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Research article

FACTORS RESPONSIBLE FOR URBAN FLOODING IN KARACHI: A CASE STUDY OF DHA

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Abstract: Flood has become an immense phenomenon in Pakistan. On August 2020 DHA Karachi was badly affected by urban flooding. This study discusses that poorly maintained drainage networks are the factors that caused urban flooding in DHA. This study aims to discover the factor that led to the urban flooding in DHA and what damages are caused. Methodology greatly includes questionnaires. GIS has been used for carrying out mapping of DHA surface drainage networks. The data collected from the questionnaires showed that poor drainage network was the main cause of urban flooding in DHA and phase 6 was mostly damaged as a lot of land encroachment has been done in this phase. Streets were mostly damaged as stagnant water caused crackers in them thus causing power outrage and difficulty in evacuation. This study may provide a guideline to disaster planning, management, and development authorities.

Keywords: Urban flooding; DHA; GIS; Drainage networks; land encroachment.

1. Introduction

When a place is inundated by the water that normally remains dry there occur a flood. When excessive rainfall occurs the drainage system capacity gets reduced and extreme runoff is created that mostly happens in urban cities (Adetunji, 2013). Severe floods have some of the worst natural catastrophes, according on ecological conditions. Because of their brutal effects, floods have a huge influence on human existence. Humans residing in the area are unable to effectively foresee the severe occurrence of Flood Risk due to the harsh external conditions (H.L Cloke, 2009).

Society inability to deal with the flood event because of reduced coping capacities thus makes it vulnerable to the extreme events and creates social unrest (Di Baldassarre, 2013). It is gaining more attention as population growth has caused people to live in urban places (Nasiri, 2004). It has been deduced that urbanization and climate change will soon increase the magnitude and frequency of the flood events (IPCC, 2014).

One of the vast spread and severe challenge is urban flooding. There are different factors like urbanization, climate change, drainage networks and population growth that are the cause of urban floods which not only make the intensity of the floods devastating but also caused an increase in its frequency leading to loss of lives, property and critical facilities as the time passes.

Countries like Europe, Africa, Asia and USA has been greatly affected by the urban floods in the past few years. The occurrence of floods in more in most and least developed nations. Lack of proper development planning, mismanagement of drainage networks and illegal dumping of waste are the causes of urban flood in developing nations while extreme rainfall, climatic variation, flash flood and storm surge triggers urban flood in developed nations.

In Pakistan about 72% of the people are living in slum areas. Since there is poorly developed infrastructure that is not resilient to floods it intensifies the urban flooding. As there is no proper development planning the protective structures fails when climatic variation occur leading to flood in these areas. Different studies have shown that Pakistan has become a subject to Floods from the past few years. Pakistan faced extreme flooding in 2010 that caused loss of life and property.

Karachi which is an economic hub is one of the cities of Pakistan that is facing urban flooding. In monsoon season the city is flooded by rain water causing extreme damage and disruption in daily activities. For climate change adaptation and systemic development planning in order to reduce the damage caused by flooding flood forecasting and vulnerability assessment is of key importance. In order to make Pakistan especially Karachi city flood resilient it is important to know the physical, socio-economic and environmental factors, flood plain and prone areas as well as vulnerability level in the city. The environmental and socio-economic factors both together make an area vulnerable to urban floods. These factors are different at different places.

Extreme rainfall leads to flooding. Anthropogenic activities also trigger flooding. These include illegal settlement along river or drainage network, mismanagement of dumping of waste, deforestation, urbanization, land degradation and poor development planning (Danumah, 2016). For safe and secure living it is important to mitigate the urban flood and it is done by proper checking of rainfall records, flood forecasting, flood prone area mapping as well as predicting and mitigating flood risks.

On 25 August 2020 Karachi City experienced unprecedented urban flooding as a result of the rain for a solo day, at 345 mm (13.58 in) which not only surpassed the historical 298.4 mm (11.75 in) recorded in 1984 but also caused massive and catastrophic inundations in the major portion of the city, that resulted in the streets to look like rivers causing extreme damage as well as also resulted in washing away of the people, houses and automobiles. Because of this at different places landslide phenomena were also seen that again caused trouble and damage to thousands of people by drowning them or causing them to suffer from electrocution as well as causing destruction of property and vehicles.

DHA Karachi being no exception. Since the city began maintaining weather reports in 1931, it is the most terrible rainfall Karachi has ever experienced. A total of 760 mm (29.92 in) of rainwater was reported during the week starting from August 28, 2020. Officials used sailboats to rescue individuals stuck in the streets around the city during the floods. Many issues arose for the estimated 15 million people of the metropolis, including downed power lines, out-of-service mobile phone towers, and significant fuel shortages due to the city's high reliance on alternate generating units. Flooding happens when water collects in areas that are not ordinarily inundated, as is widely known. They commonly arise in urban areas as a result of extreme rainfall, which causes an excess of runoff that exceeds the capacity of drainage systems, or when an extreme event occurs in a susceptible physical and socio-economic surroundings, outstripping society's capacity to control or remain viable as a result of the outcomes. The disposal of waste especially the solid ones and encroachment on natural drainage patterns by the katchiabadis residents are one of the reasons for extreme flooding in Karachi city.

2. Method

2.1. Methodology

This research applies thematic analysis method to assess factors that caused urban flooding in DHA Karachi with constraints of sparse data. Also, the purpose of analyzing flood factors is not only to spatially locate flood hazard but to be able to quantitatively or qualitatively deduce significance of the risks (Smith, 2003). As a result, all the risks related to a country, region, or a city need to be taken into account for risk assessment of spatial nature (Greiving, 2006).

1.2. Data collection from DHA

There are two types of studies namely quantitative and qualitative. A rigorous, objective, and formal approach is adopted to collect measurable data in quantitative research while viewpoints, behaviors, and experiences of people are studied in qualitative research. This is quantitative research that aims at discovering the causes that resulted in DHA flooding with the help of GIS.

The methodology that is adapted to carry out this study includes primary data. In primary data, questionnaire will be developed to collect data from DHA and thematic analysis would be used. The basic data related to DHA flooding was collected with the help of a standardized questionnaire that was distributed among the residents living in all eight phases of DHA.

1.3. Targeted population and Sample size

DHA Karachi has a total population of about 661,000, whereas the total targeted population is 1000 in all 8 phases for example phase 1 has 125, phase 2 has 75, phase 3 has 140, phase 4 has 100, phase 5 has 125, phase 6 has 175, phase 7 has 150 and phase 8 has 110. Stratified random sampling also known as proportionate random sampling is used to complete the sampling process. It is a probability sampling approach that distributes the entire population into strata also termed homogeneous groups (Qualtrics, 2021). This sampling method focuses on the demographic make-up of the population for collecting the population sample. Since each stratum is randomly chosen there is no biasedness in the process thus this approach is fair for the participants.

In 1976 a sample size computation technique was developed by a statistician named Taro Yamane to calculate the given population sample size. The formula applied for calculating the sample size of this research is devised by (Yamane, 2016).

