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Spatial Hazard Assessment Practices in Data Poor Areas: A Participatory Approach towards Natural Disaster Management

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Abstract

For the post assessments of flash flood disaster, Participatory GIS (PGIS) technique in a combination of spatial domain is developed for understanding the local community's perception. The settled methodology has been used in this study by surveying 1273 households in the affected areas of Dera Ghazi Khan (D.G Khan) city Pakistan. Kriging as a geo-statistical technique was applied for analyzing the flash flood inundation level with respect to the topography of the area. Quantitative assessments of physical vulnerability are made by using damage/loss function scheme. Synthetic techniques are repressed and attention was paid to the actual loss and susceptibility of buildings and population in response to water depth and duration. Risk as a function of exposure, hazard and vulnerability was premeditated in the form of map. Results of the study substantiate that vulnerability has a direct relation to the construction type of the buildings; however intensity of the flash flood event, high population density, less distance of the area from the source and high duration of the flash flood event results in an increase in the risk of the affected areas of D.G Khan. The findings of the study could be impacted for the relief programs and for the designing of coping mechanisms against such events at local level.

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1. Introduction

Flash floods are among one of the disastrous natural hazards. Because of their sudden and fast impact nature, flash floods are considered as dangerous of all types of floods [23]. In recent years, increased trend in the frequency of floods has enormously damaged human socio-economic environment. According to the statistical record of the National Civil Affairs (NCA), on average, a global loss of 3-6% in gross national product is caused by flash floods each year [10]. Flash flood events are frequently observed in United States, England, Peru, Spain, and France [4,7,3,11]. According to [18] last decades shows several, flash flood, disastrous events in central Europe however [12] states that in many developing countries of South and South Asia flood events have dominant occurrence over other natural hazards.

In Pakistan, the most devastating flood type is flash flood. Numbers of mountainous and sub-mountainous region in the country are extremely vulnerable to such events. Recent years show flash floods in Pakistan tends towards an increasing pattern owing to changes in weather pattern [2]. In Pakistan, flash floods are mostly caused by monsoonal torrential rains, and a shift of monsoonal pattern has increased the frequency of flash flooding [9]. Hill torrents of south-west Punjab (Pakistan) are extremely vulnerable to flash floods. History reveals that the flash floods of small to large intensity frequently damage rural areas in the west of .D.G. Khan (a big city of south-west Punjab, located in east of hill torrents). The main source of flash flooding in these areas are the Hill torrents situated nearby the area including Wador, Chachar, Mithawan, Sakhi Sarwar, Kaha, Sanghar and SoriLund.

Vulnerability analysis is by far the most important perceptions widely used in hazard risk management. For better management of disastrous events proper vulnerability assessment of community to flood is required [15]. Local knowledge plays an important role in both quantitative and qualitative risk and vulnerability assessments. Numbers of approaches have been used to implore community level data to incorporate with GIS. Participatory GIS techniques use community involvement with more weightage or relegate groups damage assessments and in decision making [5,6]. Depending upon scenario and data availability PGIS researchers either use existing data or engage directly with the community [14]. References [8,12,22,13] use PGIS technique in prospective of community mapping for flood risk and vulnerability assessment in data poor areas.

In September 2012, heavy spells of Monsoon rainfall on Suleiman hills (Wador torrent) of D.G. Khan causes disastrous conditions in the city area and adjoining rural areas. An unaccepted over-flow occurred in D.G. Khan Canal resulting in inundation of the area. Accurate assessment of risk element and vulnerability is a key step towards the proper management of such events.

2. Objectives

The forgoing research use PGIS technique for the collection of input data with the aim to maximize the weightage of local community's perception about the flash flood event of 2012. The community in question was a small, localized area prone to flash flooding. In this context the study seek to address the risk and vulnerability of the area in spatial context with objectives:

- Identification of potential affected areas of the flash flood event of 2012 (PGIS)
- Flash flood depth and exposure analysis using community based approach (PGIS)
- Quantitative assessment of flash flood physical vulnerability using damage function method
- Risk zone mapping of affected area using modified equation of risk.

