Using Remote Sensing and GIS Techniques in Monitoring and Mitigation of Geohazards in Najran Region, Saudi Arabia

A. Abd El Aal · **M. Kamel** · **A. Al-Homidy**

Abstract Many sources of data (remote sensing and meteorological data, soils and groundwater samples) were used to estimate the magnitude of geological hazards, which are confirmed with field and laboratory investigation in Najran area, Kingdom Saudi Arabia. Najran area is one of these locations. It is subjected to a range of geo-hazards due to its intrinsic physiographic and geologic nature. Najran area is a growing urban and agricultural development region; however, some infrastructures have been constructed in vulnerable locations to geo-environmental hazards. The potential geo-hazards that may occur under desert conditions include sand accumulations, dune movement, mass westing and rock fall hazards, flash floods, sand stroom and problematic soils. The current study throws more light on all these geo-hazards in Najran area. Also, remediation methods for geo-hazard should be proposed to avoid these natural hazards. The present study is a trail to calculate and evaluate the drainage basins properties and potentiality using remote sensing and (GIS) tools. Twenty morphometric parameters were measured, in order to identify and evaluate flash flood hazards. Flash flood hazards in the Wadi Najran watershed is classified into three groups based on their morphometric parameters results; namely, highly, moderately and low slightly hazard degree. Our findings indicate that Najran area needs more attention and care. The Saudi Government has to join together with other people to reduce the resulting geological hazards.

Keywords Geo-hazards · Mitigation · Remote sensing · GIS · Morphometric parameters · Wadi Najran · Saudi Arabia

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1 Introduction

Najran region is one of the most important areas in the Kingdom of Saudi Arabia (KSA) in terms of renewable water resources due to rainfall-runoff recharge events. Because of the rapid growth in population, and usage of existing facilities, nowadays the government of KSA is resorting to the construction of infrastructure such as roads, urban and agricultural lands into places close to the hazard regions. The impact of the disaster directs proportionally with the susceptibility of the land and increases since it was based on the vulnerability of the society (Verstappen 1995).

The satellite imageries and DEMs data have been processed and managed to detect the impact of geological hazard in arid and semi-arid areas (Robinnove et al. 1981; Jensen and Toll 1982; Fung 1990; Pathirana 1999; Wyatt 2000). The natural hazards are considered one of the most factors causing the death to a large number of people and property damages. Flash floods, mass wasting and rock fall, expansive soils, sand and dust storms and water quality are among the most destructing geohazards. The current study focuses and gives an overview on the evaluation of these geologic hazards, as well as developing and creating a geo-hazard sensing map using GIS and remote sensing techniques for Najran area, Saudi Arabia.

Any area has high steep slope and subject to high-intensity rainy storms probably it will be liable to flash flood risk. The time and the places of occurrence nature hazards are unknown. So, the protection of people and infrastructure is absolute unachievable and unsustainable. National and international agencies should take into account all measures required to reduce, avoid and prevent these geological hazards that obstruct the development train in the countries.

Recently, the utilization of GIS and remote sensing techniques are the best suitable methods in modeling, representation and prediction flash flood hazard (Billa et al. 2005; Pradhan and Shafiee 2009; Haq et al. 2012; Youssef et al. 2016). GIS becomes very important and the effective tool to compute and detect morphometric parameters which are useful to estimate the vulnerable areas for different flood events (Gogoase et al. 2011).

Many authors have been focused and interested in flash flood assessment and hazard estimations in different arid and semi-arid areas; (Subyani and Al-Dakheel 2009; Al Saud 2010; Al-Ghamdi et al. 2012; Dawod et al. 2013; Kamel 2015(.

El Khrachy (2015) used an ArcMap application based on (SPOT 5 and SRTM) data to extract the drainage network, as well as delineate the flood hazard areas in Najran city, KSA. El Khrachy (2017) used HEC-GeoRAS with ArcGIS and HEC-RAS in addition to two SAR images acquired before and after the flood event on 23 March 2015 for flood inundation mapping in steady flow conditions for Wadi Najran. The extracted main flood channel in Najran lies beside and parallel to the King Abdullah Road to investigate the effect of the flash flood and to protect it by any structure against the flash flood. All institutions and governments have a strong desire to understand and know the details of different geological hazards and their impact on the vital areas.

2 Location and Geological Setting

Najran area is covering about 360,000 km^2 of the total area of Saudi Arabia. It is characterized by agricultural activities, and it has the Najran dam at the beginning of the Wadi, which is one of the largest dams in Saudi Arabia, with a storage capacity of about 85 million m^3. Wadi Najran has represented the main principal drainage systems at KSA (Fig. 1a). It runs from E to W direction. Wadi Najran region is a part of the Arabo-Nubian basement massif rocks which are mainly composed of granitic rocks, meta andesite, meta basalt, gneisses, synorogenic granitoids, and gabbro-diorite intrusions. As well as the eastern part of the study area is covered by sedimentary rocks (Fig. 1b).

Najran area is divided into three major distinct geomorphic units. These units are mountains of basement rocks, low lying land of sand dunes and cultivated land areas (Fig. 2). Based on the drainage net map and the outlets of wadis drain in the study area there are nine hydrographic drainage sub-basins which were chosen for this study; from west to east B1, B2, B3, B4, B5, B6, B7, B8 and B9 (Fig. 3).

3 Materials and Methodology

The integration of available remote sensing, ASTER DEMs, meteorological data, soil and groundwater samples and geological maps were used to achievement the principal target in this study (Fig. 4). These data include the followings:

3.1 Computer Programs

The available remote sensing data and ASTER DEM were processed and analyzed using a number of specialized computer software, named; Erdas imagine (2014), Envi 5.2, Arc-GIS 10.2.2 and Google Earth Pro.
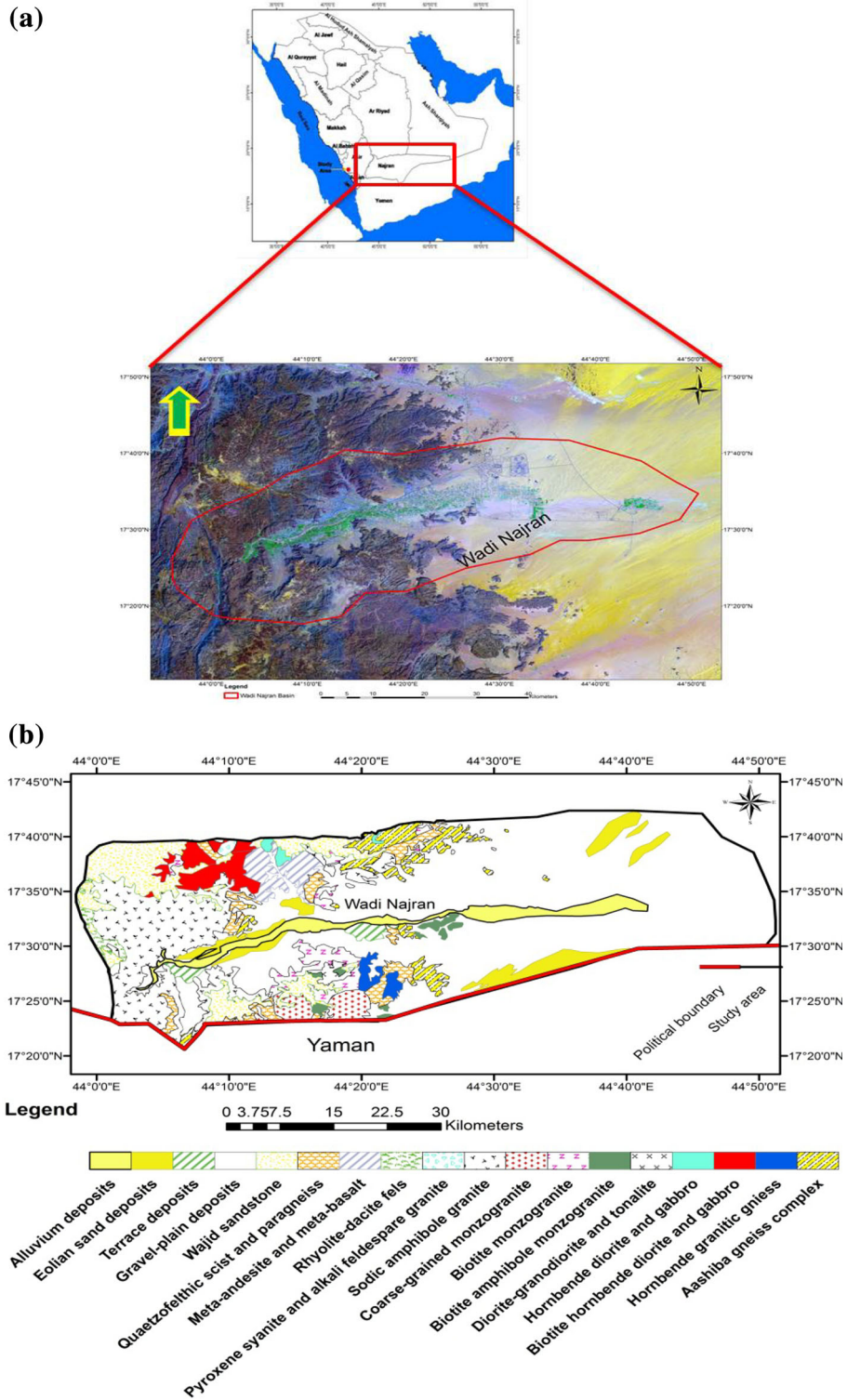
(a)

(b)

Fig. 1 a Landsat-8 operational land imager (OLI) image showing the location map of the study area. **b** Digitizing geologic map of the Najran area (after Edward G. Sable 1985)
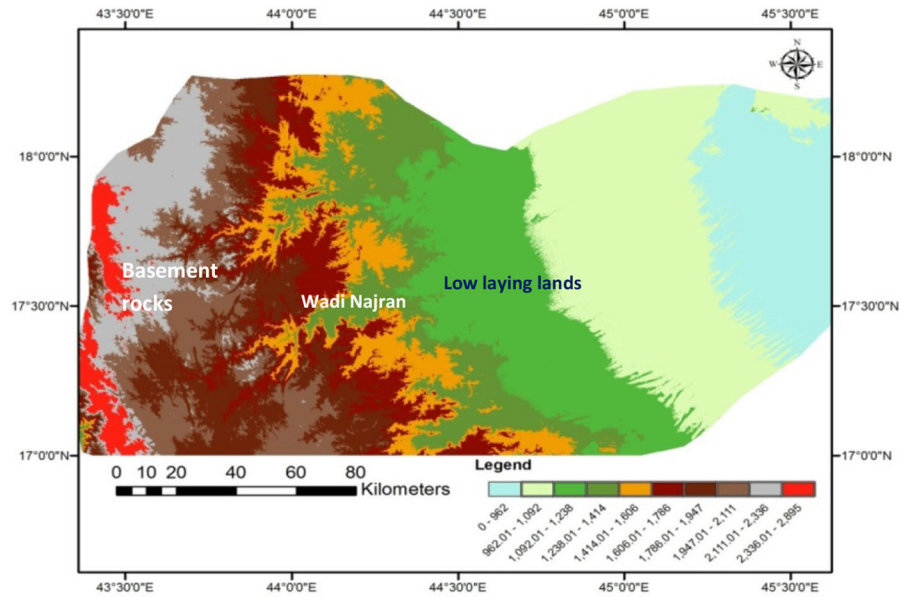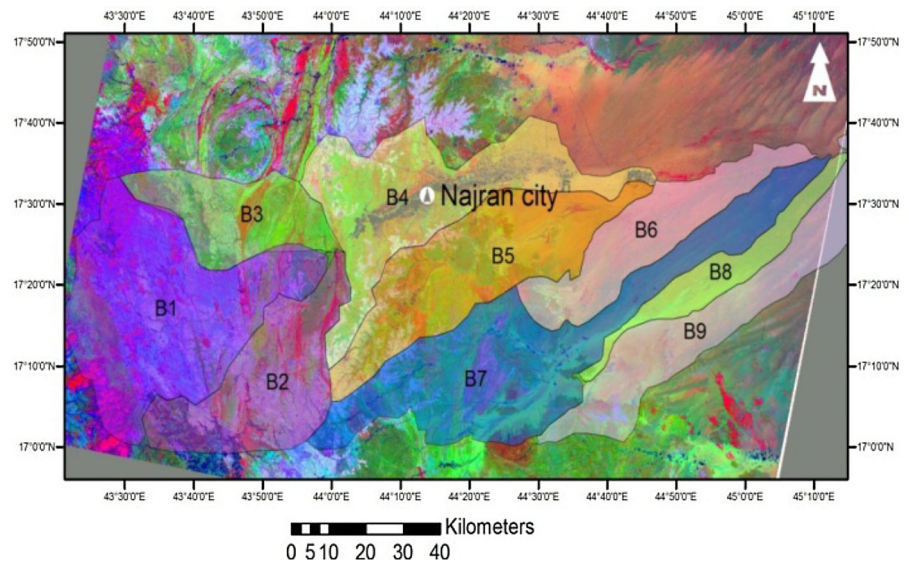
Fig. 2 Digital elevation model (DEM) of the (ASTER) data showing topographical units of the study area

**Fig. 3** Sub-basins watersheds of Wadi Najran area

3.2 Geologic Maps

One geologic map with scale (1:250,000, sheet 17 G) that covers the current area was used to show the distribution of different lithological units in Najran area.