$n = N/ 1+N (e)^2$

Where n= Size of the sample

N= Size of the targeted population

e = Margin of the error acceptable or measures of precision is 0.05

$n = 1000/ 1+1000 (0.05)^2$

$n = 1000/ 1+1000 (0.0025)$

$n = 1000/ 1+ 2.5$

$n = 1000/ 3.5$

$n = 285.7$

$n= 286$

The above result suggests that 286 people were sampled from an overall population of 1000, which is a good sample size.

Table 1. Sample Size

DHA Phases	Target Population	Sample Size
1	125	125/1000*100 = 12.5% of 286 = 36
2	75	75/1000*100 = 7.5% of 286 = 21
3	140	140/1000*100 = 14% of 286 = 40
4	100	100/1000*100 = 10% of 286 = 29
5	125	125/1000*100 = 12.5% of 286 = 36
6	175	175/1000*100 = 17.5% of 286 = 50
7	150	150/1000*100 = 15% of 286 = 43
8	110	110/1000*100 = 11% of 286 = 31
Total	**1000**	286

Determination of sample size is critical in that research that uses primary data for collecting responses through a questionnaire. By using the Taro Yamane technique sample size is calculated as shown in the table mentioned above. To develop the sample this technique adopted a stratified random sampling that is proportionally representative of the population.

2. Result

2.1. Analysis

In this chapter, the method adopted to obtain the result included primary data that was obtained with the help of questionnaire and the data obtained is analyzed, processed, and interpreted with the help of GIS in the form of maps.

The thematic analysis was applied to the questionnaire to collect data. The pie charts were used to tell the different percentages of the respondent's answers and the table showed the response of the DHA authority. This research is carried out by handing out and opened ended questionnaire to DHA authority and 1000 closed ended questionnaires to the residents of DHA Karachi of which 714 were not properly answered while 286 were free from any error. These 286 questionnaires were then used for displaying, analyzing, and interpreting the data. The questionnaire was divided into two parts the first part includes the general introduction of the respondents while the second part includes the question related to the urban flooding in DHA Karachi. There were a total of 23 questions of which 5 were related to personal information while 18 were related to the damages, issues, and problems being faced by the respondents. The respondents included 42.5% females and 57.5% males. The analysis of questions is done using pie charts in which percentages show the different responses given by the respondents. These questions are given below:

1. What was the targeted population in each DHA phase?

The targeted population was taken from all the eight phases of DHA. Out of 100%, about 12% of responses come from Phase 1, 7% from Phase 2, 14% from Phase 3, 10% from Phase 4, 13% from Phase 5, 18% from Phase 6, 15% from Phase 7 and 11% from Phase 8. From the pie

chart, it could be seen that the highest number of responses were from Phase 6 and 7 while the least responses came from Phase 2.

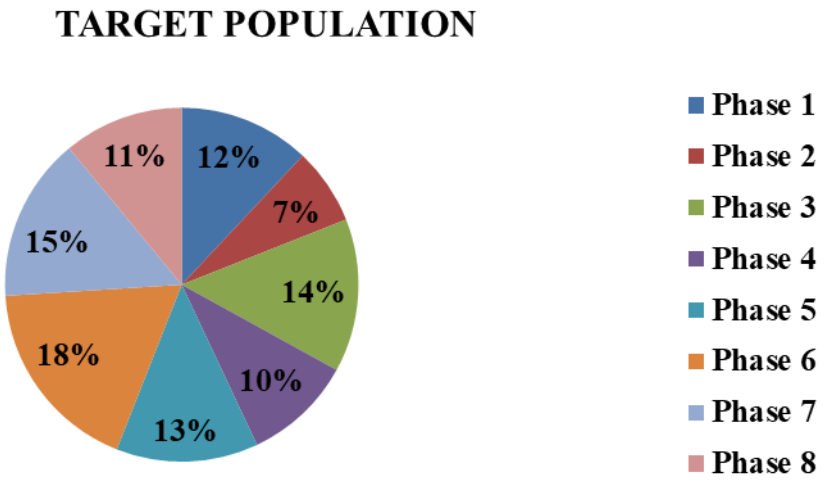

Figure 1. Target population

2. How many responses were received from each Phase?

12% of the response was received from Phase1 and 2, 9% of the response was received from phase 3, 14% from phase 4, 6% from phase 5, 29% from phase 6, 12% from phase 7, and 6% from phase 8.

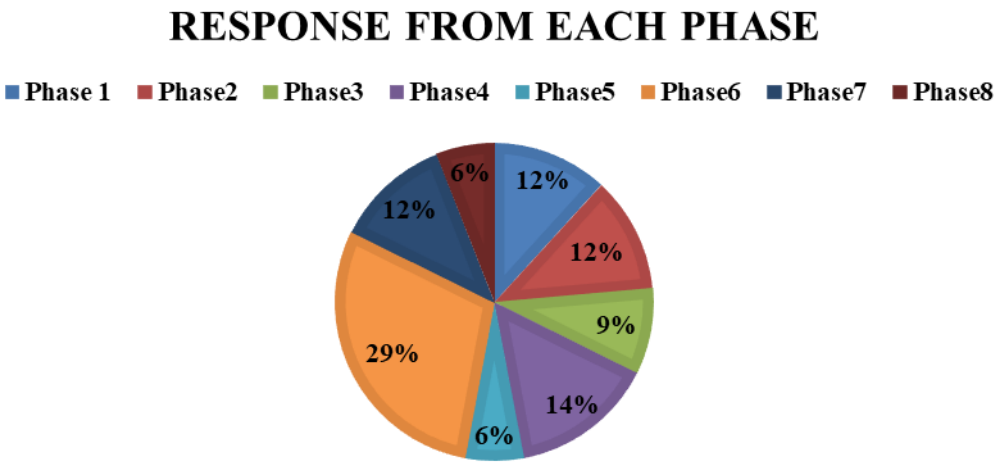

Figure 2. Response from each Phase

3. **In your opinion what is the cause of urban flooding in Karachi?**

Four opinions were given and according to 79% of the respondents, the urban flooding was because of the poor drainage and sewerage system. 14% of the respondents think it is because of climate change. 5% of respondents think it is due to urbanization while 2% of the respondents said it is because of population growth.

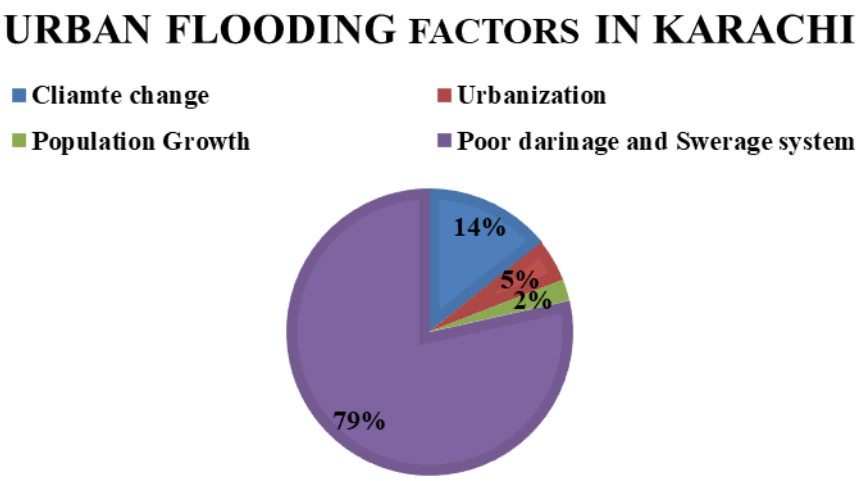

Figure 3. Urban Flooding Factors

4. What are the factors that caused urban flooding in DHA Karachi?

From the pie chart, it could be seen that 55% of the respondent's weak drainage and sewerage system is the cause that led to urban flooding in DHA while 38% say it was because of the lack of development planning. According to 5% of the respondents, it was due to poor governance while 2% believed a reduced infiltration rate was the cause of urban flooding.

