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# Assessing Hydrological Elements as Key Issue for Urban Development in Arid Regions

Mohamed Tahir Hussein and Faisal Kamal Zaidi
*SGSRC, Department of Geology and Geophysics,*
*College of Science, King Saud University, Riyadh,*
*Saudi Arabia*



## 1. Introduction

In search of better livelihoods and facilities more people are moving towards urban centers. At present approximately half the world population resides in cities. Cities provide greater social and economic benefits to their inhabitants as compared to rural areas and this has resulted in massive demographic shift especially in the developing world which in turn has threatened the environmental stability.

According to the UN Reports, 2008, roughly 75 percent of the population lives in urban areas in the industrialized nations and will continue to grow at a rate of less than half a percent in the coming twenty years. On the other hand cities in the developing world will see about 95 percent growth in urbanization in the coming twenty years mainly due to migration, population increase and conversion of rural settlements into urban areas. A combined increase of this urbanization in the developed and the developing world will be that about 60 percent of the world's population will be living in cities by 2030.

Though cities occupy less than three percent of the world area, the high density of population and industrialization has resulted in severe environmental degradation. The worst environmental issues are faced close to the homes in the developing nations. They include inadequate domestic water supply, excessive waste accumulation and lack of proper hygiene and sanitation. The main reason for these environmental issues is that the infrastructural development has not kept pace with the increasing population. Other environmental issues associated with urbanization include severe air pollution, ground and surface water pollution, habitat loss, soil erosion, loss of bio-diversity and ecological disruption.

Arid regions of the world, especially those of middle-east Asia are not far behind as far as this demographic shift from rural to urban areas are concerned. The petroleum based economy of these regions have led to the springing up of major urban centers in countries like Saudi Arabia, United Arab Emirates, Oman, Qatar, Kuwait and Bahrain,(Bonine, 2009).

With proper planning and management cities can actually reduce pressure on the natural resources and increase energy efficiency. Innovative building designs, better waste management and improvement in transportation infrastructure can help in building sustainable cities. However often hydrological and climatological parameters such as the amount of rainfall, the volume of runoff generated, infiltration rates and drainage basin characteristics are neglected during urbanization process. These features are more commonly neglected in the arid regions mainly due to the lack of sufficient data which restricts the modeling capacity for extreme events. Topography is one important parameter which is not taken into consideration during town planning in these regions and instances of flash floods and water logging are becoming common due to such negligence.

Use of satellite imageries, digital elevation models, field observation and geophysical and hydrological investigations can help in reducing the complications related to urbanization in arid regions.

This book chapter focuses on the elements of hydrology which should be taken care of during urban planning and development with special emphasis on arid regions. A few case studies assessing the hydrological elements for urban planning have been cited as examples for arid region models.

## 2. Methodology

To implement the above mentioned tasks, the scientific methods adopted are mainly GIS based, confirmed with field measurements in the site under study. Nowadays the use of modern remote sensing technologies with the help of satellite imageries such as SRTM, SPOT 5, IKNOWS, QUICKBIRD, supply detailed coverage with resolution of 90, 20, 10 and 1 meter respectively. Digital Elevation Models (DEM) can be worked out to visualize in three dimensions, the topography and, drainage, flow direction and undulations on the topography of the area under study. An initial pilot visit to the area is needed to observe the major features of the area, the ground conditions including rock and soil type. Pounding areas and potential pounding areas to be figured- out and located. Analyses of collected topographic maps for identification of natural drainage of the site and the surrounding areas, and delineation of the catchments boundary are a necessary step in these procedures.

Collection of meteorological data (precipitation, temperature, evaporation, wind speed and directions) and topographic maps is an important aspect to evaluate the climate and hydrology of the area. This is followed by processing of collected data. The data are presented in tables and graphs. Mean, maximum and minimum of each variable are calculated. Rainfall distribution maps, frequency analyses, estimation of surface runoff are worked out. The maximum rainfall and run-off generated should be taken note of.

The above mentioned accomplishments are then subject to detailed desk study. The baseline data thus include: site overview plan, satellite image of the area, DEM, site topographic survey plan, and drainage network map.

The methodology involves carrying out detailed morphometric analysis of the basins within the area under study. Morphometric parameters such as basin shape and basin relief influence the nature of hydrographs and hydrological variables.

Based on the result of the hydrological processing identification of flow direction, flow accumulation and stream generation can be obtained and drainage channels can be classified into different orders using Strahler's 1964 classification. Other basin parameters such as basin area, basin perimeter, basin length and stream length are further used to obtain the different ratios such as Drainage Density, Bifurcation Ratio, Stream Frequency, Form Factor, Elongation Ratio, and Circulatory Ratio.

Ground surveys include essentially preparation of a geologic map of the area, showing the main structural elements of the earth that may affect the units of urbanization such as buildings, roads etc., and gathering information on the subsurface stratum to depth in the order of few meters to some 30 meters. The subsurface picture can be elucidated using geo-electrical techniques, (Reynold, 2011). A number of instruments are available to achieve this goal. Nonetheless the use of SYSCAL-Pro 72 unit proved to be very useful. Resistivity surveys using multi-electrode resistivity technique gave good results. Dipole-Dipole configuration with the unit electrode spacing ranging from 2.5 meters to 5 meters depending upon the ground clearance can be adopted. Dipole-Dipole configuration is selected for the survey as it gives the best horizontal resolution as compared to all the other methods present. RES2DINV Software, (Loke, 2002) can be used for inverting the apparent resistivity values to a resistivity model section. The least square fitting technique (Loke and Barker, 1996) is used for getting the best fit for the resistivity model by iterations.

Infiltration is another important hydrological element for urban development studies. Field measurements of both infiltration capacities and infiltration rates of the different soil types in the area are necessary to accomplish the hydrological picture of the water budget in the area, (Hopmans, 2011).

All these accomplishments and measurements, as mentioned earlier, should be GIS based so that the different layers can be compared and inter-layer relationships can be worked out. Based upon these relationships the area under study can be zoned according to hazard prone areas as far as hydrological elements are connected to urbanization.

## 3. Case studies

### 3.1 Delineating the wet/dry zones in the Qassim province of Saudi Arabia (Faisal K. Zaidi et al, 2010)

#### 3.1.1 Introduction

Central Saudi Arabia experiences an arid type of climate with mean annual rainfall rarely exceeding 150 mm. The low rainfall has resulted in scanty vegetation in the region except for the wadis where farms and date palm plantations can be seen due to the availability of groundwater. However the chance of flash floods increases to a great extent due to lack of vegetation cover in the events of heavy rainfall.

The city of Buraidah which is the administrative capital of the Qassim province has undergone rapid urbanization in the recent years and due to lack of proper urban planning a lot of low lying areas and stream channels have been allotted to housing colonies. During the heavy rainfall in the month of November 2008 and March 2009, many such housing colonies in the low lying areas were inundated by flood water.

The stagnant water in the lakes became a threat for the environment by providing the breeding ground for mosquitoes and other water borne disease. Thus it was decided to drill a few bore wells in these manmade lakes with the dual purpose of recharging the aquifer and getting rid of the stagnant surface water thereby preventing environmental degradation.

Electrical Resistivity Survey was carried out at 4 locations (Figure 1) for investigating the depth of the wet zone in these localities. Based on the depth of the wet zones the approximate depths of injection bore wells were estimated.


Fig. 1. Location of the 4 localities in Buraidah, Qassim

### 3.1.2 Methodology

The resistivity survey was carried out using the multi-electrode resistivity technique. The surveys at all the 4 locations were carried out using the Dipole-Dipole configuration with the unit electrode spacing ranging from 2.5 meters to 5 meters depending upon the ground clearance using the SYSCAL-Pro 72 unit. RES2DINV Software, (Loke, 2002) was used for inverting the apparent resistivity values to a resistivity model section. The least square fitting technique (Loke and Barker, 1996) was used for getting the best fit for the resistivity model by iterations.

### 3.1.3 Results and conclusions

Site 1

The first site M1 was in the Buhairatil Khaleej, Figure 2, which is situated in the South of Buraidah City. The total line length of the survey was 360 meters with the unit electrode spacing of 5 meters using dipole-dipole configuration. The depth of investigation at this site was around 72 meters.


Fig. 2. Location map of Buhairatil Khaleej with the direction of the survey line

Result

Figure 3 shows the result of the resistivity survey. The resistivity values range from 7.07 ohm.m to 36.9 ohm.m.

Conclusion

The depth of investigation in the present case is about 72 meters. The resistivity value for the total depth of investigation does not show a very high contrast and in general is very low ranging from 7 ohm.m to 37 ohm.m. indicating the presence of a wet zone throughout the entire depth of investigation. However at a depth of about 30 meters from the surface the resistivity value increases indicating the presence of relatively dry zone. This boundary (Figure 4) can well be the contact zone between alluvium and weathered limestone as the site is situated in a stream channel. The 2 zones of relatively high resistivity shown in Figure 6 may be due to the presence of less weathered limestones.