3.3 Meteorological Data

The factor of meteorological prevailing has a direct effect on the sustainable development of an area. Najran area is characterized by an arid to semi-arid region and receives a few amounts of rainfalls. These climates tend to be extremely hot in the summer and warm in the winter. The southwestern area of Saudi Arabia is receiving the highest amount of precipitation

Fig. 4 Flow chart showing remote sensing methodology for the study area
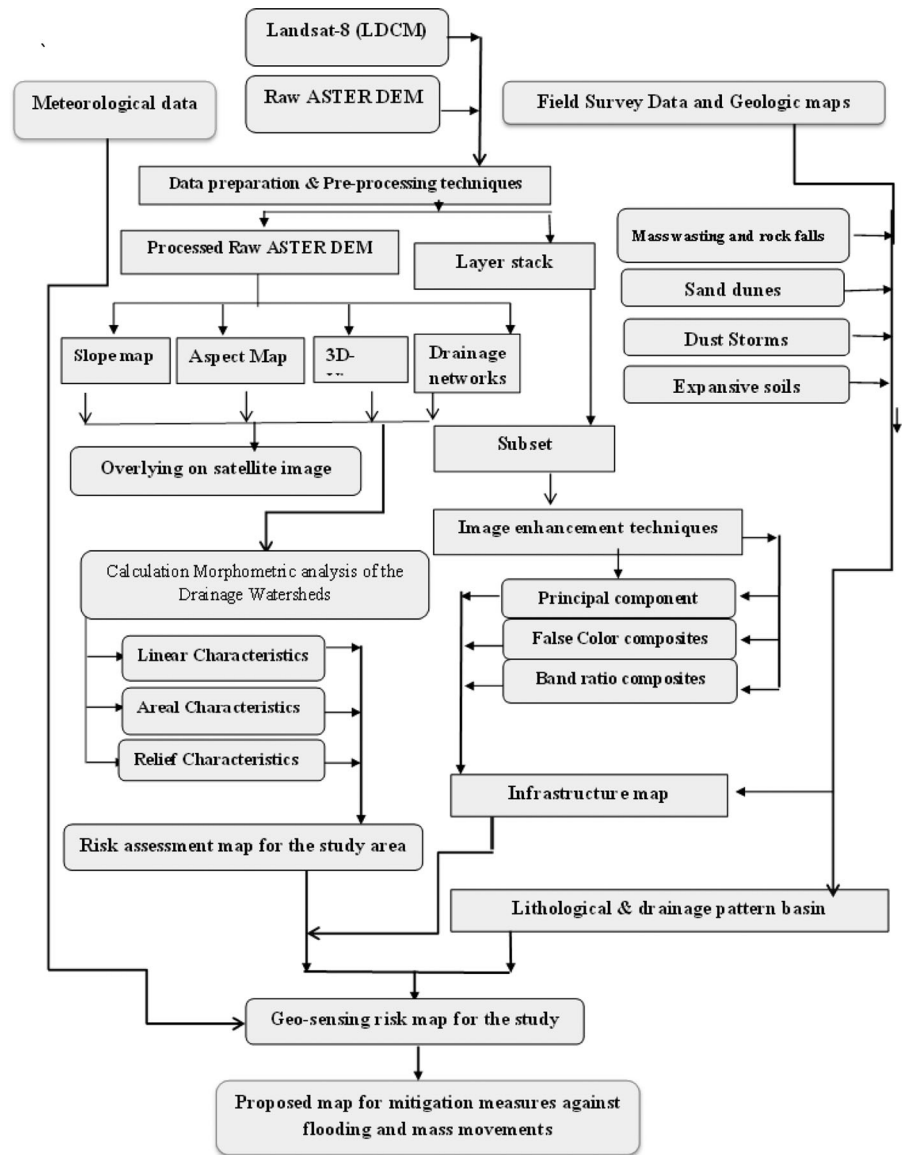
more than the other areas. According to the nearest available meteorological data that was collected from 2006 to 2014 (https://www.wunderground.com/-Municipality of Najran Region). The minimum and maximum average of temperature values in the study area are 17.7 °C and 34 °C, respectively. The relative humidity ranges in values between 13.6 and 37.87%. The average annual rainfall is between 0.3 and 110 mm. The highest rainfall value was recorded in May 2008 is 137.07 mm.

3.4 ASTER DEM

Available ASTER (DEMs) 30 m data which were free download from http://www.gdem.aster.ersdac.or.jp are used for visual interpretation, interpolation, analysis and modeling of topographic surface processes in the present study. A DEM map shows that the study area ranging in elevation from 0 m asl at the east to 2200 m asl at the west part of the present area. Four maps were generated from the ASTER DEM input data in Arc GIS environments (3D-view, elevation, aspect, and slope maps) to help us in knowing and

understand the general intensity and direction of slope in the study area (Fig. 5a–d). These different maps were combined with hydromorphologic information in a GIS database to know the direction of the flow of floods.
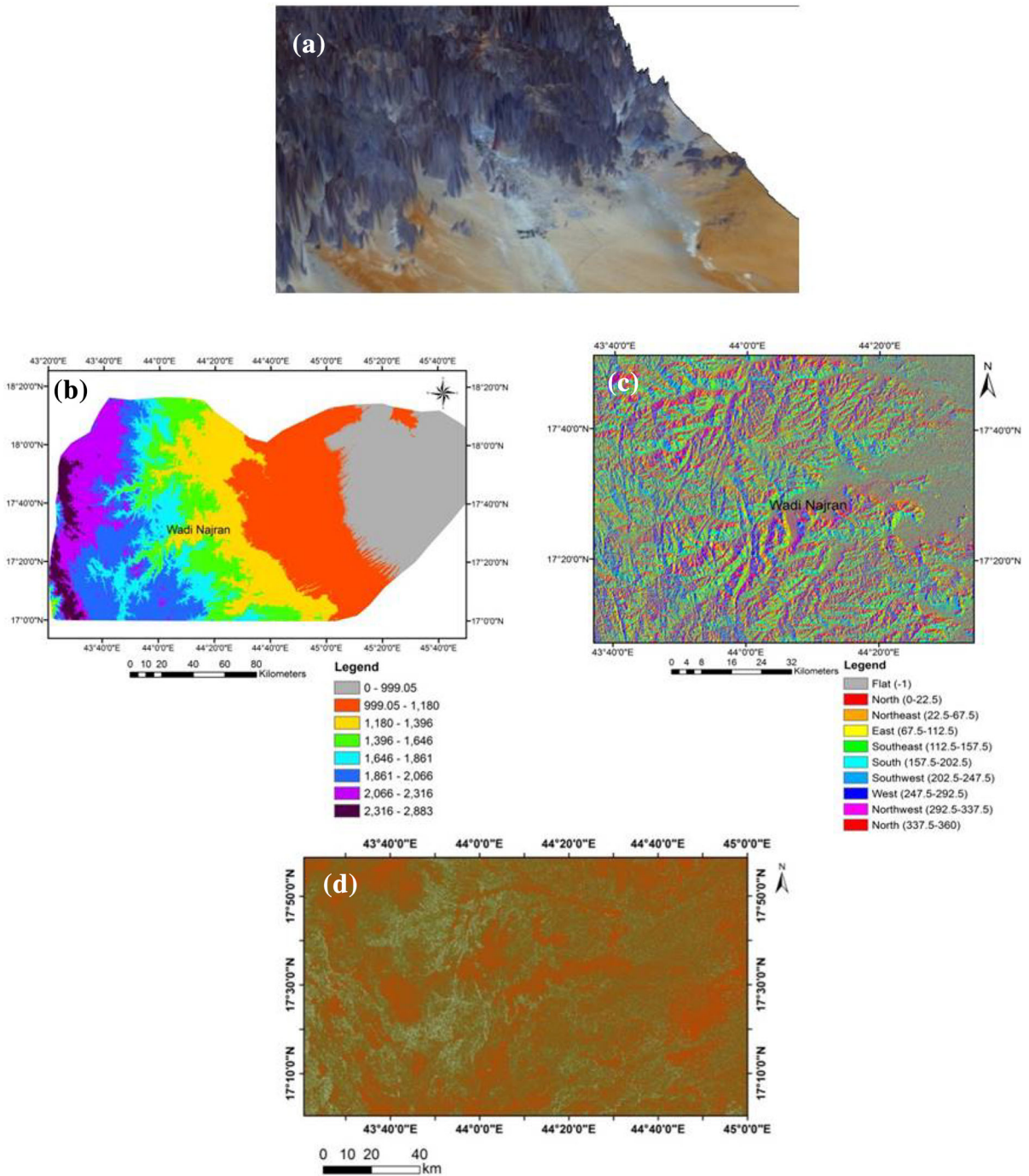

Fig. 5 Outputs derived from DEM data, **a** 3D view, **b** elevation, **c** aspect and **d** slope maps
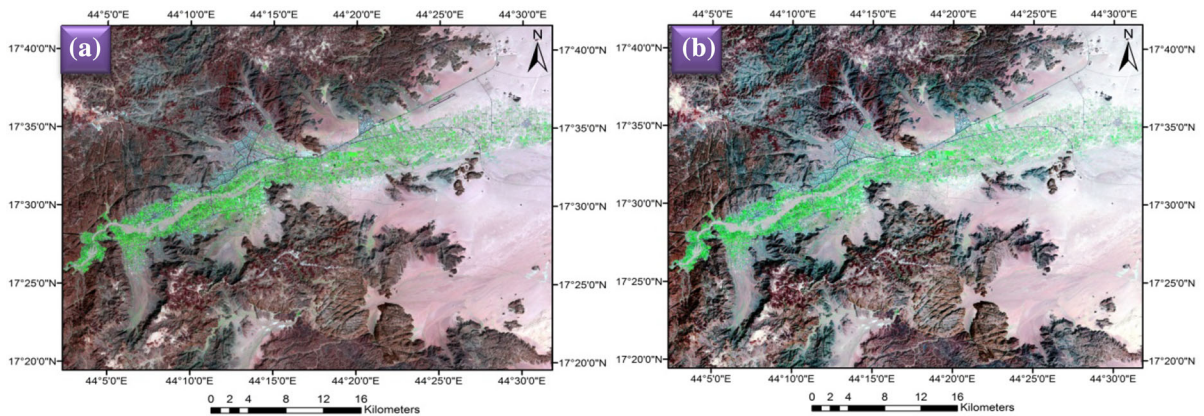
Fig. 6 Landsat-8 image **a** before histogram equalization stretching, **b** after histogram equalization stretching

3.5 Remote Sensing Data Analysis

Landsat-8 OLI has been launched in February 2013. Landsat-8 image includes 11 bands; five channels in the (VNIR) (0.433–0.885 μm) with (30 m), two channels in the (TIR) Thermal Infrared region (10.30–12.50 μm) with (100 m), two channels in the SWIR region (1.560–2.300 μm) with (30 m), one band in the Pan region (Cirrus) (1.360–1.390 μm) with (30 m) and one panchromatic channel (band 8) 0.500–0.680 μm) with (15 m). The study area is covered by one scene path/raw 166/048 which was acquired in 24 March 2015. These images subjected to pre-processing techniques such as geometric and radiometric corrections.