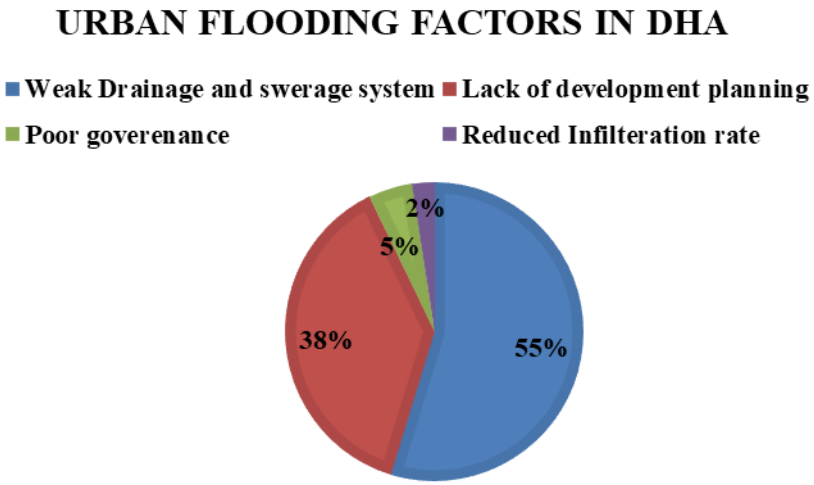

Figure 4. Factors in DHA

5. Was your house damaged due to urban flooding (material damage)?

19% of the respondent's houses were not damaged by the floods, 60% of respondents' houses were slightly damaged, and 16% of respondents said their house was half damaged while 5% said their house was completely damaged.

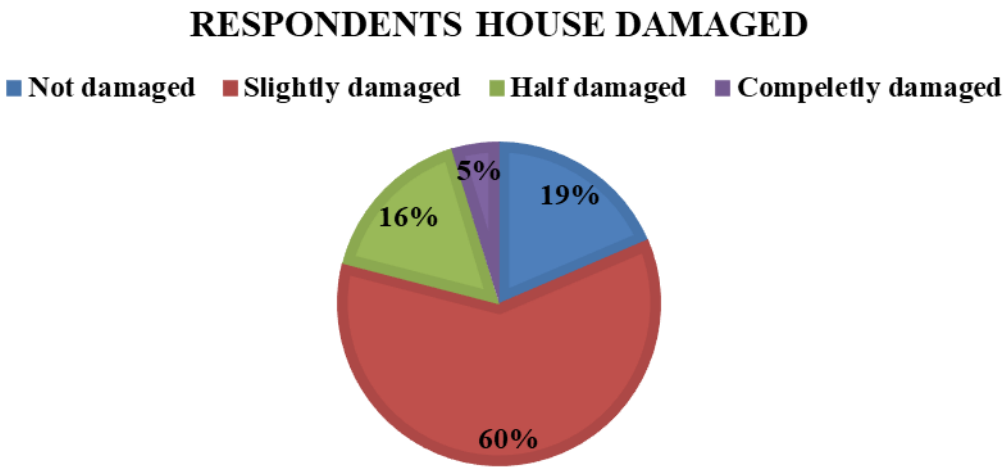

Figure 5. Respondent's House damage

6. What do you think was mostly damaged by flooding?

Because of urban flooding infrastructure as well as critical facilities had been damaged. The greatest damage was posed to the roads and about 49% of the roads and streets were affected by the flooding. 9% of schools and shopping markets were damaged and mostly the ground floor was damaged. 5% of the hospitals and 28% of houses were damaged.

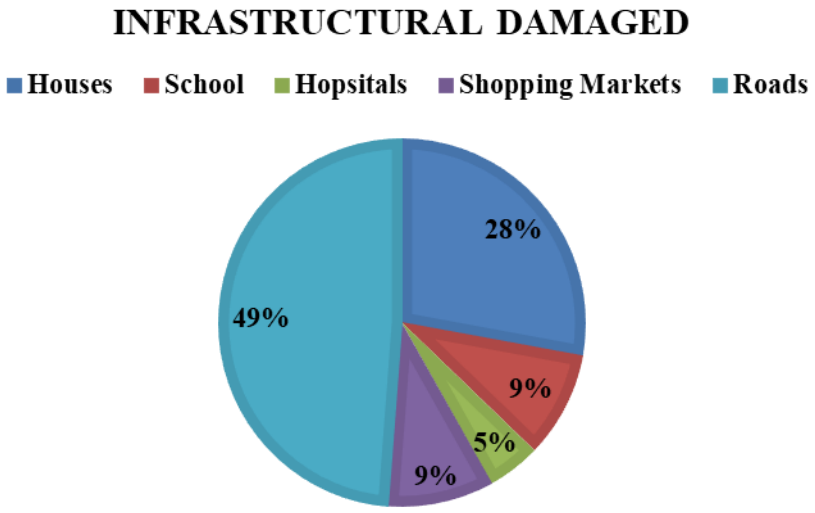

Figure 6. Infrastructural Damage

7. **How many people in your area lost their lives?**

21% of respondents said there was no loss of life in their area, 14% said between 1-5 people lost their lives in their area. 9% said between 5-10 people lost their lives while 56% said the loss of life in their area was more than 10.

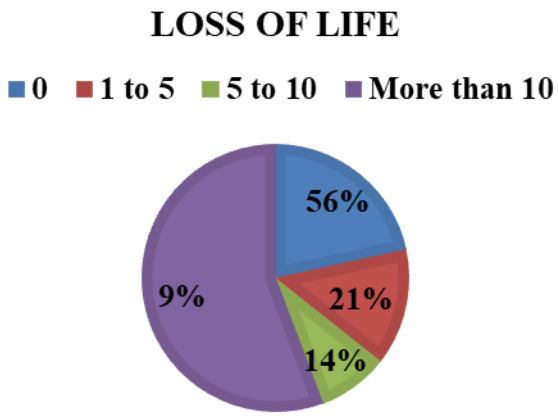

Figure 7. Loss of Life

8. **Who rescued you?**

When it was asked who rescued them about 5% said the Provincial government rescued them, 44% said they were rescued through Army, 21% were rescued by DHA and 30% were self-rescued.