3. Study Area

The study area is a part of D.G. khan Tehsil Municipal Ad-ministration (TMA) of District D.G. Khan. The district composed of three tehsils including Tunsa Shariff, D.G. Khan and Tribal tehsil (figure 1). The area lies in a strip between Indus River in the East and Suleiman mountain range in the West. In the context of climate, area lies in an arid zone with an average annual rainfall of not more than 150 mm. Seasons of hot summers and cold to mild winters make the area's climate more abrupt, with a temperature range of 13° to 50° C. The area is categorized as rain-fed in general, as the hill torrents in western side of the city receive torrential rains in summer monsoon [21]. The inundation of the area is cause by heavy Monsoon spell of September. Hill torrent water from Suleiman range in the west hits the D.G. Khan canal directly causing to breach the canal lies in vicinity of the city area.

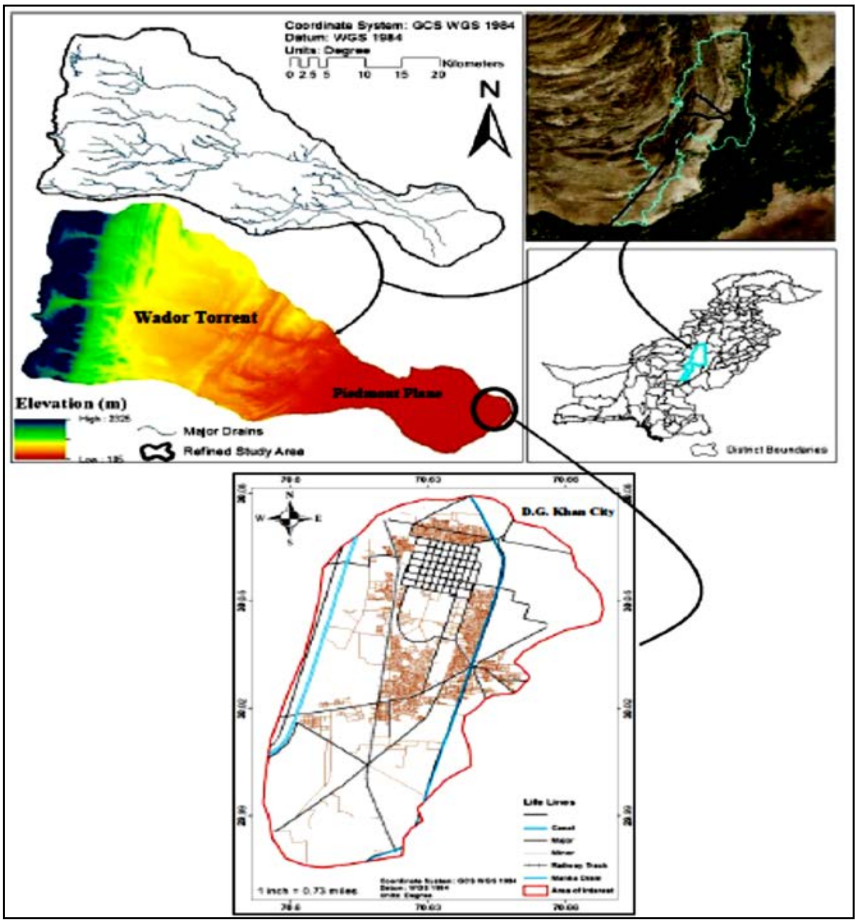

Figure 1: Geographical location of Study area

4. Data and Methodology

4.1. Participatory GIS

Participatory GIS is a technique practiced for the collection of basic data use for the analysis of damage as well as vulnerability and risk analysis as per local community perception. References [8,16,22,19] used PGIS as a community based approach to collect data for flood physical vulnerability and risk analysis.