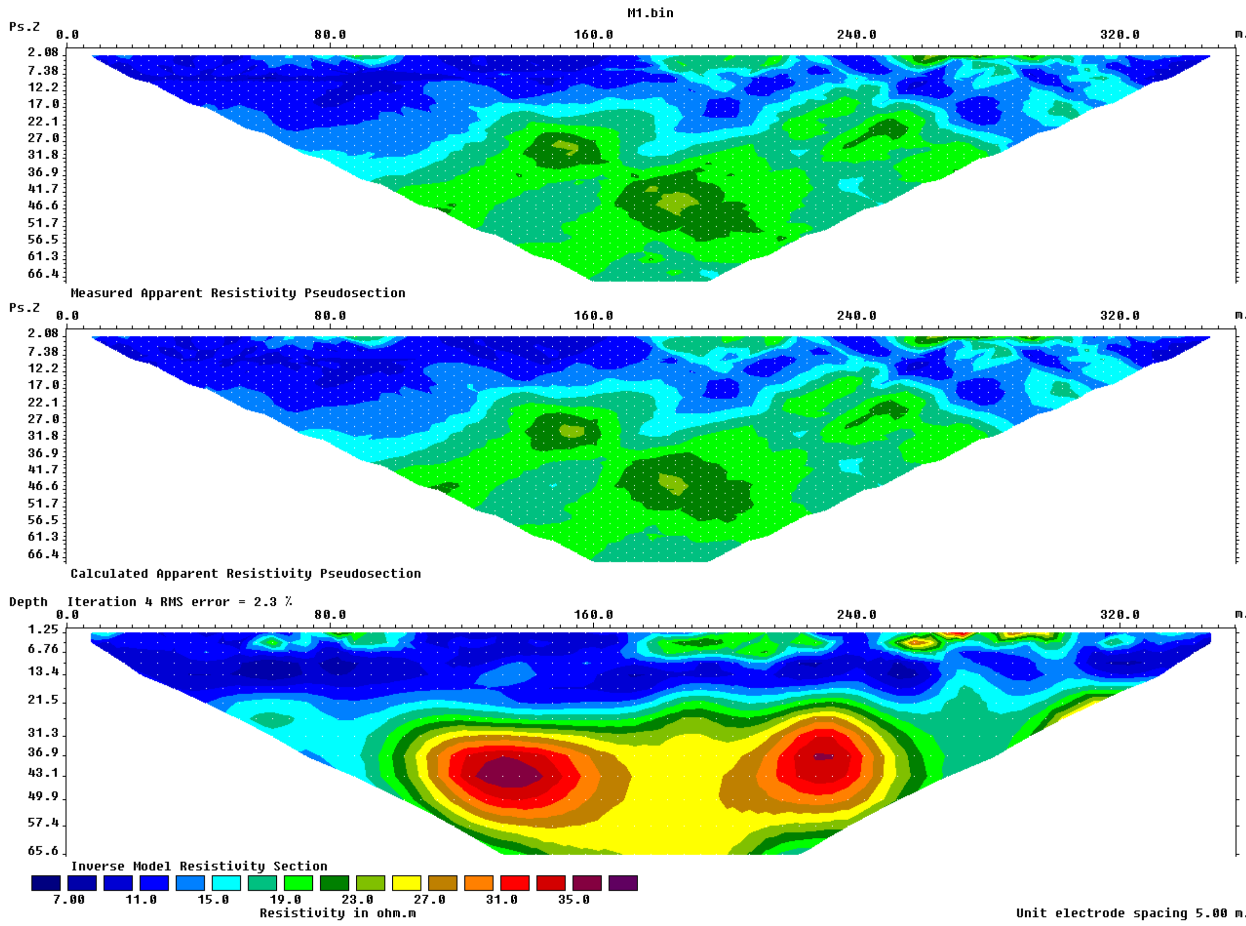


Fig. 3. Results of the resistivity survey at site M1

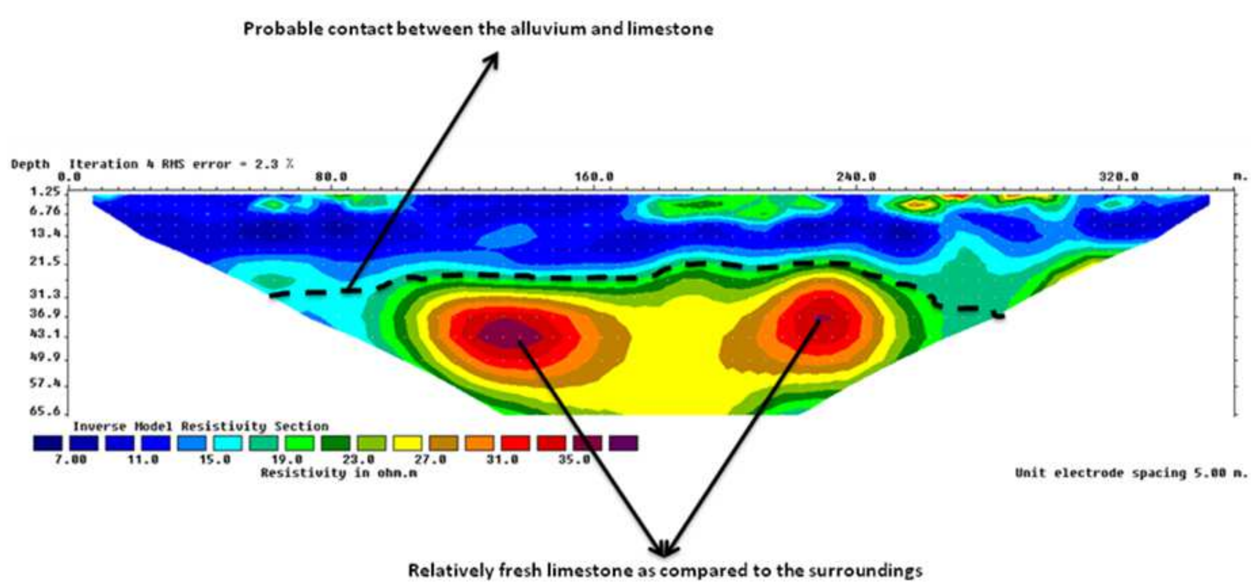


Fig. 4. Interpretation of the resistivity results at Site M1

Site 2

The second site M2 was in the Bohairatil Iskan Qadeema (Figure 5) which is situated in the Buraidah City Center. The length of the profile for this survey was 288 meters with the unit electrode spacing of 4 meters using Dipole-dipole configuration. The depth of investigation at this site was around 57 meters.




Fig. 5. Location map of Bohairatil Iskan Qadeema with the direction of the survey line

Result

Figure 6 shows the result of the resistivity survey carried out at Buhairatil Iskan Qadeema. The resistivity values range from 2.93 ohm.m to 7000.5.6 ohm.m.

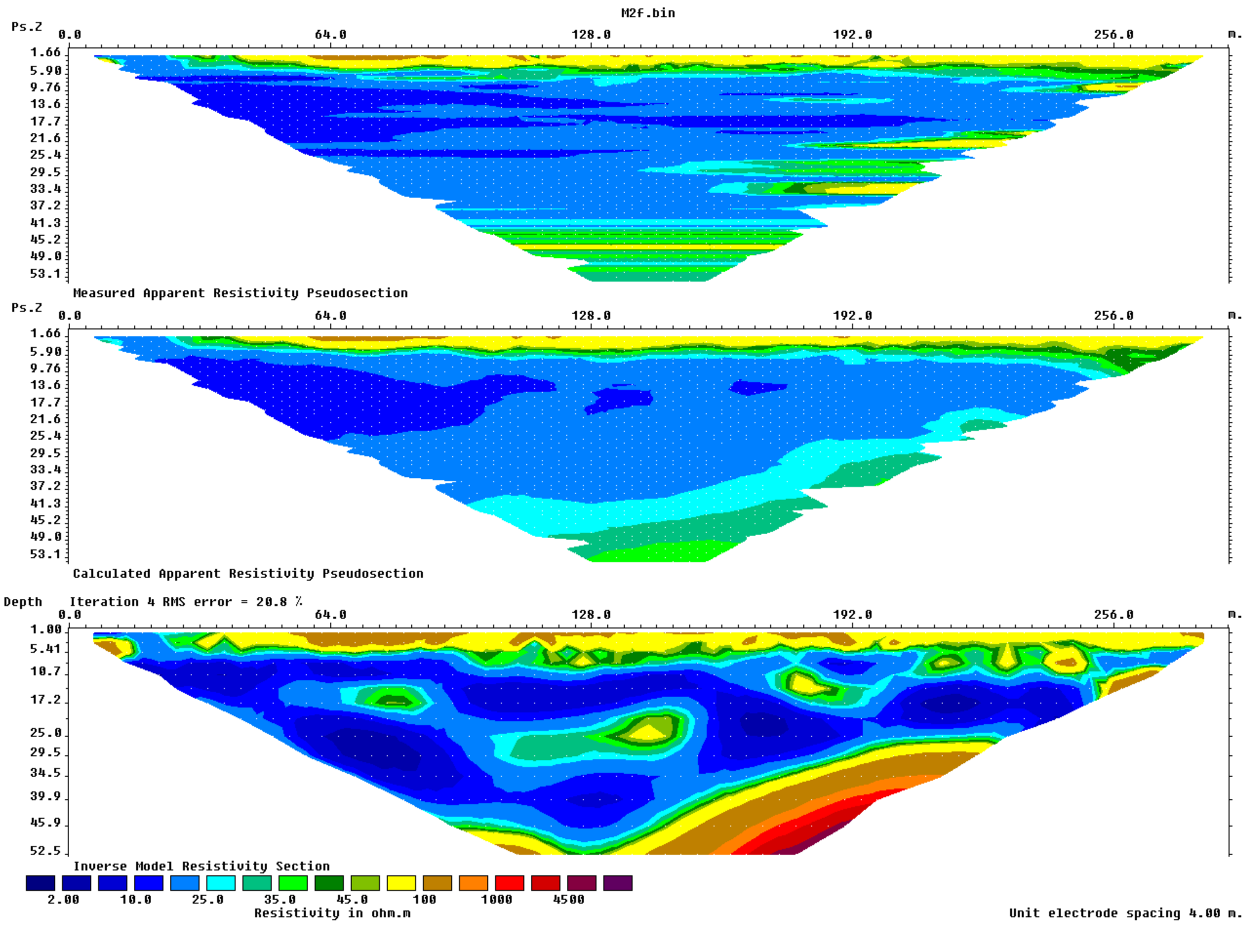


Fig. 6. Results of the resistivity survey at site M2

Conclusion

The results (Figure 7) clearly indicate the presence of an approximately 40 meters thick wet zone starting from 6 meters below ground level up to 46 meters below ground level. The resistivity values within this zone range from 2.93 ohm.m to about 30 ohm.m. The lake still had some water and this probably explains the presence of a thick wet zone. Bore wells drilled to a depth greater than 45 meters could be helpful in injecting the water collected in this lake during rains.

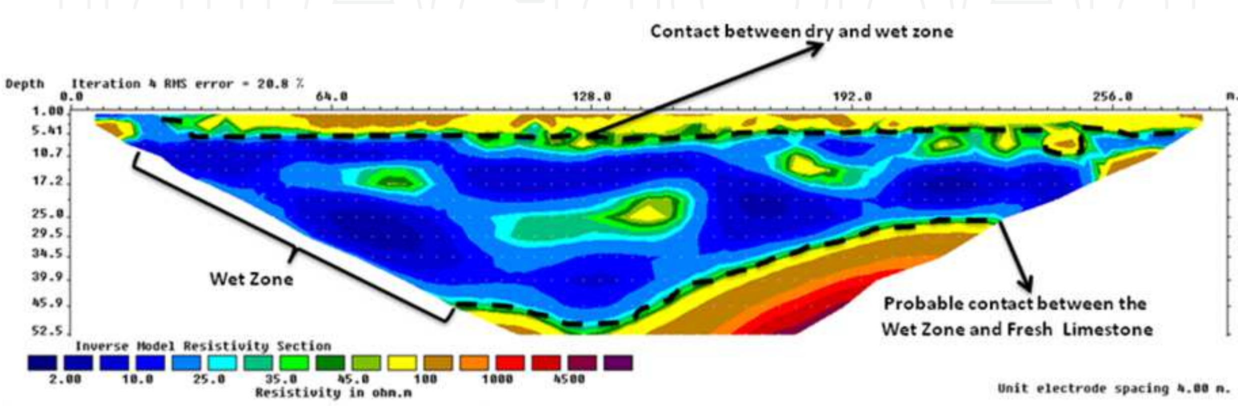


Fig. 7. Interpretation of the resistivity results at Site M2

Site 3

The third site M3 was in the Bohairatil Iskan Jadeeda (Figure 8) which is situated about 1 km North East of the site M2. The length of the profile for this survey was 288 meters with the unit electrode spacing of 4 meters using dipole-dipole configuration. The depth of investigation at this site was around 57 meters.



