proposed approach is sufficient to identify the micro-flood zones which might not be captured by the traditional analysis methods. The case study of Gaza Strip in Palestine is considered for validation of the approach and identification of the approach potential and limitations.

Key words: Micro-floods, Flood Risk, Poorly Developed, Urban Areas, Participatory Approach

1. Introduction

In comparison with other natural disasters, floods has the most devastating impact on economy, and affect the highest number of people every year [1]. The vulnerability to flood risks and risk of displacement are reported in direct link to the rapid urbanization [2]. The human factors add to the climate change and other natural complexities and emerge in a complicated dilemma. Hence, only comprehensive approaches that involve the governments, the private sector, civil society and the international community can be employed [2]. The successful or demonstrated approaches of risk mitigation and management cannot simply be replicated at any region. The type of the risk differs according to the prevailing conditions of each society. For example, the flood-induced mortality was found to increase with the decrease in the per capita GDP; while in contrast, the economic loss increases with the increase of GDP [3]. This means that the ultimate objectives of risk mitigation plans would equally vary from one region to another.

On the other hand, the ability to manage to the flood risks and the level-up the resiliency against disasters is governed by the availability of accurate and reliable data. This can be inferred from the positive correlation that was noticed between the smartness index of the Chinese cities and the overall resiliency and the infrastructure resiliency indices [4]. In developing countries, the lack of the essential information required for hydrological analysis stand as a major challenge that hinder the full understanding of the risk and proper preparedness [5]. The lack of essential data leads the stakeholders to investigate alternate approaches that are based on participation and collaboration with stakeholders and community representatives in developing their highly accurate risk maps and mitigation plans [6], [7].

The flood mitigation measures are applied at a wide margin of scale and resolution. However, it

was demonstrated that applying the mitigation measures of the flood risk at the aggregated spatial scale would be economically inefficient for some cases, and the risk would persist at others [8]. In well developed urban areas, such micro-flood zones are locally resolved by drainage or sustainable systems. However, these limited scale floods emerge in a severe hardship and property losses for the residents of poorly developed urban areas. Thus, the risk mitigation plans should be able to identify these hotspots, characterize them, and propose proper measures.

The current paper discusses an approach proposed for identification of micro-flood zones in poorly developed urban areas. The case study of Gaza Strip, Palestine is considered to present the different aspects and challenges that could be encountered for similar cases.

Gaza Strip is a coastal region with a total area of 37067 Km^2. The region is geo-politically confined, while the population is characterized by a high growth rate [9]. This emerged in an average population density in the region that is approximately 4,400 inhabitants/km^2, which makes of it one of the most densely populated areas in the world [10]. The unstable political environment and the limited available investment downgraded the priority of stormwater management giving the big share to water supply and sanitation services. However, the historical storm occurred between the 10th and the 14th of December 2013 brought the flood risk to the concern of stakeholders and humanitarian relief organizations due to the unprecedented scale and severity of the catastrophe and the high economical cost. According to the Humanitarian Needs Overview Report (OCHA, 2015) [11], 75 per cent of the usual average precipitation occurred in four days. This caused heavy floods in Gaza Strip that forced displacement of around 10,000 people to temporary shelters, and damaged approximately, 21,000 homes. The losses due to the floods were estimated at over USD 130 million [11]. In fact, the

The characterization of the flood risks and identification of risk mitigation measures in Gaza Strip encounter the following issues:

1. The region is densely populated and poorly planned and developed.
   The impact of the rapidly expanding urbanization is not fully studied, despite that the flooding frequency and magnitudes increased by the expansion of the impervious surfaces.
2. Insufficient information on the stormwater infrastructure and its efficiency.
   The stormwater infrastructure was reported to have differential performance according to its age, overloading, sediments accumulation, etc. However, no specific measurements are available.
3. Insufficient information on the historical record of the rainfall.
   Standard hyetographs and intensity-duration frequency curves are not available. Only rainfall intensity records are available on the 24-hour basis.

The identification of the flood risk and the mitigation measures for such a case require a non-conventional approach that overcome the challenges and eventually emerge in sufficient and reliable data by exploiting all the available resources.

