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Landforms Classification of Wadi Al-Mujib Basin in Jordan, based on Topographic Position Index (TPI), and the production of a flood forecasting map.

Yusra, Al-husban *

ABSTRACT

The main target of this study is to classify the landforms of wadi Al-Mujib Canyon, as considered one of the main wadi draining towards the Dead Sea. Based on Topographic Position Index (TPI), and depend upon Shuttle Radar Topography Mission (SRTM) data for preparing digital elevation model (DEM) which is available with 30*30 m ground resolution. By using the TPI, the landforms were classified into both Slope Position index and landform types. Landform categories were generated by combined two TPI grids at different scales (neighborhoods: (a 1km radius and 2km radius). TPI defended as: algorithms of Weiss and Jenness used to measure the topographic slope positions and automated landform classifications. TPI values are depended upon the cell size, type, elevation, and the standard deviation (SD) of TPI. By using TPI, the study area classified into slope position index with 6 classes; Valley, Lower slope, Flat slope, Model Slope, Upper Slope, Ridge, and the Landform categories with 10 classes are as follows; canyons / deeply incised streams, middle slopes, drainage, shallow valley, upland drainage, head water, u-shaped valleys, Plains, open slope, upper slope, local ridges, hills in valleys, midslope ridges, small hills in plain, and mountain tops, high ridge. Canyons / deeply incised streams, valley and ridge were forming the majority of landforms patterns, forming about 78.5% of all six landforms classes and the tenth-landform categories. Landforms pattern have strong relationship with the natural hazards including flash floods; thus about 37% from the total of the study area facing high risk of flooding.

Keywords: Landform classification, Wadi Al-Mujib Canyon, TPI, SPI, DS, hazards.

1. Research background

Landform classification considered a central research issue in geomorphometry (Pike, et al 2009; Dikau, et al, 1995). The Landforms are defined as the specific geomorphic features on the earth`s surface, ranging from large-scale features such as plains and mountain ranges to minor features like an individual hills and valleys (Blaszczynski, 1997; Tagil and Jenness,2008; Jenness,2005; Jenness,2010). Since 1970s advances in computer technology, new spatial analytical methods, and the increasing availability of DEM data which is get used on the geomorphometry studies (Alhusban, 2014; Al-husban and Zraigat, 2012; Pike, 1999; Seif, 2014; Merina, et al.2011). Derivation of landform units can be carried out using various approaches such as: classification of morphometric parameters, filter techniques, cluster analysis, and multivariate statistics. Morphometric studies usually begin with the extraction of the relief aspect including; elevation, slope, and aspect (MacMillan and Shary, 2009; Schmidt and Hewitt, 2004; Draut and Blaschke, 2006; Drăguţ and Eisank, 2011; Al-husban and Zraigat, 2015). Weiss, and Jenness introduced a new GIS application for the automated landform classification well known the Topographic Position Index (TPI), (Weiss, 2001; Jenness, 2006; 2008; 2010). Using TPI at different scales geomorpholgests can easily classified the landscape into both slope position (Valley, Lower slope, Flat slope, Model Slope, Upper Slope, Ridge), and landform category (Canyons / Deeply incised streams, Middle Slopes, Drainage, Shallow Valley, Upland Drainage, Head water, U-shaped valleys, Plains, Open Slope, Upper Slope, local Ridges, Hills in Valleys, Midslope Ridges, Small Hills in plain, and Mountain tops, High Ridge), (Jenness, 2007).TPI measures the difference between elevation at the central point (z0) and the average elevation around it within a predetermined radius (R) , TPI compares the elevation of each cell in a DEM with the mean elevation of a specified

* Faculty of Arts, the University of Jordan, Amman, Jordan. Received on 25/9/2017 and Accepted for Publication on 28/10/2018.

neighborhood around that cell (Weiss, 2001; Jenness, 2006). For that since the creation of an ESRI Arc View 3.x extension by (Jenness, 2006). TPI has been widely applied in the geomorphology fields (Tagil and Jenness, 2008; De Reu, et al.2013; Seif, 2014A; Seif, 2014B). And many studies adapted TPI at different scales to classify the landscape into both slope position and landform category (Naydenova and Stamenov, 2013; De, Reu, et al, 2013; Seif and Mokarram,2013).With regards to Flash floods; Floods are the most catastrophic natural disaster that occurs in arid land over the world (EM-DAT, 2008, at http://www.emdat.be/). Which have a significant negative impact on Human and infrastructure in the study. Flood hazard mapping is therefore a crucial tool for monitoring the flood risk in our study area; which are characterized by low rainfall, and in contrast their high intensity. Many geographical factors contribute to the flooding problem, and influence flash flood severity in arid and semi -arid land; Among these factors are: topography (altitude, slope), drainage network and basin properties, land use/land cover, the rainfall intensity and duration **.**To determine areas of potential flooding and levels of risk, in W.Al-Mujib basin and its relationship with the landforms patterns; geomorphometric, daily rainfall, and LULC, parameters were used as input data ,applying GIS tools (Elkhrachy, 2015).