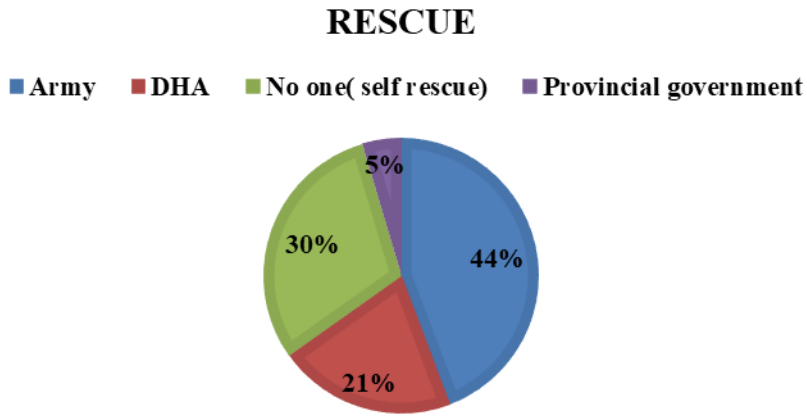

Figure 8. Rescue

9. How much time was taken to rescue you?

When it was asked how much time was taken to rescue them about 20% said they were rescued in less than 5 hours, 12% were rescued in 5 hours, 5% said one day was taken for their rescue while 63% said more than 1 day was taken to rescue them.

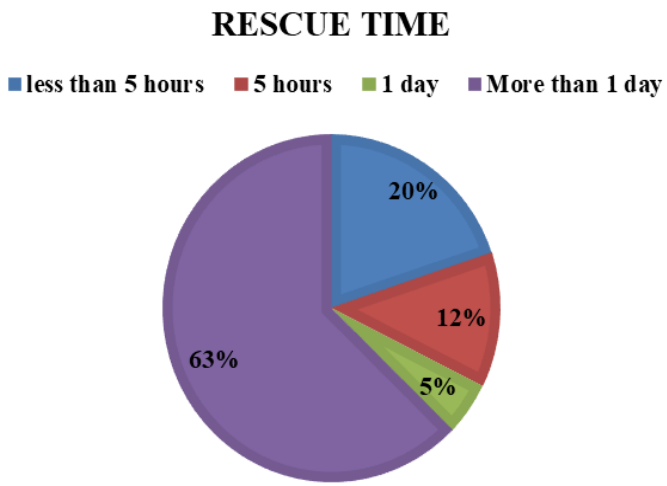

Figure 9. Rescue time

10. **What methods were adopted for your rescue?**

The rescue process was carried out through different means. From the pie chart, it could be seen that the maximum number of respondents who were rescued through other means is 52% which mostly includes self-rescue. 22% of the respondents were rescued by vans, 21% by boat and 5% by helicopter.

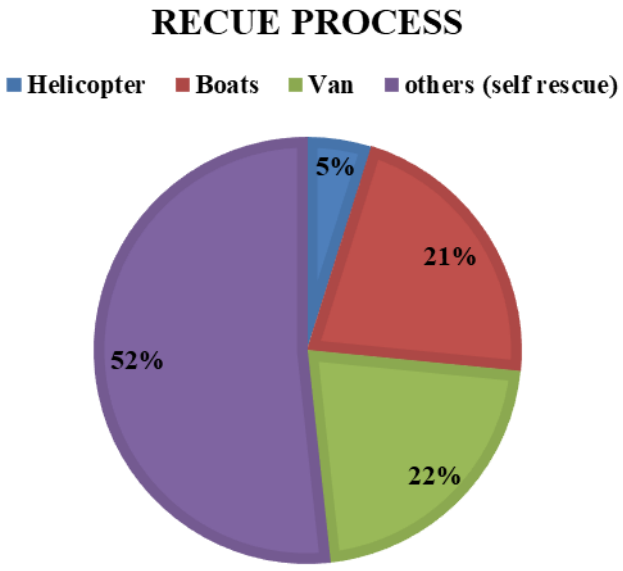

Figure 10. Rescue process

11. What were the major problems faced by you?

The main problem that was faced by the respondents was power outrage and about 44% of them faced this problem. 39% faced were not timely rescued, 12% did not have anything to eat while 5% did not face any problem at the time of urban flooding in DHA.

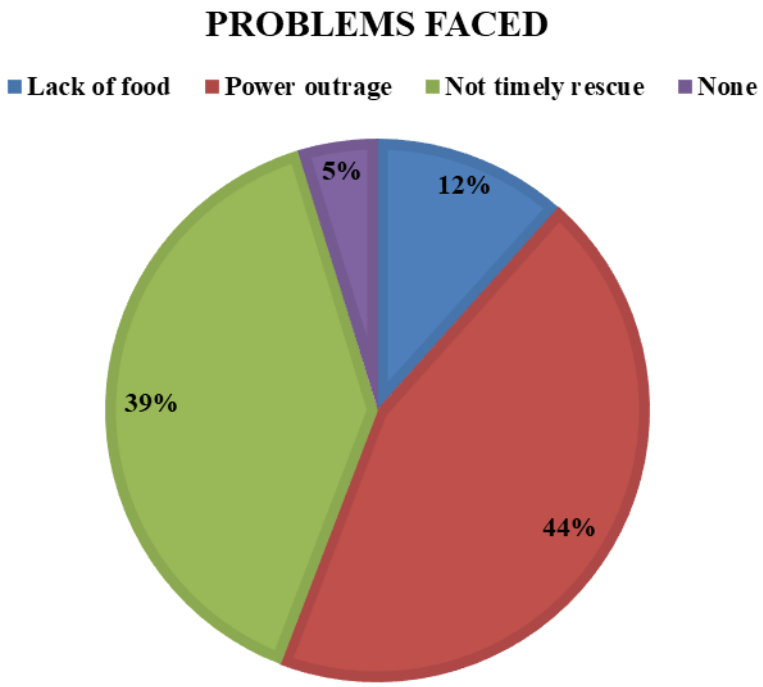

Figure 11. Problem Faced

12. How many houses in your area were damaged (material damage)?

About 5% of the respondents said there was no damage to the houses in their area. About 31% said between 1 to 5 houses were damaged in their area. According to 38%, the damaged houses in their area were 5 to 10 while 26% said the damaged houses were more than 10% in their area.

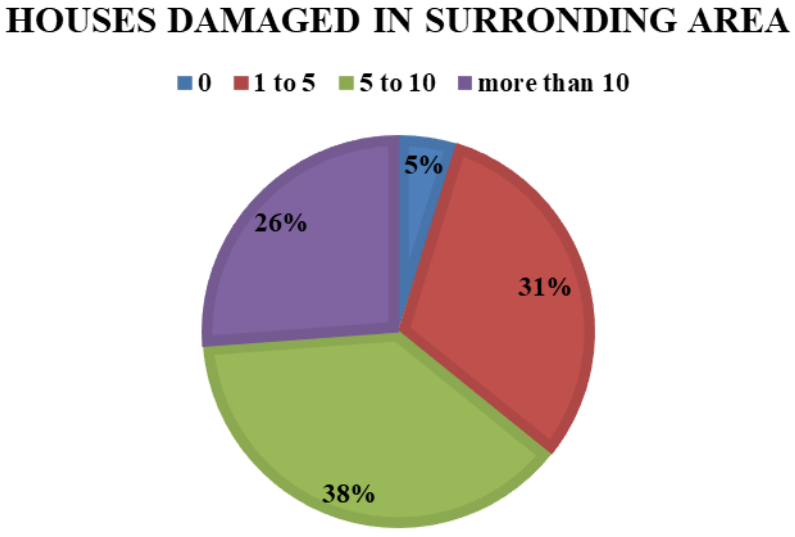

Figure 12. House damaged in surrounding of DHA

13. **Was there any stagnant water in your street?**

As a result of urban flooding, the streets were flooded with rainwater. About 83% of the respondents show stagnant water in their streets while for 17% there was no stagnant water.