For the implementation of PGIS technique base map of the city was generated with primary to tertiary information attached. PGIS technique was used for the identification of potential affected sites of the city during flash flood event of September 2012. For this purpose, base map discussion with the officials of local government and community members were set. As a result 17 potential sites were selected with the demarcation of the affected area during the flash flood event (figure 2). Within the defined potential sites, a field survey was conducted for the generation of geo-database of risk elements (buildings, population).

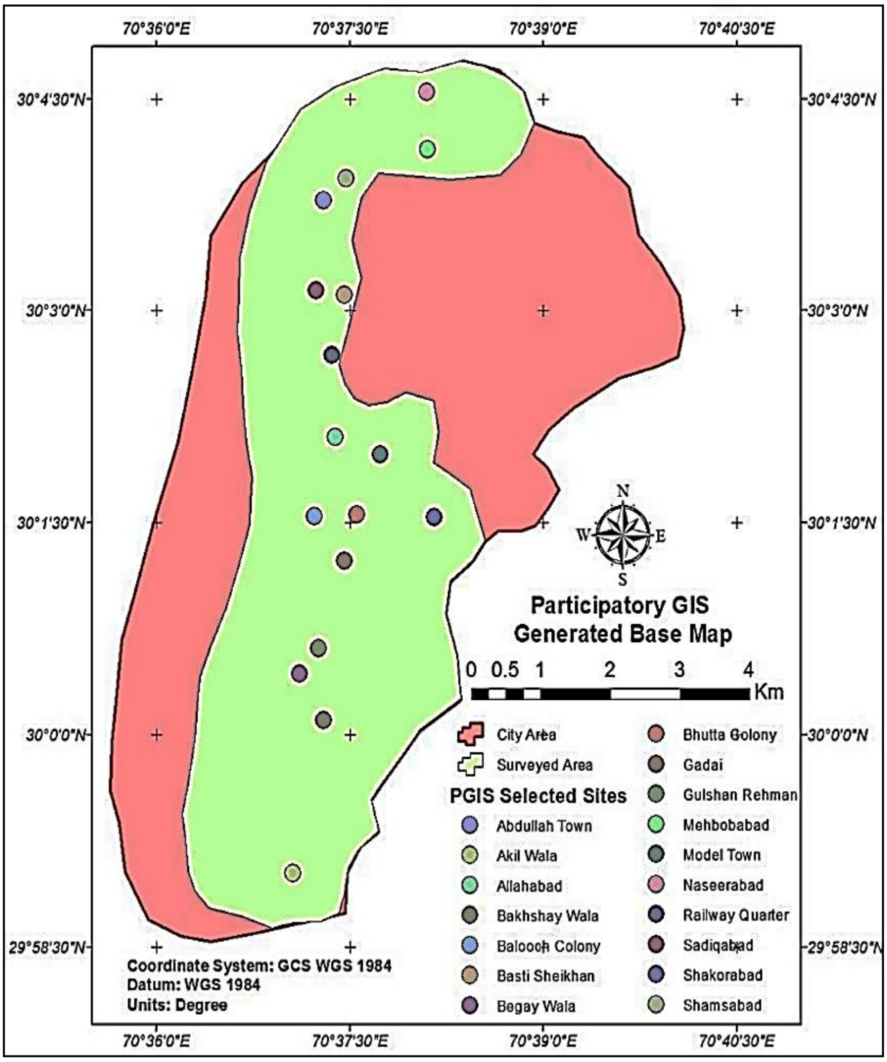

Figure 2: Selected potential affected sites and delineated area for survey (PGIS).

Stratified random sampling technique was used as the way to acquire information of the loss data at individual potential site. Reference [17] uses stratified random sampling technique for different types of building and for constructing loss function in South Africa. The PGIS data was incorporated into GIS environment for assessment of physical vulnerability and risk.

