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Geo-Environmental Assessment of a Landfill Site Southeast of Riyadh, Saudi Arabia

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Abstract

Landfilled wastes manifest slow decomposition, producing emanation of gases, and outflow of leachate. Waste mass shows various chemical reactions and complex evolutions that occur under the influence of natural agents, as rain and micro-organisms. These reactions lead to biologic, physical and chemical transformations of wastes. The intensity of the phenomenon is related to the air and the humidity. These factors originate from the initial composition of the solid waste, the operating mode of the landfill and the geological and hydro-geological conditions. Leachate is considered a major source of groundwater pollution. It has a complex nature; it typically contains high concentrations of chemical hazardous including heavy metals, chemical compounds that may severely pollute the environment. The main objective of this study is to shed light on the environmental consequences of a landfill site located in the southeast of Riyadh City, Saudi Arabia. It constitutes a peculiar case because of its situation, its exploitation mode and nature of buried wastes. The study made use of satellite MSS, TM, ETM and SPOT images for the years 1972, 1987,1990, 2000 and 2007 respectively. Geological, morphological hydrological, hydro-geological detailed drainage analyses were performed. Records of meteorological stations were also used in this study. The satellite images illustrate the evolution of the site through time since its start in the nineties of the 20th Century. The main geological units outcropping in the area are the Sulaiy Formation, the Yamama Formation, Khabra deposits, flood-plain deposits, alluvium, and sheet gravel. Drainage analyses shows a dendritic nature for the network, a total area of 2113 km2, basin slope of 0.016, perimeter of 430 x 103, and a mean elevation of 635 m. Annual rainfall is around 100mm, evapo-transpiration is about 2900mm, wind speed averages at 5.1 km/hr and runoff peak is within 2.7 -4.7 m3/sec.

Planners, environmentalists, decision makers and other interest groups can use the findings of this study for environmental management of the landfill and protection of the downstream part of the Sulaiy tributary from leachate contamination.

The results indicate the importance of monitoring landfills through the combined use of ground and satellite monitoring.

Keywords: Landfill, Satellite Images, Environmental, Sulaiy, Riyadh, Saudi Arabia.

Introduction

Landfill sites are where local authorities and industry can take waste to be buried and compacted with other wastes. A landfill is generally used for any type of general household waste without any attempt at sorting or recycling. As a result it will consist of mixed metals, food scraps and other kitchen waste, paper, plastic and glass. Countries with functioning sorting of rubbish will have a content biased towards kitchen scraps, paper and plastic, but this will not apply to the older landfill sites. In general, there should not be any hazardous or toxic wastes present, although a certain amount is inevitable due to the nature of people and general ignorance, thoughtlessness or sheer indifference to the possible environmental consequences of these activities. As soon as separation of waste into categories becomes complicated or expensive, the system will tend to break down.

The organic waste dumped in a landfill site will decompose with time. Assuming a relatively impervious surface below the waste, the waste will become waterlogged and decomposition will be basically anaerobic (in the absence of oxygen). This will lead to a production of mostly methane gas from the waste. This methane will slowly work its way up through the waste and be vented into the atmosphere. There will be other gases produced as well, which are generally responsible for the odor level of a landfill site. Should there be efficient draining of the site, then there will be a mixed form of decomposition, anaerobic producing methane lower down and aerobic decomposition producing carbon dioxide near the top of the heap. These reactions lead to biologic, physical and chemical transformations of wastes. The intensity of the phenomenon is related to the air and the humidity. These factors originate from the initial composition of the solid waste, the operating mode of the landfill and the geological and hydro-geological conditions. Leachate is considered a major source of groundwater pollution. It has a complex nature; it typically contains high concentrations of chemical hazardous including heavy metals, chemical compounds that may severely pollute the environment.

The trend in recent years is definitely away from indiscriminate use of landfills for dumping all waste. Space is becoming limited and the recycling of waste is finally becoming more common. This will tend to reduce the total amount of waste that is placed in landfill sites as well as alter the consistency. Metals and plastics will slowly disappear, as will glass and other, easily recycled quantities.

The factor that will have the most effect on the use of landfill sites for gas production is probably paper and cardboard. Kitchen wastes will probably still be present, but a lot of the paper and cardboard that support long-term decomposition will no longer be available. The tendency to incineration will also reduce the total number of landfill sites available. This will nevertheless take a long time to become a serious problem for seekers of gas supplies and the number of existing landfills will supply a lot of present needs. The main objective of this study is to shed light on the environmental consequences of a landfill site located in the southeast of Riyadh City, Saudi Arabia.

Methodology

To achieve the above mentioned objective, the following methods were adopted. A field visit to the site was executed, in which the boundaries of the study area walked over and major features on the area were noticed, ground conditions including rock and soil type were identified. Collection of meteorological data (precipitation, temperature, evaporation, wind speed and directions) and topographic maps. Processing of collected meteorological data. This data are presented in tables and graphs. Mean, maximum and minimum of each variable were calculated. A study of collected topographic maps and data for 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, data analysis and discussions.

Data Sources and Analyses

The baseline data included:

1- Site overview plan,
2- Satellite image of the area,
3- Site topographic survey plan, and
4- Drainage network map.

Additional data include:

1. Meteorological data (temperature, evaporation, rainfall, wind speed and direction) were sourced from Presidency of Meteorology and Environmental Protection (PME) and Ministry of Water and Electricity,. The sourced data were recorded at Old Riyadh Airport, King Khalid Airport and Hair stations. The data included the period 1985-2005.
2. Landsat MSS, TM, ETM images for the years 1972,1987,1990 and 2000 respectively source from Global Land Cover Facility, University of Maryland (GLCF) and Satellite SPOT images for the year 2007, were made available from King Abdulaziz City for Science and Technology (KACST)
3. Topographic map (scale 1:50,000) from Ministry of Petroleum and Mineral Resource, Saudi Aerial Survey Department (1982).

4. Digital Elevation Model (DEM) from Shuttle Radar Topographic Mission (SRTM),produced using remorte sensing technology.
5. Additional daily total rainfall records for the period (1985-2006), King Khalid Airport and Old Riyadh Airport Stations from Presidency of Meteorology and Environmental Protection (PME, 2006).

The acquired data were analyzed and presented using Microsoft EXCEL, ERDAS Imagine 9.1 (Leica Geosystems), WMS V. 7 (Environmental Modeling Systems, Inc.) and Arc GIS V. 9.2 (ESRI).

Results

Site Description

Landfill sites in Riyadh City lies, away from the urban center, at a distance of some 30 km. There are two sites lying in the southeast of the City. The first site covers a surface area of 1.5 km^2. It is now full and the Municipal authorities started in planting it for recreational purposes. The second site, which is the subject of this study, lies in the same location at a distance of some 3km to the east of the first cite. It is underlain by Phenorozoic sedimentary rocks forming a gentle homocline with an average dip of about 1 degree to the northeast. These rocks are covered to a large extent by Quaternary deposits. According to Vaslet et al (1991), the exposed rocks in Riyadh area belong to Shagra and Thamama Groups of Dir'iyah Supergroup (Powers et al, 1966 and Vaslet et al 1991). Figure (1) illustrates the general geology and figure (2) shows the fractures directions as main structural features in Riyadh area.