2. Study area:

Wadi Al-Mujib is located in the middle part of Jordan Rift Valley (JRV) with an area of 7205.057 km², and extends between 35 º 20′ 0 to 36 º 20 ′ 0″ E and 30 º 20 0″ to 32 º 0 ′ 0″ E. Topographically wadi Al-Mujib lies with maximum elevation of 1267m below mean sea level (b.m.s.l) which is located in the southern east and southern west of the basin, while the lowest elevation decline to - 425 m (b.m.s.l) which is located in the western part of the basin at its outlet the Dead Sea (DS). (DS): the lowest point on the land and its base level has dropped during the last 64 years ago for -34m vertical distance (Al-husban, 2003. Geological structures in the area are affected by the Jordanian – Dead Sea Rift Valley, and the dominant tectonic features are the East – West Siwaqa fault and WE – SE Karak wadi Al-Fiha fault (Bender, 1975; 1988), Figures 1and 3. Wadi Al-Mujib and wadi Al-wala join at 1km east of the Dead Sea. The climate in Al-Mujib basin varies from semi arid in the upper basin mountains, with an annual precipitation 350 mm to the arid regions in its lower part at the Dead Sea shore with an annual rainfall average of 70 mm for the last decade .The average temperature in the lower basin is 40ºC in summer and 15ºC in winter, while in the upper part of the basin is 35ºC in summer and 10ºC in winter (Shehadeh, 1991). Here it is necessary to mention the impact of the decline of the Dead Sea surface water level upon the development of unique patterns of landform in Wadi Al-Mujib; as wadi, Al-Mujib forms one of the main canyon wadi draining to the Dead Sea. The Dead Sea level declined as a result of the water utilization in the Dead Sea Basin (DSB) by riparian counters:occupied Palestine, Jordan, and Syria, besides the impact of Climatic Change Which represent lower precipitation and higher temperature has also an impact on the dramatic decline of the DS level; which led to a significant reduction in inflow over the last 64 years, a drop of about -34 m in the mean sea level, (- 0.53 m/year) has occurred and has resulted in a continual adjustment of the wadi Al-Mujib to a new base level; the impacts of this lowering led to develop the river basin Canyon as one of the major canyons draining into the Dead Sea, by vertical and headward erosion for a unique set of shore-line terraces developed (Al-husban, and Almanasyeh, 2017;De Jaeger and De Dapper,2002;Odeh and Salameh, 2005; Odeh and. Salameh, 1996; Odeh.1998; Salameh, 1980; Hasan and Klein, 2002; Frumkin and Elitzah, 2002).

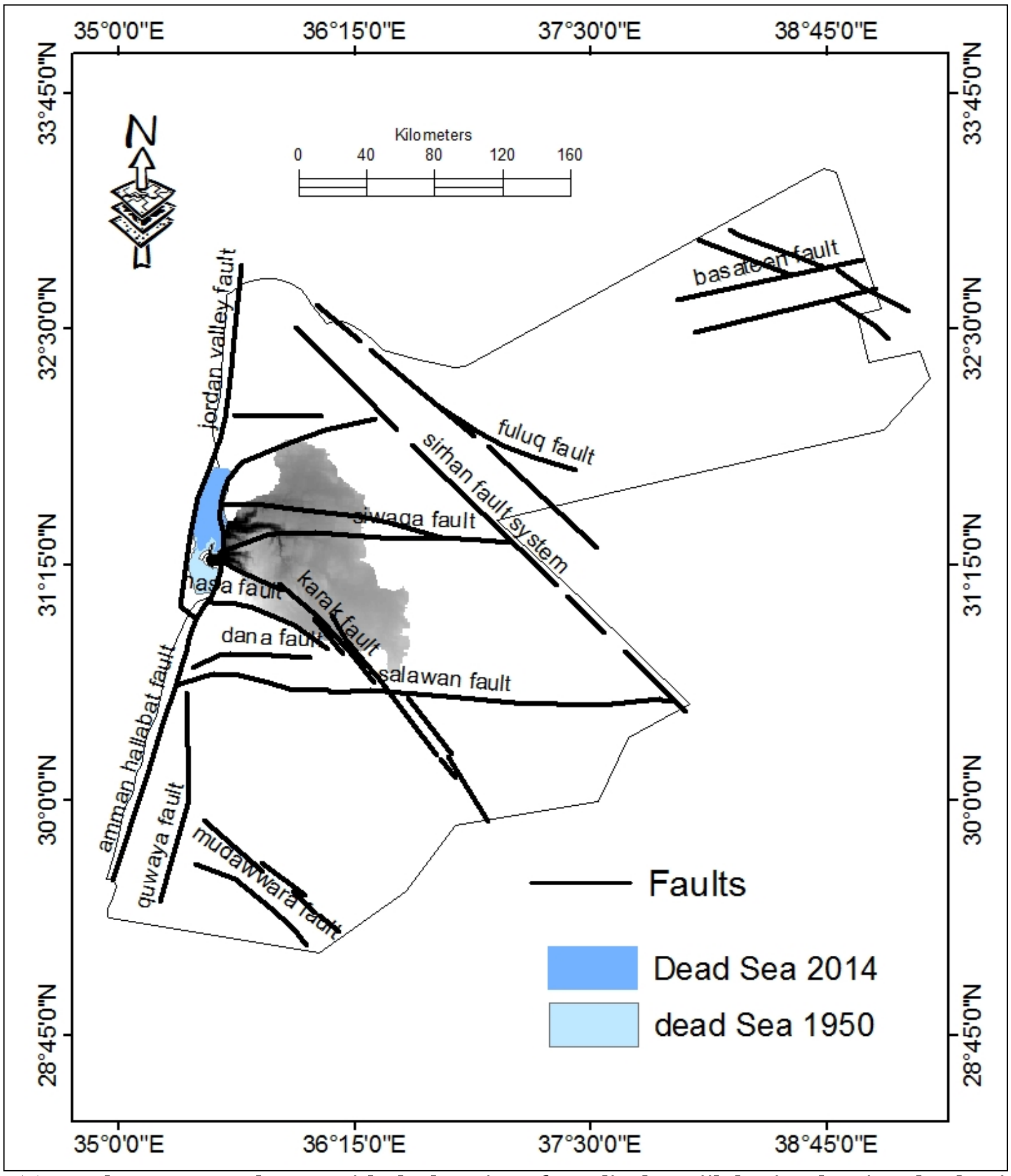

Figure. 1. (1). Jordan Structural map, with the location of Wadi Al-Mujib basin, showing the dominate faults that affects the study area.