4.2. Physical Vulnerability

Physical vulnerability analysis was performed by using the dam-age/loss function. The function is used for the measurement of direct losses during natural hazards and other disastrous events. Smith, (1994) use damage/loss function for the assessment of vulnerability for different building types in South Africa. Quantitative assessment of physical vulnerability was performed in accordance to the classified damage/loss function of identified risk element and flash flood inundation level. Building inventory was selected as potential risk element in the study area. The observed affected buildings were categorized into two categories:

- Type 1: Concrete floor with brick cemented wall.
- Type 2: Mixed wall including brick with clay.

As per demand of the area damage states of the classified building inventories were encoded in damage functions with respect to the inundation level (table 1).

Table 1: Classified damage/loss function

Sr	Damage State	Encoded Damage Function
1	No Damage	0
2	Wall Deterioration	0.25
3	Minor to Medium Cracks	0.5
4	Immediate Patchwork Required	0.75
5	Wall Collapse	1

However, flood inundation map was generated by utilizing key source (PGIS) data that was collected through community survey. Kriging as a geo-statistical interpolator was used for the interpolation of collected point (1273) data into a continuous surface for analyzing the flood inundation level at each potential site. The Kriging technique was preferably used over other interpolation techniques for its accuracy at local level. Digital Elevation Model (DEM) of Advance Spaceborne Thermal Emission and Reflection Radiometer (ASTER) product was used to analyze the flash flood inundation level for the different areas of the city with respect to the topography of the area. The physical vulnerability was demonstrated in terms of curve formation with flood inundation level and damage/loss function as an abscissa and ordinates respectively.

4.3. Flash Flood Risk Analysis

The surveyed data of risk elements was used for the assessment of risk of the area (figure 3). Risk map of the area was generated by incorporating the physical parameters of flash flood event with the use of generalized equation for risk calculation [23].

$$Risk = (Hazard \times Exposure \times Vulnerability) \qquad (1)$$

Where, hazard demonstrates the intensity of the event, exposure describes the exposed risk elements and vulnerability depends upon the technique adopted. The generalized equation was modified through the expert opinion to more appropriate form for the assessment of risk in such terrains.

$$Risk = [(Distance\ from\ source + Flood\ Depth + Flood\ Duration) \times (Exposed\ population \times Population\ density) \times (Vulnerability\ curve\ graph)] \qquad (2)$$

Distance of the sampled point was calculated from the two breach points that were selected as a source. The modified form results in normalized risk values ranging from 0-1.

5. Results

5.1. Flood Depth and Exposure

The canal breaches in the North of bridge Wador and in the north of Bridge no. 28 (figure 4). Due to the overflow and breaching of canal near Wador Bridge, water level rise in nearby areas among which Abdullah Town and Sadiq-a-bad were observed with the maximum inundation level of approximately 4.5m. Whereas in the south, near bridge no.28 Baloch colony, Bhutta colony, Gadai and rural areas of the city were observed in devastating conditions (figure 5).