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),SRTM and SPOT image. Wadi Sulaiy occupies a total surface area of 2113 km^2, a perimeter of 430 x $10^{3,}$ and a mean elevation of 635 m.

Analysis of the topography 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 2).The southern part occupies the relatively lower most elevations in the study area. Within the study area, the general slope is towards the south (0.016). Drainage analysis of the study area shows a dendritic system that drain towards the south and finally joining Wadi Hanifa (Figure 3).

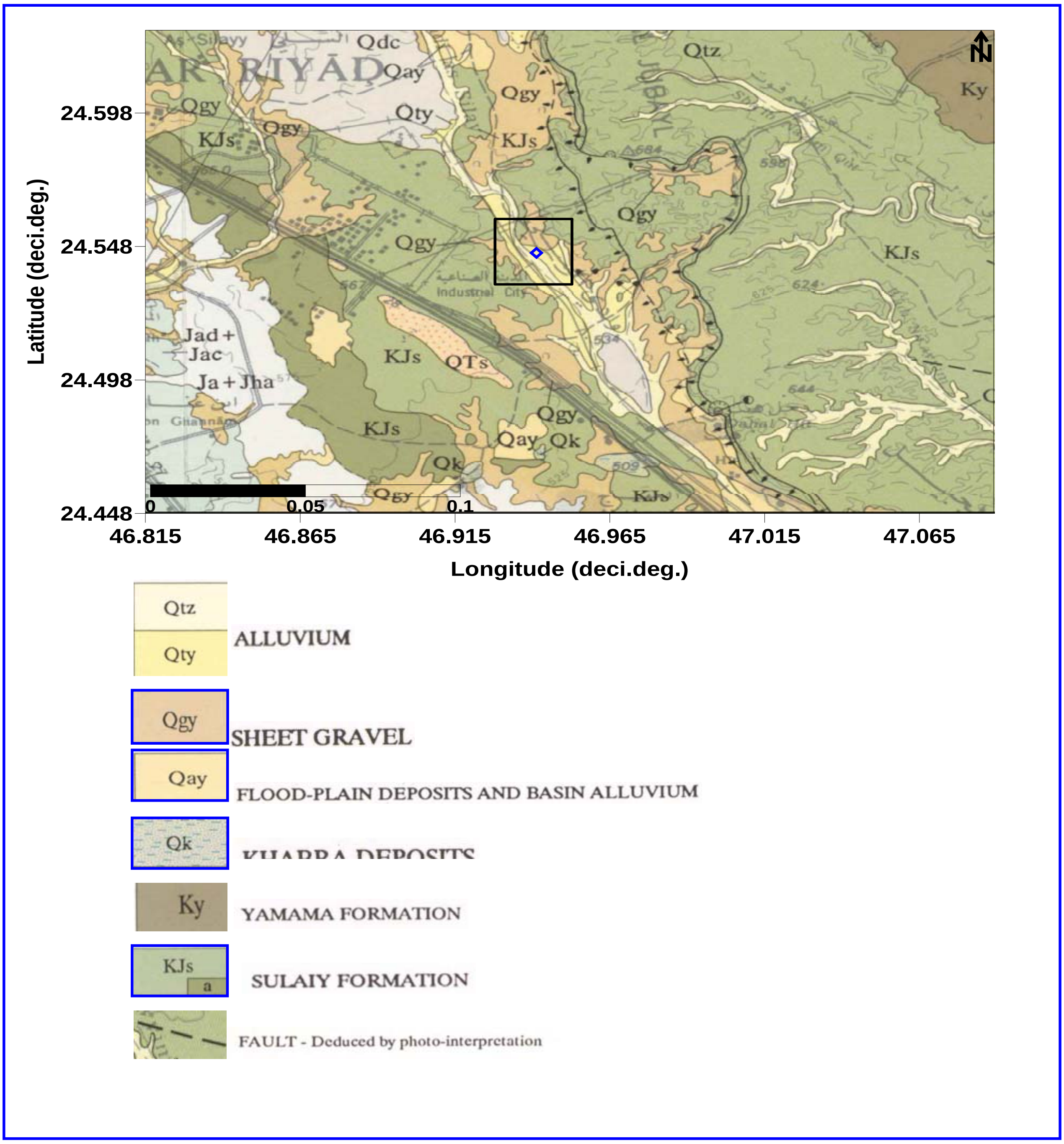

Figure 1 Site location and general geology of the study area (Modified after Vaslet et al, 1991).

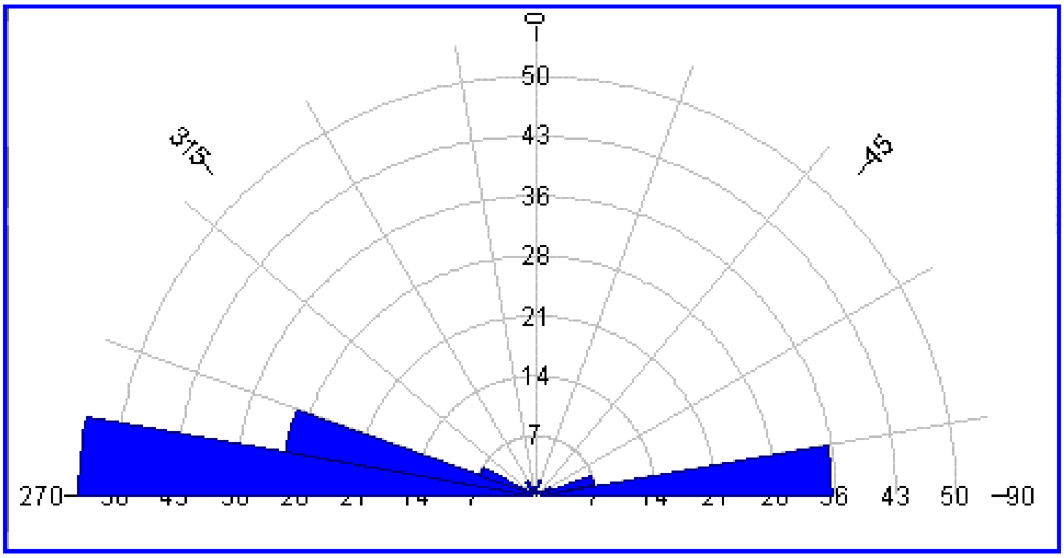

Figure 2. Rose diagram showing the main directions of fractures in the study area.

Climate

Riyadh 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 some time in April to the beginning of September (PME, 2006).

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 1985-2006 is shown on Figure 4. 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). Table 1 gives the summary statistics for rainfall data for the period 1985-2006.