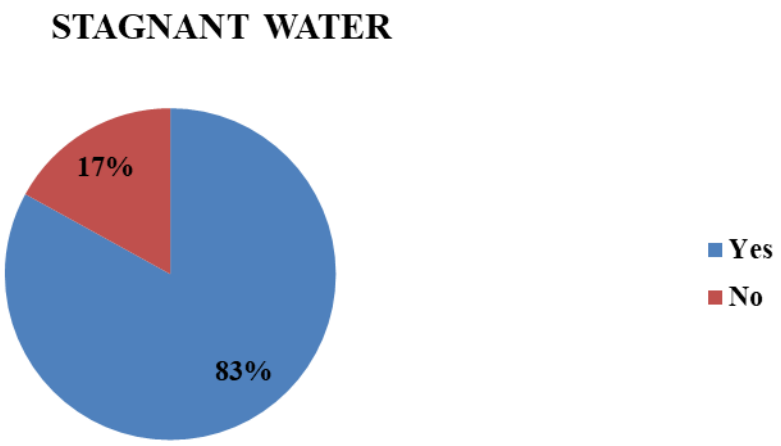

Figure 13. Stagnant Water

14. How much time was taken to remove that stagnant water?

Since eighty-three percent of the streets were covered with stagnant water and the time taken to remove this water was different in every phase. 7% of the respondents said it was removed in one day whereas 29% said two days were taken for the removal of stagnant water while 63% said the time taken to remove the stagnant water from their streets was three days.

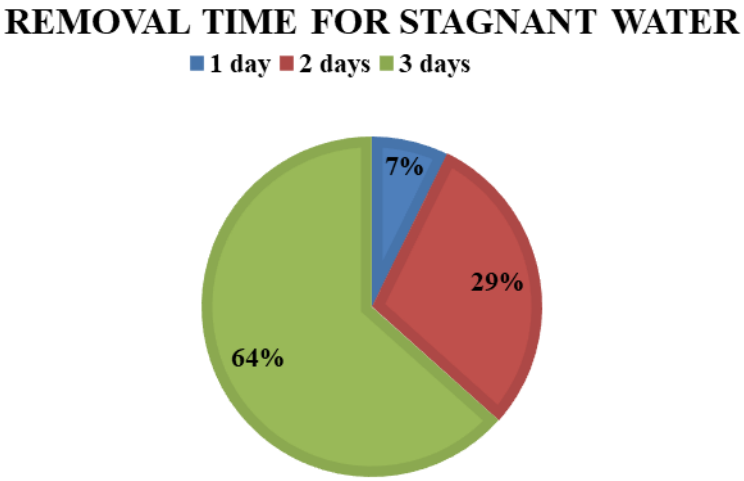

Figure 14. Removal time for stagnant water

15. Does any school in your area was damaged?

69% of respondents said the schools located in their area were damaged because of flooding while 31% said no school located in their area was damaged.

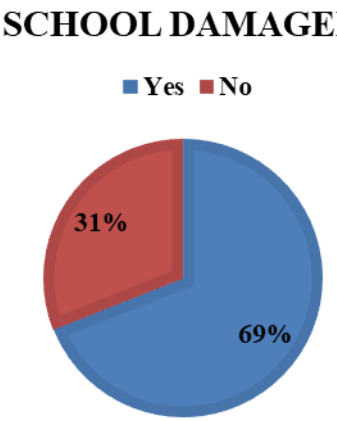

Figure 15. School Damaged

16. **Does any hospital in your area been damaged?**

About 12% of answers from the respondents showed that hospitals were affected by the flooding while 88% of responses showed there were no damaged hospitals.

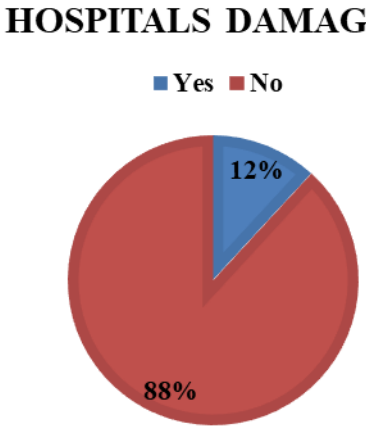

Figure 16. Hospital damaged

17. Was there any help from DHA?

When it was asked the respondents that DHA help them during the time of crisis only 34% said yes while 66% said there was no help from the DHA.

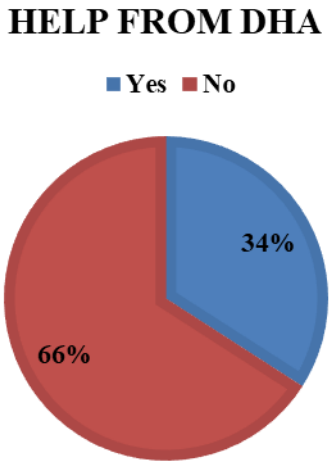

Figure 17. Help from DHA

18. **Do any mitigation measures are adopted by DHA to avoid urban flooding in the future?**

61% of the respondents think that there are no mitigation measures that DHA has adopted to avoid future urban flooding and while according to 39% DHA had worked on flood mitigation measures to avoid flooding in the future.

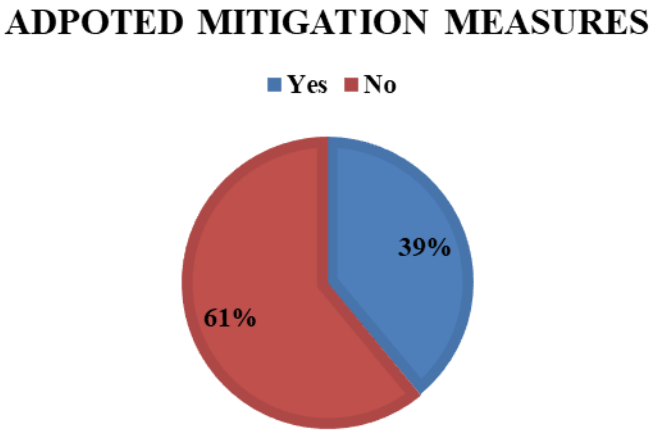

Figure 18. Adopted Mitigation measures

19. Are you satisfied with the work of DHA?

Respondents were asked about their satisfaction level regarding working with DHA. Everyone had different points of view 39% of them were highly unsatisfied, 7% were satisfied, 14% were just satisfied, 20% were neutral as well as 20% were unsatisfied with their work.