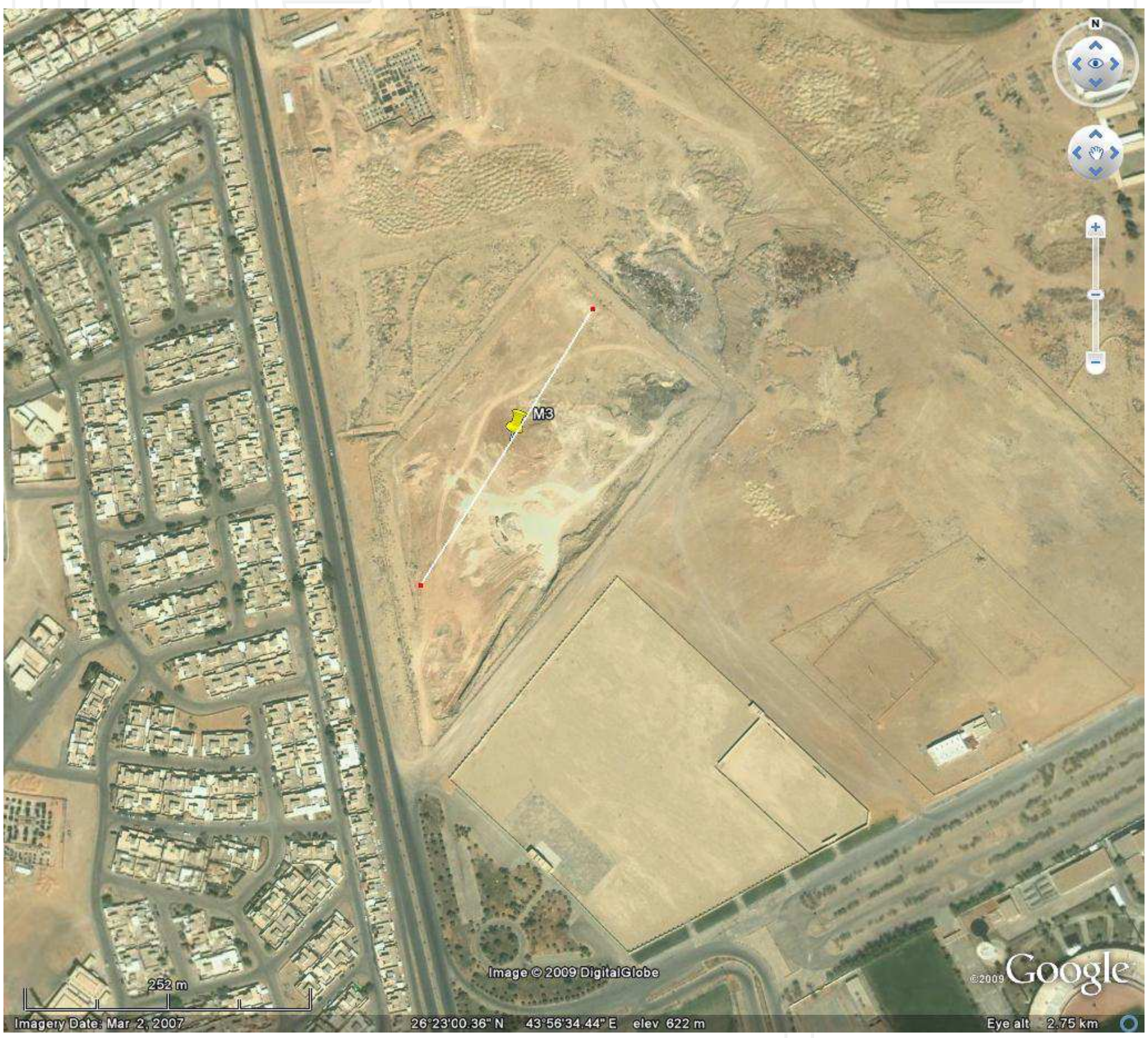


Fig. 8. Location map of Bohairatil Iskan Jadeeda with the direction of the survey line

Result

The cross sections of the lake walls showed the presence of weathered Limestones with calcrete infillings and the presence of folds. Figure 9 shows the result of the resistivity survey carried out at Buhairatil Iskan Jadida. The resistivity values range from 0.17 ohm.m to 2258.20 ohm.m.

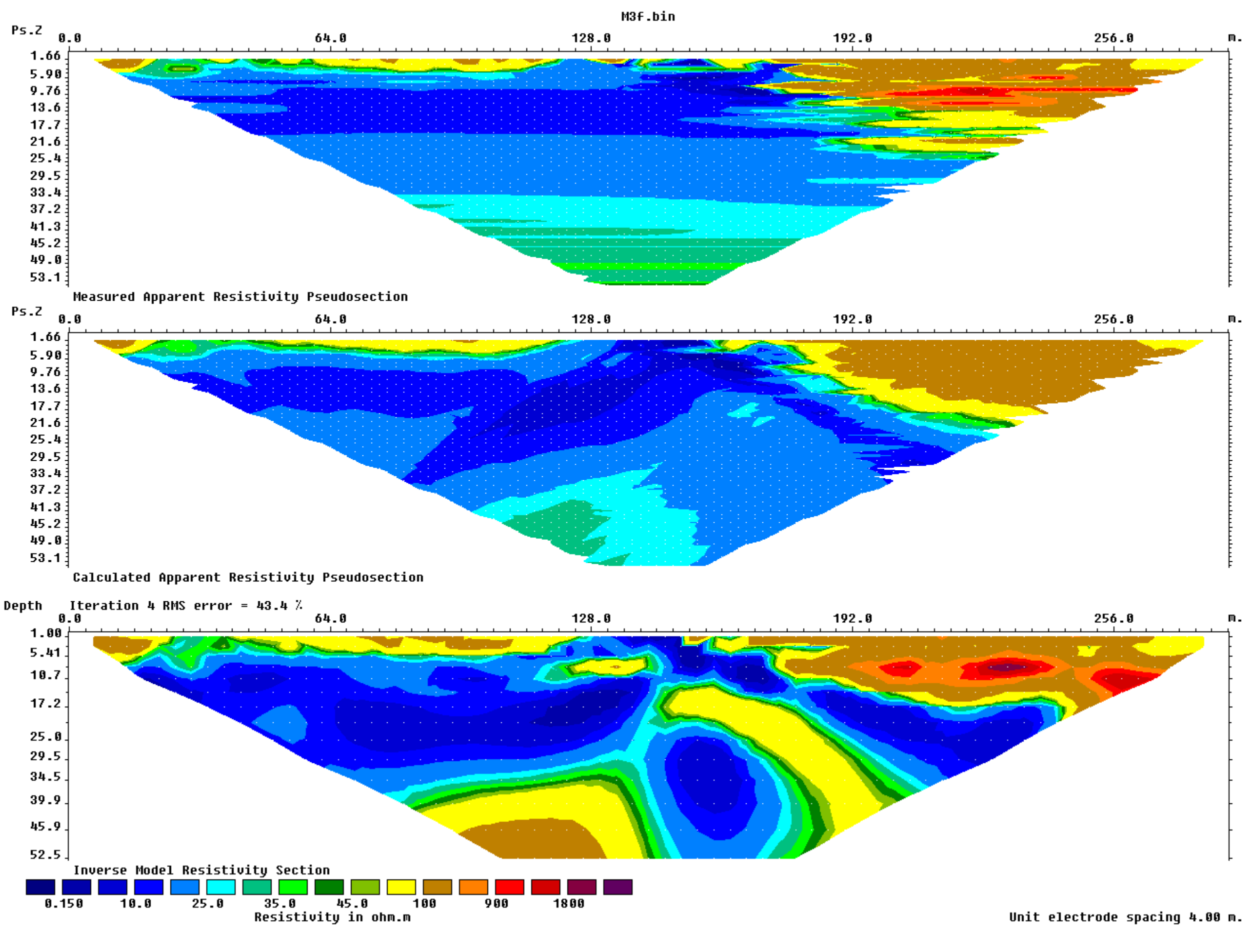


Fig. 9. Results of the resistivity survey at site M3

Conclusion

The wet zone thickness in the present locality is about 35 meters with some local variations as seen in the middle of the section where the wet zone extends up to the entire depth of investigation. This fact could be explained by the presence of structural features which might have resulted in partial weathering of the limestones thus resulting in varying degree of water saturation. The difference in water saturation around this zone is clearly reflected in the resistivity contrasts in the cross-section in figure 16. In the Eastern part of the profile some fresh limestone outcrops were present and it has been reflected in the form of high resistivity in the right side of the profile, (Figure 10). In general the wet zone thickness in the section varies from about 6 meters below ground level to about 40 meters below ground level. Injections well drilled to a depth of around 45 meters could solve the purpose of getting rid of excess water at this site.

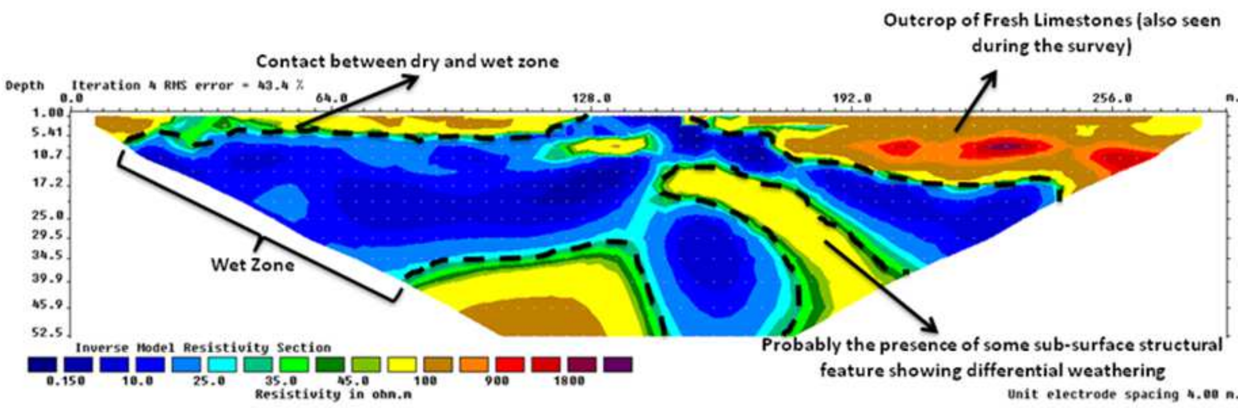


Fig. 10. Interpretation of the resistivity results at Site M3

Site 4

The fourth site M4 was in the Bohairatil Riyan (Figure 11) which is situated in the North Western part of Buraidah City. The total line length of the survey was 180 meters with the unit electrode spacing of 2.5 meters using dipole-dipole configuration. The depth of investigation at this site was around 36 meters.


Fig. 11. Location map of Bohairatil Riyan with the direction of the survey line

Result

The cross sections of the lake walls showed the presence of weathered limestones with calcrete infillings and the presence of nodal structures. Figure 12 shows the result of the resistivity survey carried out at Buhairatil Riyan Jadida. The resistivity values range from 0.81 ohm.m to 137.60 ohm.m.