Daily total rainfall for the period 1985-2006, recorded at King Khalid and Old Riyadh Airport Stations (PME, 2006), were sorted and treated statistically. Summary statistics is shown on Table 2. The maximum total daily rainfall records at King Khalid Airport station is shown in Figure 5. 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.

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 6). The average monthly temperature is in the range 14.1° C to 43° C.

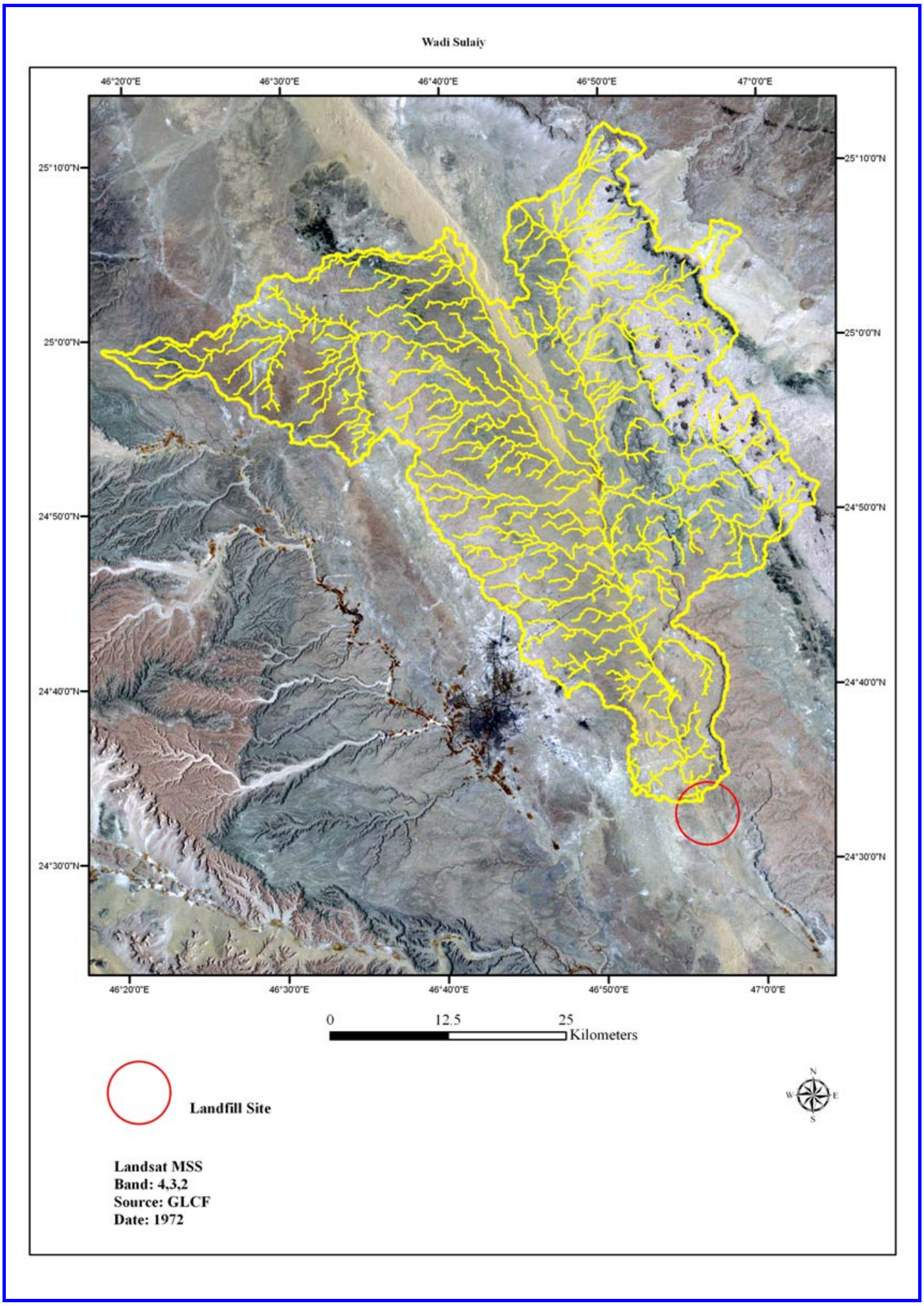

Figure 3. Catchment Area of Wadi Sulaiy.

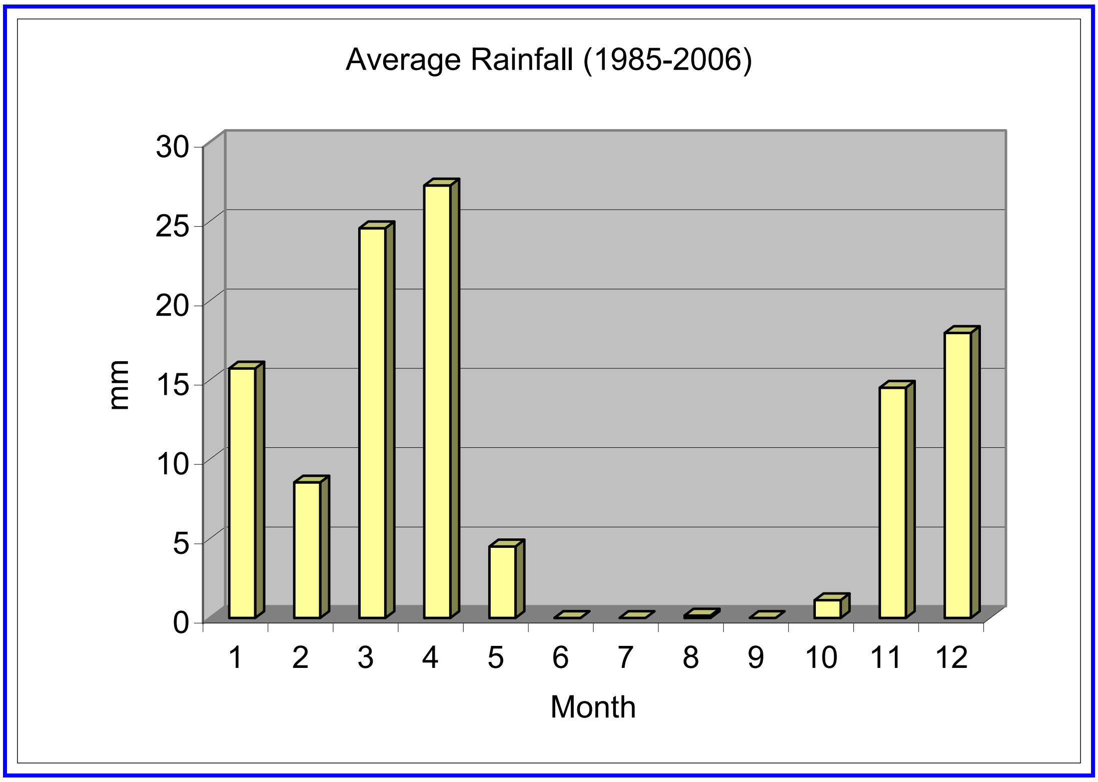

Figure 4. Average total monthly rainfall

Statistics	Jan	Feb	Mar	Apr	Nov	Dec
Mean	16.48	8.43	25.62	26.71	9.95	16.85
Standard Deviation	17.05	14.14	28.34	28.20	32.34	25.50
Sample Variance	290.86	200.07	816	795.02	1045.94	650.28
Kurtosis	1.86	3.97	1.64	1.48	17.35	3.50
Skewness	1.37	2.16	1.44	1.42	4.09	2.02
Range	64.10	47.35	95.65	101.85	145.40	87..90

Table 1. Summary statistics of monthly total rainfall data for the period (1985-2006) (Data sources are Old Riyadh Airport and King Khalid Airport).