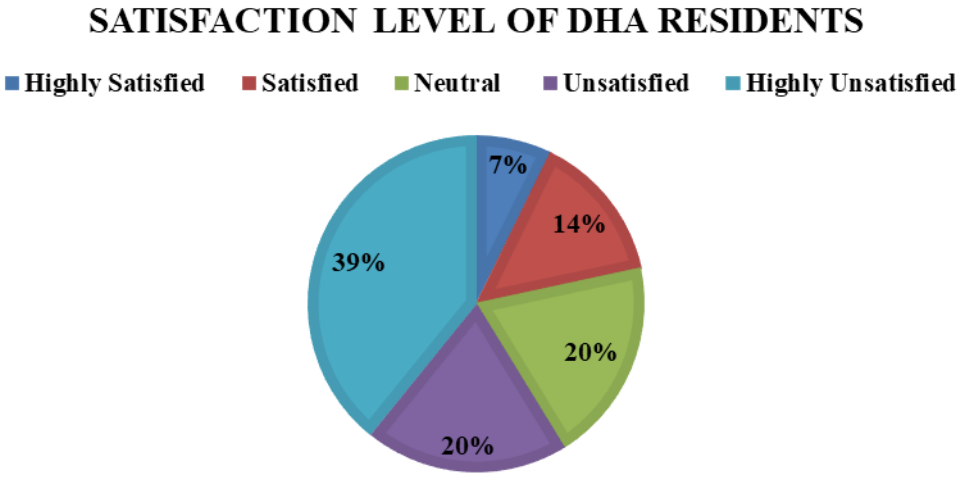

Figure 19. Satisfaction level of DHA Residents

Table 2. Questionnaire filled by DHA Authority

Q. No.	Questions	Answer	
1	What is the estimated population of residents in DHA Karachi?	6,61000	
2	What is the estimated number of houses in DHA Karachi?	31,833	
3	What is the estimated number of houses in each Phase?	Residential	
		Phase-I	1091
		Phase-II & II Ext	1832
		Phase-IV	2787
		Phase-V&V Ext	5546
		Phase-VI	6964
		Phase-VII & VII Ext	3877
		Phase-VIII	5020
		Phase-VIII (E-8)	25
		27142	
		Commercial	
		Phase-I	51
		Phase-II & II Ext	1060
		Phase-IV	224
		Phase-V&V Ext	1156
		Phase-VI	1338
		Phase-VII & VII Ext	529
		Phase-VIII	330
		Phase-VIII (E-8)	3
		4691	
4	What is the total number of schools, roads, hospitals, public offices and shopping centers in DHA Karachi?	School	35
		Hospital	5
		Public Buildings	
		Police Station	4
		Telephone Exchange	3
		Post Office	3
		Graveyard	8
5	How many houses were damaged in each Phase?	Nil but many houses faced material loss.	
6	How many people lost their lives?	Mr Faizan S/o Ghulam Muhammad (Age about 18x yrs) died on spot due to elec shock at 4th Tariq street near Masjid Zubair, Ph-VII, (Extension).	
7	Which Phase had the largest number of damages in terms of houses and individuals?	Phase-IV, Phase Vl, Phase-VlI and Phase Vlll. Map showing details is attached at Annexes.	
8	Total number of damaged schools, roads hospitals, public offices and shopping centers in DHA Karachi?	Map showing affected area attached in annexes.	

9	Who rescued the people and through which means?	Army called on to Relief Op during Rain Emergency 2020.
10	How much time was taken to rescue the people?	S&V Dte responded instantly to rescue people form houses, roads, basements and commercial markets by utilizing available equipment/ vehicles. However, worst areas were:- a. Kh-e-Badban b. Kh-e-Bahria c. Old Sunset Blvd d. Kh-e-Hilal e. Kh-e-Shujaat f. Kh-e-Shahbaz to 26 street g. Rahat Commercial h. Nishat Commercial i. Shahbaz Commercial j. Bukhari Commercial k. Kh-e-Amir Khusro l. Kh-e-Tariq m. Kh-e-Qasim to Kh-e-Ittehad
11	How much time was taken to clear the debris and stagnant water?	Approx 1x week was consumed to clear debris and stagnant water completely.
12	What methods were adopted for the removal of stagnant water?	Lifting of water form pounded area through the employment of bowsers and pumps.
13	What were the major problems faced by the residents as well as the rescuing authority?	Problem faced by residents of affected area: - a. Power loss due to shut down. b. Gas sup discontinued where pumps exposed to rainwater. c. Communication stalled. d. Road under poundage. e. School closed. f. Sewerage choked.
14	What was the reason that led to the urban flooding in DH Karachi?	Causes of Flooding a. Drains are choked not properly cleaned. b. Sewerages are connected to drains causing lowering the capacity of drainage system. c. Dumping of sewage in drains. d. Maintenance became the issue due to inaccessible drains. e. Phase-II of const of SWD halted.
15	What measures are adopted by the DHA to avoid urban flooding in future?	**Rain Emergency work Measure to avoid urban flooding** a. Hydrological study to ascertain causes of flooding. b. Hiring of consultant M/s Zeerukfol vetting of already executed works and planning, design & supervision of left over storm water drainage network and linking sewage from Mehmoodabad drain to TP-4 in DHA. c. CA for execution of left over drain with NCL. d. Formulated rain emergency scheme for DHA Karachi.

3. Discussion

At the eastern border of Karachi city, DHA is situated on the Karachi-Hyderabad highway. DHA is divided into 8 phases that are distributed into 17 sectors which are further branched into subsectors namely A, B, C, D, etc having a population of about seventy thousand. Each phase has its park and commercial area. There are six major lanes and streets in DHA. Phase 4, 5, 6, 7, 8 has normal lanes and streets, Phase 4 has commercial and gizri lanes and streets, Phase 5 has zamzama streets, Phase 1 and 2 has north, south, central as well as sunset lane and streets. A few features of the area are:

- Surrounded by the Arabian Sea including its Creeks on three sides.
- The elevation is at mean sea level with numerous areas being lower than mean sea level
- A major portion of land use is on reclaimed land from the sea.
- Malir Nadi is the main natural water channel that flows from North to South on the Eastern Side of DHA Karachi and subsequently falls into the Creek.