3. Material and methodology

3.1Global Digital Elevation Model (GDEM)

The dataset for the study area originates from a (GDEM) with resolution of 30*30 m (SRTM), which was downloaded from http://srtm.csi.cgiar.org. Since the creations of topographic position index (TPI) by Weiss and Jenness (Weiss, 2001; and Jenness 2006) the geomorphologies used this TPI at different scales, to classify the landscape into both slope position (Valley, Lower slope, Flat slope, Model Slope, Upper Slope, Ridge), and landform category (Canyons / Deeply incised streams, Middle Slopes, Drainage, Shallow Valley, Upland Drainage, Head water, U-shaped valleys, Plains, Open Slope, Upper Slope, local Ridges, Hills in Valleys, Midslope Ridges, Small Hills in plain, and Mountain tops, High Ridge). The TPI is the basis of the classification system and represents the difference between a cell elevation value and the average elevation of the neighborhood around that cell (Tagil and Jenness, 2008). Positive values mean that the cell is higher than its surroundings represented Upper Slope High Ridge…etc. while negative values mean it is lower which represented Valley Lower …etc. The degree, which is higher or lower, plus the slope of the cell, used to classify the cell into slope position (Jenness, 2007; 2008). TPI compares the elevation of each cell in a DEM to the mean elevation of a specified neighborhood around that cell, within a predetermined radius (R) (Weiss, 2001; Jenness, 2006; De Reu et al, 2013). TPI with local window options of, circular adapted for landforms classification in this study, TPI grids generated from 1km and 2km was presented in figure 4.and table. 1 using extension for Arc View 3.x, v. 1.3a. Jenness Enterprises. Available at: http://www.jennessent.com/arcview/tpi.htm. Applying (**Eq.1):**

$$TPI_t = z_0 - \frac{\sum_I -n\, z_n}{n}$$

Where;

z0 = elevation of the model point under evaluation Zn = elevation of grid within the local window

n = the total number of surrounding points employed in the evaluation.

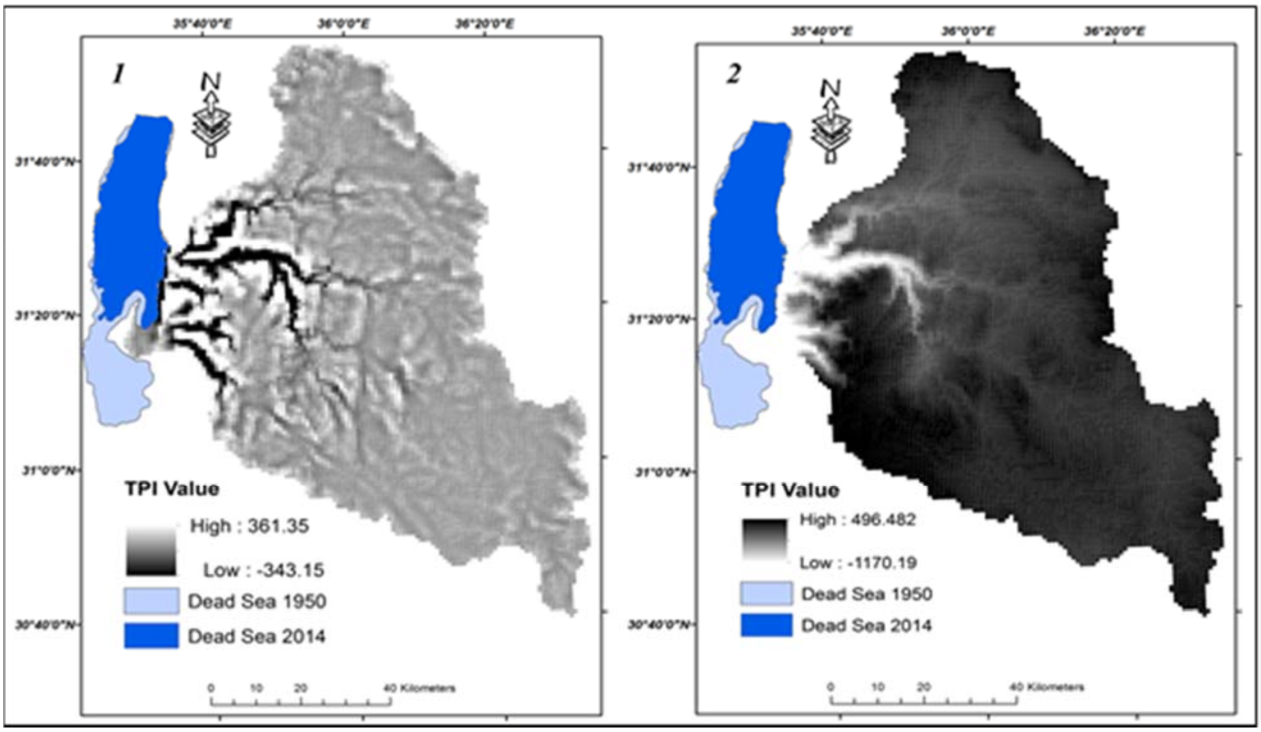

Figure 2. Two TPI at different neighborhood sizes scales (1).1km and (2).2km

Table 1. The attributes of Two different Neighborhood size.