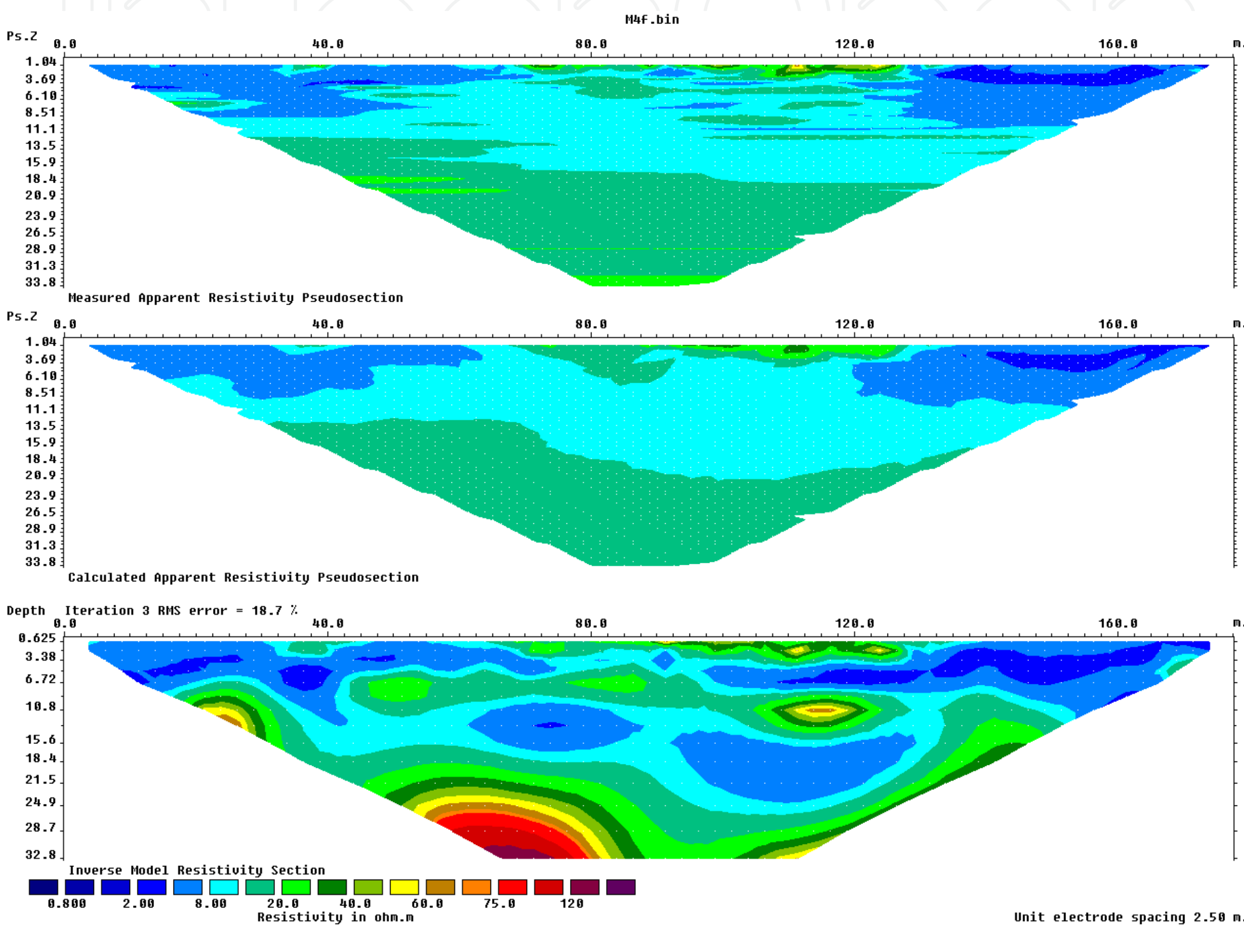


Fig. 12. Results of the resistivity survey at site M4

Conclusion

As mentioned earlier the resistivity values for this site ranges from 0.81 ohm m to 36.9 ohm.m. which is very low. In general the section shows the presence of wet zone through the entire depth of investigation. However the depth of investigation in the present case is limited only to 36 meters due to the unavailability of open space for laying the resistivity cables. On the lower left portion of cross section in Figure 13 the probable contact between the dry and wet zone is shown at about a depth of 25 meters. From the general depth of the dry zone in the previous 3 sections it can be concluded that drilling injections wells to the depth of about 45 meters may solve the purpose of getting rid of the excess water at this site as well.

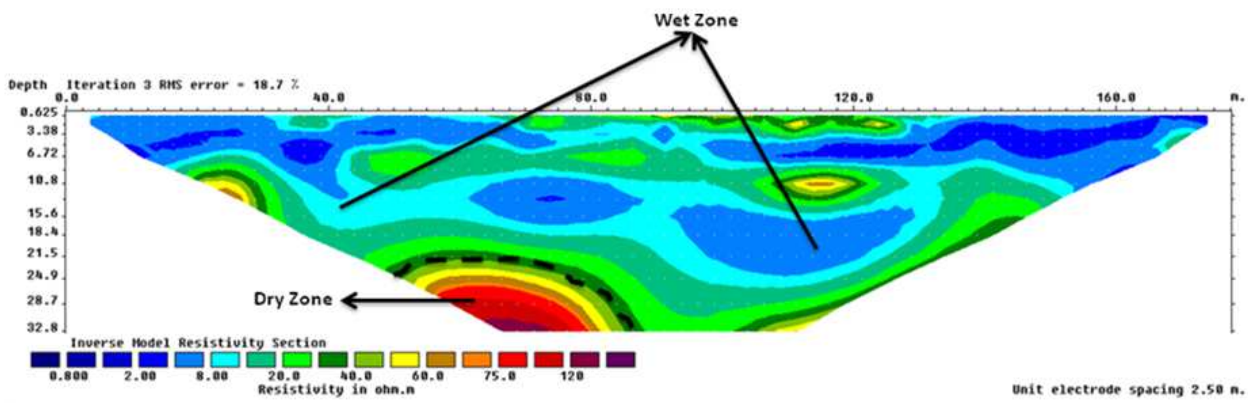


Fig. 13. Interpretation of the resistivity results at Site M4

### 3.1.4 Discussion

The probable presence of alluvium was detected only at the first site M1 at Bohairatil Khaleej with a sharp contrast in resistivity value at around 30 meters from the surface and is in accordance with the field observation which shows that this site is located in the course of a Wadi. The resistivity values are low at the other 3 localities as well indicating the presence of wet and weathered limestones. Presence of alluvium in these localities can be ruled out based on the exposed wall sections in the lakes which show beds of limestones intercalated with calcrete infillings. At the locations M2, M3 and M4 a contrast in resistivity values are observed at a depth ranging from 30 meters to 45 meters below ground level. It is recommended that wells drilled up to depths ranging from 45 meters to 55 meters in all the 4 localities can be efficient in getting rid of the excess rain water collected in these lakes during rainfall.

### 3.2 Assessing elements of surface hydrology for environmental quality characterization of a site northwest of Riyadh, Saudi Arabia (M. T. Hussein et al, 2009)

### 3.2.1 Introduction

Elements of surface hydrology, specially rainfall and surface runoff, are important factors in environmental quality characterization for urban development. In arid regions, these elements are difficult to forecast and may cause negative complications, especially in planning and design, if not been aware of. The study area under consideration lies within an urban center in the north west of Riyadh City, Saudi Arabia (Figure 14), between longitudes 46º 37´ 26" E- 46º 39´ 20" E, and latitudes 24º 45´ 00" N- 24º 46´ 45" N. The main purpose of this study was to workout elements of surface hydrology as part of an environmental assessment for urban development.

The tasks undertaken to achieve this purpose were:

- Review of the published topographical information to identify significant hydrological features such as, current and historic stream flow paths and potential ponding areas.
- Review of the already existing infrastructure to identify significant features such as culverts and any potential surface flow restrictions.

- Collate and review any existing data relevant to the site and the immediately surrounding area were reviewed and collated. This included but was not limited to ground conditions, meteorological records, historic records and/or photographs of flooding or pounding.
- Site visit to assess broad surface hydrology.
- Identification of relevant standards and guideline values.
- Identification the approximate extent of catchments contiguous with the site, and estimate the approximate flow rates, flow directions and pounding levels in typical and severe rainfall events.

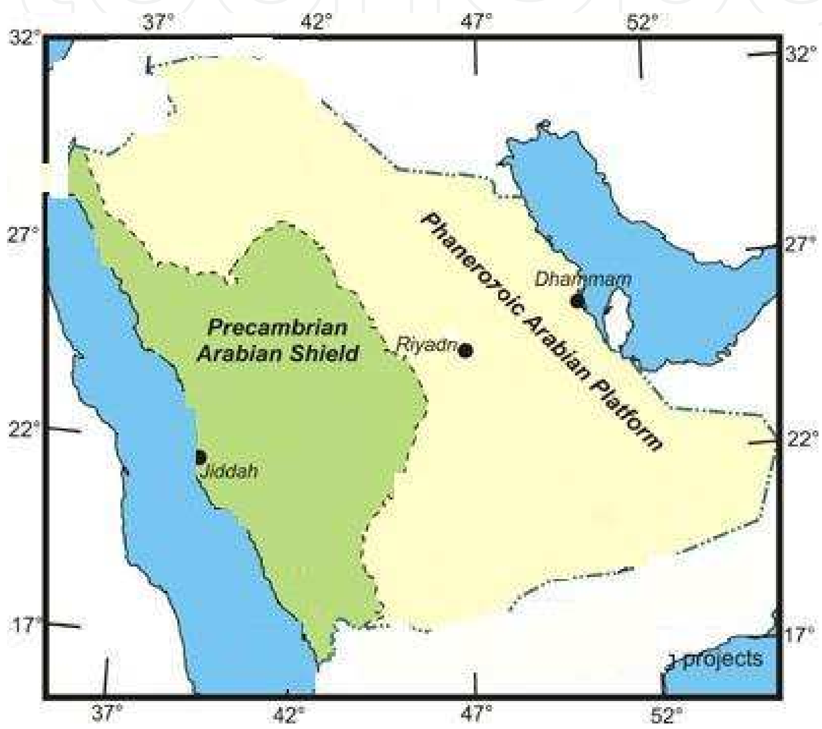


Fig. 14. Location map of the study area

#### 3.2.2 Methodology

A field visit to the site was made, in which the boundaries of the study area was walked over and major features on the area were noticed, ground conditions including rock and soil type were identified. Ponding areas and potential ponding areas were figured- out and located. Meteorological data (precipitation, temperature, evaporation, wind speed and directions) and topographic maps were collected. The meteorological data were then treated for statistical analysis

The collected topographic maps and data were used for the identification of natural drainage of the site and the surrounding areas, and delineation of the catchments boundary.

The above mentioned accomplishments were subject to detailed desk study, and data analysis. The acquired data were analyzed and presented using Microsoft EXCEL, Global Mapper V. 6 (Global Mapper Software LLC), and WMS V. 7 (Environmental Modeling Systems, Inc.) GIS V. 8 (ESRI).

Site description

The site is comprised of three blocks and it is bounded to the east by the Riyadh-Al Qassim highway and to the south by the North ring road. To the north and west, the site is bounded by residential areas.

The Jurassic Arab Formation limestone underlies most of the site (Vaslet et al., 1991). Unconsolidated deposits of silt, sand and gravels are observed on the wadies. The only hydraulic connections in between the site and its surroundings are the culverts under the roads surrounding the area. Dumped fill material and construction debris covers about 3% of the site area.

#### 3.2.3 Results

Field observations

GPS locations, types, dimensions of all culverts within the project site were measured (Table 1). The coordinates were measured by a hand held Garmin GPS and are reported in degrees, minutes, and seconds. The culverts in the site include three types: multispan box, double tube and single tube pipe culverts. Table 2 shows locations, and dimensions of existing ponding areas in the site and potential ponding areas.

| Culvert No. | Coordinates | | Culvert Type | Dimensions | Location | Remarks |
|---|---|---|---|---|---|---|
| | Latitude | Longitude | | | | |
| 1 | 24.76898 | 46.74325 | Multispan box (3) | 18X1.25 m | Block A | in |
| 2 | 24.76843 | 46.64344 | Single pipe | 0.9 m | Block A | in |
| 4 | 24.76392 | 46.64519 | Single pipe | 0.9 m | Block A | in |
| 5 | 24.75934 | 46.64331 | Single pipe | 0.9 m | Block A | in |
| 9 | 24.75852 | 46.64165 | Single pipe | 0.9 m | Block B | in |
| 6 | 24.75905 | 46.63718 | Multispan box (3) | 7.4X1 m | Block A | out |
| 7 | 24.76052 | 46.63682 | Multispan box (5) | 22.1X 1.4 m | Block A | out |
| 8 | 24.77024 | 46.63979 | Double pipe | 2.0X0.8 m | Block B | in |
| 3 | 24.76792 | 46.63875 | Single pipe | 0.8 m | Block A | in |

Table 1. Culvert types and dimensions

| Coordinates | | Approximate Dimensions | Location | Remarks |
|---|---|---|---|---|
| Longitude | Latitude | | | |
| 24.76898 | 46.74325 | 20X40 m | Block A | wet |
| 24.76354 | 46.64509 | 22X30 m | Block A | dry |
| 24.75866 | 46.64159 | 20X25 m | Block A | Partially wet |
| 24.75856 | 46.6416 | 30X35 m | Block A | dry |
| 24.75939 | 46.63317 | 15X20 m | Block A | dry |

Table 2. Pounding and potential pounding areas

Catchment area and drainage analysis

Catchment area and drainage analysis of the study area were depicted with the help of published topographic maps (sheet 4624-14), SPOT 4 image and DEM analysis.

Analysis of DEM of the area show that the western part topography is land marked by part of Wadi Hanifa Escarpments, high lands occur towards the north east of the study area (Figure 15).The southern part occupies the relatively lower most elevations in the study area. Within the study area the general slope is towards the south (0.02). Drainage analysis of the study area shows four sub dendritic systems that drain towards the south and finally joining Wadi Hanifa (Figure 16).