The Landsat-8 OLI data used were digitally processed through ERDAS imagine 2014 and Envi 5.2 software to improve the quality of the raw data. The processing and visual interpretation of the Landsat-8 OLI images such as false color composite images, band rationing and principal component analysis were applied and used to determine and differentiate between lithological units and drainage network mapping in Najran area.

Pre-processing functions involve those operations that are normally required prior to the main data analysis and extraction of information, subsetting is the process of breaking out a portion of a large image file into one or more small files.

Histogram Equalization Stretching (HES), False Color Composite (FCC), Principal Components Analysis (PCA) and Color Ratio Composite (CRC) techniques were used to discriminate between the different

rock types and delineate watershed sub-basins within the study area. The original input pixels of the histogram have been redistributed to produce a uniform population density of pixels along the output horizontal digital number (DN) axis and each DN value becomes equally frequent. Histogram equalization stretching technique has been applied to the images under the same condition. Applying this option brings good results as well as found to increase significantly the overall contrast and brightness of all images (Fig. 6).

False color composites (7, 5, 3) and (7, 4, 6) in R, G, B respectively, were selected to be the best two images that can be used in discriminating between different rock types. Also, the drainage pattern networks are recognized in these images (Fig. 7a, b).

Two principal component analysis images (PC4, PC3 and PC2), and (PC5, PC3 and PC4) in RGB respectively, are proposed to know the different rock units, moreover, this PCA-image is excellent to detect and identify drainage networks in the Najran area (Fig. 7c, d). In PC-image PC4, PC3 and PC2 in RGB, the agricultural lands indicated by reddish violet, the sedimentary rocks show dark blue color on the image, whereas the basement rocks exhibit green image signatures.

Band rationing combination of (7/5, 6/4, 4/3) and (6/5, 5/4, 4/2) in RGB of the Landsat-8 (OLI) images were used and proved to be very effective in the lithological discrimination, as well as in the drainage network delineation. In band ratio image (7/5, 6/4, 4/3) in RGB (Fig. 7e), the sand dunes appear as light violet color, while agriculture lands appear as green color,
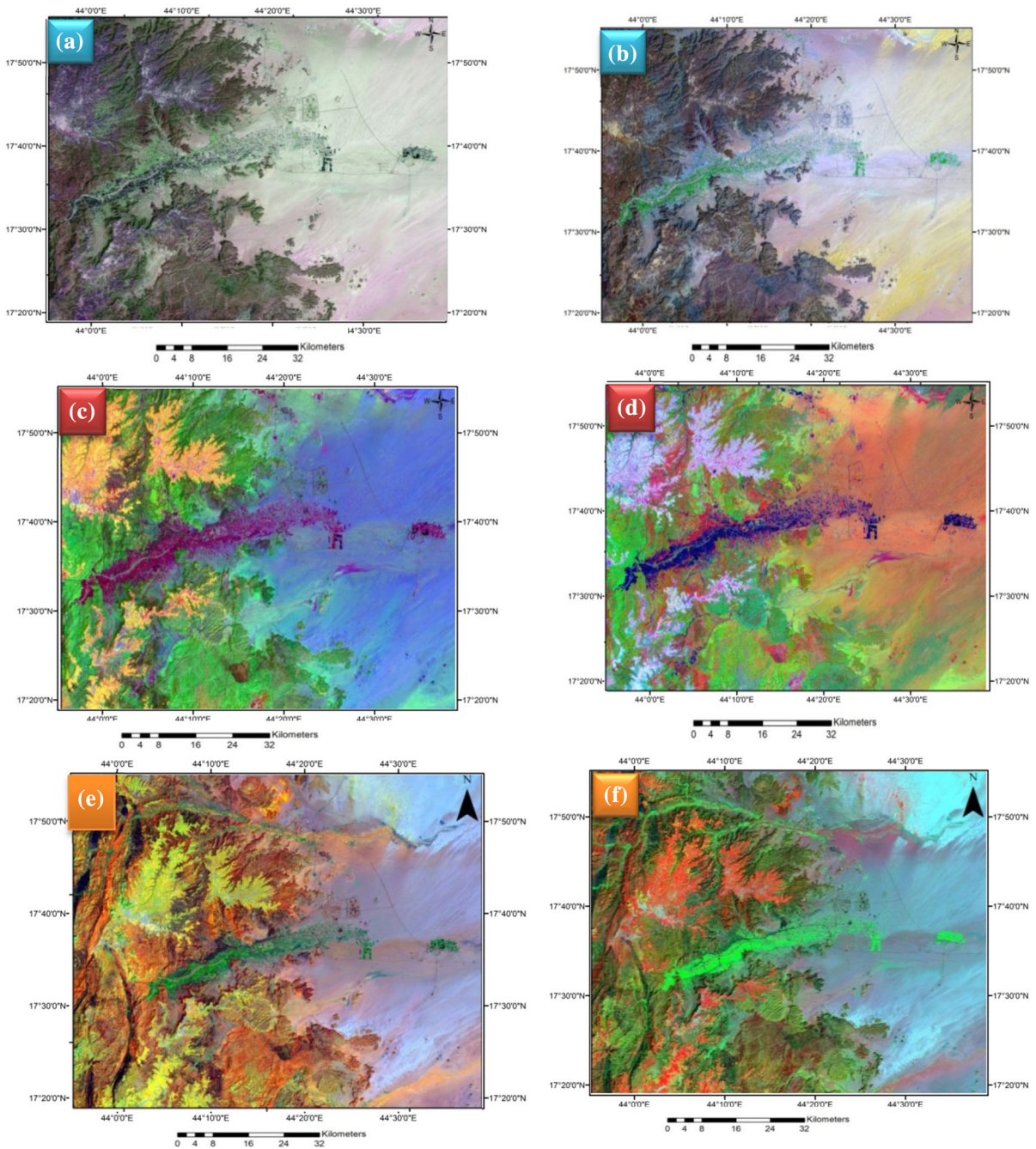
Fig. 7 Landsat-8 (OLI) false color composite images (**a** FCC 7, 5, 3, **b** FCC 7, 4, 6), principal component analysis (**c** PC4, PC3 and PC2, **d** PC5, PC3 and PC4) and color ratio composite (**e** 7/5, 6/4, 4/3, **f** 6/5, 5/4, 4/2) in R G B for the study area

the sedimentary rocks which cover the eastern part of the area show a yellow color, basement rocks have variations in color range between red and brown color according to the type of the rock. As well as, this band ratio is the best in delineation and recognition the

drainage networks in the study area. Whereas in the band ratio image (6/5, 5/4, 4/2 in RGB Fig. 7f), the agricultural lands in Wadi Najran appear as green color in this ratio image, the sedimentary rocks show a red color, basement rocks have varied in color range

Fig. 8 Distribution of geological hazards in Najran area
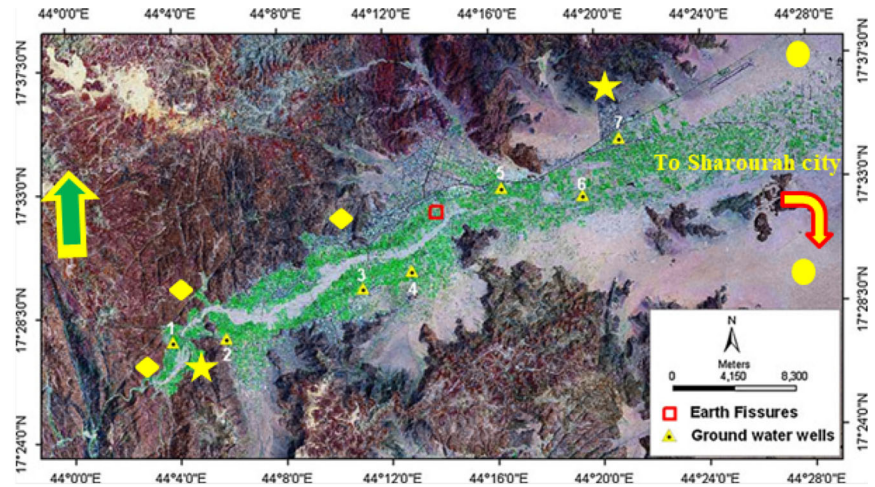
Geological hazards in Najran Area
⬙ Groundwater wells
★ Mass wasting and rock falls
⤵ Expansive soils (To Sharourah city)
● Sand dunes
◆ Flash flood

between green and brown color. While sand dunes appear white in color.

4 Geological Hazards

Najran area represents a desert environment which is very weakly and is highly affected by human activities. The geological hazards which cause many problems for human life mainly caused by urban development and infrastructures leads of new city under construction. The most important factors that lead to the appearance of these hazards are climatic conditions, geology, geomorphic, and human activities. The geological hazards may occur under desert conditions that include sand and dune movement, slope stability hazards, flash floods, and problematic soils. The distribution and occurrence of geohazards in Naran Area is illustrated in Fig. 8.

4.1 Geological Hazards Associated Groundwater

The pollution is an impairment factor for water quality by chemicals, heat or bacteria to a degree that does not necessarily create an actual public health hazard. The percentage of pollution mainly detects which the water are stabile for normal, domestic, farm, municipal or industrial use. The term 'contamination' to denote impairment of water quality by chemical or bacterial pollution to a degree that creates an actual hazard to public health. The greatest danger of groundwater pollution is from surface sources including animal manure, sewage sludge, leaking sewers, polluted streams and refuse disposal sites. Ground water provides drinking water for more than one-half of the Nation's population (Solley et al. 1993), and is the sole source of drinking water for many rural communities and some large cities.

To investigate the groundwater samples were collected in 1-L polyethylene plastic bottles from the different bore holes examined in the study area. The available productive bore holes in the study area were chosen. For the rock fall and mass wasting, 10 stations are selected to investigate the fissures and collocating the samples to laboratory tests such as unconfined compressive strength and density. 10 samples from the expansive soil are subjected to laboratory test to investigate the expansive characters.