TPI	Neighborhood option/ size	Max Value	Min Value	SD
TPI (1)	Circle/Radius (1)	361.35	-343.14	6.99
TPI (2)	Circle/Radius (2)	496.482	-1170.19	7.6

3.2. Floods forecasting map:(*)

In the present investigation morphometric analysis and the use the hydrological modeling tools, along with remote sensing data and digital elevation model (DEM) employed for assessing the susceptibility of sub-basins to flash flooding. Risk map layer were generated for the 104 sub-basins of W. Al-Muijb basin, after that the flood map generated by using overlaying tools in Arc GIS V.10.4).

3.3. Landsat ETM (8) acquired in 13/7/2017, with spatial resolution 30 *30, WRS Row 38, Path174 was used to generate LULC by adapting supervised classifications method.

3.4. The 14 meterological stations with daily rainfall were used to genreat the spatial distribution of the rainfall,

(*)Details in next paper: entitled "Environmental risk patterns in W.Al-Mujib".

using interpolation tools in Arc GIS V.10.4)

3.5. Topographic and morphometric characteristics were derived from the DEM, applying Hydrology tools for delineation of drainage networks and the watershed. All data are geo-referenced to the UTM coordinate system (WGS 1984, Zone 36˚N) based on the shape file of the study area border.

4. The effects of the Topographic and drainage networks attributes upon the Landforms Patterns.

Elevation, contour, Slope and Slope aspect, maps computed from DEM; Figure 3. Using Arc GIS.V10.4 (Spatial Analyst-Surface tools), while Stream order computed from DEM using Arc GIS V.10.4 according to Strahler's system (Strahler, 1964). Relief is the elevation between the highest and lowest point, (Schumm, 1956). The relief decreases gradually from east to west. Although the study area can be described as hilly flat in nature, and it can be divided according to elevation to three categories: 1). The first one where the elevation ranges between -425 to 0 m (b.m.s.l) in the western part which formed 22% from the study area. 2). The second one where the elevation ranged between > 0 to 790 m (a.m.s.l) formed 15%. 3). The third zone with elevation between >790 to 1267m (a.m.s.l) formed 63%. The relief within the study area is 1692m, Figure 3. Slope is one of the most important terrain parameter which is explained by horizontal spacing of the contours and landforms patterns. In general, closely spaced contours represent steeper slopes and sparse contours exhibit gentle slope, (Strahler, 1956; Schumm, 1956). Slopes in the study area have been shown in Figure 3. Most of the area about 65% classified as hilly flat slopes (0°-2º). while a hilly moderate slope (2°-6°) forms 15%, and 20% from the study area with slopes more than >10º steeply sloping to Cliffs. Slope aspect identifies the steepest down slope direction from each cell to its neighbors and show the magnitude and the direction of the surface topography Figure. 3 showed that about 68% from the slope aspect towards west, and southwest to JRV.

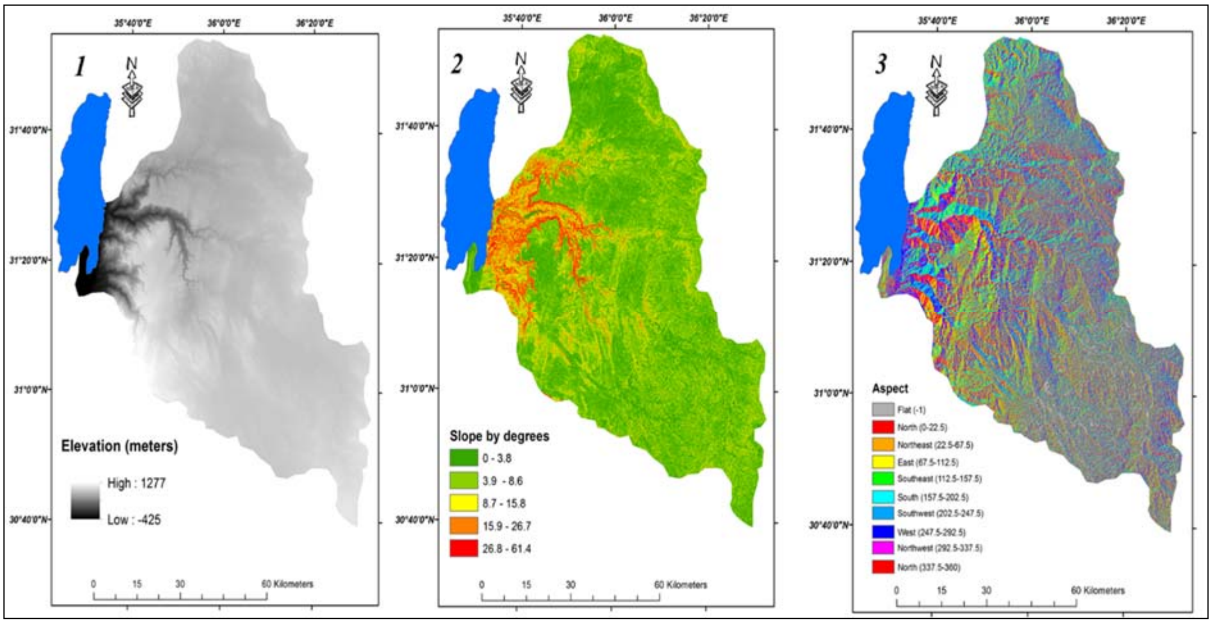

Figure 3. Topographic attributes: Elevation (M), Slope (Deg), Slope aspect, numbers (1-3) respectively.