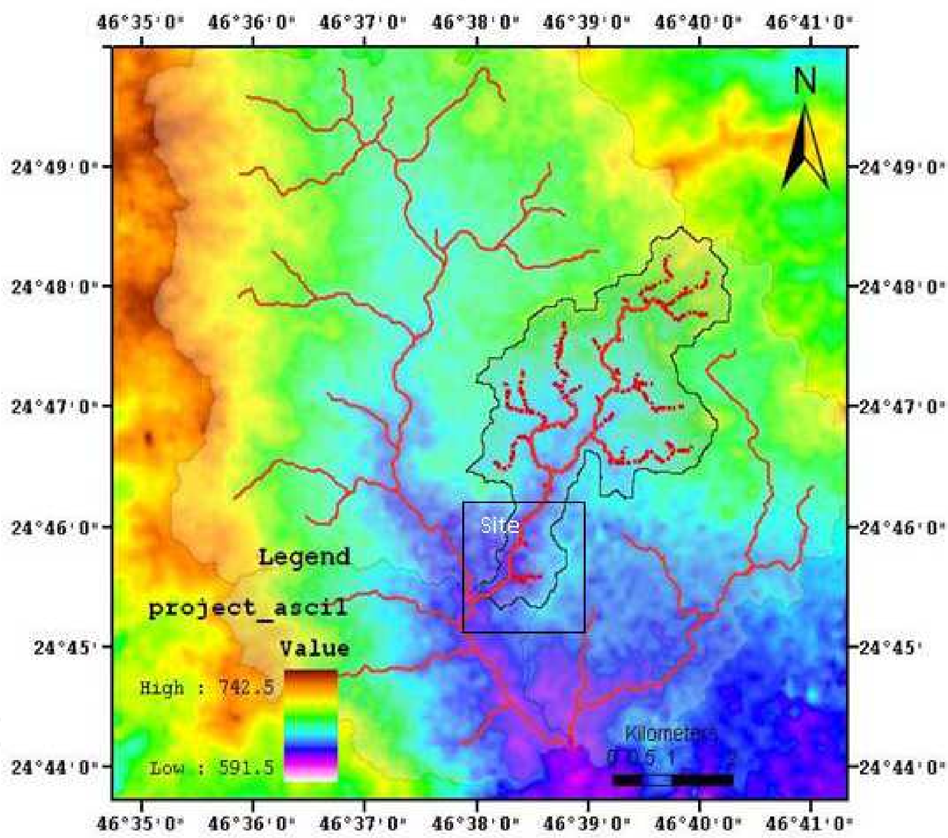


Fig. 15. Topography and general drainage systems of northwest Riyadh

The site of the present study lies in the downstream of the middle sub catchment. This sub catchment (Figure 4) covers a surface area of about 11.25 km2. The stream length within the site varies from 68.29 to 686.16 m with an average of 396.23 m. Within the site the stream slope varies from 0.0009 to 0.016 with an average of 0.00632 (Table 3).

The site represents the trunk of the sub catchment under consideration. All calculations of surface hydrology are based on the surface area of this catchment (Figure 17).

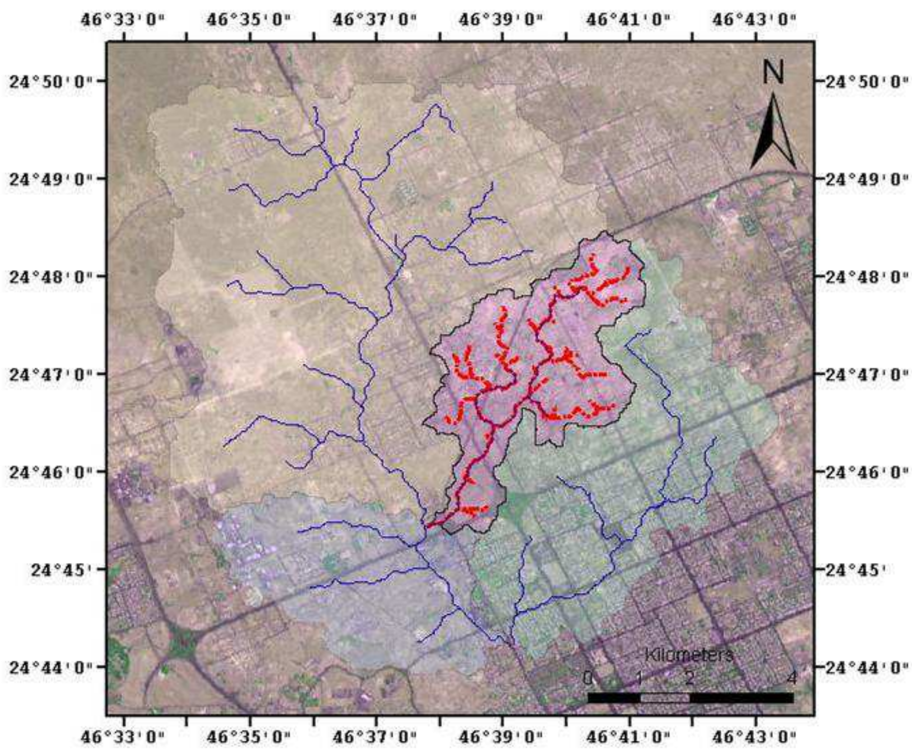


Fig. 16. The four sub drainage systems and their catchments areas.

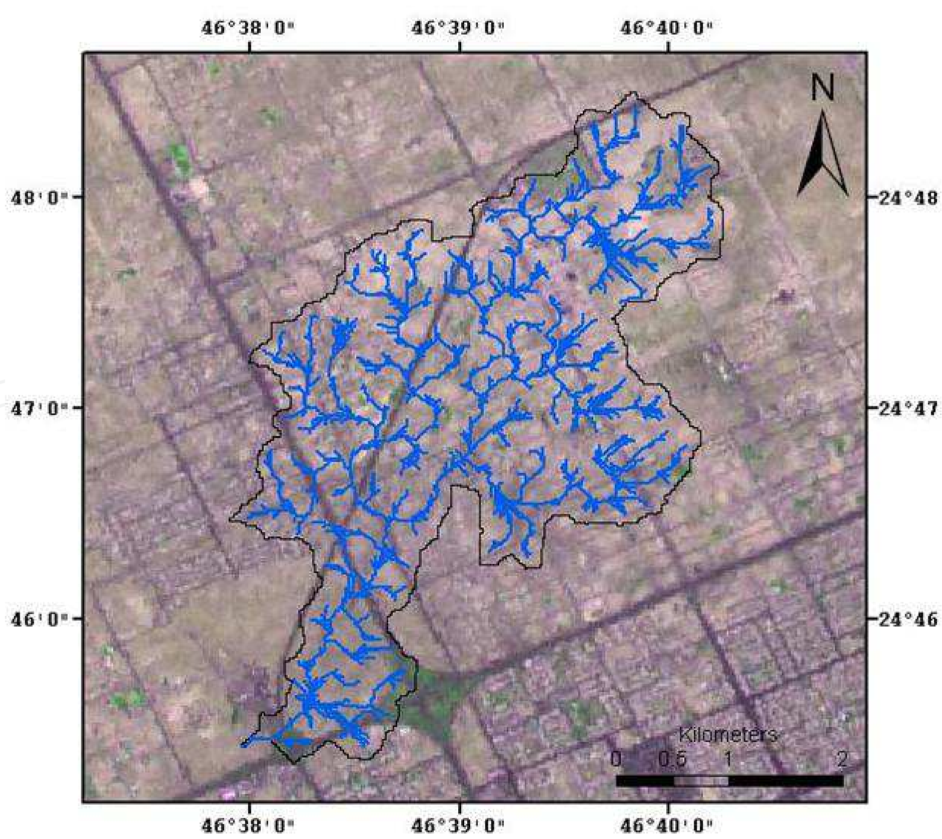


Fig. 17. Detailed drainage system of the site and its surroundings.

| | |
|---|---|
| Area (km2) | 11.26 |
| Slope | 0.02 |
| Shape Factor | 3.87 |
| Sinuosity | 1.18 |
| Perimeter | 27369.96 |
| Mean elevation (m) | 649.47 |

Table 3. Sub basin characteristics

Climate

Climate is characterized by a very hot summer, mild winter and little irregular rain with much variation in quantity. In general Riyadh area is influenced by the Mediterranean winter, precipitation and by local factors, such as the relief and distance from the sea. During winter time (November-February) the middle latitude cyclones tend to travel from the Mediterranean Sea towards the equator and then travel inland reaching the Najd Plateau. Monsoonal rains are caused by the tropical type cyclones in the Indian Ocean and travel over the Red Sea. The coldest month is January. Summer extends from sometime in April to the beginning of September (PME, 2005).

Rainfall

In Riyadh area the amount of rainfall is irregular through the years and through the months. Winter and spring is the rainy season, there is almost no rain between May and September.

Average monthly rainfall for the period 1985-2005 is shown in Figure 18. Rain occurs mainly in November-January, through February and relative higher quantities of some 25 mm occur in March and April period. Less than 3 mm may occur during the month of October. The amount of rainfall is extremely variable from year to year and from month to month. Annual rainfall rarely exceeds 125 mm (PME, 2005).

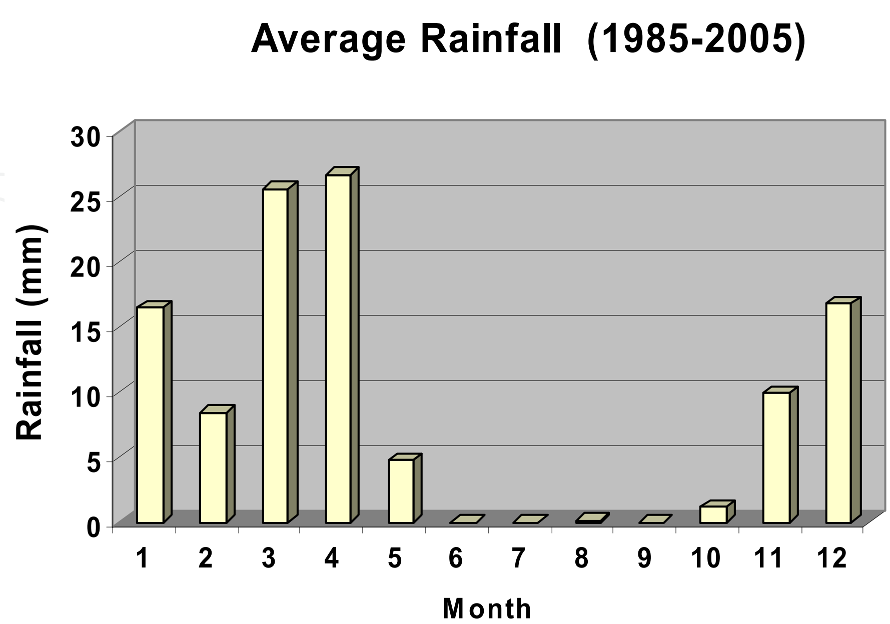


Fig. 18. Average total monthly rainfall

The maximum total daily rainfall records at King Khalid Airport station is shown in Figure 19: Maximum daily total rainfall The maximum recorded daily rainfall was 47.8 mm and it was on December, 20th 1995. The minimum was 25.4 mm and was recorded on April, 11th 1991.