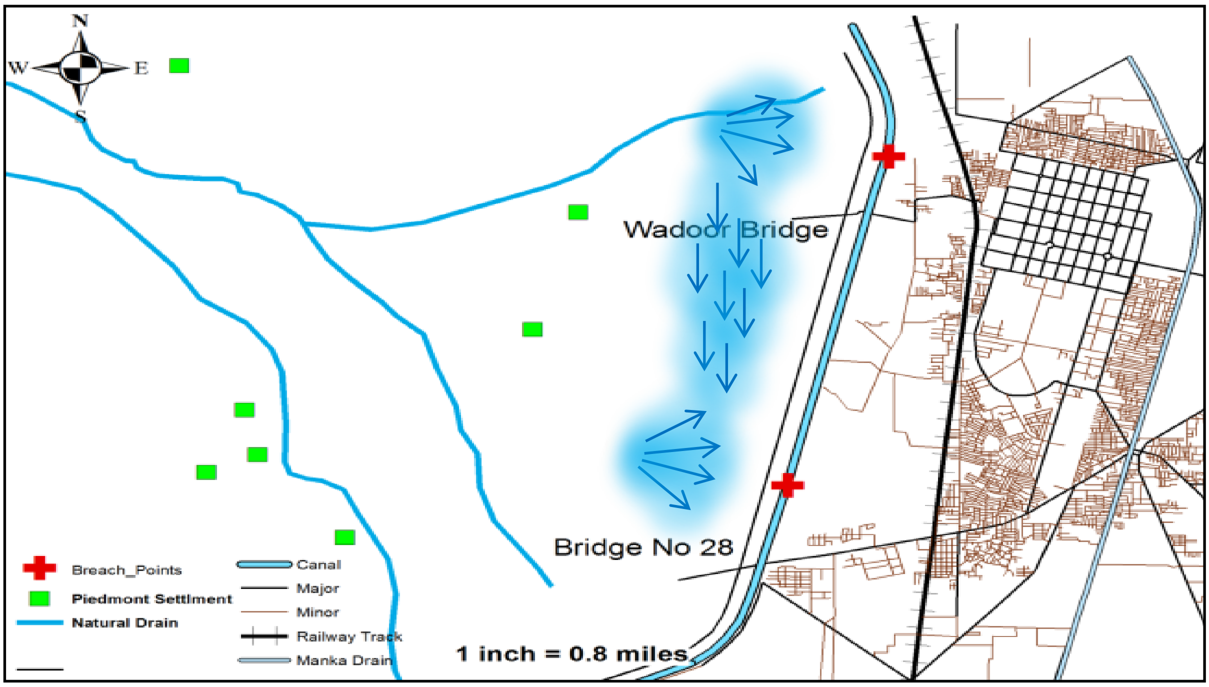

Figure 4: Breach point location map.

The breach point in the South results in inundation of rural union councils and agricultural fields with average depth of 1.2m. Baloch colony and Gadai area was recorded at hit list due to the proximity of the area towards D.G. Khan Canal. As per the local community perception, due to the south breach point, more area was exposed by flash flood water. The communities residing in the south of the city are the rural sides with majority of the houses of the type 2. The affected population statistic shows that more than 10,000 people were affected by the flash flood scenario of 2012 (figure 6).