The total drainage basin boundary and major drainage networks were delineated from DEM. It was found that this drainage basin is a 7th order stream; [(**)] .The total area of W.Al-Mujib is 7205.057 km², divided in to 22 sub-basins, Figure 4.

[(**)] The total number of sub-basins and even the stream order depended upon the Conditional (con) value, the (con) value in this study is >500.

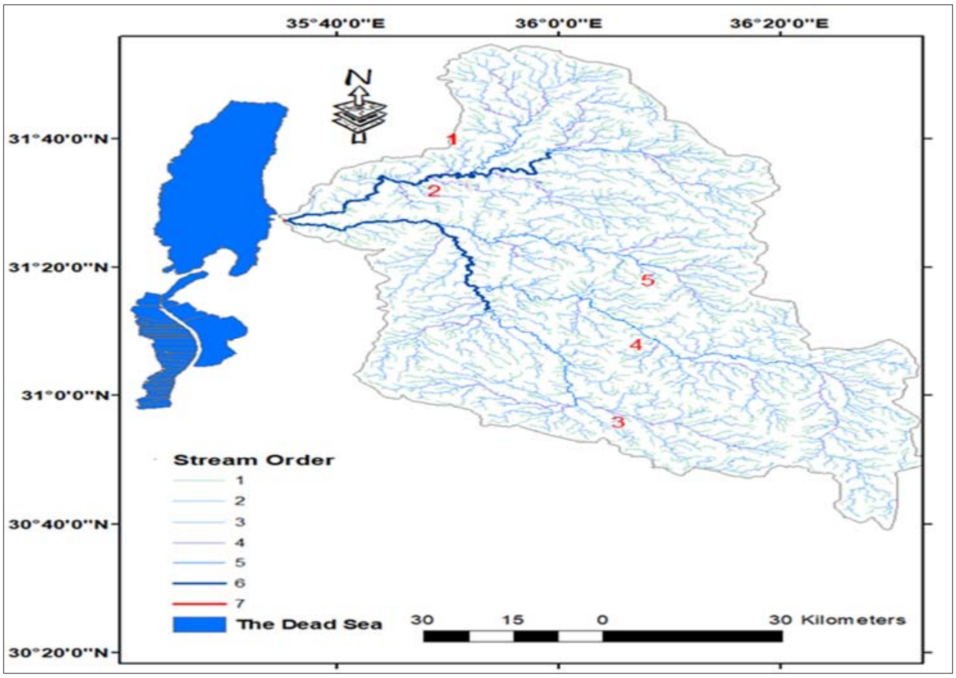

Figure 4. Stream order according to Strahler, 22 sub-basins, and the location of dams (1). Wala dam. (2).Al-Mujib dam. (3).Sultani dam. (4).Qatranah dam. (5).Swaqa dam.

5. Landform classification

The researcher applied the method of (Weiss, 2001,and Jenness, 2006) that classifies the landscape into direct slope position classes using the standard deviation (SD) of TPI, six classes were defined in table 2.and Figures 6-7. In addition, the parameters from two neighborhood sizes circle Radius (1km and 2km) are combined in order to identify complex landscape features, because such a combination provides more information about topography and highlight variety of landforms, (Weiss, 2001; Tagil and Jenness, 2008; Re, Deu, etal, 2013). Figures 5-7 and table 3. Summaries the 10 produced landform classes.

5.1-Slope position index: (SPI) classification based on (SD) for TPI 1km neighbourhood sizes was used; Six classes were defined; the valley and the ridge are the most dominated landform almost 91.6%; while the flat areas are calculated with values near zero. Almost 4% of the basin has TPI value less than 0, and is classified as flat.

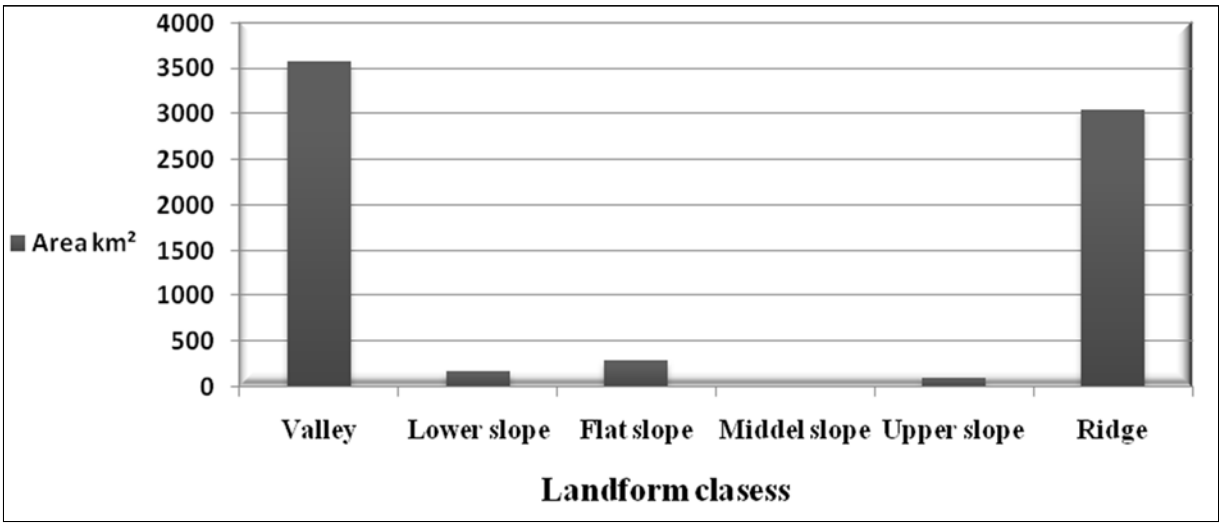

Figure 5. Landforms classes by area, based on slope position classes on TPI grids for 1km.

