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Assessment of Flood Hazard in Jeddah Region - KSA

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Abstract:
Over the last few years, Kingdom of Saudi Arabia (KSA) has suffered from the catastrophic impact of many flash floods that covered several regions. This climate dependent natural hazard has increased recently both in frequency and magnitude with continuous increase of fatalities and socio-economical loss and damage. Several elements are suspected to play an important role in such increase of impact, among them climate change, population growth, lake of regulation and non-enforcement of existing codes and standards in planning and construction of new settlement and industrial zones. This paper discusses the importance of studying the risk of floods using Geographic Information System (GIS) techniques and produces a potential hazard map for Jeddah region, one of the most affected and populated region of Sarthe study integrates all parameters that contribute to the formation of flood and provides reference criteria for planning of city extension and construction projects. The study identifies, delaminates and classifies the zones exposed to flooding in addition to the location of main streams which forms the basis for flood risk mitigation in the region. Flood protection structures and future water recovery projects can be planned in the region accordingly.

Keywords: Flood Hazard, GIS, KSA, Risk Assessment, Watersheds, DEM.

1. INTRODUCTION

The impact of climate change in arid regions is widely recognized as most devastating and catastrophic for local population. In such regions, where lives and livelihood depend on little resources of water and vegetation, any negative change in the environment destabilizes the critical equilibrium of eco-system and leads to catastrophic events. The fragility of environment combined with the little on non-preparedness of local population make them most vulnerable to any climate dependents hazards. This fragility is widely encountered in Sahara and Sub-Sahara regions in Africa and equally in the Arabian Desert having a surface of 2.3 millions square kilometer and covering most of KSA.

These events include atmospheric, hydrologic and geologic phenomena that have potential risk to affect adversely humans, constructions and social activities. Climatic Hazards are such extreme weather events that cause damage and losses because of their, severity, frequency and location and in this region, the most common weather related natural disasters are draught, sand storms, desertification and paradoxically flash floods. Such phenomenon that occurs over a short period and covers a relatively small area has an amplified impact where dense human activities are developed. Since 2009, the frequency and magnitude, of short localized rainfall, has increased creating many flash floods with large social and financial damages in different regions of KSA.

These floods are considered to be one of the worst weather-related natural disasters. They are dangerous because they are sudden and are highly unpredictable following brief spells of heavy rain. Flood hazard seems to be increasing as climate change takes effect. Floods cause about one third of all deaths, one third of all injuries and one third of all damage from natural disaster **Error! Reference source not found.**.

2. WATER RESOURCES

Water scarcity is one major concern for local authorities as the kingdom falls in very harsh natural desert environment with no rivers or lakes and average yearly rainfall of less than 100mm [2,3,4]. KSA utilizes conventional and unconventional water resources to satisfy the ever increasing water demand. The conventional water resources include surface water and groundwater. Surface water consists of seasonal runoff flowing Wadis during the months of November and April [2**Error! Reference source not found.**. The runoff water ranges from 2 to 2.4 billion cubic meters per year mostly in the southwest and coastal area where rainfall is reasonably abundant and regular [2**Error! Reference source not found.**. Small and large scale dams are built to capture the runoff water and the largest 8 dams collect about 0.6 billion m3 each year [5**Error! Reference source not found.**.

3. DESCRIPTION OF JEDDAH REGION

Jeddah is located on the southwest coast of Saudi ArabiaFigure1.It is the biggest port on the red sea and the kingdom's second biggest city after the capital Riyadh. Jeddah has a population of over 4million persons with population density over 2700capita/km2. The city is considered a transit hub for highly visited regions of Mecca and Medina and realizes large economic benefits from its strategic location.