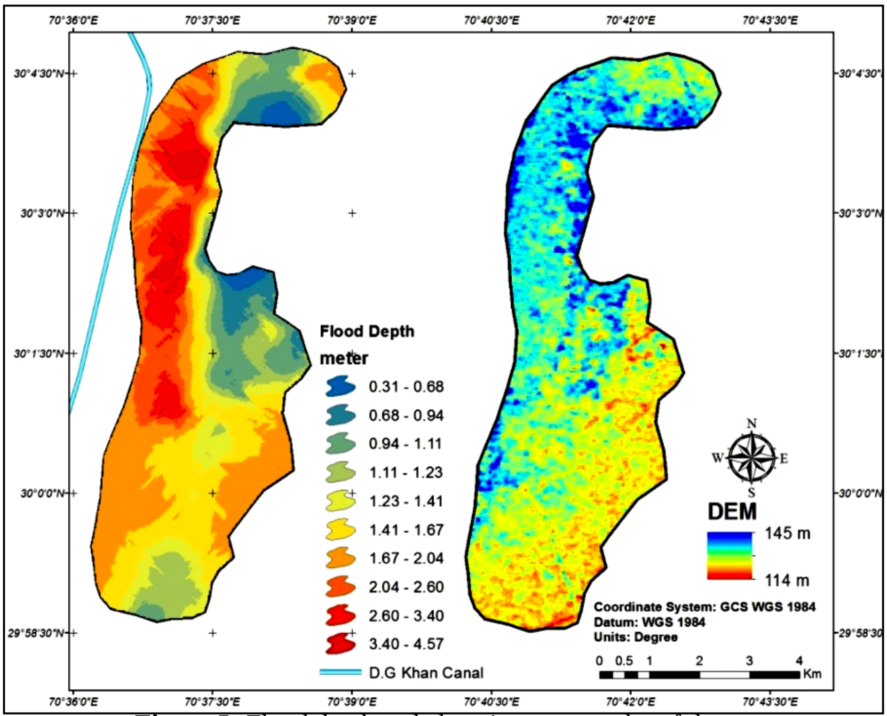

Figure 5: Flood depth and elevation topography of the area.

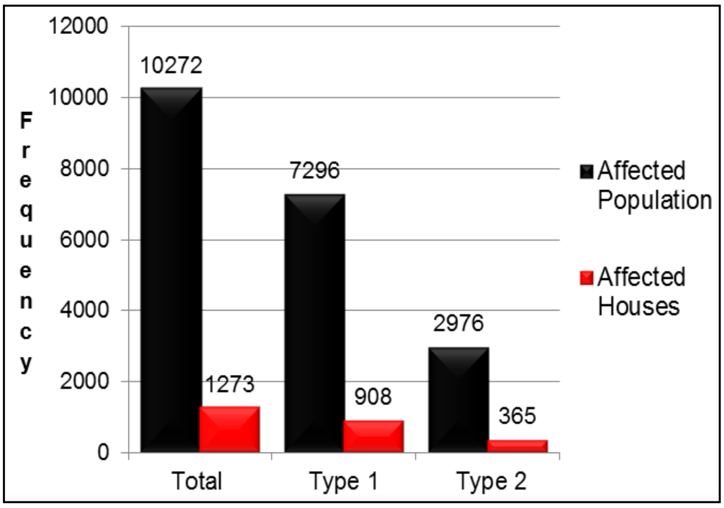

Figure 6: Affected population statistics for flash flood scenario 2012.

The results show that majority of the area was exposed to the flood water depth of approximately 1.2 - 2.2m. Houses of type 1 were exposed to the devastating flood depth of more than 4.9 m. However houses of type 2 were exposed to a maximum flood depth of 3.6m (figure 7)

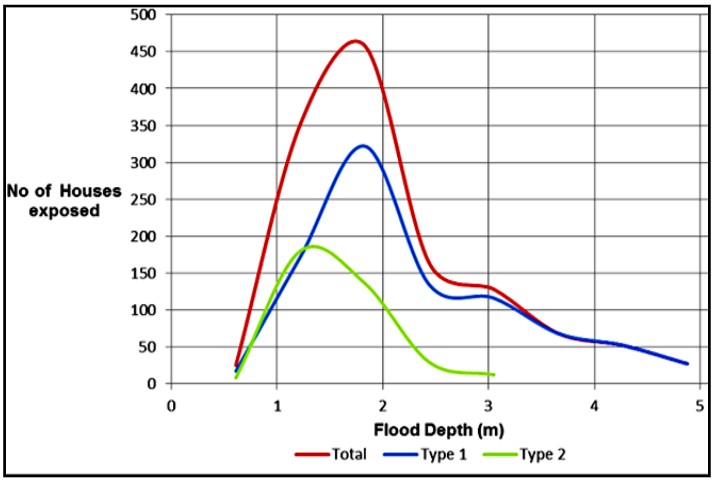

Figure 7: Flood depth exposure graph.

5.2. Physical Vulnerability and Risk Analysis

Among the risk elements, building type was considered as potential risk element as it is directly related to the flood depth and exposure of the event. On the basis of defined damage function and flood intensity in terms of flood depth, physical vulnerability curves were generated for the individual house type. Houses of structural type 2 (mixed wall including brick with clay) with maximum inundation level of 3.2m were observe more vulnerable as compare to the houses with structural type 1(concrete floor with brick cemented wall) although these houses were inundated to a more devastating level. The drastic increase in the vulnerability to these types of houses was due to the poor standards of construction, meanwhile the age of house, locality and its association to the surroundings also contributes to the fluctuation and sudden increase in the vulnerability curve at low flood depths.