Tabel 2. Landforms classification based on TPI for 1km m by area.

Landform Classes	Slope Position Classes	Area (km²	Percent (%)
1	Valley	3576.518825	49.63900806
2	Lower slope	170.3822206	2.364758816
3	Flat slope	302.315356	4.195877367
4	Middle slope	1.507807262	0.020927069
5	Upper slope	106.3004119	1.475358376
6	Ridge	3048.03238	42.30407031
Total		7205.057	100

5.2-Landform classification by combined Two TPI different neighborhood sizes:

In addition to that, landform classification based on combined neighborhood sizes1km and 2km. Such a combination provides more information about topography of the studying area and can proved more information about the general shape of the landform than TPI values from single neighborhood therefore more complex landforms features can be identified by combining TPI grids generated at difference scales (Tagil and Jenness, 2008; Weiss, 2001). The 10 produced landform classes in Figures 6 and 7.and the description of the landforms is in Table 3.

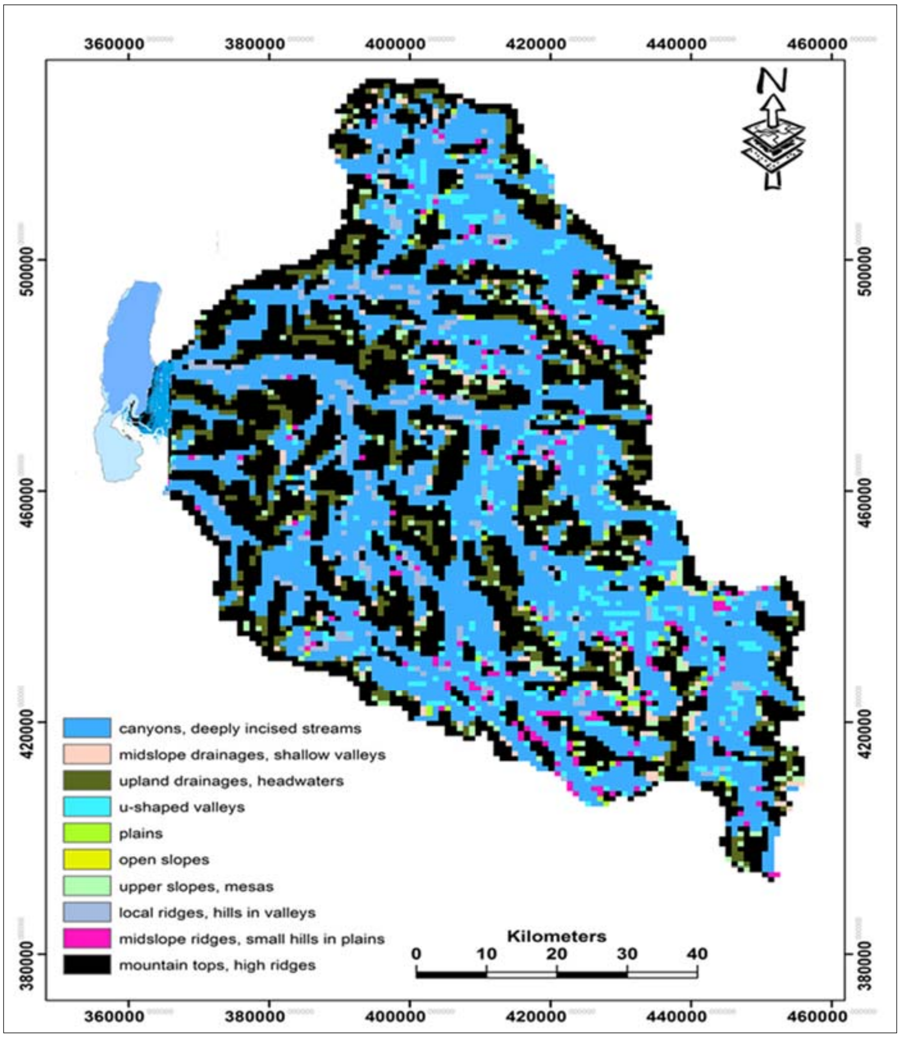

Figure 6. 10 Landform categories based on 1000 and 2000 TPI grids.

Figure 7 Landform categories by area.

Table 3: Landform classification based on combined Two TPI neighborhood sizes1km and 2 km.