2. Methodology

The approach that is described by the current paper is composed of four major activities, as shown in Figure 1. The approach illustrated herein is designed to identify the hotspots prone to the micro-floods and to develop a reliable database enriched with the information that is required for the development of the mitigation plan. Each of the shown components are composed of several tasks that will be explained later-on in this section.
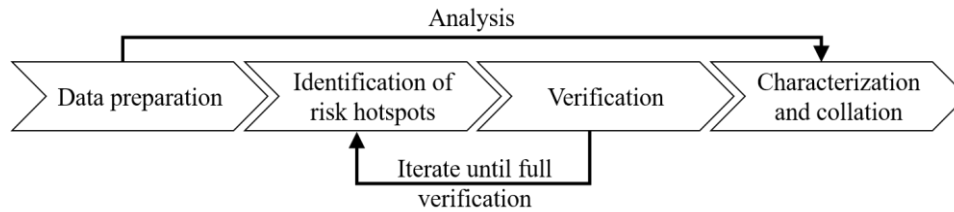
Figure 1. Flowchart of the applied approach

The characterization of the flood hotspots paves the way for development of conceptual designs for the flood mitigation measures and identification of the detailed design requirements.

2.1 Data preparation

The first activity includes the data preparation, which involves the collection, compilation and processing of the data needed for the subsequent activities. As mentioned in previous, this represent a major challenge for developing countries. Thus, this effort should focus on exploitation of what is available and mining any possible data.

The digital elevation model (DEM) is the keystone for any hydrological analysis. However, snapping the micro-floods require a high-resolution DEM, which might not be available for some regions in the developing countries. One alternative is the globally available topographic data such as Shuttle Radar Topographic Mission (SRTM) [12]. However, such datasets should be used with caution and realization of the effect of the low horizontal and vertical accuracies. For development and calibration of the conventional hydrological models, such data was considered inappropriate [13]. For the case of Gaza Strip, the DEM was interpolated from a huge dataset of elevation points acquired by plain field surveying. Data needed a careful filtration and quality check before being used. The interpolated surface was generated at a resolution of 10 m.

The Open Street Map (OSM) was used to apply conditioning process to the generated DEM. This process helped the delineation of urban catchment areas at the early stages of the analysis.

Land cover and land use maps were acquired from local authorities. IDF of a nearby station that is 10km away from the north borders of Gaza Strip was employed. These data were used for the hydrological analysis at the final stage.

2.1 Identification of risk hotspots

The approach employed for the identification of the micro-floods was based on the assumption that they occur at the depression zones of different scales, as shown in Figure 2. Such concept was described in literature identifying what is called "Bluespot", which stands for the area prone to inundation [13]. These bluespots are calculated by subtracting the original DEM from a processed for filling the sinks and depression zones [14], [15]. This results in a map where the areas of inundation are shaded according to depth of water, which is governed by the storm intensity. However, the selection of the critical depth of the flood is arbitrary and is not necessarily associated with the risk. Thus, the current approach relied on identification of the lowest point in every depression zone. By decreasing the depth, new bluespots start to appear. Therefore, the lowest points in the emerging zones are identified as risk hotspot. These hotspots are where the ponding starts.

The next step is to identify the size of the of the inundation area, the attributing micro-catchment, the existing stormwater infrastructure, and the urban facilities that are under risk. This process resulted in a draft map where potential hotspots are marked as points.
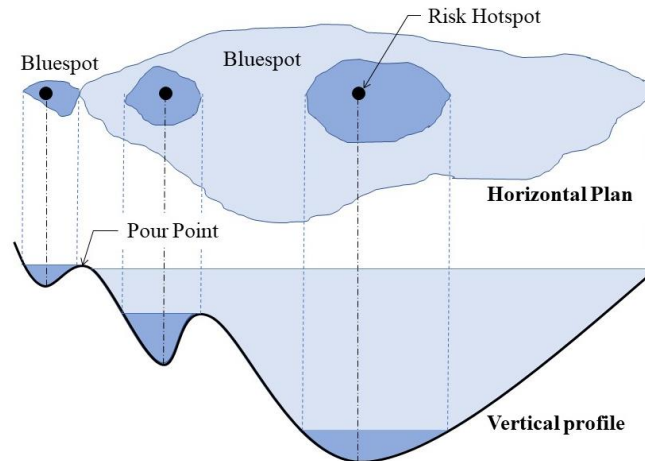
Figure 2. The concept of Bluespots and the risk hotspot