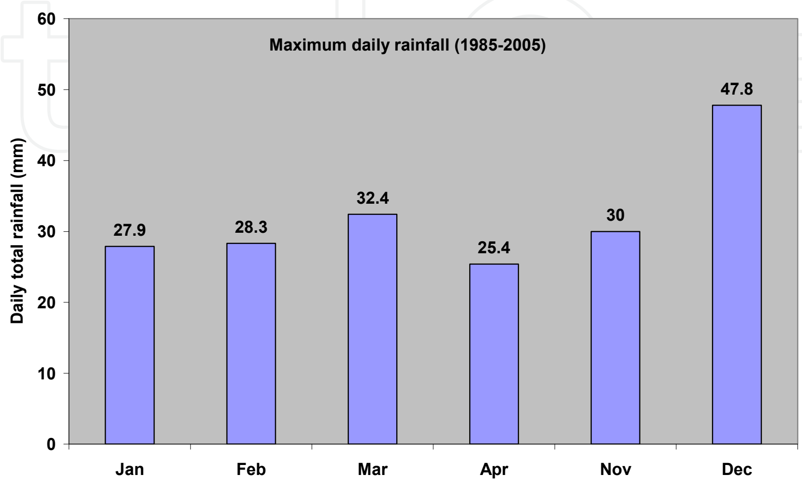


Fig. 19. Maximum daily total rainfall

Air temperature

The maximum air temperatures are reached during summer (June, July, and August) and minimum temperatures are attained during winter (December and January). Air temperature ranges from 8◦ C in winter to some 43◦ C in summer (Figure 20). The average monthly temperature is in the range 14.1◦ C to 43◦ C. The annual average temperature is 24.6◦ C. The coldest month is January while the hottest months are June, July and August.

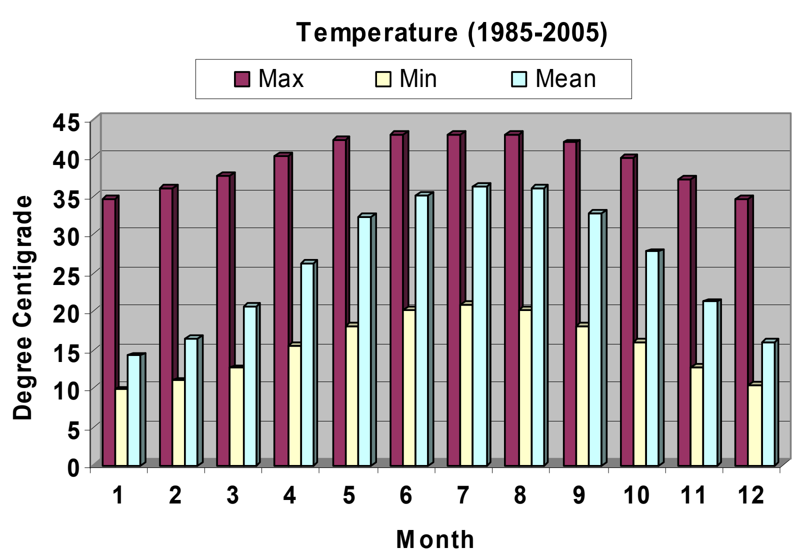


Fig. 20. Minimum, maximum, and average monthly temperature.

Relative humidity

Since Riyadh city is located on the Najd Plateau, away from any water body, the relative humidity is very low. The Average values for relative humidity ranges from 19.5% in June and 52.5% January (Figure 21). Annual average relative humidity is 34.4%. These values reflect very dry or hyper arid climate.

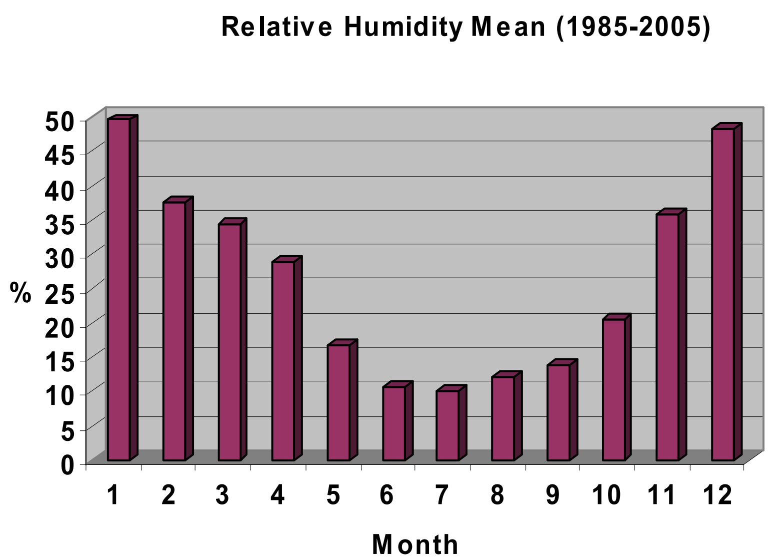


Fig. 21. Average monthly relative humidity

Solar radiation

Solar radiation is an important factor that influences evaporation in the area. In Riyadh area the monthly solar radiation ranges from 328 cal/cm2 per day (January) to 597 cal/cm2 per day (June). Cloudness ratio is 0.721 (January) to 0.765 (June). The average annual value for solar radiation is 477 cal/cm2 per day.

Wind

Mean monthly speed value ranges from 3.8 km/hr in October to some 6.8 km/hr in July. In March it reaches its maximum at some 6.9 km/hr. The average annual wind speed is 5.1 km/hr. The prevailing wind directions are primarily North and Northeast (Figure 22 and Figure 23).

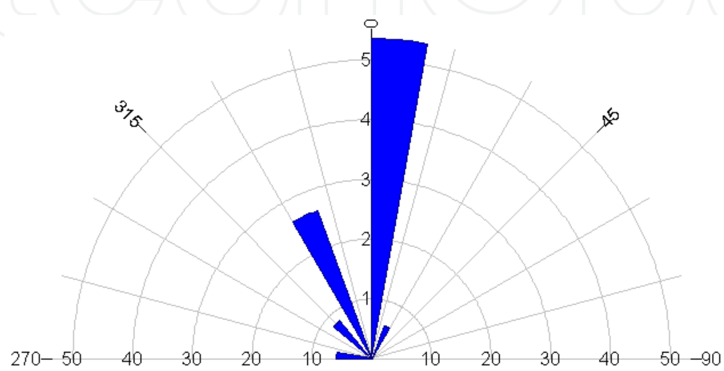


Fig. 22. Prevailing wind direction (Years 1985-2005)

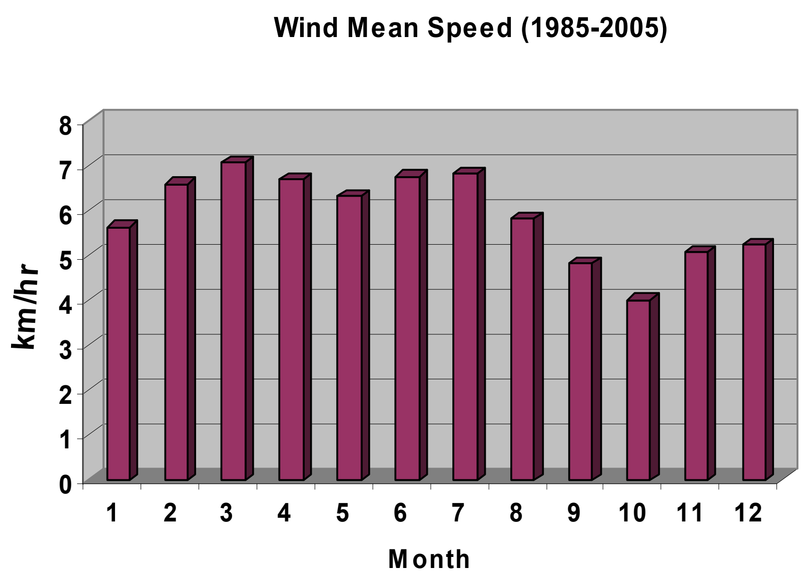


Fig. 23. Average monthly wind speed

Evaporation

Pan evaporation rates are very high in Riyadh throughout the year (Figure 24). Annual average evaporation has been measured at King Khalid Airport station as 2910 mm. During rainy months of December, January, February, March and April, rainfall exceeds evaporation.

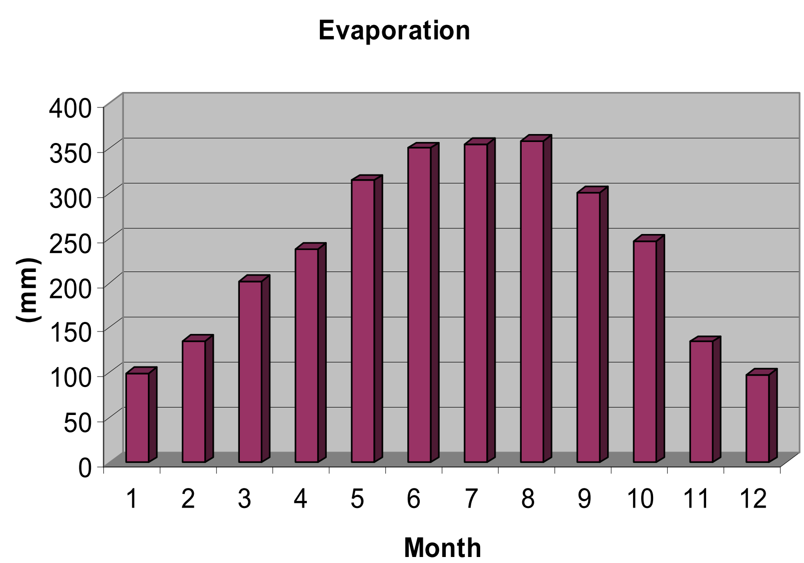


Fig. 24. Evaporation (1985-2005)

Runoff

Surface runoff in the site was calculated by the Rational Method (U.S. Soil Conservation Service, 1964; Chow et al., 1988; McCuen, 1998; Willson, 1990; McCuen, 1998). The Rational method is used primarily for computing peak flows for small urban and rural watersheds.

This Rational formula is characterized by consideration of the entire drainage area as a single unit, estimation of flow at the most downstream point only, and the assumption that rainfall is uniformly distributed over the drainage area. The Rational Formula is as follows:

$$Qp=0.278\ C*I*A$$

where:

Qp = Peak runoff rate($m^3$/sec)
C = Runoff coefficient (dimension less)
I = Rainfall intensity (mm/hr)
A = Drainage area ($km^2$)

The Rational Formula follows the assumption that:

the predicted peak discharge has the same probability of occurrence as the used rainfall intensity (I), the runoff coefficient (C) is constant during the rain storm and the recession time is equal to the time of rise.

Peak runoff rates have been calculated by the Rational Formula using the maximum total daily rainfall records for the period 1985-2005 (PME, 2006). The runoff coefficient, (C) was taken to be equal to 0.75 corresponding to residential area/business area/asphalt streets. The total daily rainfall was converted into rainfall intensity (I) in mm/h. The results of calculation are shown on Table 4.

| Month | Rainfall (mm/day) | Rainfall intensity (mm/h) | Peak runoff (m3/sec) |
|---|---|---|---|
| Jan | 27.9 | 1.16 | 2.73 |
| Feb | 28.3 | 1.18 | 2.77 |
| Mar | 32.4 | 1.35 | 3.17 |
| Apr | 25.4 | 1.06 | 2.48 |
| Nov | 30 | 1.25 | 2.93 |
| Dec | 47.8 | 1.99 | 4.67 |

Table 4. Peak runoff rates for maximum daily total rainfall Period (1985-2005)

According to maximum total daily rainfall record reached on December 20th 1995 at 47.8 mm/day, the peak runoff has been calculated using the rational formula to be 4.67 m3/sec.