Class	landform	Area (km²)	Percent (%)
1	Canyons, deeply incied streams	3014.106716	**41.83321126**
2	Midslope drainage, shallow valleys	126.65581	**1.75787381**
3	Upland drainage, headwaters	444.0492386	**6.163021869**
4	U-shaped valleys	312.8700068	**4.342366852**
5	Plains Open slope	77.65207398	**1.077744062**
7	Upper slope, mesas	181.690775	**2.521711834**
8	Local ridges, hill in valleys	272.1592107	**3.777335984**
9	Midslope ridge, small hills in plans	129.6714245	**1.799727948**
10	Mountain tops, high ridges	2646.201744	**36.72700638**
Total		7205.057	**100**

5.3. Landforms results and flash floods;

The floods phenomenon is widespread in arid and semi-arid lands, which are characterized by the short duration, high flood Peaks and rapid flows (Kumar, and Abdullah, 2011;Sharma, 1996). There are astrong relationship between landforms patterns and natural hazards, (Al-Weshah, and El-Khoury 1999) including; floods, erosion, _despite the scarcity of water resources_; the last flood occurred in 19/1/2018. In this study Slope and altitude play a key role in the occurrence of floods, besides the patterns of land use/cover (LULC) and rainfall amounts and its duration. Identification of possibility of spatial distribution of flood risk areas was in the study area performed using the landforms patterns, altitude, slope, daily rainfall and land use/land cover, applying Arc GIS Spatial analyst tools (Hydrology and Overlay).

5.4. Floods forecasting map

Morphometric method El-Shamy's approach was adapted for assessing susceptibility of all 22 sub-basins to flash flooding risk based on the relationship between bifurcation ration (*Rb*) and drainage density (*Dd*), (El-Shamy, 1992).In addition to land use/cover (LULC) daily rainfall amounts in the study area during the period 1980-2015,were used by overlaying tools .

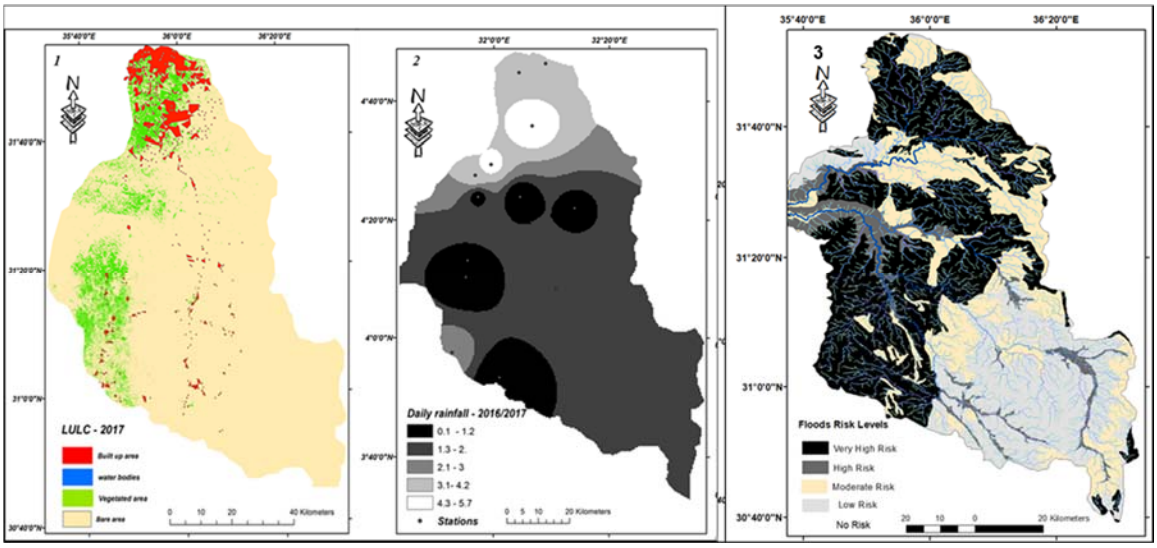

Figure 9. (1) LULC map (2) Daily rainfall/mm/daily, and (3) Probability of flooding risk map.

5.5. Landforms pattern and flood levels distribution;

From Figure 9. (3). The Probability of flooding risk map we can illustrated and classified the spatial distribution of the floods risk into five categories as;

(1).Very high risk: forms 37% from the study area, elevation reaches up to 1277 m and down to -425m (b.m.s.l), vegetated area are concentrated in this zone formed more than 40% from the total vegetated area.

(2).High risk: steep slopes, form 26% from the study area, vegetated area about 25% from the total vegetated area, daily rainfall varied from (1.3 to 3) mm/D and 20% from the buildup area.

(3). Moderate risk: with elevation ranges 750-920m, and formed about 17% from the study area, 30% from the vegetated area, daily rainfall ranges between (3.1-5.7) mm/D and 60% from buildup area.

(4). Low risk: with elevation 800m, represent flat area, exposed bedrock, daily rainfall less than (1.3) mm/D and form 21% from the study area.

(5). No risk: forms only 5% from the study area, barren land, daily rainfall varied from (0.1 to 2) mm/D, Figure 12 and table 4.

Table 4 Landforms pattern and flood risk levels.

Landform Classes/Risk levels	Very High Risk	High Risk	Moderate Risk	Low Risk	Very Low Risk	No Risk
Valley	51	43	22	16	11	13
Lower slope	5	11	12	25	32	21
Flat slope	10	6	18	21	19	23
Middle slope	4	8	15	16	24	19
Upper slope	6	4	11	13	12	16
Ridge	24	28	22	9	2	8
Total	100	100	100	100	100	100