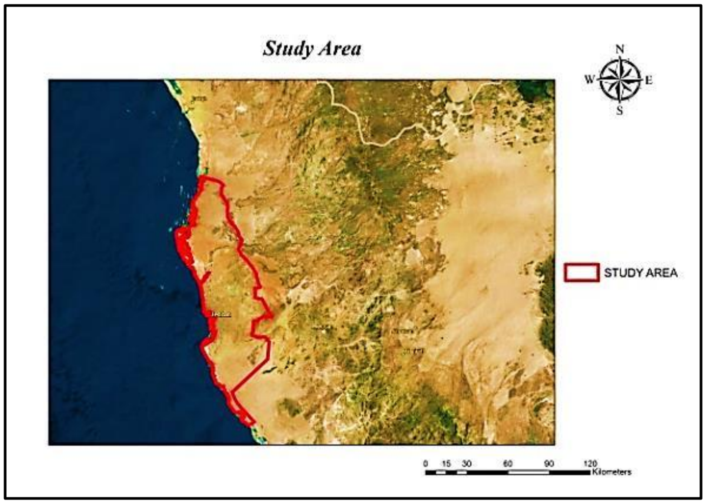


Figure.1. **The Study Area (Jeddah)**

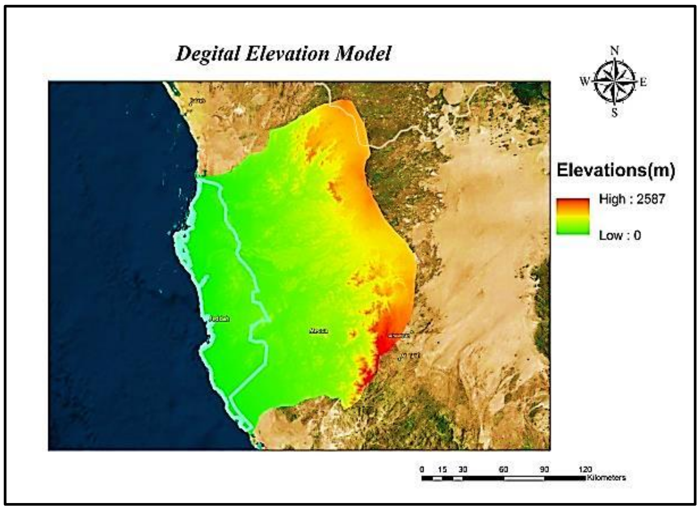


Figure.2. **DEM OF the Study Area (Jeddah)**

3.1 Topography

Jeddah region is part of a larger zone that contains many watersheds and large network of streams. The actual studied zone is delimited from the east by the El-Hizaj chain of mountain and from the west by the Red Sea with an elevation difference of exceeding 2400m between its highest and lowest points. The elevation of this area is extracted from a global digital elevation model (DEM) and presented at as shown in Figure2

3.2 Rainfall

The rainfall in Jeddah region is generally sparse, and usually occurs in small amounts in November and December. The total rainfall in this region varies from 60mm to 100mm per year (Figure3) and heavy thunderstorms are common in winter. The thunderstorm of December 2008 was the largest in recent memory, with rain reaching around 80 mm in 24hours. The climate data used in this study were collected from General Authority for Meteorology& Environment Protection (GAMENP) [6] and processed to obtain the height of rainfall for different storms. To estimate the rainfall for 50-year return period storm, a statistical flood frequency analysis was performed to analyze the maximum yearly rainfall at each meteorological station (Figure4&5).