Assuming higher values of rainfall storms at 2.5 mm/h and 5 mm/h, recalculation of peak runoff under these assumed conditions will be as shown in Table 5:

| Rainfall Intensity (mm/h) | Q, peak flow (m3/sec) |
|---|---|
| 2.5 | 5.86 |
| 5 | 11.73 |

Table 5. Peak runoff assuming high values of rainfall

#### 3.2.4 Conclusions and recommendations

The assessment of topography, drainage and meteorological data of the in northwest of Riyadh City in Saudi Arabia showed that the site represents the mouth of a catchment area that drains towards the main course of Wadi Hanifa. The surface area of the catchment was found to be about 11.2 km2 with an average slope of 0.02. The analyses of the flow path indicated that the flow is towards the southeast. The climate is characterized with a very hot summer, mild winter and little rain. The prevailing wind direction is towards the north and northeast. Total rainfall data showed that the maximum daily rainfall for the period 1995-2005 was 47.8 mm. Peak runoff was calculated using the Rational formula to range between 4.7 and 11.73 m3/sec.

Based on the results of this study, hydraulic design of storm water drainage system should take in consideration that almost all of storm water will flow through the middle of the site. This study forms a small model showing the importance of characterizing hydrological elements as part of a comprehensive environmental analysis for future urban planning. Historic meteorological data and particularly rainfall, estimation of peak runoff integrated together with satellite image interpretation and digital elevation model are important for any detailed urban design.

### 3.3 Identification of areas prone to hydrological hazards in Riyadh city, Saudi Arabia (Faisal K. Zaidi, et al, 2011)

#### 3.3.1 Introduction

Saudi Arabia is one of the most arid regions of the world however this has not prevented it from the growth of big cities along the coasts like Jeddah and Damam and along the ancient Wadi system such as Riyadh, Madinah and Makkah. Though the average annual rainfall in Saudi Arabia is only about 100 mm/year,(PME, 2005), it is not free from hydrological hazards especially in the big cities like Jeddah and Riyadh mainly due to rapid urbanization which has led to the development of housing colonies in topographically low lying regions and obstruction of the natural drainage systems. The flood hazards in the city of Jeddah in November, 2009 as result of heavy rainfall and blockage of natural drainage system is a good example in the recent times.

The present study focuses on the city of Riyadh, (Figure 25) which has grown rapidly over the past few years and can be subjected to flooding hazards in events of heavy rainfall. The objective of the study is to identify the areas in Riyadh city which may be prone to such hydrological hazards.

Riyadh city has grown from an area of 1 km2 in 1901 to about 2435 km2 in 2010, (www.arriyadh.com). The population of the city is about 4.8 million. The temperature varies from 43° C in July to about 8° C in January. The overall climate of the city is arid with average annual rainfall not exceeding 105 mm/year, (PME, 2006). The city is typically bordered by a complex system of valleys (known as wadis in local language) along its western limits. The average elevation of the city is about 690 meters above mean sea level with the main drainage following a Northwest-Southeast pattern and is typically controlled by the Najd Fault system, (Powers et al, 1966).

### 3.3.2 Methodology

The methodology involved carrying out a detailed morphometric analysis of the basins within the Riyadh city. Morphometric parameters such as basin shape and basin relief influence the nature of hydrographs and hydrological variables. Drainage basin morphometric analysis of the study area was carried out using the SRTM DEM data, (http://srtm.usgs.gov/data/obtaining.html). The DEM from SRTM is available on 90 m by 90 m spatial resolution. The DEM was treated before it was subjected for hydrological processing in GIS.

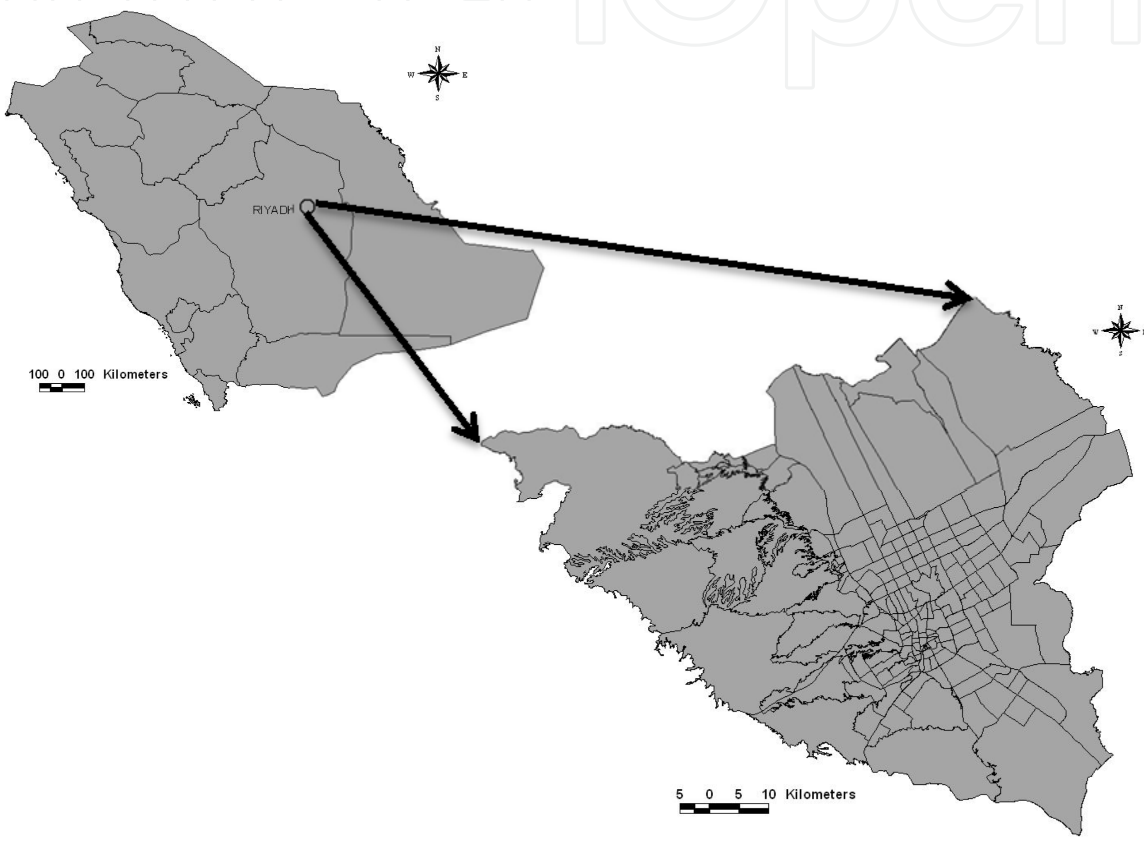


Fig. 25. Location of Riyadh city (study area) within Saudi Arabia

Based on the result of the hydrological processing which involved the identification of flow direction, flow accumulation and stream generation, (Figure 26), the Riyadh city was divided into two basins which are identified as the Hanifa Basin and Sulay Basin, (Figure 27). The drainage channels were classified into different orders using Strahler's 1964 classification. Other basin parameters such as basin area, basin perimeter, basin length and stream length were obtained which was further used to obtain the different ratios such as Drainage Density, Bifurcation Ratio, Stream Frequency, Form Factor, Elongation Ratio, and Circulatory Ratio.

### 3.3.3 Results

Based on the results of the hydrological processing, the DEM of the study area was divided into two basins namely the Hanifa basin which trends in a Northwest-Southeast direction and lies in the western part of the study area and the Sulay Basin which trends in a more or less North-South direction. Hanifa basin occupies an area of 4199.51 km2 whereas the Sulay basin has an area of 1514.43 km2 .The various morphometric parameters for the two basins were calculated and have been discussed in the following sections, (Table 6. Figure 28 shows the two basins with the stream patterns and the city of Riyadh.