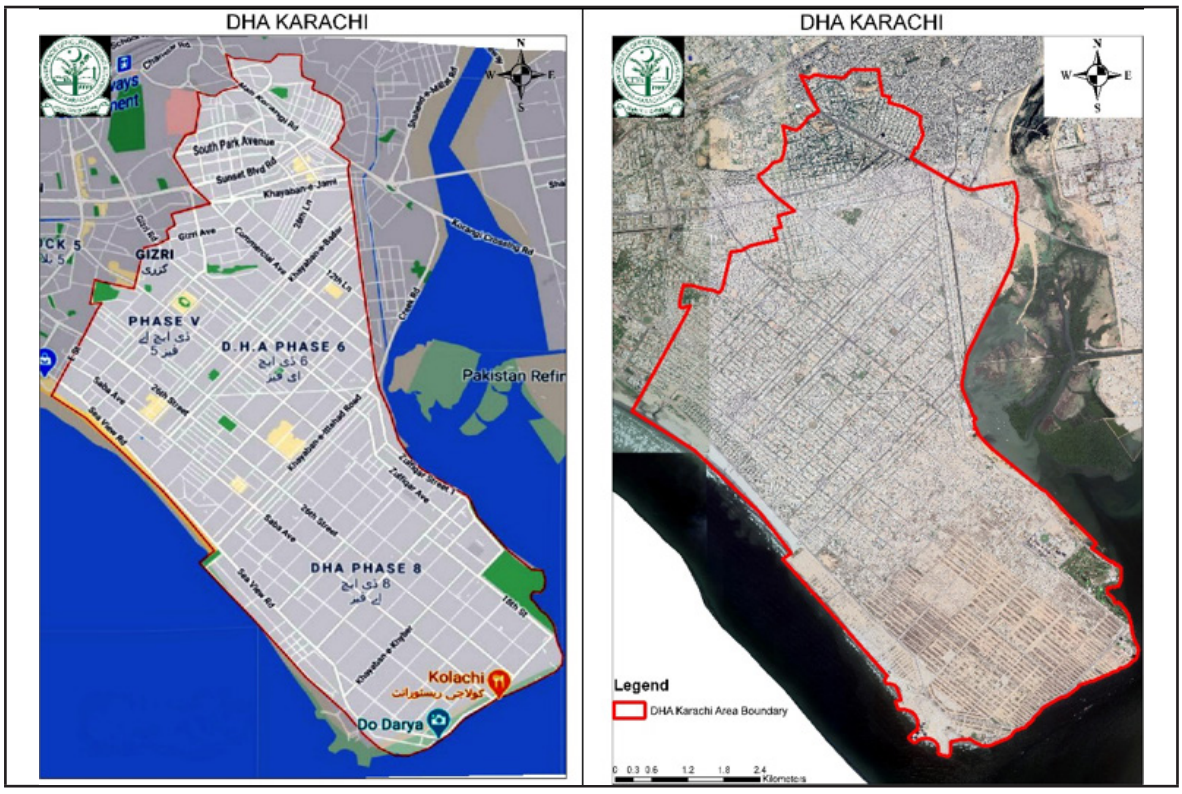

Figure 20. Location Map of DHA Karachi

Flooding happens when water collects in areas that are not ordinarily inundated, as is widely known. Urban flooding occurs in DHA as a result of heavy rain, which causes an accumulation of water that exceeds the capacity of drainage systems, resulting in a susceptible physical and socioeconomic environment that exceeds DHA's ability to regulate or withstand the repercussions.

The red outline in the figure shows the boundary of the DHA Karachi. From the analysis, it is concluded that DHA has been built on the flood plain area and the reason why it was flooded with monsoon rainwater was that many houses were built (land encroachment) on the commercial car parking area. Along with this the drainage system is not properly developed and maintained by the authority due to stormwater inundating the whole society. The drainage system capacity is lesser than the dumping of solid and liquid waste into it by

the residents. Most of the damage was observed in phases 5,6,7 and 8. Streets were mostly cracked due to the standing water and those houses that were single units faced structural as well as material loss. Most of the residents self-rescued either by evacuating or moving to the roof of their houses. To avoid future urban flooding, a proper development planning process needs to be developed for DHA in those areas that have the highest risk of inundation should be made residential free as well as a comprehensive design for stormwater drains and flood water training works should also be provided to ensure safety and sustainability. The system will also accelerate and improve analyses for future land-use planning and ensure timely decision-making.

3.1. The factor that causes urban flooding in DHA Karachi

The image of the DHA Karachi taken from the Google earth map has been shown below:

Figure 21. DHA Google Earth Image

The figure 22 shows the generalized surface drainage pattern of DHA Karachi with likely accumulated areas. With the help of GIS (DEM), this drainage map has been created that shows the flow of incoming water from the surrounding areas of Karachi into DHA. The flow pattern of the internal water and its accumulation in different areas of DHA had also been seen. The accumulated areas are represented by the red dots. The areas where these dots are bigger are the areas that are mostly inundated like phases 5 and 6 while those areas that have small dots are the least accumulated areas like phases 1,2 and 3. The blue arrows indicate the flow pattern and direction of stormwater from the drainage network that is spread throughout the DHA.

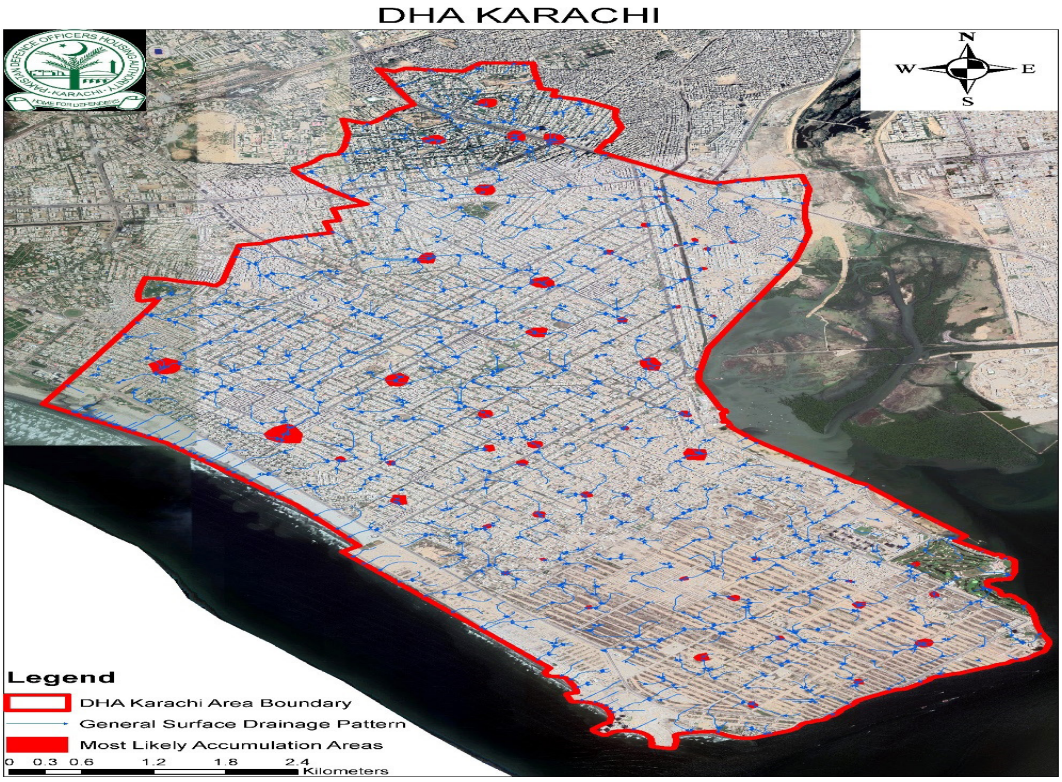

Figure 22. Generalized Surface Drainage Pattern DHA Karachi with Likely Accumulation Areas

To remove the stagnant water from the accumulated areas borehole tests were performed. The different location that was best for conducting this test is shown in the figure below. The profile of the soil, as well as groundwater regimes, was first identified through this test. And then the stagnant water was removed. To stop the dumping of sewerage waste into the drainage of phase 6 proper place should be given for its disposal without creating any environmental hazards. Also, the structural design of the drainage and sewerage system needs to be updated to avoid urban flooding in the future.