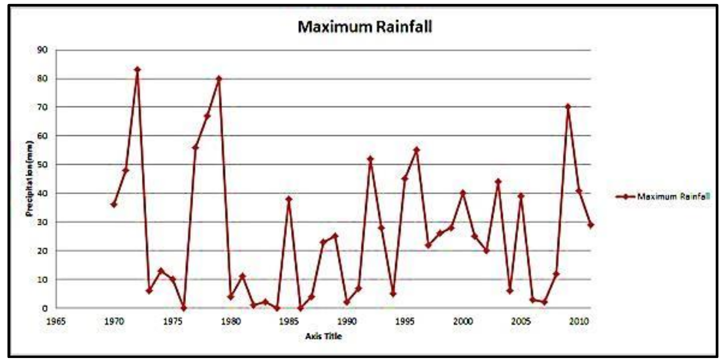


Figure.3. **Historical Rainfall in Jeddah**

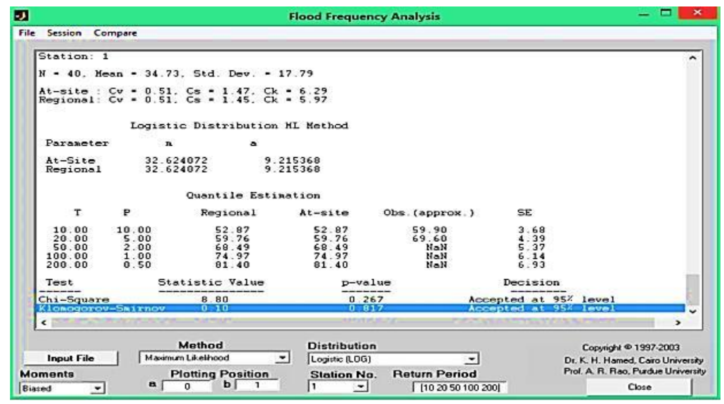


Figure.4. Rainfall height for 50-years RP storm- Jeddah station

3.3 Geology

The area of study is part of western Arabian Shield, covered by Neoproterozoic rocks of various volcanic and volcaniclastics types, together with several varieties of intrusive diorites, granodiorites and granites. These rocks are covered by Tertiary and Quaternary lavas with Sabkhas formed during more recent sedimentation process. The area can be divided into three distinct geologic units from oldest to youngest; the Neoproterozoic basement, the Tertiary lavas, the Holocene sediments and sabkhas**Error! Reference source not found.**. The Neoproterozoic rocks lie in the eastern part of the area which is occupied by the red sea hills and pediments. They consist of volcanic rocks, comprising andesite and dacite, intruded by plutonic rocks including diorite and granite. Formations that are covered by basaltic lavas represent the Tertiary rocks which cover the area east of Jeddah city. The Holocene unit includes the recently emerged marine deposits and corals, the recent basaltic lava flows, thewadi alluvium, sabkha deposits, the aeolian sands along the coastal plain and the pediments as illustrated in Figure (6)**Error! Reference source not found.**.

4. DELINEATION OF THE WATERSHEDS IN THE STUDY AREA

To identify the watersheds in the studied zone, the heights of all points in the defined area are extracted from the global Digital Elevation Model with precision of 30m for cell size. All watersheds in Jeddah region were delineated and classified with respect to their area as shown in Figure (7).The geomorphology characteristics for each watershed are used to characterize each basin and summarized in Table (1). The characteristic data include; area, length, slope, perimeter, maximum stream length, maximum stream slope and mean elevation of the basin.