Figure 5. Example of bluespot Map: zones prone to inundation

2.3 Verification

The second activity, which is the "identification of the risk hotspots", aims at identification all the critical locations that are prone to micro-flood risks. This process was conducted through an iterative approach of verification of the find-outs due to the variety of field conditions and available information. Thus, the complementary verification process is revisited as much as needed for full verification that no further hotspots are missing, and all erroneous spots are removed from the list. Implementation of those two activities begin by meeting with specialists and the personals in charge for stormwater management in the local municipalities. These meetings involve a through revision of the hotspots that were identified and the delineation of the urban catchment areas. This was conducted using either digital maps or printouts, as shown in Figure 3. These discussions were used to eliminate or add the hotspots, and to collect any available data and photos on the floods in these hotspots. The second step involves conducting field visits, and talking to residents, inspection of any visible signs of the floods, and acquiring any available photos. This step was found very informative as the residents are the only witness for the flood behaviour during the storm. It was possible to compare the scale appearing on the flood to the scale predicted by the hydrological

models.

The experience from the field revealed several conditions that could lead to the underestimation of the flood zones. Some of the residents, especially in the poorly developed regions try to adapt to the flood risk and do not raise the issue to the decision makers assuming that it is part of the life hardship, and it occurs few days every year. Realization of such locations was only possible by GIS analysis and by field visits, talking to the residents in the area, and inspecting the impact of the former floods (or even during the storms). Such field visits were highly informative as it provided valuable information on the scale and exact causes and consequences of the floods. Residents were willing to share old photos of the floods and the measures taken to mitigate the losses due to floods, as shown in Figure 4. Such information was valuable in validating the hydrological analysis that was conducted later on by the current study.

Figure 3. The printouts used for verification of the analysis outcomes with the municipality staff

Figure 4. An example of the measures applied by local residents at one of the red hotspots of flood

2.3 Characterization and collation

Once the verification process was accomplished, the risk hotspots were enumerated and coded. A GIS map was developed classifying the hotspots into four classes as shown in Table 1. This classification is based on the risk potential and the urgency of the intervention.

The red hotspots are reportedly occurring micro-floods that impose risk to human lives and properties. Intervention at these points in highly appealed. The yellow color was assigned to hotspots where the stormwater infrastructure effectively prevents floods. However, such points are critical in cases of historical storms. Also, any unplanned activities that can be conducted on the

upstream could raise the flood risk at these locations. For example, the poorly planned expansion of the impervious surfaces was noticed as the major cause of the floods in the downstream. Another practice that caused floods in the areas served by a drainage system is the unplanned loading of the old systems by new connections.

The green hotspots are located in agricultural lands and undeveloped areas. This category was made explicit due to the different type of interventions required to deal with the risk. Also, they were remarked in order to guide future development work to be conducted in caution. The blue hotspots are zones of land depression where no floods were reported or observed, and insufficient data are available.

After developing the spatial database, it should be enriched by all the information and the photograph that are linked to the hotspots, including the cause of the flood and the potential solutions. The flood area was characterized estimating hydrograph characteristics, and inundation map, and number of affected people.

Table 1. Classification and definition of

Class	Description
Red	Area is prone to frequent floods. Risk to human lives and properties is imminent. Intervention is highly appealing.
Yellow	The hotspot has a record of floods; however, it was resolved by specific interventions. It is a critical point that might be exposed to floods if unplanned interventions are conducted.
Green	Hotspots detected or observed at agricultural lands and undeveloped areas.
Blue	A potential flood hotspot that could not be verified or the available information is insufficient.

3. Specific Results

The micro-flood identification process appears in a set of outcomes which are essential for the any subsequent risk mitigation activities. A map of identified hotspots was produced according to the color code shown in Table 1. Each point was associated with an attributes table that involve all the collected information on the history of the hotspot, flood risk, cause of the flood, and the characteristics to the flow to that area. The resulting spatial database documented the knowledge and experience that is only associated with the personals who are working in the field and introduced it in informative manner for any users in the future.

Another valuable outcome is the map of the actual delineation of the urbanized areas, as shown in Figure 7. The urbanization activities were frequently noticed to alter the natural delineation. For some cases limited-scale infrastructure, such as a street bump or a the curbstone, deviated the flow paths and created a totally different shape of the catchment area. This real delineation is essential for characterization of the flood risk and proposal of the potential interventions.