Table 1 Results of physical parameters of bore holes in the study area (mean ± SD)

Locality	pH	Turbidity	DO	TDS	E.C.
Al Jurba	7.7 ± 0.25	0.4 ± 0.04	0.03 ± 0.003	249 ± 2.0	496 ± 0.9
Al Balad	7.06 ± 0.09	0.53 ± 0.03	1.93 ± 0.03	292 ± 1.9	573 ± 1.6
Al Hadan	7.22 ± 0.12	0.6 ± 0.04	0.21 ± 0.02	1.74 ± 0.04	3.49 ± 0.02
Al Ragam	8.05 ± 0.08	0.36 ± 0.03	4.09 ± 0.1	299 ± 0.71	599 ± 5.9
AalManjam	7.0 ± 0.2	0.57 ± .04	0.01 ± .01	1.37 ± 0.04	2.75 ± 0.04
Al Athayba	7.7 ± 0.31	0.35 ± 0.02	0.21 ± 0.01	282 ± 1.0	566 ± 1.5
Badr El Janob	8.02 ± 0.06	0.38 ± 0.04	4.65 ± 0.1	126 ± 0.5	254 ± 0.9
Al Haira	7.27 ± 0.22	1.25 ± 0.14	2.46 ± 0.1	199.9 ± 0.7	19.9 ± 0.6

The pH was measured with pH-meter Hi 8424 HANNA

Turbidity: turbidity was measured with Lovibond Turbidity meter

Dissolved oxygen (DO): readings for dissolved oxygen were done with DO-meter 850,041

Total dissolved solids (TDS) and electrical conductivity: readings for TDS and E.C, were done with Conductivity-TDS-Salinity-meter 850,038)

4.1.1 Physical Characteristics

The physical parameters of groundwater samples were determined and measured in the field. The physical parameter results are summarized in Table 1.

4.1.2 Chemical Characteristics

Six chemical components (nitrite (NO_2), nitrates (NO_3), chloride (Cl), Sulfate (SO_4), iron (Fe) and fluoride (F)) have been examined in groundwater samples in the studied area (Table 2).

Nitrate, is potentially harmful if its concentration is high in water and serve as a good indicator of chemical polluted water. Since nitrate and nitrite are nutrients, their presence in high concentrations can nurture the growth of algae in the water and consequentially impair the water quality (Bastawy et al. 2006).

The nitrite ion is relatively unstable and can be formed by the reduction of nitrate in poorly oxygenated waters. It is rapidly oxidized to nitrate and is seldom present in well oxygenated or chlorinated supplies. Chemical and biological processes can result in further reduction to various compounds, including ammonia, or oxidation back to nitrate (APHA 2000).

All concentrations of nitrite and nitrates in groundwater samples from the study area are within the allowable concentrations of the drinking water standards as adopted by the WHO's standards (2004). Only high concentrations of nitrates were detected in the locality of El Hayra in which nitrates is 52 mg/L (Table 2).

The aim of this part is to investigate the groundwater quality extracted from bore holes and dug wells in the area of Najran town. Groundwater samples will be collected from both bore holes and dug wells if available. The chemical analysis will be conducted to investigate the groundwater characteristics and if there is any pollution. Radiochemical analysis should also be carried out. This will show us if there is any radioactive contamination and its possible source, since the area is surrounded by many outcrops of different geological formation and contains different minerals with wide chemical composition and crystal structures which mainly characterize the acidic igneous rocks such as feldspars, micas and quartz.

The final results of this work will show us the nature of groundwater in the area of Najran and may lead us for more investigations about the geology of the area, water quality and its extent of pollution. The major anions analyzed in the groundwater collected from the study area show that they are detected in low concentrations and even absent in some localities. Ammonia (NH^{4+}) and chlorides (Cl^-) are not detected in the groundwater. $Nitrite_2^-$ and $Nitrates_3^{-2}$ are found to be in low concentrations, where their maximum levels are 0.3 mg/L and 52 mg/L respectively according to the WHO standards (1984) for drinking water. High nitrates levels are recorded at Al Hayra (52.1 mg/L).

Table 2 Results of chemical analysis of water bore holes in study area (mean ± SD)

	Locality	NH_3	NO_2	NO_3	Cl	SO_4	Fe	F
1	El Jurba	0.00	0.01 ± 0.006	0.02 ± 0.01	19.8 ± 0.6	47.4 ± 0.9	0.08 ± 0.01	0.15 ± 0.03
2	Al Balad	0.00	0.03 ± 0.004	4.9 ± 0.1	5.4 ± 0.3	9.80 ± 0.7	0.01 ± 0.01	0.02 ± 0.02
3	Al Hadan	0.00	0.01 ± 0.006	19.40 ± 0.3	154.0 ± 0.7	159.0 ± 0.7	0.08 ± 0.01	0.09 ± 0.02
4	Al Ragam	0.00	0.034 ± 0.001	5.0 ± 0.3	5.70 ± 0.4	15.0 ± 0.7	0.50 ± 0.1	0.07 ± 0.01
5	AalManjam	0.00	0.01 ± 0.005	23.7 ± 0.9	92.10 ± 0.6	137.9 ± 1.2	0.07 ± 0.02	0.02 ± 0.01
6	Al Athayba	0.00	0.03 ± 0.01	9.0 ± 0.3	6.91 ± 0.3	12.4 ± 0.3	0.09 ± 0.02	0.05 ± 0.01
7	Badr El Janub	0.00	0.03 ± 0.01	0.9 ± 0.03	205.0 ± 0.7	2.0 ± 0.6	0.07 ± 0.01	0.01 ± 0.01
8	El Hayra	0.00	0.04 ± 0.01	52.0 ± 0.6	64.6 ± 0.4	46.4 ± 0.8	0.07 ± 0.01	0.05 ± 0.01

These chemical wastes have more negative effects on human health. Bacterial, viral and parasitic diseases like typhoid, cholera, encephalitis, poliomyelitis, hepatitis, skin infection and gastrointestinal are spreading through polluted water. It is recommended to examine the water quality on regular basis to avoid its destructive effects on human health. Domestic and agriculture waste should not be disposed of without treating (Khan and Ghouri 2011; Juneja and Chauhdary 2013).

4.2 Mass Wasting and Rock Falls

Transportation systems such as roads and highways are associated with rockfalls/rockslides wherever they cut across or skirt along mountains, plateaus, ridges and similar topographic features (Bunce et al. 1997; Hungr et al. 1999).

The unstable blocks represent hazards and may cause risks to the traveling public, to the transportation infrastructure, to local economies and to the environment. Road and highway cuts fail from time to time. High groundwater pressures (after heavy downpours) can trigger large rock blocks or even larger assemblages of rock to crash down on the road surface below such as the Najran-Abha road, and Najran-Habona road. Often, the failed material is contained in the ditch area. Sometimes, the material spills out onto the road and causes damage to the road surface or to vehicles traveling along the road as well as injury and death to occupants of vehicles occur. New requirements to establish civil infrastructure across difficult terrain as population centers expand in coming decades will increase the number of rock cuts along

transportation systems (Dai et al. 2002). In the Najran area, the roads and highways have been established between Najran and Abha city have more dangerous areas (Fig. 9). These highways and roads connect many cities that are located in high elevation of the mountains with other cities. Along these areas many rock falls have occurred that not only block the roads, but also damage infrastructure and cause injuries and fatalities, some of which remain unreported (Fig. 9). In general, rockfall assessment of slopes requires comprehensive information about the geology and engineering geology of the area such as geological structures, the properties of the rock mass discontinuities for the structural controlled failures, as well as the characteristics of the rock cut faces for the raveling type failures (Maerz et al. 2005; Youssef et al. 2012). Other factors related to the traffic density and road designs are also required, because these affect the risk to moving vehicles such as Najran-Habona road (Fig. 9a–d). Recently, a rock fall hazard rating system will be established for the Najran area to deal with rock and slope cuts also to deal with the best method for remediate and mitigate these areas Table 3. The calculations of rock mass rating (RMR) ratings for the studied rock slopes (Table 3) show that most of the studied sites of Najran-Abha road were described as; good to very good, Stable condition, but some block failures could occur in these natural slopes by rain and seasonal stream water Table 3.

4.3 Expansive Soils Hazards (Problematic Soils)

In arid and semi-arid areas the precipitation of various dissolved components of groundwater can give rise to

Fig. 9 a, Field photograph showing the rock falls in central part of Najran, **b**, in highway between Najran-Abah road; and **c**, **d** slope failure in Najran Habona road

surface hardening of silty clay soils by the development of crusts. If the soils are subjected to wetting or drying marked volume changes may take place and the possibility of overloading underlying weaker horizons should also be borne in mind. Expansive soils derived from residual soils can exert uplift pressures, which can do considerable damage to houses and other infrastructures. Expansive soils owe their characteristics to the presence of swelling clay minerals (Abd El Aal 2013). As they get wet, the clay minerals absorb water molecules and expand conversely, as they dry they shrink, leaving large voids in the soil. Potentially expansive soils can typically be recognized in the laboratory by their plastic properties (Liquid and plastic limits).

Expansion of soils can also be measured in the laboratory directly, by immersing a remolded soil sample and measuring its volume change. However, there are many methods that could be used to determine the swelling pressure as on Odometer. In addition, in the field, expansive clay soils can be easily recognized in the dry season by the deep cracks.

Expansive soils in many parts of the Najran area such as Sharourah and Sultanah Government have a significant hazard to foundations for buildings and infrastructures (Abd El Aal 2013). Government and private sectors pay out millions of dollars yearly to repair homes distressed by expansive soils. Infrastructures such as buildings, roads, and other facilities located above the expansive soil are very much prone to damage. The expansive soil in Sharourah and Sultanah is derived from different types of sediments such as shale, claystones, and calcareous clays. The absence of a sewage network in some places and the

Table 3 Rock mass classification of study stations according to Bieniawiski (1989)

Station	UCS (MPa)	RQD%	Spacing of discontinuities	Condition of discontinuities	Water general condition	Point load (MPa)	Density g/CC	RMR	Probability of failure
1	156	57	0.9 m	Slightly rough surfaces Separation < 1 mm Slightly weathered walls	Completely dry	5.4 MPa	2.56	80	No failure
Rating	12	13	15	25	15	12			
2	187	69	1.2 m	Slightly rough surfaces Separation < 1 mm Slightly weathered walls	Completely dry	6.3 MPa	2.64	80	No failure
Rating	12	13	15	25	15	12			
3	178	72	1.4 m	Slightly rough surfaces Separation < 1 mm Slightly weathered walls	Completely dry	6.2 MPa	2.43	80	No failure
Raring	12	13	15	25	15	12			
4	145	70	1.56 m	Slightly rough surfaces Separation < 1 mm Slightly weathered walls	Completely dry	5.1 MPa	2.45	80	No failure
Rating	12	13	15	25	15	12			
5	123	75	1.2 m	Slightly rough surfaces Separation < 1 mm Slightly weathered walls	Completely dry	4.5 MPa	2.44	80	No failure
Rating	12	13	15	25	15	12			
6	159	66	0.9 m	Slightly rough surfaces Separation < 1 mm Slightly weathered walls	Completely dry	5.9 MPa	2.51	80	No failure
Rating	12	13	15	25	15	10			
7	81	55	178 mm	Slightly rough surfaces Separation < 1 mm Highly weathered walls	Completely dry	3.2 MPa	2.44	65	No failure
Rating	7	13	10	20	15	10			
8	76	62	145 mm	Slightly rough surfaces Separation < 1 mm Highly weathered walls	Completely dry	3.3 MPa	2.54	65	Some block failure
Rating	7	13	10	20	15	10			
9	88	77	1.69 m	Slightly rough surfaces Separation < 1 mm Highly weathered walls	Completely dry	2.1 MPa	2.21	70	Some block failure
Rating	7	13	15	20	15	10			
10	65	69	1.78 m	Slightly rough surfaces Separation < 1 mm Highly weathered walls	Completely dry	2.3 MPa	1.87		Some block failure
Rating	7	13	15	20	10	10		65	

UCS (MPa), unconfiid compressive striegth; RQD%, rock quality dissegnation; RMR, rock mass rating

existence of the so-called tanks for sewage down or near houses contemplate a dangerous problem especially when these tanks are broken or filled with wastewater. The wastewater will be absorbed by expansive soil. This wills cause increasing in its ability of swelling natur because of richness of wastewater with organic matter which increases plasticity and swelling potentiality of these clayey-soils (Abu Seif 2017). Moreover, a lot of geotechnical problems in these constructions such as horizontal and diagonal wall cracks and sometimes foundation tilting were recorded (Fig. 10a–d). The movements and foundation damage occurred by expansive soils usually occurred gradually and do not cause rapidly hazardous effects such as hurricanes and earthquakes but often they are much worse, even causing major structural distress (Coduto 1999). To study the expansive behavior, ten and disturbed samples were collected from four boreholes in Sharourah area.