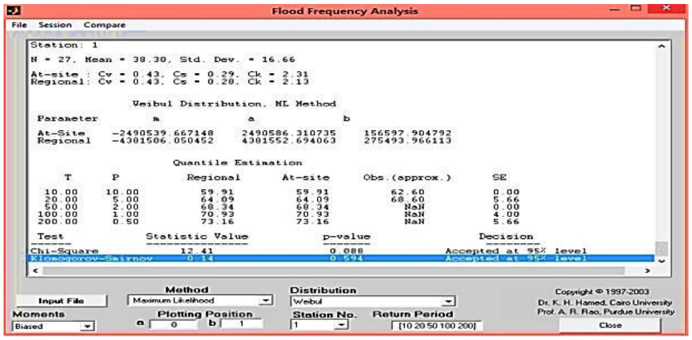


Figure.5.Rainfall height for 50-years RP storm - Mekka station

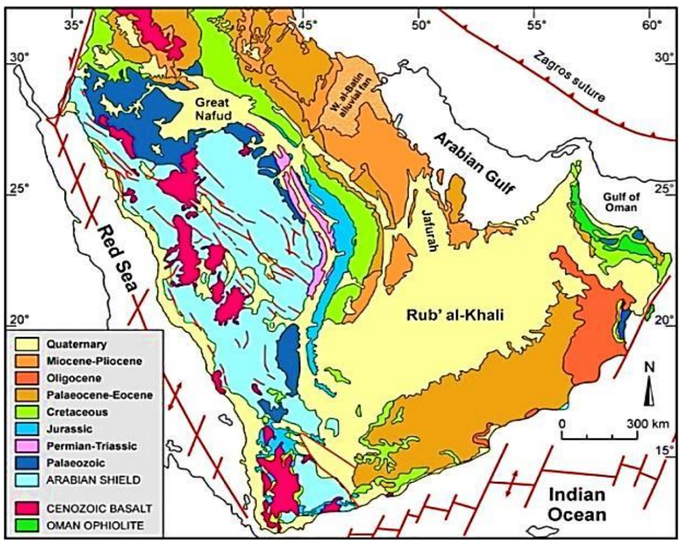


Figure 6 General geology of Kingdom of Saudi Arabia

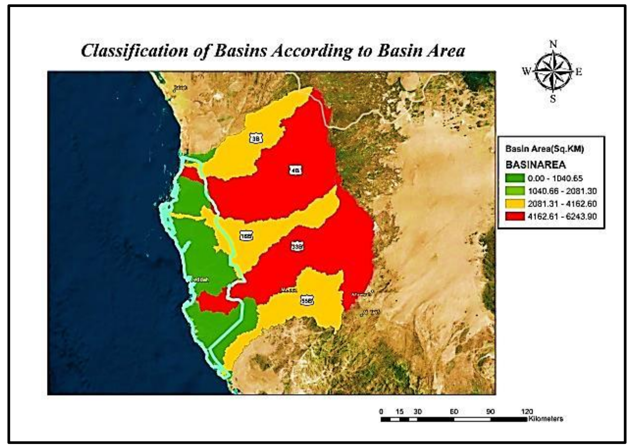


Figure 7 Major watersheds in the study area

5. SURFACE RUNOFF

All watersheds of Jeddah region are analyzed using The Watershed Modeling System (WMS) hydrologic model. The Soil Conservation Service (SCS) hydrograph method is used to compute the runoff hydrographs. Rainfall data for 50-year design storm is input to the Hydrologic Engineering Center hydrologic model (HEC-1) in the WMS software. For the SCS method, the land use and soil type maps were used to calculate the curve number that estimates the water losses for each basin. As a result of the hydrological analysis, runoff volumes are calculated for expected storm of 50-year return period. Figure (8) shows the hydrograph for the largest five basins in the working region with total volume of discharge ranging from 93 to 349 million m^3. All major streams in the studied area discharge into the red sea with stream discharge rate ranged from 929 m^3/sec to 2082 m^3/sec

Table 1 The charactraristics of basin in jeddah region

BASIN ID	Basin Name	Basin Area (km^2)	Basin Slope (m\m)	Maximum Stream Length(km)	Maximum stream slope(m/m)	Basin Length (km)	Perimeter (km)	Mean basin elevation (m)
3	Wadi al Kura	2257	0.130	146	0.010	115	437	491
4	WadiGharaiyah Wadi Hablyn	5203	0.118	204	0.007	121	618	703
16	Wadi Abhar Wadi Hility	2406	0.073	205	0.006	132	587	387
33	Wadi al Asala Wadi Murayyakh	5072	0.135	267	0.007	148	766	743
55	Wadi Ashir Wadi Mathwab	2437	0.163	172	0.014	121	535	517