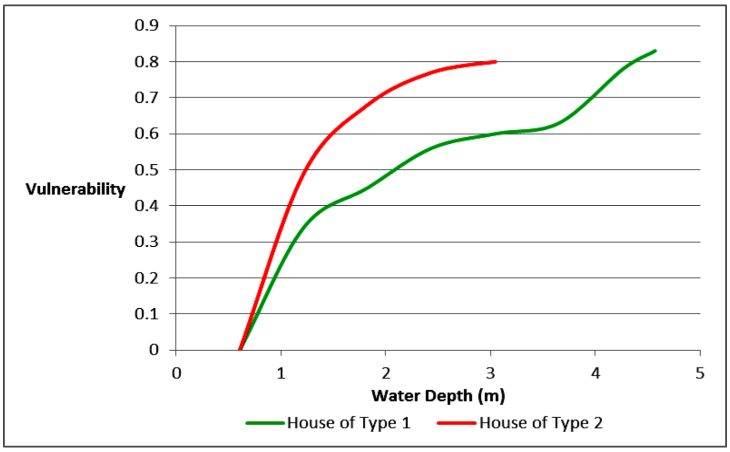

Figure 8: Physical vulnerability curve graphs

However, for the risk analysis, distance from the source (breach points) was calculated. Minimum distance from the source was 0.73km whereas maximum distance was observed as approximately 3.5km. The risk map was classified into 10 classes, ranges from 0 – 1 on the basis of geometric intervals of the data (figure 9).