Ten samples were subjected to consistency limits (liquid, plastic limits and plasticity index) were done according to ASTM D4318 (2005) as well as X-ray diffraction of < 0.2 μm was done for representative samples. Soils with smectite clay minerals, such as montmorillonite (5% by weight), exhibit the most profound swelling and geotechnical characteristic X-ray diffraction pattern of the studied soil and indicating that montmorillonite (54%), and reddish clay of medium to high plasticity. The clay minerals

composition of fine-grained soil is likely to be the most important controlling factor for many properties and knowledge of the composition may thus simplify problems. Potentially expansive soils can be determined in the laboratory by experimental test such as their plastic properties. Inorganic clays of high plasticity, generally those with average liquid limits exceeding 54% and plasticity index more than 33, usually medium to high inherent swelling capacity Table 4. The consistency limits are generally used to classify and assess the swelling ability of fine-grained soil. Plasticity index (PI) can be used as an excellent indicator for expansive soil classification (Seed et al. 1962; Abdullah et al. 1999). Finally, based on the plasticity index (PI) and clay content (%) values the studied soil samples are classified as expansion potentiality. The PI values of these soils range from 33 to 38% (Table 4). Accordingly, these soils are classified as medium to high swelling potentialities (Chen 1988).

4.4 Sand Dunes

In arid regions, in particular, because there is little vegetation, wind action is much more significant than elsewhere. By itself, wind can only remove undocumented rock debris, but once armed with rock particles, the wind becomes a noteworthy agent of abrasion. Sand dune morphology primarily depends

Fig. 10 Wall slipping/subsidence/fissures due to expansive soil, Sharourah, Najran area
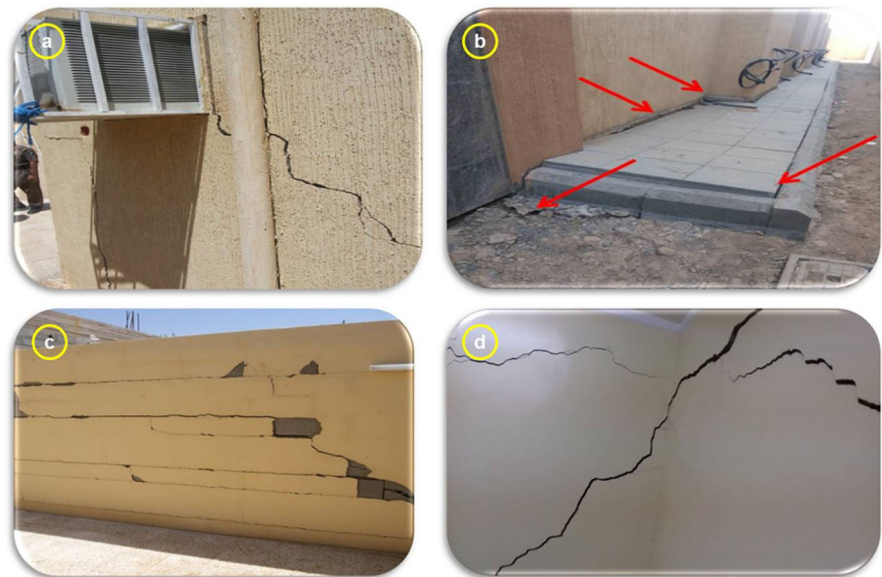
Table 4 Consistency limits of the studied soil samples

Sample no.	Liquid limit, LL (%)	Plastic limit, PL (%)	Plasticity index, PI
1	55	20	35
2	54	18	36
3	56	20	36
4	54	19	35
5	56	18	38
6	53	20	33
7	52	18	34
8	55	19	36
9	51	18	33
10	57	22	35

upon the amount of sand supply, shape, size and composition of the sand grains, surface topography, wind speed, direction and duration, humidity, and nature of the surface vegetation (Edgell 1990). The deposition of sand and subsequent formation and accumulation of dunes generally occurs as a result of an interruption of sand-laden wind masses due to the presence of obstacles or variations in the ground relief (Bagnold 1951). In most arid environments throughout the world, the geologic processes of sediment weathering, transport, and deposition are constantly ongoing within active sand transport pathways.

The analysis of sand accumulation, composition and movement is critical for the interpretation of past climatic conditions, local geology, environmental hazards, and future desertification potential. This type of comprehensive study typically involves many years of data collection, mapping and sample classification (Muhs and Holliday 1995). Recently, the use of remote sensing over the past several decades as a tool to study dynamic features such as dunes and sand accumulations have given the geologist a synoptic view of entire Eolian systems as well as their sediment sources (Breed et al. 1979; Blount et al. 1990; Edgett and Christensen 1995) (Fig. 11a–d). In addition, the ability to examine changes over time allows for the extrapolation of past climatic regimes and the monitoring of marginal areas susceptible to future desertification (Otterman 1981; Tucker et al. 1994). Sand accumulation areas (sand dunes) could be stabilized by vegetation, by fences, by chemical spraying or by other mechanical means. Watson (1985) reviewed the different methods of sand control with special reference to Saudi Arabia. The use of vegetation and/or naturally occurring stabilizers usually shows better

performance than man-made chemicals or fences. The design of a remedial measure is usually based on quantitative estimates of the magnitude of the affected area, the amount of drifting sand or dune movement rate, the prevailing wind direction, and the types and rate of growth of the selected vegetation.

4.5 Sand and Dust Storms

Dust storms are a common phenomenon in arid deserts, such as Najran area where storm winds capable of raising huge amounts of fine-grain particles from the ground into the atmosphere to the degree that impair the vision to less than 1 km (El-Ossta et al. 2013). In Najran area, a wide diurnal temperature variation that causes turbulence in the atmosphere, which favors formation of dust storms during daytime (Edgell 2006) (Fig. 12a–c). Dust storms play a critical role that modifies the energy budget in the atmosphere by scattering and reflecting incoming solar radiation and, hence affecting the air temperature (Li et al. 1996).

Dust storms also have more negative impacts upon human life, because it is a significant source for airborne diseases and promotes nuisance; causes road and air traffic retardations; and damages communication facilities (El-Ossta et al. 2013). Dust particle size varies considerably, smaller the particle size, larger the distance it gets carried away and longer periods (sometimes over a week) it remains suspended in the troposphere. Quartz is the main constituent of the dust; other minerals found are feldspar, calcite, dolomite, micas, clay minerals, gypsum, halite, opal, amorphous inorganic and organic material (Pye 1994). The dust particles are lifted from ground and the factors that
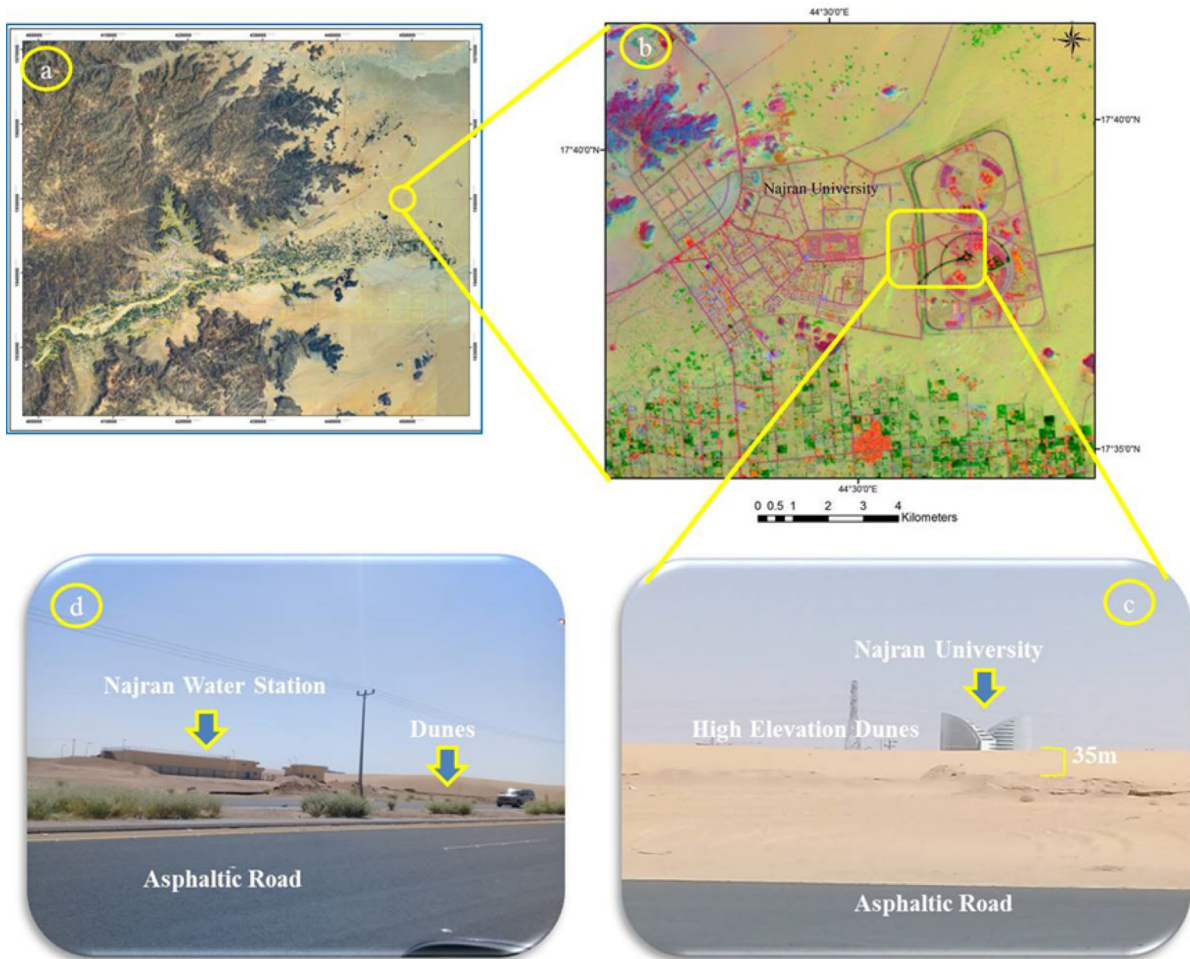
Fig. 11 **a**, **b** Sand accumulations to the east of Wadi Najran, **c** the destructive effect of sand dunes along asphalt roads in the studied area towards main building of Najran University, **d** Najran water station

control the character of storms are the nature of the wind, the nature of the soil or sediment, and the presence of any surface obstacles to wind flow (Middletonand and Goudie 2001).

The wind systems that interact over Najran area are coming across the Rub Al-Khali desert. Dust storms are several thousand feet thick and adversely impact airline services, airports shut down, disruption of road transport, and sand blasting has also been reported to strip the paint off of cars. Dust storms are known to cause respiratory and eye problems and spread diseases across the globe by blowing virus spores into the atmosphere and spreading them all around. They also cause soil loss from the dry lands and they preferentially remove organic matter and the nutrient-rich lightest particles, thereby reducing agricultural

productivity. They can also have beneficial effects on agriculture by distributing mineral nutrients that have bad effects on agriculture land.