6. MAPPING OF HAZARD AREAS

The term "hazard" defines the potential event that may cause damage and loss to properties, infrastructures and income. The vulnerability of local society depends on the strength of building and construction to resist natural elements, the social and economic resilience of local community to cope with the natural disaster and recover from its impacts. The geographical zones at highest risk are identified as the location where hazard is combined with vulnerability of local community. The selection of criteria that affect different natural hazard is an important step disaster risk assessment and in decision analysis[8].The most important factors that contribute to flooding are rainfall height, basin slope, drainage density, size of watershed, land use and the soil type 0**Error! Reference source not found.**.Flash flood occurs when rainfall is too intense, infiltration of the ground is low and high slope of the watershed exists. The infiltration capacity is the ability of the ground to quickly absorb water. It has a direct impact on the quantity of the runoff and it is related to the soil type of the study area. Another factor affecting the runoff volume is the land use. Soil covered by impervious material like roads will have no infiltration capacity and result in much higher risk of flood compared to vegetated soil. However, the combination of soil type and land use is expressed by soil conservation system curve number. When combined with large basin area and heavy rains, the quantity and duration of flood becomes very important [10]. Therefore, the critical factors used for classification of watershed are:

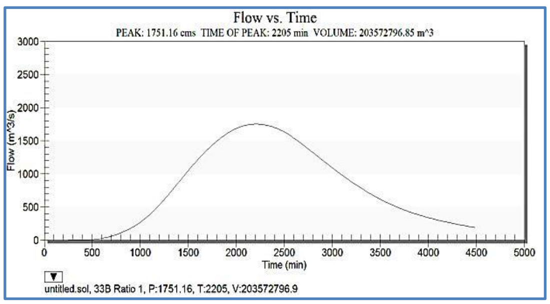
1. Expected maximum rainfall height of specific storm
2. Area of the watershed.
3. Slope of the basin.
4. Type of soil and land use.

For each factor, the importance weight is defined based on its physical contribution in causing flood **Error! Reference source not found.**. Each factor is then divided into four classes (low, medium, high, very high) with internal relative weight defined for each class based on the maximum and minimum values observed globally for similar floods. The limits for maximum and minimum relative weight are chosen as 8 and 2 respectively and the range between the two values is divided into four equal intervals as shown in Table (2). The risk assessment for flash flood in the actual study is carried for a storm with 50-y RP. Hazard of floods in the present study is estimated as the total sum of the weight for each selected factor. The flood hazard areas are classified according to these values as follows 0:

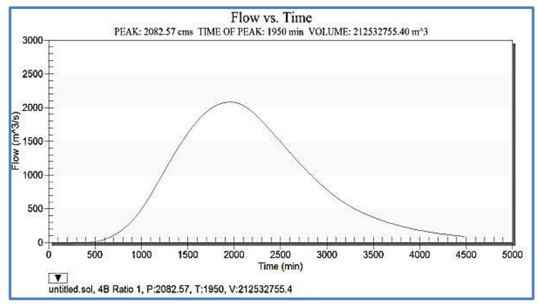
-Area with total weight > 80 (Very high)
-Area with total weight > 60 - 80 (High)
-Area with total weight > 40 - 60 (Moderate)
-Area with total weight > 20 - 40 (Low)
-Area with total weight < 20 (Very Low)

Table (3) shows the classification for the five largest basins in Jeddah region with total weight for each class defined as the sum of weights of each individual factor0.