The annual average temperature is 24.6° C. The coldest month is January while the hottest months are June, July and August

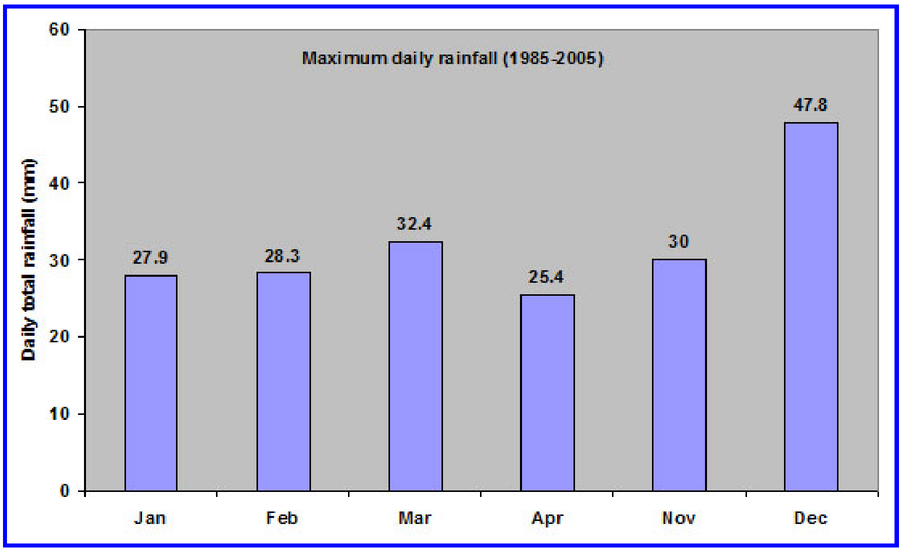

Figure 5. Maximum daily total rainfall

Statistics	Jan	Feb	Mar	April	Nov	Dec
Mean	7.3	4.7	0.7	4.6	7.2	5.5
Standard Error	1.102	1.003	0.082	0.644	1.429	0.919
Standard Deviation	7.866	6.728	3.227	5.505	8.811	7.691
Sample Variance	61.880	45.270	10.413	30.305	77.627	59.155
Kurtosis	0.393	5.105	41.572	2.481	1.179	13.222
Skewness	1.189	2.317	6.093	1.656	1.573	3.128
Range	27.800	28.200	33.300	25.300	29.900	47.700
Minimum	0.10	0.10	0.10	0.10	0.10	0.10
Maximum	27.90	28.30	32.40	25.40	30.00	47.80
Confidence Level(95.0%)	2.212	2.021	0.161	1.284	2.896	1.834

Table 2. Summary statistics of daily total rainfall for the period 1985-2006 (Old Riyadh Airport and King Khalid Airport Stations)

Relative Humidity

Since Riyadh city is located on the Najd Plateau, away form 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 7). Annual average relative humidity is 34.4%. These values reflect very dry or hyper arid climate.

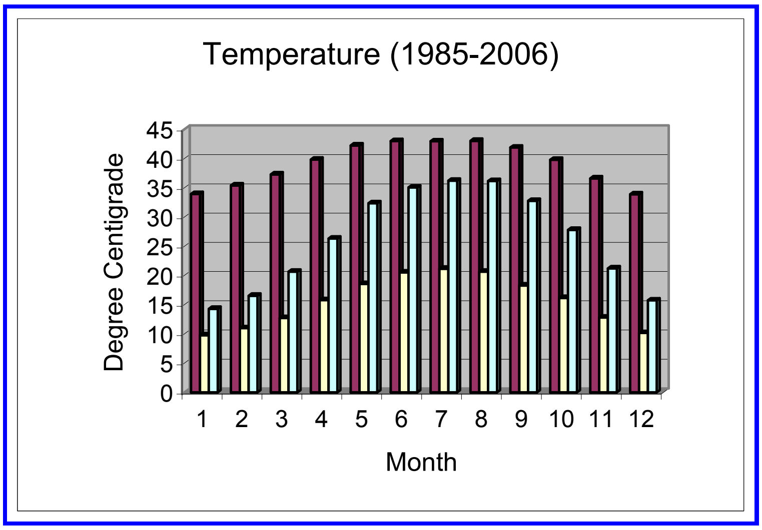

Figure 6. Minimum, maximum, and average monthly temperature.

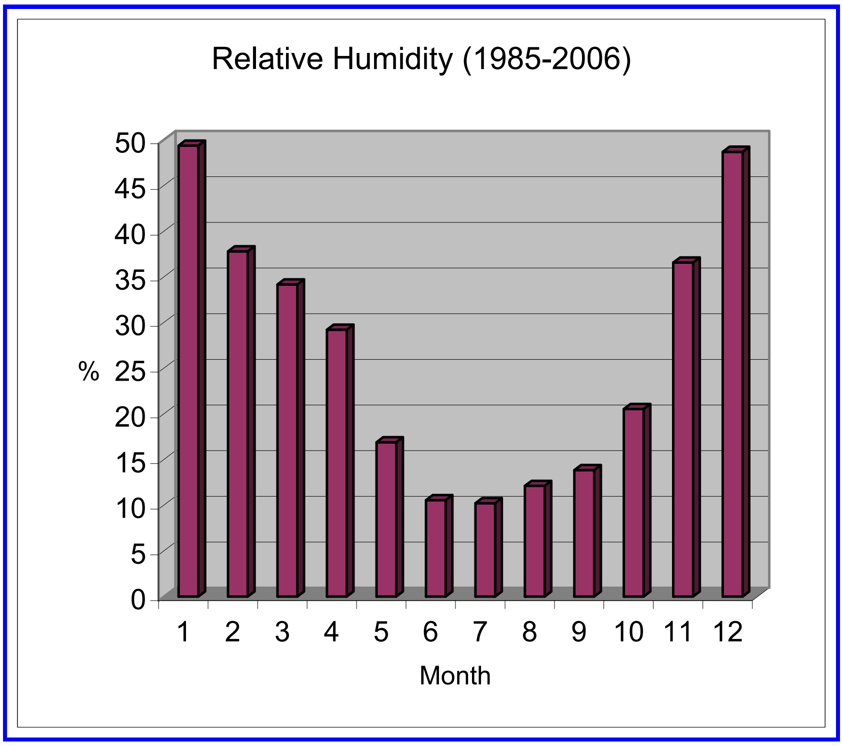

Figure 7. Average monthly relative humidity

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/cm^2 per day (January) to 597 cal/cm^2 per day (June). Cloudness ratio is 0.721 (January) to 0.765 (June). The average annual value for solar radiation is 477 cal/cm^2 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 (Figures 8 and 9).