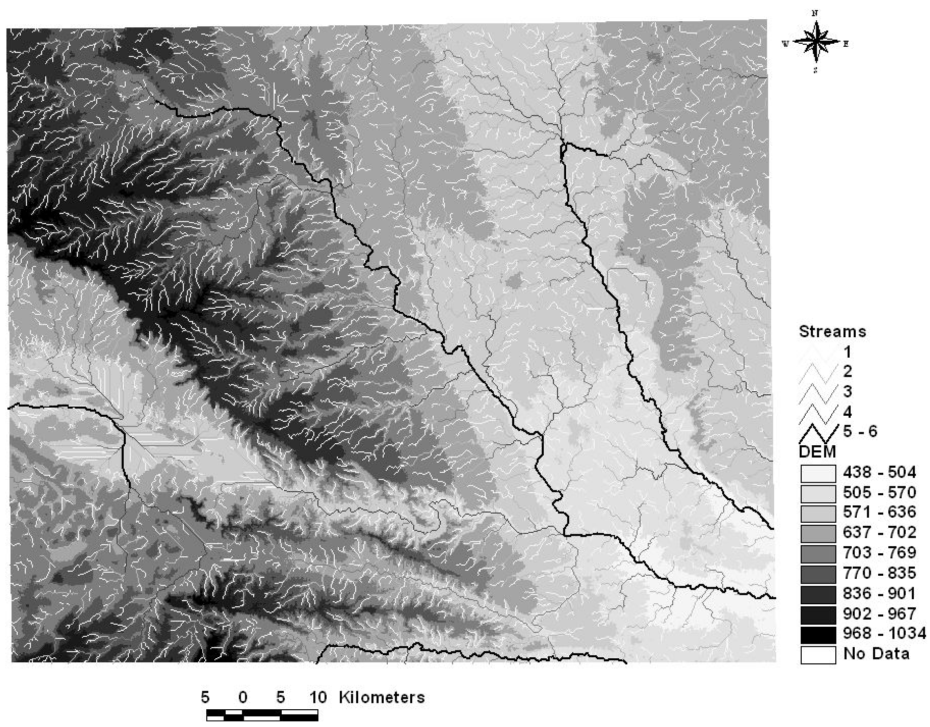


Fig. 26. DEM and the streams in the study area

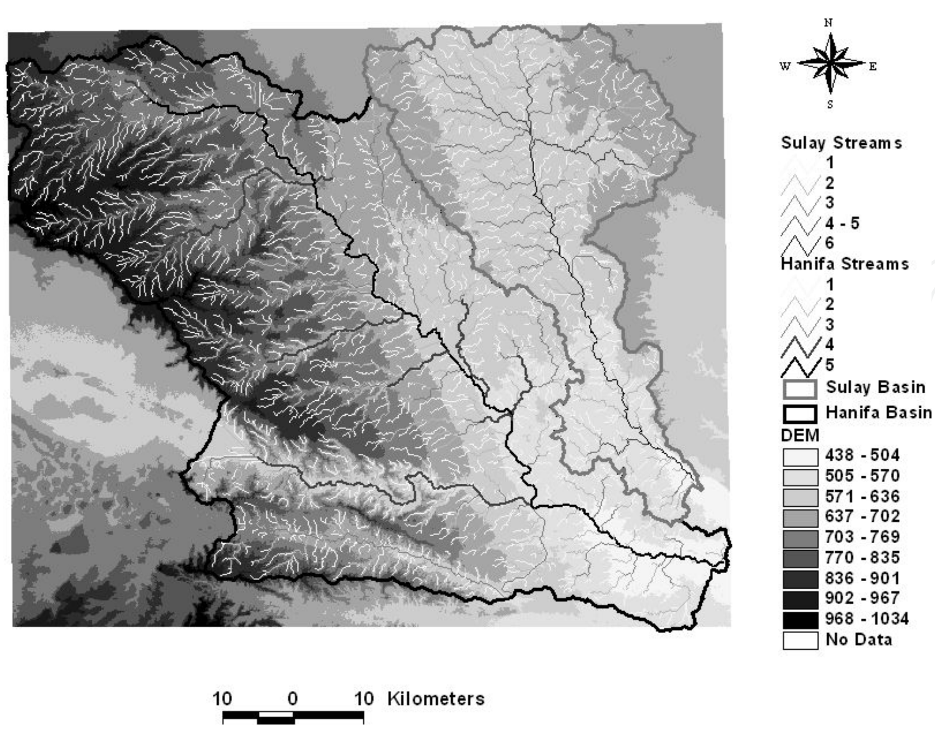


Fig. 27. Hanifa and Sulay Basins

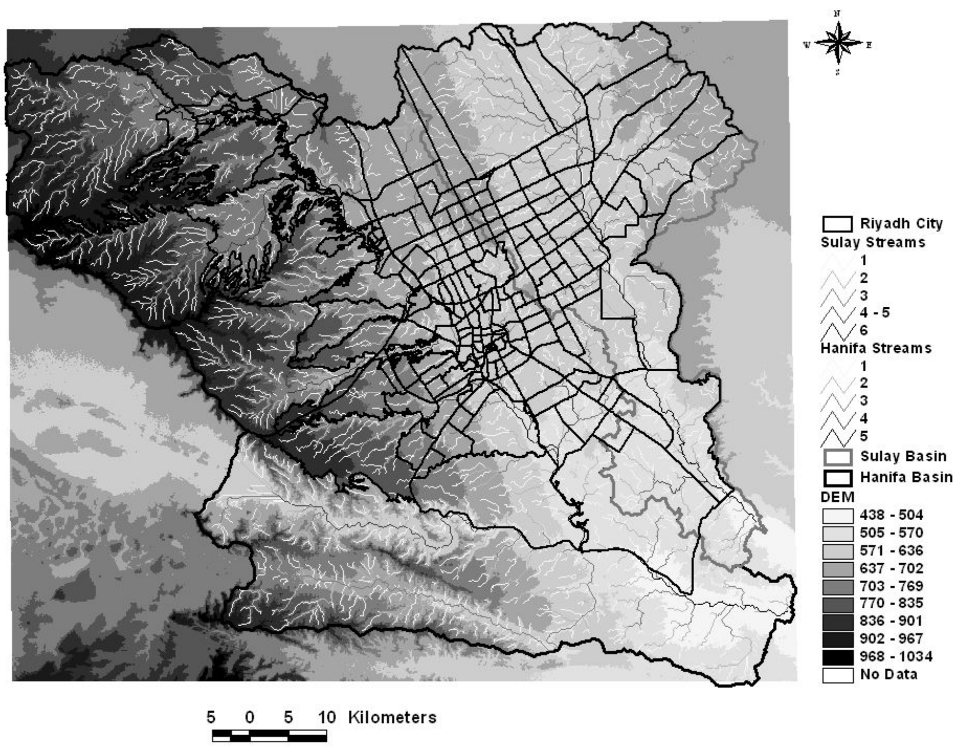


Fig. 28. Extent of Hanifa and Sulay Basin and the city of Riyadh

Drainage density

Drainage Density is the ratio of the total stream length in a given basin to the total area of the basin, (Strahler. 1932, 1945). The drainage density of the Hanifa Basin is 0.88 km/km2 as compared to 0.92 km/km2 for the Sulay Basin.

Bifurcation ratio

Bifurcation Ratio for the Hanifa basin is 6.45 where as it is 3.38 for the Sulay basin. Bifurcation ratio is the number of streams of any given order to the number of streams in the next higher order, (Horton, 1932). A high bifurcation ratio indicates more chances of flooding as water from different channels tend to accumulate in a single channel rather than spreading out.

Stream order

Strahler's, 1964 system was taken for the stream ordering. The number of streams gradually decreases as the stream order increases. Hanifa basin is a 5th order basin whereas the Sulay basin is a 6th order basin.

Stream length

The total stream length for the Hanifa basin is about 3700 km whereas the total stream length for Sulay basin is about 1390 km. The length of stream is maximum in case of first order in both the basins.

| Basin | Hanifa | Sulay |
|---|---|---|
| Area (km2) | 4199.51 | 1514.43 |
| Total Stream Length (km) | 3707.55 | 1389.71 |
| Drainage Density(km/km2) | 0.88 | 0.92 |
| Total number of Streams | 1651.00 | 630.00 |
| Stream frequency | 0.39 | 0.42 |
| Drainage Texture | 0.35 | 0.38 |
| Bifurcation Ratio | 6.45 | 3.58 |
| Length (km) | 125.50 | 76.50 |
| Basin Perimeter (km) | 410.68 | 289.52 |
| Ht Max (mts) | 1033.00 | 714.00 |
| Ht Min (mts) | 438.00 | 484.00 |
| Basin Relief (mts) | 595.00 | 230.00 |
| Form Factor | 0.26 | 0.46 |
| Elongation ratio | 0.58 | 0.57 |
| Circulatory Ratio | 0.31 | 0.23 |
| Slope (%) | 6.60 | 2.30 |
| Relief Ratio (m/Km) | 3.30 | 2.29 |

Table 6. Morphometric parameters of Hanifa and Sulay Basins

Stream frequency

Stream frequency is the ratio of the total number of stream segments of all the orders in the basin to the total area of the basin, (Horton, 1945). The stream frequency for the Hanifa Basin is 0.39/km2 and 0.42/km2 for Sulay basin. The stream frequency is dependent on the rainfall and the temperature of the region.

Basin length

Basin length is the longest length of the basin from the head waters to the point of confluence, (Gregory and Walling, 1973). Hanifa basin has a length of 125.50 km and Sulay basin has a length of 76.50 km.

Form factor

Form factor is the ratio of the basin area to the square of the basin length. The form factor varies inversely to the basin length. Circular basins have a form factor close to 1. The form factor for Hanifa basin is 0.26 and 0.46 for Sulay basin indicating the presence of elongated basins which is quite evident from the Figure 3.

Elongation ratio

It is the ratio of the diameter of a circle having the same area as the basin to the basin length. The elongation ratio for the Hanifa Basin is 0.58 whereas it is 0.57 for the Sulay Basin. The elongated shapes of the basins are a result of the guiding effect of thrusting and faulting in the basin, (Vaslet et al, 1991).

Circulatory ratio

It is the ratio of the basin area to the area of the circle having the same perimeter as the basin. The circulatory ratio for Hanifa basin is 0.31 and the circulatory ratio for Sulay Basin is 0.23. This factor is influenced by the lithological characteristics of the basin

Slope

The Hanifa basin shows a high relief ratio (3.30 m/km) and has an average slope percentage of 6.6 as compared to Sulay Basin which has a relief ratio of 2.29 m/km and an average slope percentage of 2.3. The results clearly suggest that Hanifa basin has a more rugged terrain as compared to Sulay basin.

### 3.3.4 Discussion

Arid areas are susceptible to flash floods mainly due to the lack of vegetation. Urbanization in such areas has further aggravated the problem, especially where human interference has obstructed the natural drainage pattern. Furthermore in arid regions it is difficult to predict the rainfall and surface run off characteristics and may cause negative complications during urban planning, (Hussein et al, 2008). This is true for most of the cities in arid regions such as Riyadh.

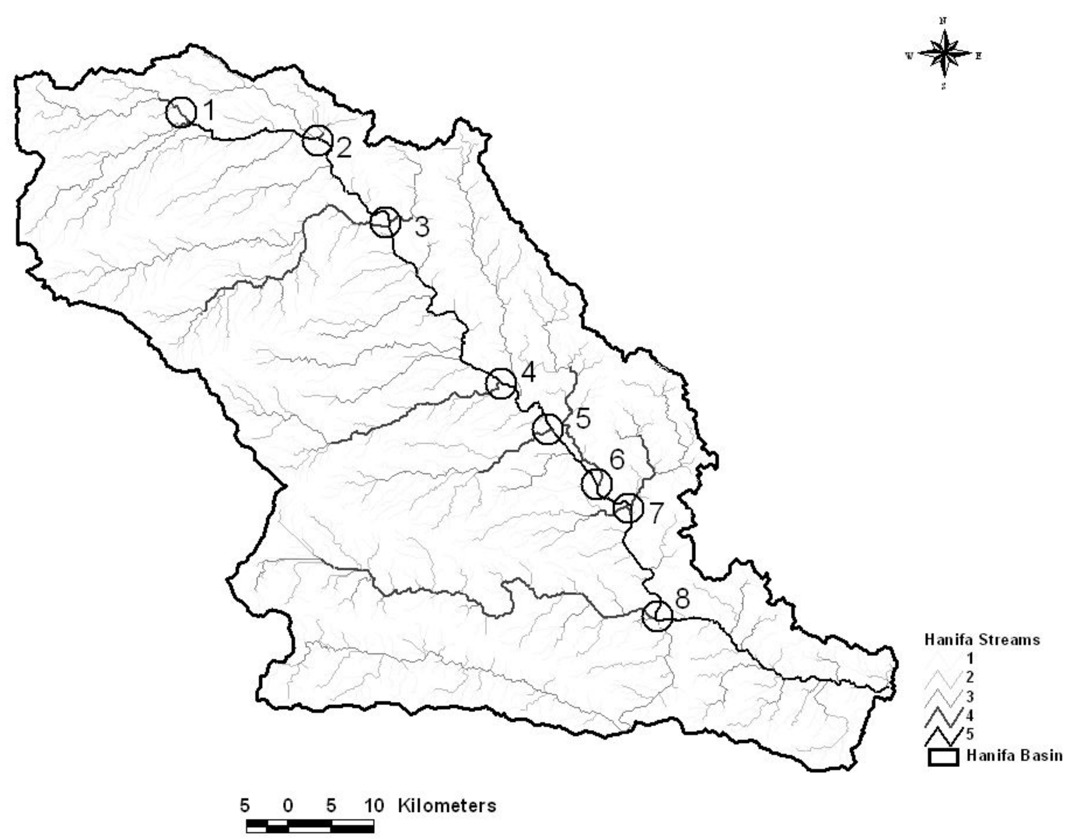


Fig. 29. Areas prone to hydrological hazards in Hanifa basin

As shown from the results above the Hanifa Basin is more important from the point of hydrological hazards mainly because of the large basin area as compared to Sulay basin.

This implies that during the same intensity of rainfall in the region, water in the Hanifa Basin will be collected from a larger catchment as compared to Sulay Basin, thus bringing a greater volume of water to the main drainage. Secondly the Hanifa Basin has a more rugged topography as compared to Sulay basin, (see Figure 27 and Table 8) which means the velocity of the water will be much higher. Third and most importantly the bifurcation ratio of Hanifa Basin is much higher as compared to Sulay Basin, (Table 8). This is true specially for the 5th order streams which clearly means that more number of 4th order streams meet at different points to form a 5th order stream in Hanifa Basin, (Figure 28). From the perspective of hydrological hazards a high bifurcation ratio increases the chances of flooding as water from a given stream order, rather than spreading out when they meet the stream of the next higher order, tend to accumulate in one place.

Based on this observation, all the 4th order sub-basins of the Hanifa basin have been identified and demarcated (Figure 29). The mouth of these basins are the potential sites for hydrological hazards in case of heavy rainfall and should be carefully monitored during the rainy seasons in the region to prevent damage to life and property.

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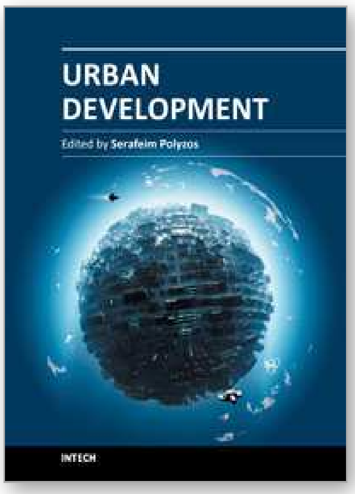


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**InTech Europe**
University Campus STeP Ri
Slavka Krautzeka 83/A
51000 Rijeka, Croatia
Phone: +385 (51) 770 447
Fax: +385 (51) 686 166
www.intechopen.com

**InTech China**
Unit 405, Office Block, Hotel Equatorial Shanghai
No.65, Yan An Road (West), Shanghai, 200040, China
中国上海市延安西路65号上海国际贵都大饭店办公楼405单元
Phone: +86-21-62489820
Fax: +86-21-62489821