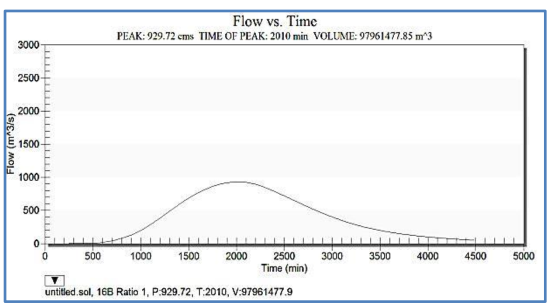
A)Basin#3



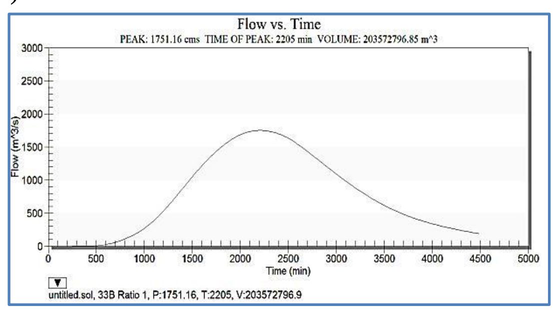
B)Basin#4



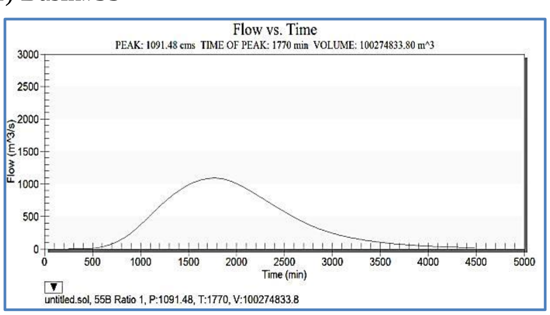
C)Basin#16



D)Basin#33



E) Basin#55



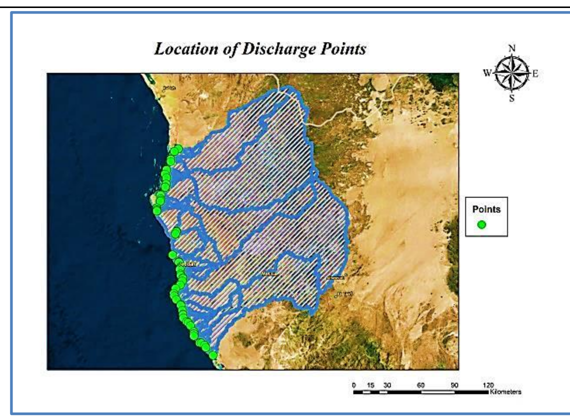


Figure.8. A,B,C,D,E 50-y RP Hydrograph for largest five streams

Figure. 9. Location of discharge points

Table.1.Basins Classification according to risk

Total Weight	Rainfall		Watershed Area		Watershed Slope		Curve Number	
	Value(mm)	Weight	Value(km^2)	Weight	Value (%)	Weight	Value	Weight
80	>70	32	>3000	24	>20	16	>85	8
60	50-70	24	2000-3000	18	10-20	12	75-85	6
40	30-50	16	1000-2000	12	5-10	8	65-75	4
20	<30	8	<1000	6	<5	4	<65	2

Table.3. weigh of each factor for the largest five basins

Basin ID	Basin Are	Basin Slop	Raifall	WS Are	WS Slop	CN	Total
3	2,257	13%	24	18	12	6	60
4	5,203	12%	24	24	12	6	66
16	2,406	7%	24	18	8	6	56
33	5,072	13%	24	24	12	6	66
55	2,437	16%	24	18	12	6	60

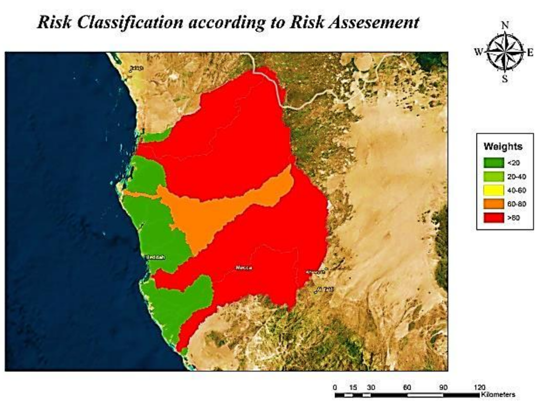


Figure.10.**watersheds classification according to Risk Assessment**

Based on the combination of all factors and the total weight obtained for each basin, a Flash Flood Hazard Map is developed for Jeddah indicating the watershed classification as shown in Figure10. Basin #4 and#33 are classified as high risk basins, while Basin#3, #16 and #55 are moderate risk basins. Combing the previous hazard map with vulnerability map representing the size of district population can produce a risk assessment map that identify the districts at high risk as shown on Figure (11).