4.6 Flash Flood Hazards

Recently, the Kingdom of Saudi Arabia is receiving a large amount of rainfall, because change in new climatic conditions. Sometime, This event leads to and causing flash floods. In vital areas that are constantly exposed to flooding, a lot of houses, infrastructures, industrial, urban, agricultural lands and other activities were pushed away during the flash flood effects. The most important reasons leading to destruction and losses the infrastructures and other human activities due to force of flash flooding are lack of awareness of

Fig. 12 Ground photos in Najran city showing the dust storm that occurred in 12 March 2017

the adequate prevention of theses risk and disappear any kind of early warning system (Fig. 13). Twenty quantitative morphometric analyses of nine sub-basins watershed in Najran area (Table 5) were calculated to estimate the characteristics of the drainage watershed in order to identify and evaluate flash flood hazards depending on ASTER DEM data with 30 m resolution.

These sub-basins originate mainly in the mountainous highland of basement rocks which are flanked in east by a relatively low dipping sedimentary strip. The drainage pattern parameters have been measured and extracted using ArcGIS 10.2.2 (Table 5). The morphometric parameters helped to predict the relative flood hazard degree and the capability of the basins for ground water recharge. They are then sorted and used for the GIS based hazard assessment analysis. The morphometric analysis is complete successfully through a number of procedures of linear, aerial and relief aspects of the drainage sub-basins (Nag and Chakraborty 2003; Magesh et al. 2012).

The results of morphometric analysis reflect the prevailing geological, topographical and structural features of the watershed basin in the area. As well as, they help us in understanding the geo-hydrological characteristics of a drainage basin.

4.6.1 Linear Properties of Drainage Basins

Stream orders (Su) and stream numbers (N) both of stream orders and stream numbers are considered very important factors to detect the other morphometric parameters of the drainage watershed. Horton (1945) was the first one to introduce the designation of stream orders system, following this system modified by Strahler (1952).

In the current study, the drainage sub-basins have orders range between 3th and 6th orders (Table 2). One drainage sub-basin has 3th order is No. B8. Most of the drainage sub-basins in Najran area have 5th orders (Fig. 14). The total stream numbers of all drainage sub-basins in Najran region are 2204 segments, 1st order has large number, 1765 segments.

Fig. 13 a Some examples of flash flood problems in Wadi Najran 2016, b damages to the urban infrastructure, c and d underground rainwater drainage systems design in the area that are subjected to floods

There is a strongly inversely proportion relationship between both of stream orders and numbers.

In other words, the relationship between stream order and runoff and infiltration is direct proportion. So, hazard impact of drainage basin increases with increasing stream order.

The basin length (L_b) is the longest extension of a basin along the main drainage line (Schumm 1956). The total basin length of Wadi Najran is about 511.2 km. While the width (Wb) of the drainage sub-basins rainging from 1.5 to 25 km. Basin perimeters (P) are varying greatly from one basin to another between 133 and 424 km (Table 6).

The total stream length (ΣL) is 10,122.356 km of all sub-basins in Najran area and its varied greatly from basin to one another. Sub-basin No. B1 has a high stream length is about 45.104 km, whereas sub-basin No. B8 has a low stream length about 3.654 km (Table 6).

Bifurcation ratio (Rb) is the number of tributaries, is computed for each successive pair of orders in each stream basin. Then, the weighted mean bifurcation ratio is calculated by multiplying the bifurcation ratio of each successive pair of orders by the total number of streams involved in the ratio Strahler (1952).

The bifurcation ratio values of the present study vary between 7.72 for sub-basin No. B8 and 3.62 for sub-basin No.B3 (Table 6). Generally, the study area has relatively high bifurcation ratios. A weighted mean bifurcation ratio (WMRb) is inversely proportional to hazard degree. Therefore, most of the area under investigation is medium in flash flooding risk.

4.6.2 Areal Properties of Drainage Basins

Drainage area (A) is a very important factor in the morphometric parameter steps of the network stream systems. Accordingly, Strahler (1958) found that the relationship between the area of basins and geomorphological characteristics of the same basins is great direct proportional. This means that all sub-basins that have similar area and form properties are also similar in their geomorphological properties. Generally, basin area increases with the increase of the stream orders.

The sum drainage area (ΣA) of Najran sub-basins is about 12,540 km^2. Drainage sub-basins vary in the drainage area between 445 km^2 in basin No. B8 and 2660 km^2 in basin No. B9 (Table 7). Spread area (A) tends to receive a large accumulation of water, so high hazard of flood based on a great runoff and amount of sediment.

Circularity ratio (Rc) It is a very important factor to detect a basin shape. The result is equal to one for circular basins and approaches zero for a straight line.

Table 5 Morphometric parameters and mathematical formulas of study area

	Morphometric parameter	Formula	References
A	Linear characteristics of the drainage watershed		
1	Stream order (Su)	Hierarchical rank	Strahler (1952)
2	Stream number (Nu)	$Nu = N1 + N2 + …Nn$	Horton (1945)
3	Stream length (Lu) Kms	$Lu = L1 + L2…Ln$	Strahler (1964)
4	Mean stream length (Lum)	See Table 2	Strahler (1964)
5	Mean bifurcation ratio (MR$_b$)	See Table 3	Strahler (1964)
6	The drainage basin length (L$_b$)	GIS software analysis	Schumm (1956)
B	Areal characteristics of the drainage watershed		
1	The area of drainage (A)	GIS software analysis	Schumm (1956)
2	Stream frequency (F)	$F = Nu/A$	Horton (1932)
3	Drainage density (D)	$D = Lu/A$	Horton (1932)
4	Constant of channel maintenance (C)	$C = 1/Dd$ or $C = A/\sum Lu$	Schumm (1956)
5	Circularity ratio (Rc)	$Rc = 12.57 * (A/P2)$	Miller (1953)
6	Elongation ratio (Re)	$Re = 2/Lb * (A/\pi) 0.5$	Schumm (1956)
7	Lemniscate ratio (K)	$K = L2/4A$	Chorley et al. (1957)
8	Compactness ratio (Co)	$C_O = P/2\sqrt{A\pi}$	Wisler and Brater (1949)
C	Relief characteristics of the drainage watershed		
1	Slope average (S)	Lb/H	Schumm (1956)
2	Relief ratio (Rh)	$Rh = H/Lb$	Schumm (1956)
3	Form factor (Rf)	$Ff = A/Lb2$	Horton (1932)
4	Texture ratio (T)	$R_t = \sum Nu/P$	Schumm (1956)
5	Ruggedness number (Rn)	$Rn = Dd * (H/1000)$	Patton and Baker (1976)
6	Slope Index (Si)	$Si = H/Lb$	Taylor and Schwarz 1952

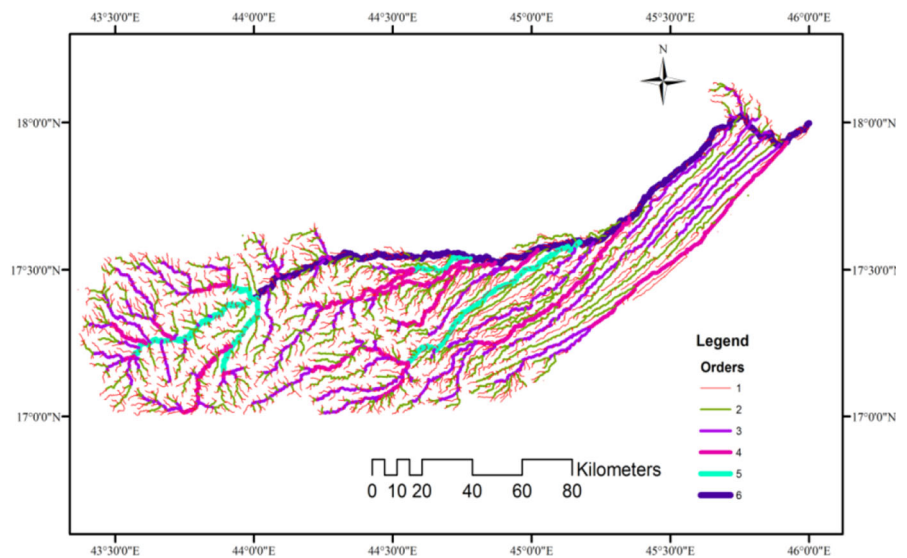**Fig. 14** Stream orders and drainage pattern of study sub-basins watershed in Najran area

Table 6 Stream numbers and orders of sub-basins in the study area

Wadi name	Orders						Total	MRb
		1st	2nd	3rd	4th	5th		
B1	NO	160	35	8	3	1	207	3.65
	L (km)	30	14	0.5131	0.5225	0.3823	45.103	
B2	NO	294	59	15	4	1	373	4.16
	L (km)	5.021	2.67	1.721	0.354	0.7015	10.467	
B3	NO	22	4	2	1	–	139	3.62
	L (km)	1.9183	0.81564	0.6321	0.2273	–	3.744	
B4	NO	186	40	8	2	1	237	3.91
	L (km)	3.47546	1.931	0.86208	0.3298	0.708316	7.306	
B5	NO	211	43	10	3	1	268	3.88
	L (km)	3.9223	2.25128	1.007	1.1416	0.29532	8.61	
B6	NO	128	22	5	2	1	158	3.67
	L (km)	2.8286	1.7534	0.5653	0.948	0.21446	6.309	
B7	NO	290	58	12	3	1	364	4.2
	L (km)	5.58617	3	1.695	0.73593	1.04633	12.06	
B8	NO	58	9	1	–	–	68	7.72
	L (km)	1.5626	1.1565	0.935	–	–	3.65	
B9	NO	328	49	12	1	–	390	7.6
	L (km)	6.9168	3.80202	4.3111	1.7727	–	16.802	

Table 7 Areal characteristics of the drainage sub-basin watersheds in Najran area

Wadi name	Area (km^2)	Perimerter (km)	Rc	Re	D	F	C	K	Co
B1	2027	336	0.225	0.72	22.25	0.1	0.045	0.6	2.1
B2	1119	173	0.47	0.54	9.35	0.33	0.1	1.1	1.45
B3	731	133	0.519	0.54	5.12	0.19	0.19	1.07	1.38
B4	1282	275	0.212	0.44	5.7	0.18	0.17	0.16	2.16
B5	1412	222	0.36	0.46	6.1	0.19	0.16	1.5	1.66
B6	876	199	0.277	0.42	7.2	0.18	0.13	1.8	1.9
B7	1988	354	0.2	0.41	6.06	0.18	0.16	1.9	2.24
B8	445	183	0.166	0.28	8.21	0.15	0.12	4	2.44
B9	2660	424	0.185	0.35	6.31	0.14	0.15	2.5	2.32

Accordingly, in the present study the drainage sub-basins are classified into two types as either elliptical or circular as follows:

- Elliptical type ranges between 0.21 and 0.43. Consequently, sub-basins No. B1, B4, B5 and B6 represented this type (Table 3).
- Circular type ranges between 0.44 and 0.62, sub-basins No. B2 and B3 in the study area are belonging to this type (Table 7).

Elongation ratio (Re) The elongation ratio values of the drainage sub-basins are ranging between 0.28 and 0.72 (Table 7). Strahler (1964) classified the drainage sub-basins into three categories; very low relief sub-basins which has values near to 1.0, while the values in the range of 0.6–0.8 refer to high relief sub-basins and steep surface slope. These values are further categorized into three types circular (> 0.9), oval (0.9–0.8) and less elongated (< 0.7). Most sub-basins watershed in the present study belong to the third type (less elongated), except only one sub-basin No. B1 belongs to oval shape type.

Drainage density (D) is an important ecosystem controlling the hazards as its densities denote the

nature of the soil and its geotechnical properties (Pareta 2004). It is an important indicator of the linear scale of land-form elements in stream-eroded topography and it may be thought of an expression of the closeness or spacing of channels (Strahler 1964). In the current study, the absolute drainage density values are ranging between 5.12 km/km^2 for B3 sub-basin and 22.25 km/km^2 for the B1 sub-basin (Table 7). The weighted drainage density map was created by assigning weights to each class (Fig. 15). There is an inverse relationship between drainage densities of a drainage basin function of infiltration into groundwater based on soil type. High drainage density values are favorable for runoff, and hence indicate low flood chance based on permeable characteristics of rock.