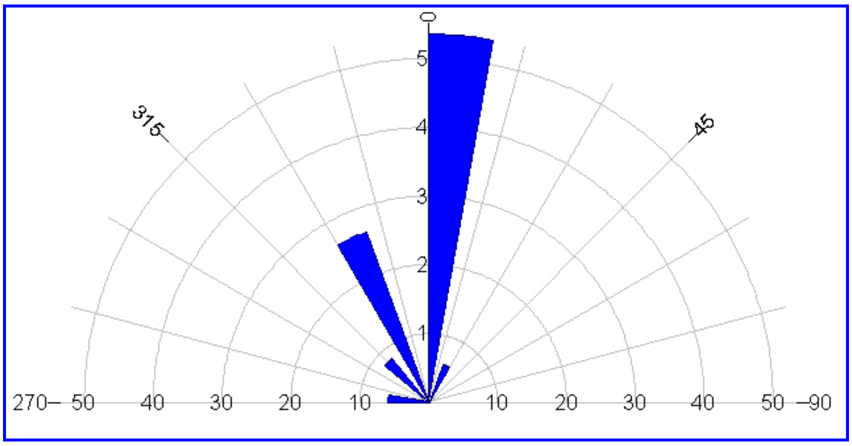

Figure 8. Prevailing wind direction (Years 1985-2006)

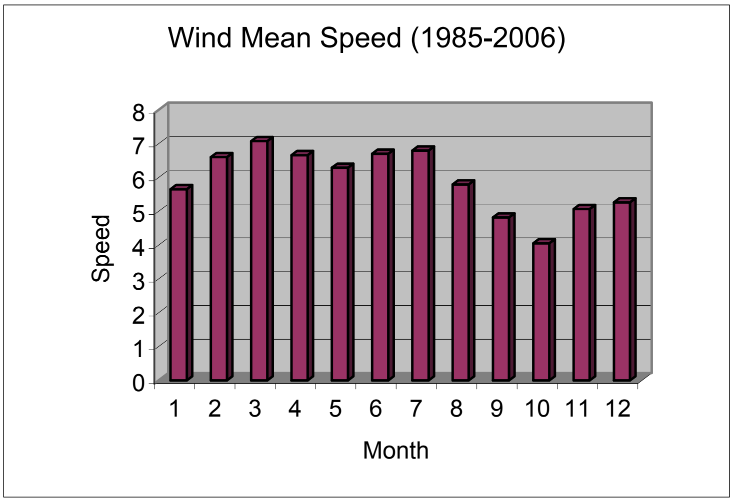

Figure 9. Average monthly wind speed

Evaporation

Pan evaporation rates are very high in Riyadh throughout the year (Figure 10). Annual average evaporation has been measured at old Riyadh Airport and King Khalid Airport stations as 2910 mm. During rainy months of December, January, February, March and April, rainfall exceeds evaporation.

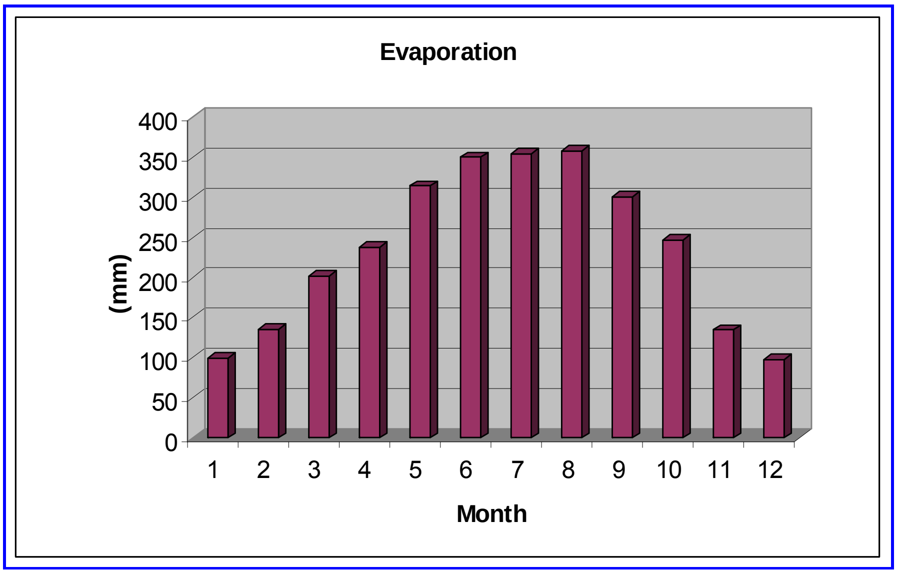

Figure 10. Evaporation (1985-2006)

Runoff

Suface runoff in the site was calculated by the Rational Method (U.S. Soil Conservation Service, 1964; Chow et al., 1988; McCuen, 1998; Willson, 1990;). 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:

1- 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.
2- Peak runoff rates have been calculated by the Rational Formula using the maximum total daily rainfall records for the period 1985-2006 (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 3.

Table 3. Peak runoff rates for maximum daily total rainfall Period (1985-2006)

Month	Rainfall (mm/day)	Rainfall intensity (mm/h)	Peak runoff (m^3/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

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 m^3/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 follow:

Rainfall Intensity (mm/h)	Q, peak flow (m^3/sec)
2.5	5.86
5.0	11.73

The site of the present study lies in the down stream of the Wadi Sulaiy catchment. This catchment (Figure 11) covers a surface area of about 2113 km^2. 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 0.02 with an average of 0.0016.

The site represents the trunk of the catchment of Wadi Sulaiy. All calculations of surface hydrology are based on the surface area of this catchment (Figure 11).