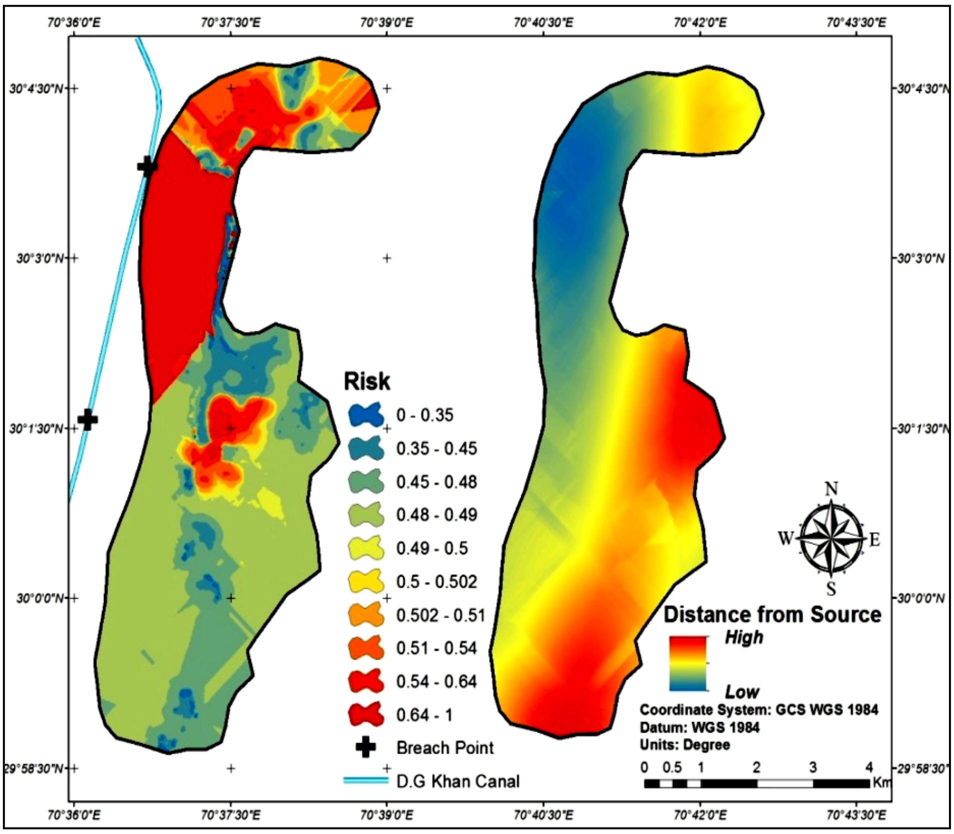

Figure 9: Classified risk map of the area.

Geometric interval classification scheme was used as to generate the classes on the basis of actual representation of the true data. Each class range represents approximately same number of values with each class. The minimum value (0-zero) represent areas with little or no risk, whereas maximum value (1-one) represents high risk areas.

6. Discussion

Participatory GIS, as an assessment tool, shows accurate data acquiring capabilities and was observed a better technique for flood depth mapping and also for risk and vulnerability assessment in data poor areas. PGIS as community based approach has played a vital role in flood depth mapping of the area along with the defined analysis of flash flood event of September 2012 in D.G. Khan. The classified areas were inundated to such a high risk level because of the area's topography. In the past these areas, which are low lying areas in comparison with the adjoining areas, were remained dumping sites with an elevation difference of approximately 3meters. Some of the strata including Sadiq-a-bad, Naser-a-bad, Shams-a-bad, Abdullah town and Railway colony lack proper drainage systems to drain the excess amount of water due to which these strata carry large duration of flood water. Buildings with confined water Chanel progressively filled with garbage, deficiencies in sewerage and run-off collection systems caused these areas to remain inundated for such durations. However, the drastic increase in the vulnerability was due to the poor standard of house construction, meanwhile the age of the house, locality and its association to the surrounding also contributes in accentuating the vulnerability values with respect to the flood depth. As with the deep interest toward observing the tangible effects of the flood event, building type was considered as a major risk element. In the vulnerable areas, the human activities have also aggravated the risk of flash floods. Local knowledge was observed a better tool over computer models as it describes the true representation of the events. However, tradeoff is always present between quality and time.

The techniques can be implemented over the adjoining areas of D.G. Khan which are frequently came under the direct influence of torrential flooding due to the torrents in the south including Chachar, Sorilund, Kaha, and Pachad. As Pakistan is one of the developing countries with high abundance of flash flooding events, the designed scheme may be useful in risk and vulnerability assessments for the relief programs and for the safety of flash flood prone areas in the country. Depth analysis is one of the key factor that directly relates to the intensity of the event, so, to map the flash flood depth levels is a fundamental step that can be helpful in monitoring intensity and trends of such events in future.

The existing literature suggests that in addition with the depth relation risk and vulnerability assessments are an essential step towards the designing of precaution measure and to define strategy for providing relief in prone areas all over the world. As with the invention of modern techniques flash flood risk and vulnerability assessment using PGIS as a community based techniques, this study will be useful for organizations working on flash flood management and other disaster risk reduction (DRR) programs. The proposed methodology is flexible and can be modified by incorporating several other parameters. Moreover, with its flexibility the methodology can be implemented as a whole for DRR projects in any other area with some minor edits. Decision makers and investors can preferably use this scheme for multi-purpose.

7. Conclusion

The results and the techniques presented in this work can be helpful to define flash flood hazard assessment and vulnerability to alleviate the disaster risk. The modified scheme of the quantitative risk estimation can be implemented on various parts of globe. Such technique may also be used for other flash flood prone areas of Pakistan. The fundamental information based on PGIS technique may be supportive in the management of flash flooding and designing of mitigation strategies including suitability of small to large dam structures on the source catchment and designing of down slope water conveyance system. As these areas carry dry weather conditions these structures would be used for multi-purposes.

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