Stream frequency (F) is reflects the geologic structure behavior and climatic conditions. The stream frequency is mainly changes in values from one basin to another based on lithological units, the gradient of the slope, stream orders and the source of watershed. Stream frequency values of the drainage sub-basins in Najran region have low values which they are ranging between 0.1 streams per km^2 for sub-basin No. B1 and 0.33 streams per km^2 for sub-basin No. B2 (Table 7).

The relative similarity of drainage density values for the studied sub-basins means that they were developed under the same climatological and hydrological conditions. This means that the most of sub-basins run in similar geologic units.

The constant of channel maintenance (C) It refers to the amount size of terrain units in a basin watershed and has a specific hereditary significance (Strahler 1957). The values range between 0.045 and 0.19 km^2 (Table 7). Generally, the absolute values are seemingly identical and low as a result of coarse texture.

Lemniscate ratio (k) The highest value of lemniscate ratio shows that the watershed occupies the maximum area in its regions of inception with large number of streams of higher order. Higher values represent elongated basins with nearly pear-shaped, tear-shaped a lemniscate. Low values indicate that basin nearly rounded and prevailing vertical and lateral erosions, which refer to the geomorphic stage development of a basin (Ashour and Torab 1991). In the present study, most sub-basins have high values of Lemniscate Ratio. Therefore, these sun-basins are elongated in shape (Table 7).

Compactness ratio (Co) refers to homogeneity between the shape of basin perimeter and basin area and similar in its sensitivity to circularity ratio (RC). It ranges in the studied drainage sub-basins between 1.38 which have been recorded in B4 and 2.44 have been recorded in B8 (Table 7). Compactness ratio (Co) is increasing with increasing curvature of water divide.

Fig. 15 Drainage density map of the study area
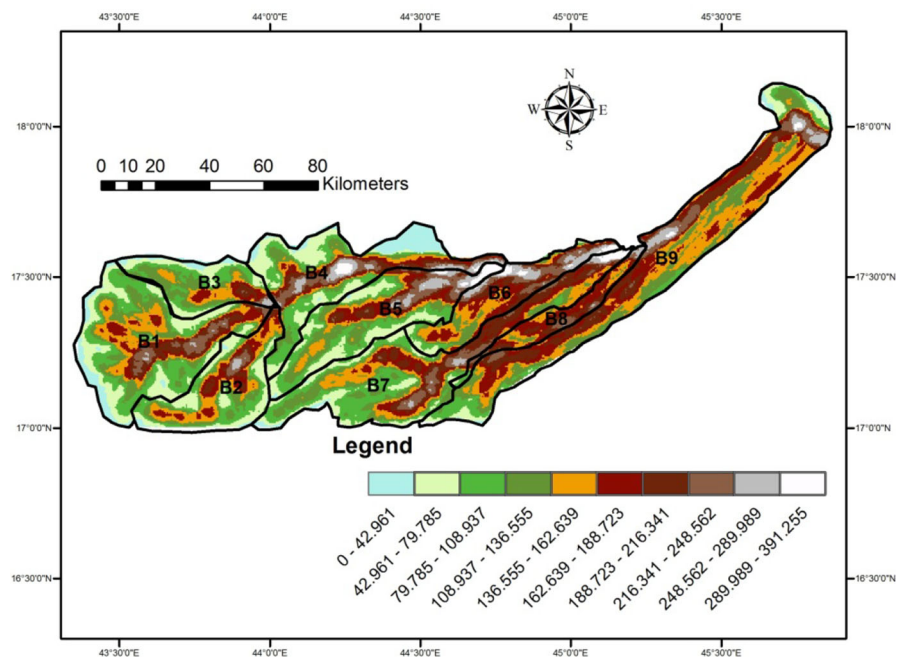
Generally, compactness ratio values in the study area are low. Low values refer to develop of the basin in its geomorphic stage (Ashour and Torab 1991; Mohammed 1993).

4.6.3 Relief Properties of Drainage Basins

Basin relief (H) is indicate to the topographical aspect of the basins, the difference between highest and lowest points in vertical dimentional of the drainage basin is basin relief. All studied drainage sub-basins are debouching into Wadi Najran downstream. The contour map which created from DEMs data of the study area (Fig. 16) Shows that there is greatly ranging in basin relief from 850 to 1450 m for sub-basin No. B9 and 1760 to 2200 m for sub-basin No. B3.

Relief ratio (Rh) is the ratio of maximum relief to horizontal distance along the longest dimension of the basin parallel to the principal drainage line (Schumm 1956). It ranges between 0.004 for sub-basin No. B2 and 0.0096 for sub-basin No. B5 (Table 8). According to this study, we noted that there is an inverse relationship between the average slope and relief ratio. Increasing Rh due to increasing shape means decrease the time required for the concentration of

runoff. So, the high relief (steeper) hill slopes and high stream gradient means high hazard.

Texture ratio (T) is based upon the underlying rock type and elevation feature of the terrain. The texture ratio values are greatly varies in the current area between 0. 37 km recorded in sub-basin No. B8 and 2.15 km recorded in sub-basin No. B2, (Table 8). Morisawa (1958) classified basins based on the texture ratio into four categories;

- (< 8 km coarse texture), (8–20 km medium texture), (20–200 km soft texture) and (> 200 km very soft texture). Consequently, all drainage sub-basins in the present area belong to the first category (coarse texture) (Table 8).

Ruggedness numbers (Rn) ranges between 0.025 and 0.19 which this value is considered as extremely high values of ruggedness number. They occur when both variables (basin relief and density) are large and when the slopes are not only steep but long as well.

The slope index (Si) it provides an indication of the intensity of erosion processes operating on the basin slopes, where steep slopes contribute large quantities of coarse debris to the stream channels. Most of the sub-basins in the present study have high values of slope index (Table 8), which indicate a short time of

Fig. 16 Contour map showing the difference in elevation in the study area
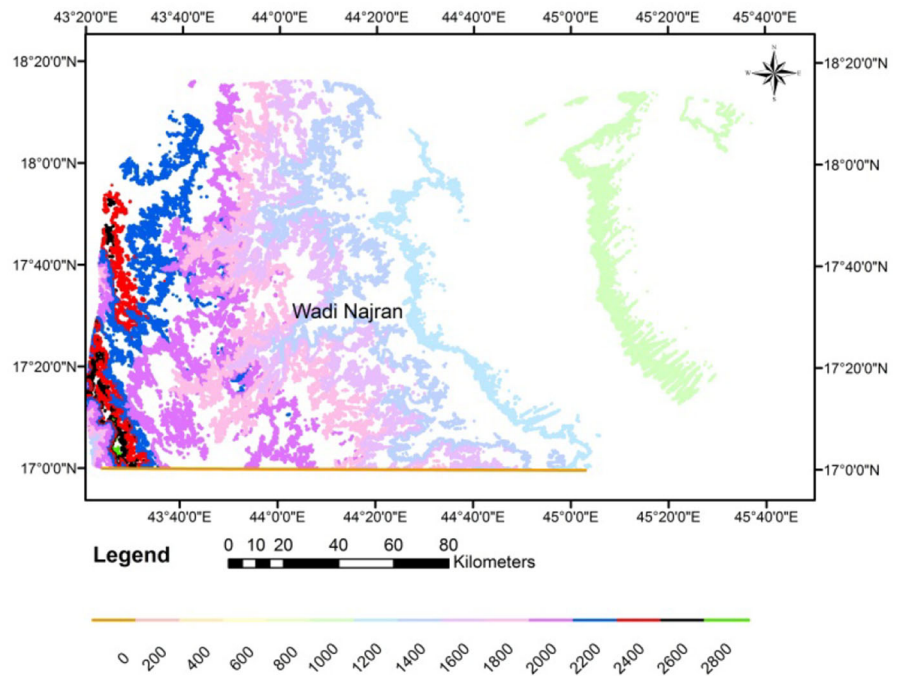
Table 8 Relief characteristics of the drainage sub-basin watersheds in Najran area

Wadi name	Basin relief (m)		Rh	T	Rn	Si	Form factor
	Max.	Min.					
B1	1950	1350	0.0085	0.61	0.19	0.33	0.41
B2	2000	1720	0.004	2.15	0.037	0.3	0.22
B3	2150	1760	0.007	1.04	0.035	0.36	0.23
B4	1860	1100	0.0084	0.86	0.048	0.42	0.16
B5	2000	1110	0.0096	1.2	0.058	0.31	0.17
B6	1550	990	0.007	0.8	0.05	0.45	0.13
B7	2020	980	0.0085	1.02	0.051	0.35	0.13
B8	1370	970	0.0047	0.37	0.038	0.82	0.06
B9	1540	850	0.0041	0.91	0.025	0.31	0.1

runoff concentration and increase in the flood potentiality.

The relation between the weighted mean bifurcation ratio and both of the drainage density and frequency is very important factor to assess and estimation of flooding hazard and feeding probabilities. Two relation graphs are created to know and category the risk basins assessment of flooding. The location of any basin on the two relations designates its runoff/infiltration potentiality (Fig. 17). The most affecting factor in risk calculation is the density and frequency of drainage segments. Hazard is directly proportional to stream density and stream frequency. Accordingly, the sub-basins in the area can be classified into three classes. Class A, class B and class C (Fig. 18).

The risk value evaluation results indicate that drainage sub-basins No. B1, No. B3 and No. B6 have high risk of flash floods and the others are low and moderate. According to morphometric parameters results sub-basins B1, B3 and B6 have the greatest influence on the human and natural activities. Najran city is located in sub-basin No. B4, this sub-basin has moderate in flash flooding hazard, but No. B1 and No. B3 sub-basins downstream run in No. B4 (Najran city). At any heavy rainstorm take place in Najran area, the flood that will be happening in sub-basins No. B1 and No. B3 will pour to and affect in sub-basin No. B4, which it includes Najran district. So, Therefore, the officials should make the necessary precautions, and the work of various dams and protection to prevent the water of these floods from the destruction of infrastructure, buildings, vital areas and the destruction of tens of acres of agricultural lands in the Najran

city. It is also necessary to protect Najran dam, which is one of the most important dams in the area. Therefore, the construction of dams will help to reduce the intensity of flooding, but it may not sufficient for absolute protection from total flooding.

The morphometric parameters assessment of drainage sub-basins have been estimated for the degree of hazard due to flooding. A scale number for the hazard degree starting with (1) lowest to (5) highest, has been given to the all parameters using the following formula equation

$$Y = \frac{(Ymax - Ymin)(X' - Xmin)}{(Xmax. - Xmin)} + Ymin \ (Davis \ 1975)$$

where Y is the relative hazard degree, Y max. and Y min. are the upper and lower limits of the proposed scale (class five or 5 degree and first class or 1 degree in this class). X max. and X min is the higher and lower estimated values of any parameter. X' is the estimated value of any parameter between higher and lower values. Therefore, the drainage basins can be classified according to the estimated degree of hazards into Extreme highly hazardous: the hazard degree of (5), highly hazardous: the hazard degree of (4), moderately hazardous: the hazard degree of (3), slightly hazardous: the hazard degree of (2), and Weakly hazardous: the hazard degree of (1).