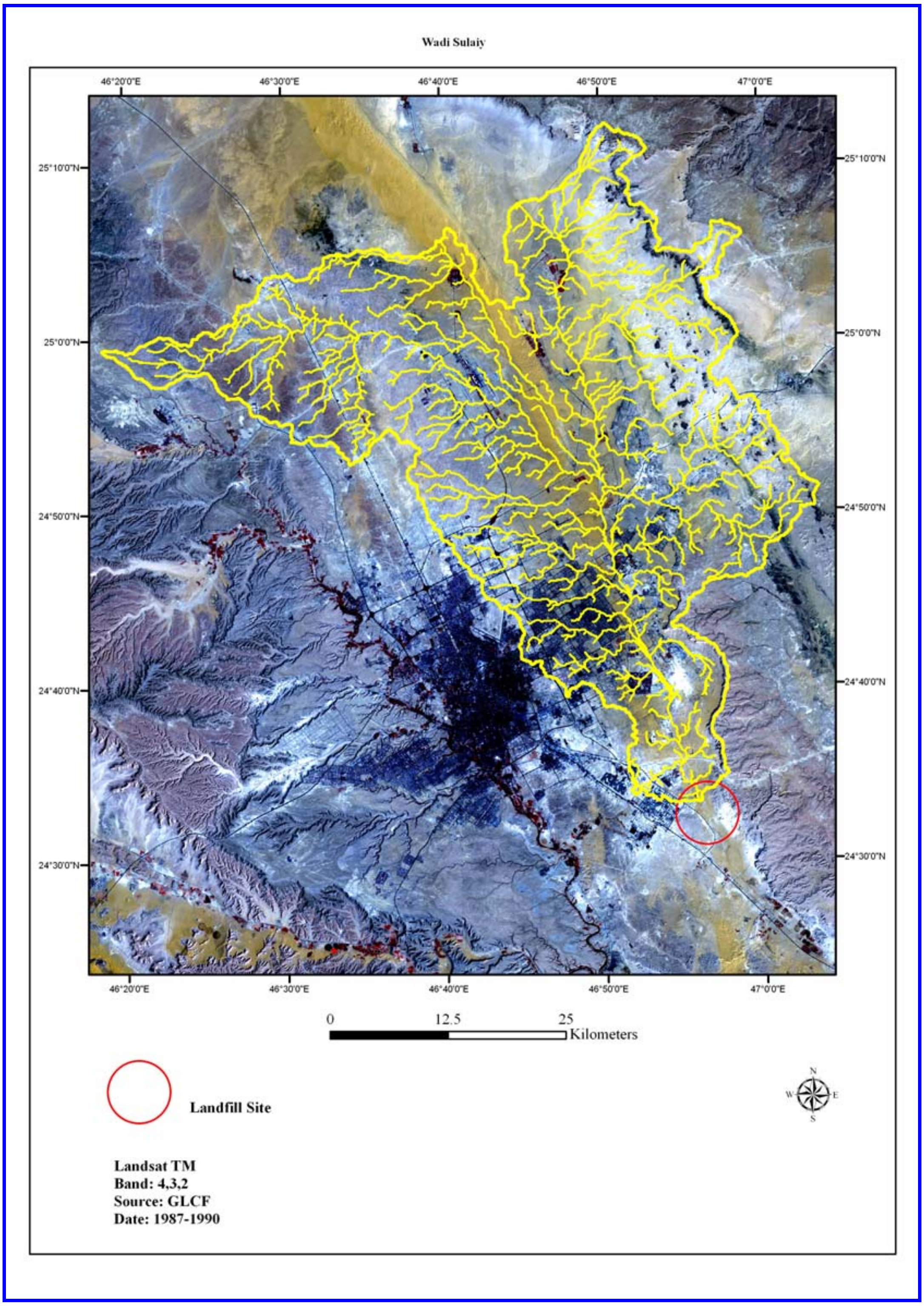

Figure 11. Catchment Area of Wadi Sulaiy, Landsat TM, 1987-1990

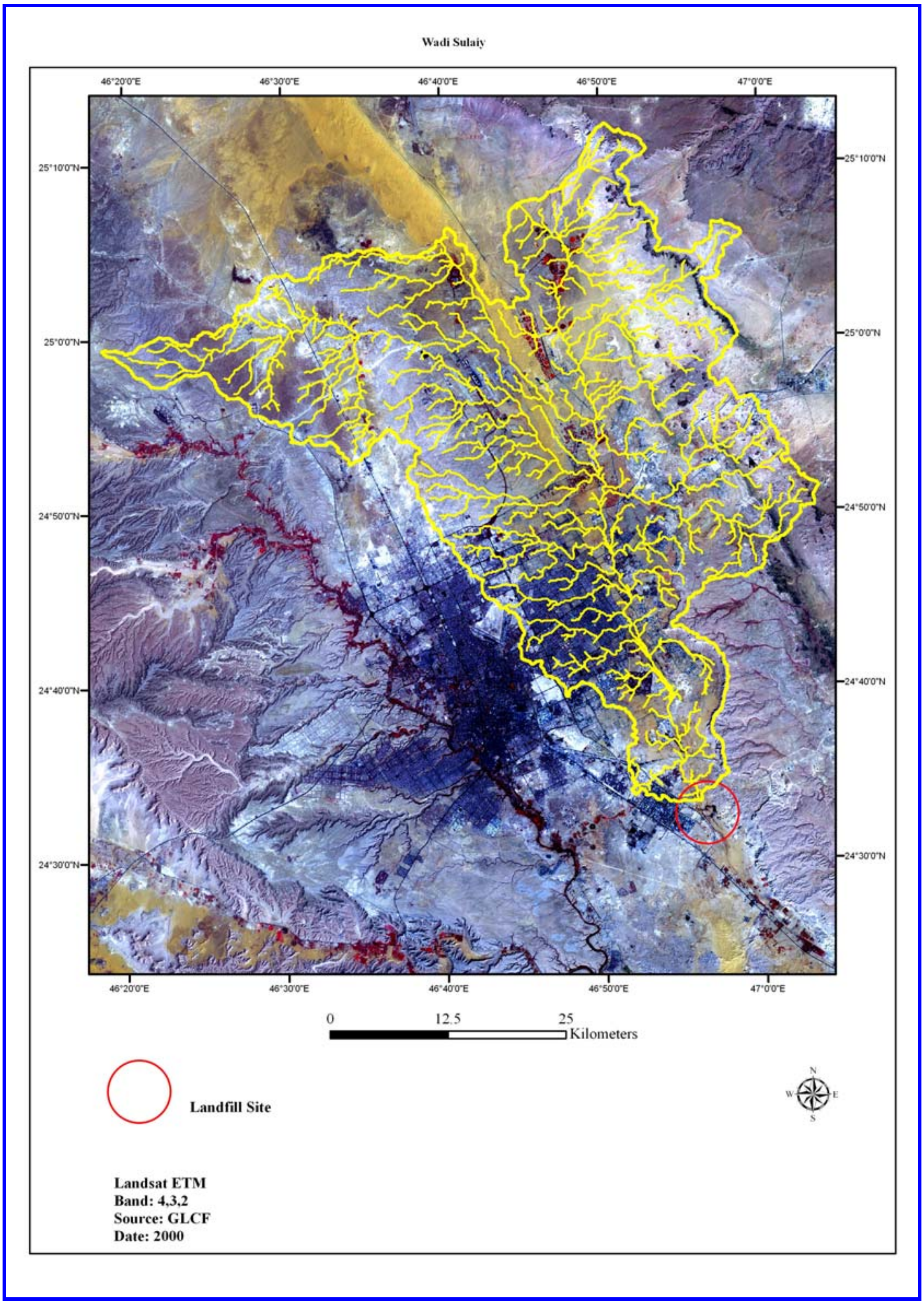

Figure 12. Catchment Area of Wadi Sulaiy,Landsat ETM, 2000.