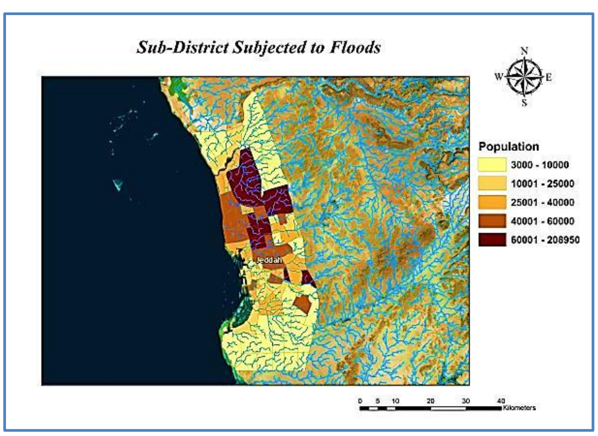


Figure.11. Districts under risk

7. RECOMMENDATION FOR FLOOD RISK REDUCTION

New legislation that protects human and assets against floods is needed for new development, settlements, building and industrial zones. The new legislation should take into consideration the effect of the flood hazard in the disaster prone zones and define obligation to protect buildings and infrastructures. From the actual study, these zones are defined for Jeddah City located in Mecca governorate; they are indicated as the watersheds area at high and moderated risk. The articles defined in the new regulation should be applied by national identities and enforced by local government during the phase of obtaining construction permits in these zones. The following amendments are proposed for the actual environmental laws:

-Article to determine the flood hazard areas

-Article identify zones of the target region that are prone to high and moderate flooding risk

-Article to design flood prevention structures

-Article to plan new land use for future developments

-Article to prevent ground water contamination

-Article to maximize the use of surface and ground water

The better water quality and quantity management requires a strategic approach and close cooperation between policy analysts, planners and implementers. Since the policy process is a circular one that moves from monitoring, analyzing, predicting the consequences of actions, to modifying policy responses and back, cooperation is needed in policy design, policy implementation.

8. CONCLUSION

In the actual study, large data was collected for Jeddah region in Kingdom of Saudi Arabia in order to assess the exposure of important constructions to Flash Flood Hazard. The Watershed Modeling System WMS has been applied to analyze and simulate the surface runoff storms using HEC-1 model. GIS techniques have been used for creating flood risk or hazard maps. This study has developed a systematic methodology for estimating flood hazard areas using GIS program. The flood hazard map from this study can be used to identify zones of Jeddah region that are prone to high flooding risk and to design flood preventing structures and plan new land use for future developing areas. Furthermore, this study can generate an actual vulnerability map for special buildings like schools or infrastructures. Not only do roads account for a large percentage of the damages in terms of repair cost. The maps developed are essential for legislators to identify the disaster prone areas and consequently develop adapted articles concerning these zones.

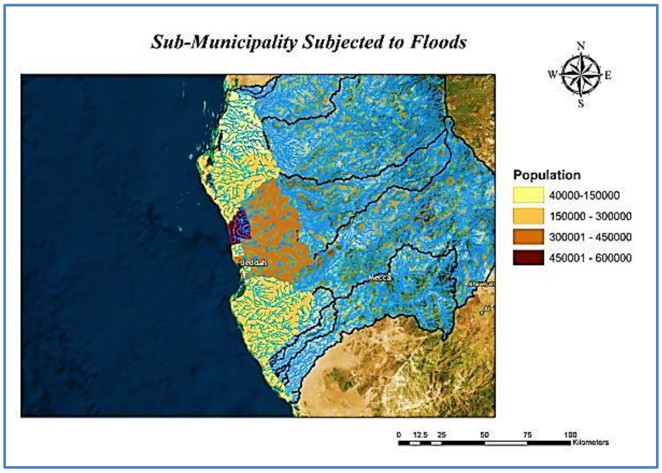


Figure.12. Sub-Municipality Subjected to Floods

Finally Jeddah region is totally under high risk of floods in its all Sub-District, Sub-Municipality as shown in Figure (12). With population approaching 4millions capita the cost for damage over the last 10years has exceeded 1.3Billion US Dollar 0.

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