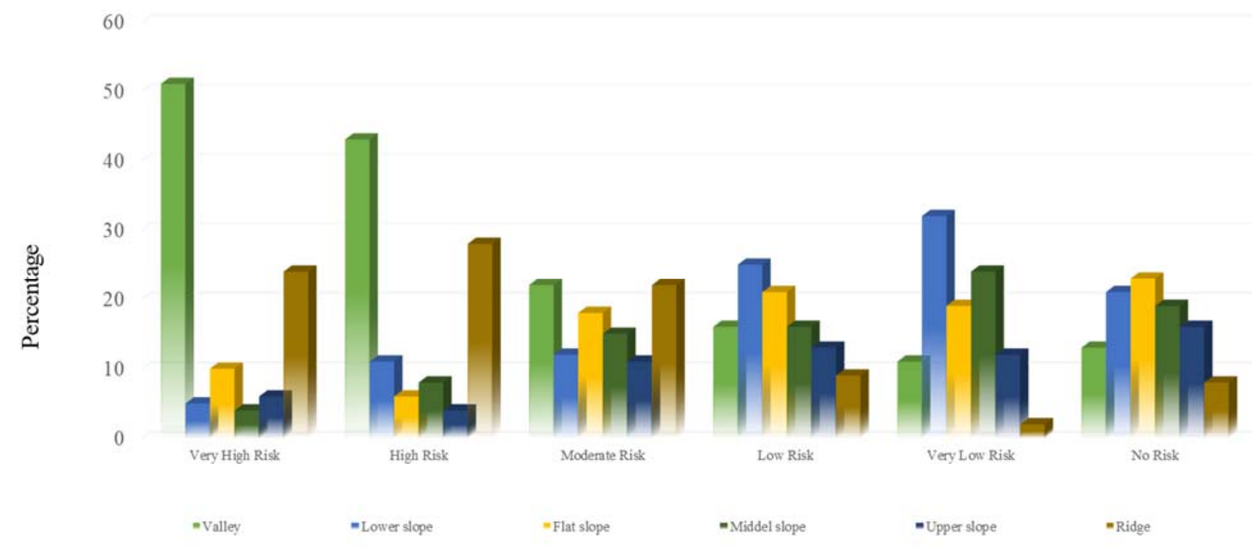

Figure 10. Landforms and flood risk levels.

6. Discussion and Results:

Classifying the landforms by TPI values can easily be classified into slope position classes, or classifying by Landform Category. It's in this study determined by classifying the landforms using Two TPI grids at different scales. The combination of TPI values from different scales suggest various landform types. Landforms and natural hazards have a strong relationship, including floods; for that GIS-based overlay tools using for the probability of flooding risk map achieved by El-Shamy's approach and the daily rainfall's map, LULC map are used for connection between the landforms and flash flood levels; by overlaying these layer we found that the areas with very high risk distributed on deep valleys and ridges which form 75% from the total area ,and high risk areas distributed on valleys and ridges which form 71% from the total area .While the low risk areas distributed on flats and lower slopes which form 45%, table 4 and Figure 10 .

7. Conclusion:

In this research algorithm of Weiss and Jenness was applied to classify the landform in wadi Al-Mujib's Canyon. Input data for landform classification was digital elevation model (DEM). The results showed that the dominated landforms are (canyons / deeply incised streams, Valley and ridge) which forms 78.5% from both all six and tenth landforms classes. Our study area is characterized by complex landscapes affected by the decline of the base level (The Dead Sea) and the faulting system, Figure 1. The canyons, deeply incised streams and the Valley and ridge were the largest category, with percentages ranging between 41.8% and 36.7%.On other hand the landform's patterns, the general topography, morphometric characteristics of the watershed, LULC and daily rainfall were used to assessment of flash flood risk. Finally, this study recommends to maintenance all five dams located in the study area, taking into consideration only Wala dam and Al-Mujib dam qualified out of five dams established in the study area, Figure 4.

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تصنيف الأشكال الأرضية في حوض وادي الموجب، اعتماداً على تحليل المؤشر الطبوغرافية المكاني، وإنتاج خريطة التنبؤ بالفيضانات

يسرى عبدالكريم الحسبان *

ملخص

هدف هذا البحث إلى تصنيف الأشكال الأرضية في حوض وادي الموجب ؛ باعتباره من أهم الأودية الخانقية المنتهية لمنطقة الصدع الأردني حيث يصب في البحر الميت على ارتفاع يبلغ −425 تحت منسوب سطح البحر . وقد اعتمد الباحث في تصنيفه للأشكال الأرضية على تحميل نموذج التضرس الرقمي المتاح بقدرة تمييزية مقدارها 30م لاشتقاق جميع الخرائط الرقمية، ومن ثم استخدام أدوات تحليل المؤشر الطبوغرافي المكاني التي يوفرها برنامج نظم المعلومات الجغرافية؛ من خلال الخطوات التالية: تحليل مؤشر الانحدار المكاني، ومن ثم تحليل المؤشر الطبوغرافي المكاني. وجاءت أبرز النتائج مايلي: 1.وفقاً لمؤشر الانحدار المكاني صُنِّفت الأشكال الأرضية إلى ستة أشكال منها: الأودية، المناطق المستَوية،المناطق الجرفيَّة. 2. وفقاً للمؤشر الطبوغرافي المكاني صُنِّفت منطقة الدراسة إلى عشرة أشكال أرضية منها: الخوانق، الأودية شديدة التعمق، السهول. 3.هناك علاقة قوية بين طبيعة الأشكال الأرضية وخطر الفيضانات ، فحوالي 37% من مساحة منطقة الدراسة معرضة لخطر فيضان شديد.

الكلمات الدالـة: تصنيف الأشكال الأرضية، وادي الموجب الخانقي، مؤشرالانحدار المكاني، المؤشر الطبوغرافي المكاني، الانحراف المعياري، الأخطار الطبيعية.

* كلية الآداب، الجامعة الأردنية، الأردن. تاريخ استلام البحث 2017/9/25، وتاريخ قبوله 2018/10/28.