Figure 13. Landfill Site ,Landsat ETM , 2000.

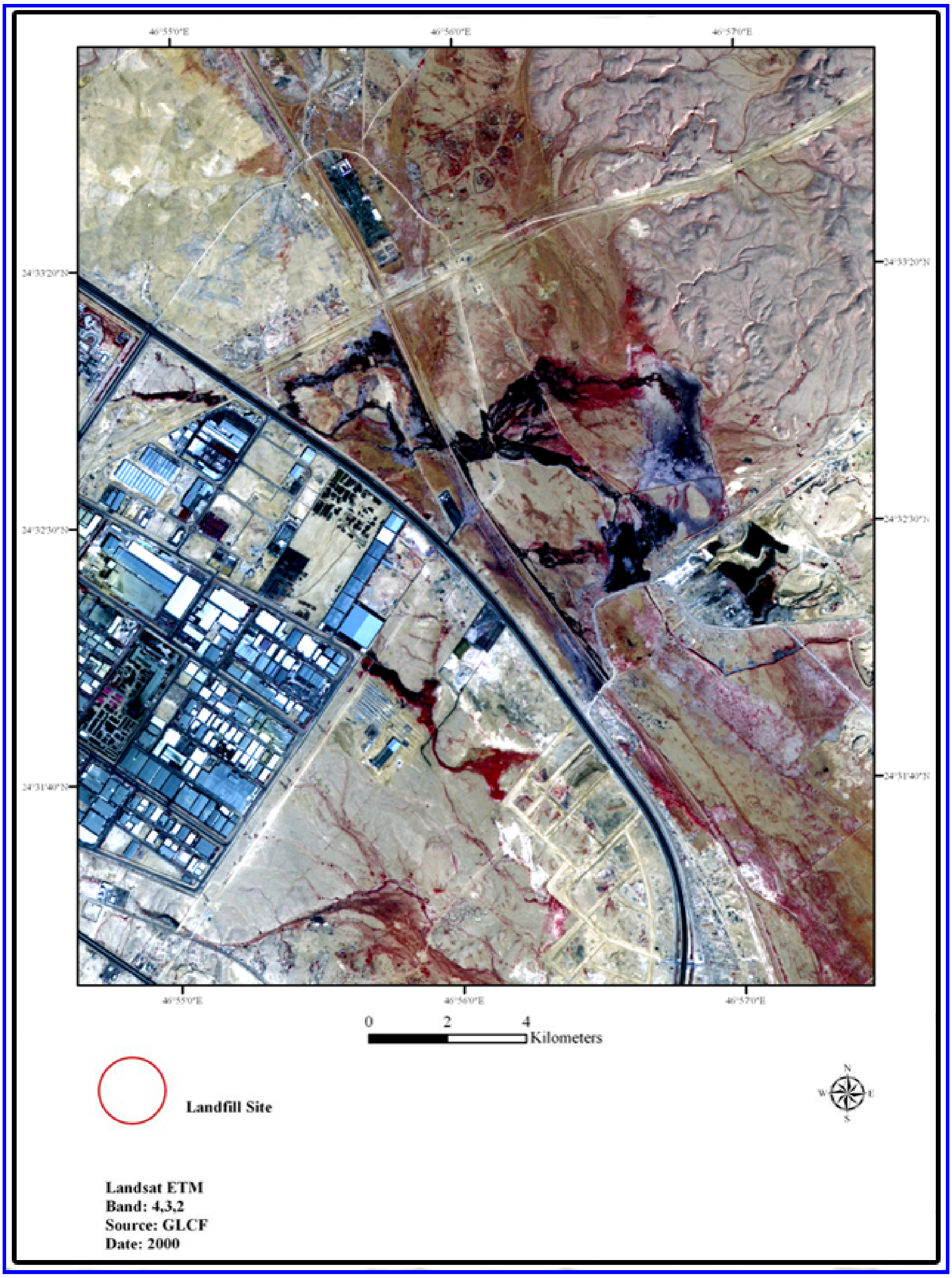

Figure 14. Landfill Site ,SPOT-5, 2007.