The values of actual hazard degrees of each morphometric parameter of the studied basin have been tabulated in Table 5. The hazard map is created according to these scales. It has been used to classify the studied sub-basins into three types highly
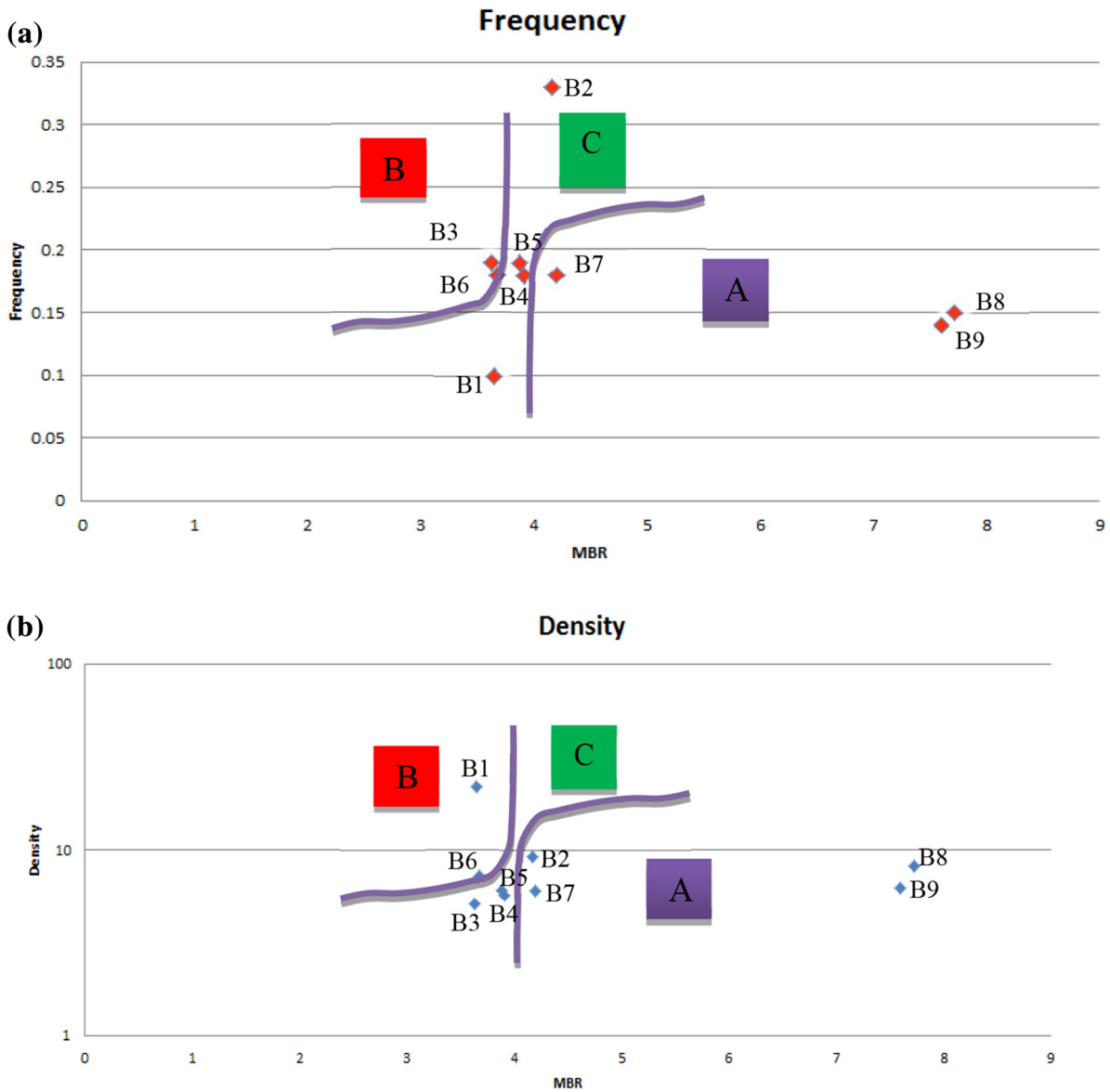
(a)

(b)

Fig. 17 Two graphs show relations between bifurcation ratio and both of drainage density and drainage frequency of sub-basins based on El Shamy's Model (1992). Designations: A: low flood possibilities and high feeding of groundwater potential; B: high flood possibilities, and low feeding of groundwater potential; C: intermediate flood possibilities and feeding of groundwater potential

hazardous, moderately hazardous and slightly hazardous (Table 9 and Fig. 19).

5 Conclusion

Najran area is considered one of the most important promising areas for various types of sustainable development (urban and industrial expansions, as well as Agriculture growth) at the present and in the future in KSA, but the natural hazards are attack and impede these sustainable development, especially sand dune movement, rock falls, problem soils, earth fissures, dust storms and flash floods.

Many factors contribute to the appearance of these problems including climatic, geologic and

Fig. 18 Flash floods and groundwater recharge possibilities map of sub-basins using some morphometric parameters based on El Shamy's Model (1992)
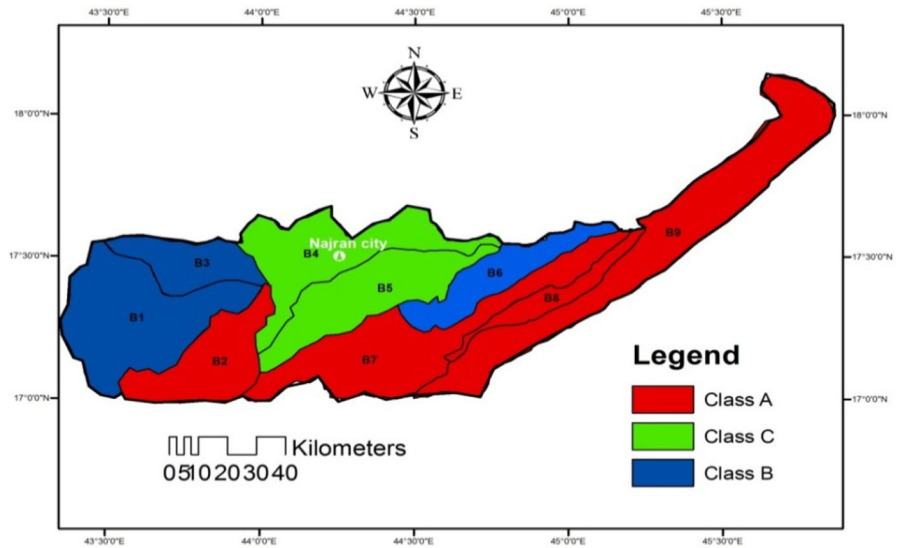

Table 9 Hazards degree of sub-basins watershed in the present study

Wadi name	A	D	F	Ru	Rt	Shape index	Rr	Ff	MRb	Hazard degree	Hazard value	Hazard degree
B1	3.85	5	1	5	1.54	1.23	4.21	5	1.03	27.87	3.09	Highly hazardous
B2	2.21	1.98	5	1.29	5	1	1	2.82	1.52	21.85	2.42	Moderately hazardous
B3	1.51	1	2.56	1.24	2.50	1.46	3.14	2.94	1	17.37	1.93	Slightly hazardous
B4	2.51	1.13	2.39	1.55	2.10	1.92	4.14	2.14	1.28	19.18	2.13	Moderately hazardous
B5	2.74	1.22	2.56	1.8	2.86	1.07	5	2.25	1.25	20.79	2.31	Moderately hazardous
B6	1.77	1.48	2.39	1.60	1.96	2.15	3.14	1.8	1.04	17.37	1.93	Slightly hazardous
B7	3.78	1.21	2.39	1.63	2.46	1.38	4.21	1.8	1.56	20.45	2.27	Moderately hazardous
B8	1	1.72	1.86	1.31	1	5	1.5	1	5	19.40	2.15	Moderately hazardous
B9	5	1.27	1.69	1	2.21	1.07	1.07	1.45	4.88	19.67	2.18	Moderately hazardous

geomorphic conditions, and human activities. The geologic setting is usually the controlling factor influencing the type of hazards that will be found. The potential geohazards that may occur in the Wadi Najran and surrounding areas under desert conditions may include sand draft and dune movement, earth fissures, rockfall and slope stability hazards, water quality, dust storms, problematic soils and flash floods.

Engineering solutions for these problems require a detailed site investigation for each new development area to determine the geological hazards that will affect the project and to assign the best remediation method to avoid the presence of these types of hazards. Wadi Najran roads represent a vital important lifeline to all people in the city, main road run from east to

west in the middle area. Also the Najran basin represents the main drainage basin, in which the Wadi Najran discharges its water to the low laying area at the east, where it quickly filled with flood water, trapping unsuspecting motorists, and caused severe damage to the economy, urban areas, infrastructural facilities, and roads. This road and some cities and villages have been subjected to flash floods once or twice annually, especially in the spring and autumn. In recent years, the frequency of flash floods increased, some of these flood events have occurred in the year 2015. To remediate the flash flood hazards, the governorate (Municipality of Najran Area) make the underground rainwater drainage systems design in the area that are subjected to floods.

Fig. 19 Risk assessment map of sub-basins watershed in the present study
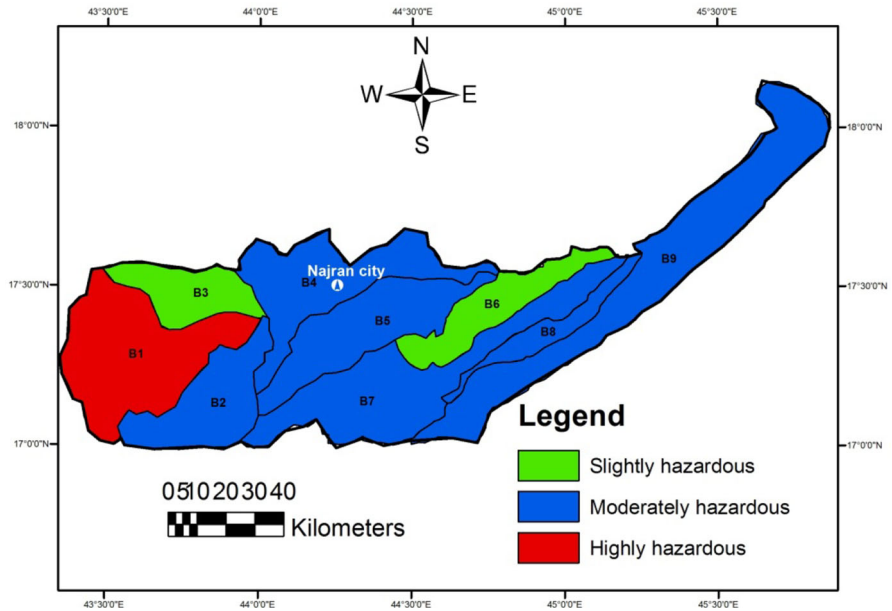
Today, flood protection is essential. It complements other preventive tools like the effective planning of the growth of cities by creating a computerized GIS database for the flood-prone areas. To avoid or alleviate flash flood damages and possibly to aid in exploitation of flood water for recharging shallow aquifers the following preventive and control measures should be considered. Construction of successive incomplete rocky dams using the available locale materials at least along the elongated main course of large wadis as drainage sub-basins No. B1, No. B3 and No. B6 to decrease the velocity of flood waters and increase their percolation into the wadi bed. A series of dams construct at strategic locations each basin may be help us to avoid future flooding of the sustainable development.

The rockfall hazards in Najran because this type of hazard is generally locally in the regions where roads and buildings are close to mountain around Najran area. Nevertheless, road armoring and fixing of hanging blocks are recommended. The present study demonstrates the importance of remote sensing as a tool for monitoring and mapping geo-environmental hazards in Najran region. Development projects should consider the ranking and severity of these hazards and should involve the safety precautions in construction costs. The outcomes of this study show that in Najran region flash floods and dust storms are the most severe among other hazards.

The regional geohazards monitoring center is recommended to gather data and to disseminate public awareness and prepare emergency plans for evacuation and remediation purposes.

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