Developing a spatial database adds potential capabilities that can be attained via the spatial analysis techniques. One of them is the prioritization of the intervention activities. It was also possible to figure out the vulnerability of different emergency and critical infrastructure to the flood risk.

The data collected would be sufficient to develop a catalogue of the proposed interventions. This catalogue involves the conceptual designs and the estimated budget. It also include, in a high

significance, the required surveying works that should be conducted in prior to the detailed designs.
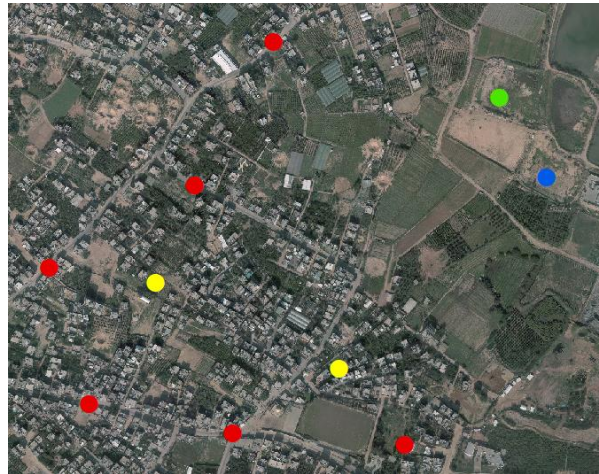

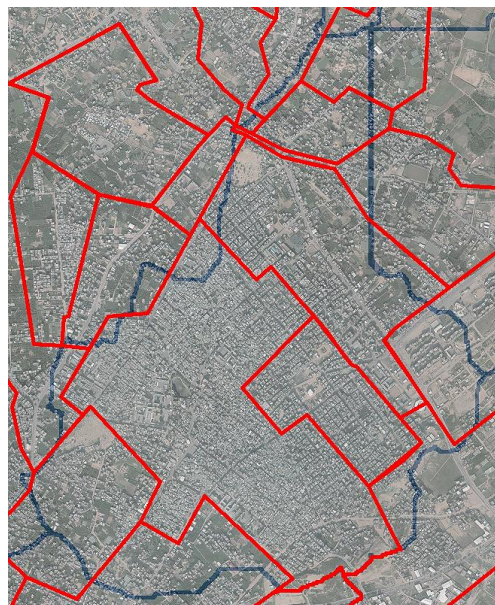**Figure 6.** Example of identified points of floods risk hotspots

Figure 7. Delineated urban areas (red) in comparison with the topography-based delineation (blue)

4. Discussion

The approach presented herein succeeded in identification of the risk hotspots at the micro-scale and development of a database of valuable data for any following intended interventions, which cannot be acquired by the conventional hydrological models. The approach dealt with the severe lack of information, which is a common challenge in developing countries. However, this approach is governed by efficient collaboration of the stakeholders and the community.

It was noticed that the hotspots which were collated in the classes presented in Table 1 share a common conditions of land topography, urbanization, infrastructure, etc. These conditions might exhibit some patterns that facilitate the realization of the risk potential. This can be conducted employing data analytics approaches such as machine learning techniques [16]. Such methods are

sufficient to provide predictions for the cases where the data required for conventional hydrological analysis techniques are incomplete or unavailable.

This approach is time and labour consuming due to the need of intensive verification. Optimal planning and management of the activities is highly required for this reason. Additional tools and applications that facilitate the verification phase can be employed.

The field experience revealed the significance of involving the community in the enumeration and reporting of the flood risk. Thus, opening an online gateway for reporting floods by the public could be of a great benefit to the stakeholders and the organizations working in the field.

The approach presented by the current paper only respond the imminent flood risks and does not provide answers to the potential impacts of the climate change. The development of means for acquisition or mining of reliable data is indispensable if the long-term response to the climate change is anticipated.

Conclusions

The participatory approach described by the current study successfully provided data of high resolution and precision for the micro-floods in a poorly developed region. The approach overcame the deficiency in essential data and characterized the risk based on data analysis, field inspection, and personal meetings.

The approach, however, offer answers to the imminent risk and is not valid for prediction of the climate change consequences. Furthermore, the method is time and labour consuming. Thus, thorough planning and management are essential, and the employment and development of the tools that facilitate the desk analysis and the field work are highly recommended.

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