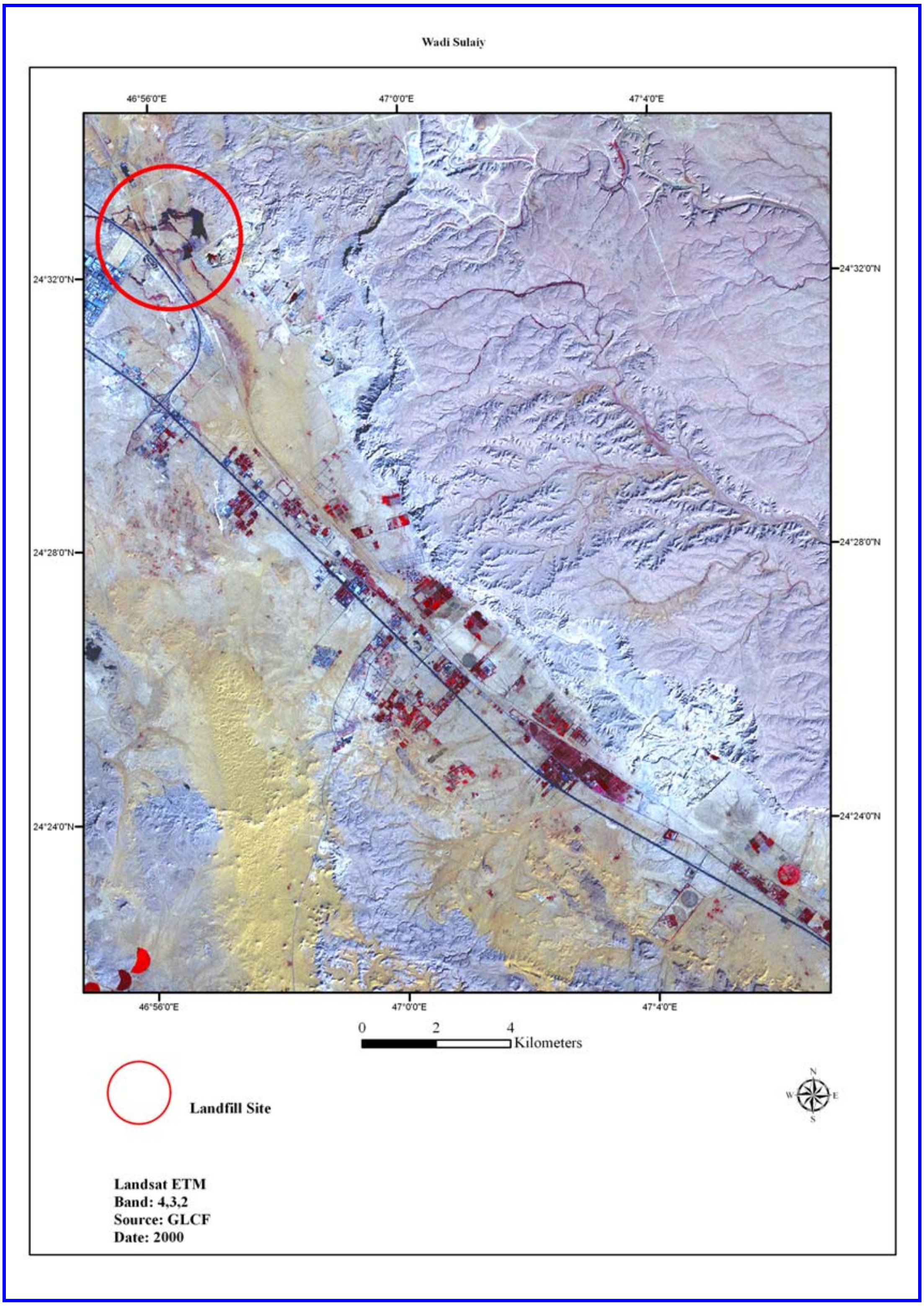

Figure 15. Landsat Image 2000 Showing downstream of Landfill Site

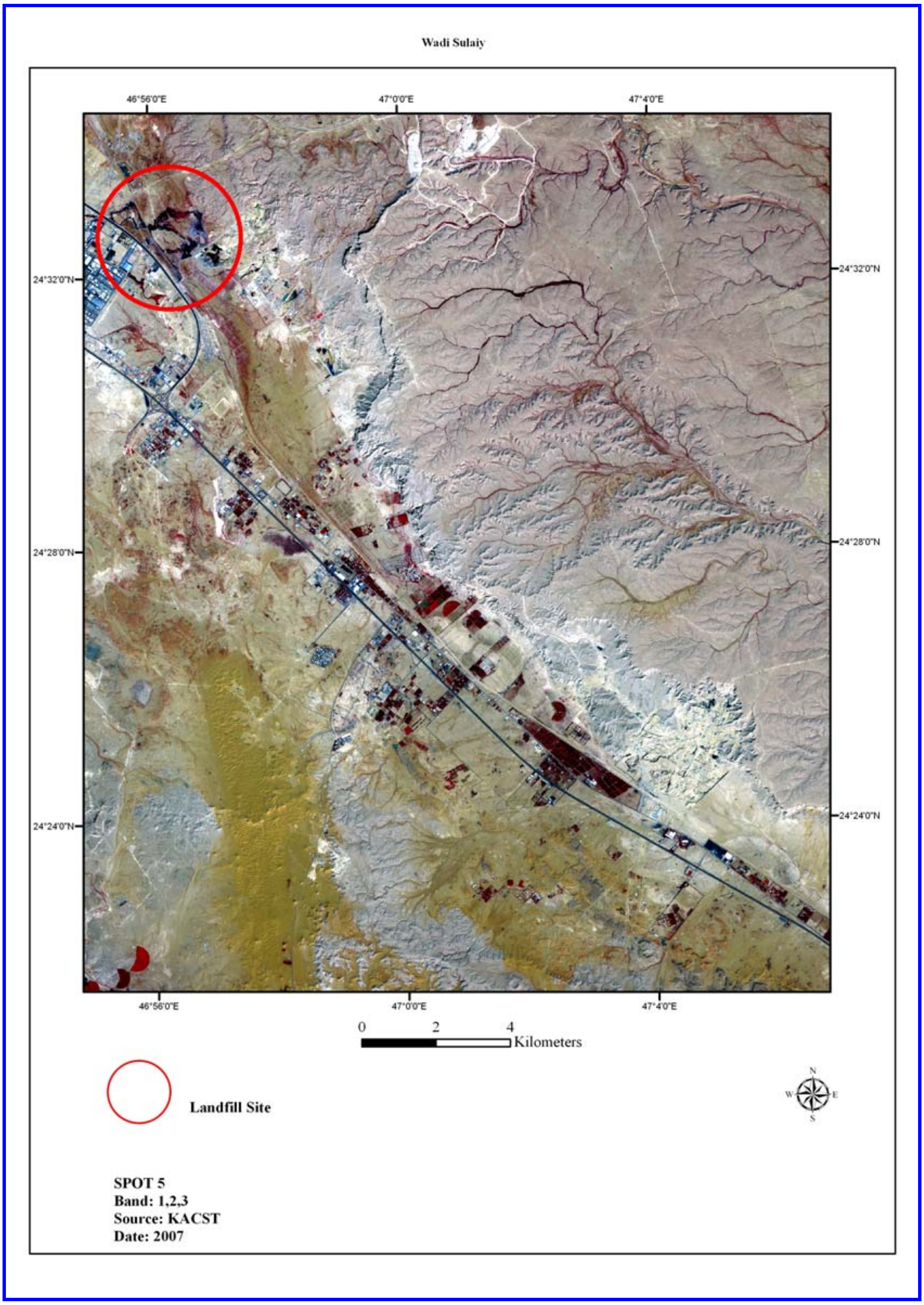

Figure 16. Spot 5 Image 2007 Showing downstream of Landfill Site

Landfill Evolution

The study made use of satellite MSS, TM, ETM and SPOT images for the years 1972, 1987,1990, 2000 and 2007, respectively, and is illustrated on figures 3, 11, 12, 13, 14, 15 and 16 These images depict the start of the landfill site and its evolution through time since its start by the end of the 20th Century. The surface area occupied by the site has increased from some 78 600 meters square as shown on the Landsat ETM 2000 (Figure 13), to some 1 620 000 meters square as shown on the SPOT image 2007 (Figure 14). The wastes in the site are dumped by earth layers of some 16 m in thickness. As result of rainy days leachate is expected to take place, and is possible to flow towards the downstream of the landfill, thus causing a possible hazard to the agricultural areas shown on figure 15 and 16.

Conclusion

The landfill site of Riyadh city lies within a typical arid area where rainfall is scarce, temperature is high, and relative humidity is low most of the year. The basement rock at the Landfill site is the Early Cretaceous Sulaiy Formation, which is mainly chalky aphanitic limestone with rare calcarenitic limestone. Most of the years are very dry but rainfall occurs at intervals of seven to ten years. During rainy days, water flow is expected to take place and together with the decomposition of waste products, formation of leachate is expected. These conditions can cause groundwater contamination and thus threaten agricultural areas in the downstream of the landfill, in the main course of Wadi Hanifa. Leachate has a complex nature; it typically contains high concentrations of chemical hazardous including heavy metals, chemical compounds that may severely pollute the environment.

Environmental monitoring through soil and groundwater sampling can be of great use in this respect.

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