3.2. Limitation and Recommendation

For flood hazards and vulnerability of Karachi city and DHA's following recommendations, are devised that will be beneficial in future studies:

- For flood hazard mapping of DHA there should be an online detailed digital geological map of the area that should be easily accessible. Since most of the people also die because of electrocution during flooding caused by monsoon heavy rainfall there should be the availability and usage of an electric transmission vector map. For any new housing society, it should be kept in mind what impact does it cause on the storm-water drains as well as on the overall drainage and sewerage system in Karachi city as well as these societies should also be recognized by the authorities in term of drainage system expansion and for that DHA Karachi should be used as a baseline study to avoid the impacts and effects that DHA has faced as a result of monsoon rainfall. Survey and questionnaire should be used for awareness of the public about flood hazards as well as for flood preparedness in terms of resilience to flooding.

4. Implication

With the help of DHA Authority Rain Emergency 2020 Plan figure 23 has been devised that shows the overall damage posted to different areas in DHA. This plan could be used while devising flood mitigation measures, also if bore hole test figure 24 are conducted in the affected areas removal of stagnant water could be removed faster.

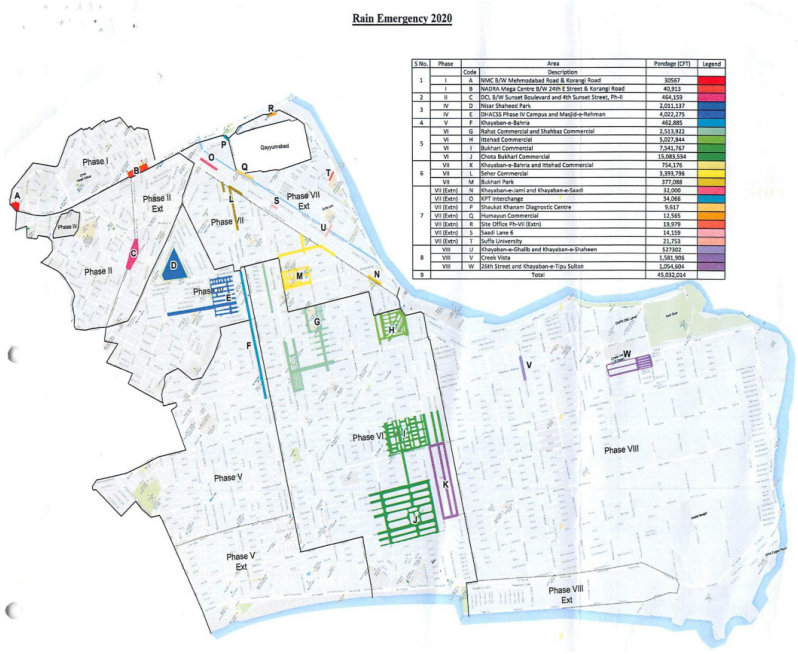

Figure 23. Rain Emergency 2020

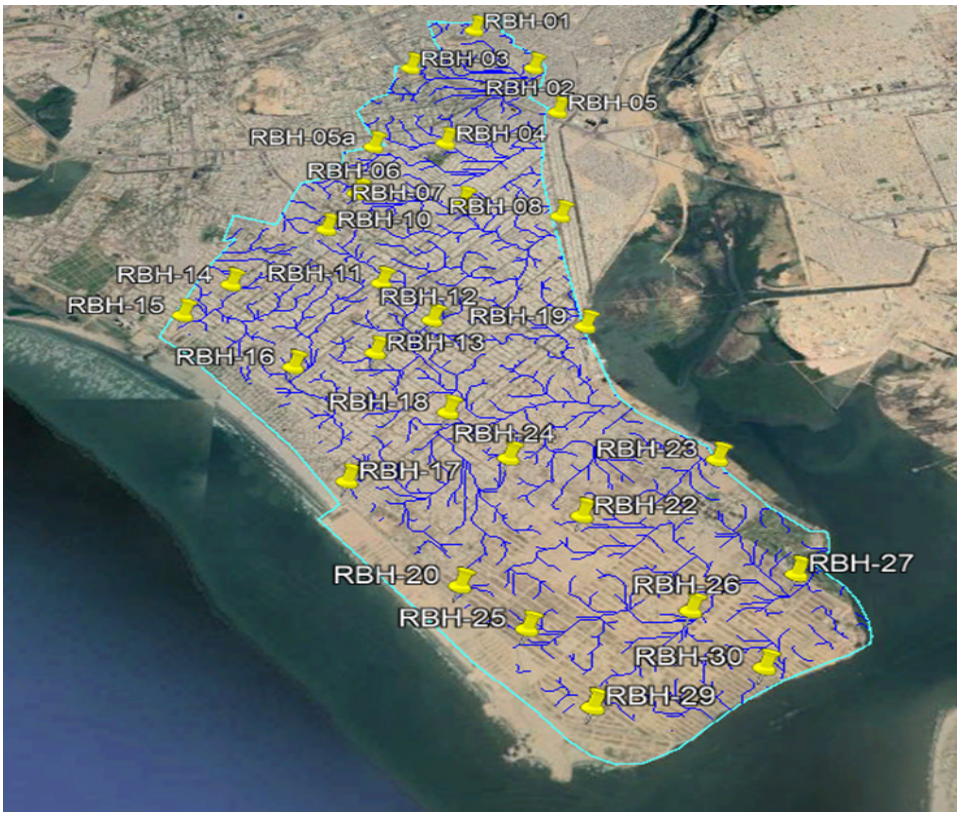

Figure 24. Identified Most Likely Locations for Borehole Tests

5. Conclusion

As a result of heavy and extreme monsoon, rainfall and storm surge Karachi city had to face the problem of urban flooding that not only results in the loss of lives but also disrupts city life. As a result of heavy and extreme monsoon rainfall and storm surge Karachi city had to face the problem of urban flooding that not only results in the loss of lives but also disrupts city life. In August 2020 DHA area of Karachi city was badly affected by monsoon rainfall resulting in massive damage and destruction. Two questionnaires were developed in order to find the cause of urban flooding in DHA and how much damage it has posed to the society. One questionnaire was distributed among the residents of DHA while second was sent to the DHA Authority. After collection of responses they were crossed checked and it was found that poor drainage and sewerage system was the main factor that led to urban flooding. And streets, roads and all transportation routes were mostly damaged.

7. Author contributions

The corresponding author Ayesha Iftikhar contribution includes: Analysis, Methodology, Software, Writing – original draft, Writing – review and editing. The second author Dr. Jawed Iqbal contribution includes: Investigation, Supervision, Visualization.

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10. Conflicts of interest

"The authors declare no conflict of interest."

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