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Original Paper

The effect of flooding and lateral erosion on the settlements setting, case study: Karkheh River, Iran

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Abstract

Rivers are one of the most important geomorphic and ecological landscapes of the earth, which human settlements take place near them. But today, the unregulated and unmanaged development of human settlements near to rivers has caused rivers to become destructive phenomenon. Objective of this study was to understand flooding and lateral erosion effects on settlement setting in Karkheh River, Iran. A part of Karkheh River between Abdulkhan and Hamidiyeh cities in Khuzestan province, Iran, was studied using AHP method (for delineating flooding prone area) and geometric parameters of river (for lateral erosion detection). The flood zonation carried out with five criteria: distance from the river, elevation, slope, lithology, land use and land cover using the AHP model. The total area of about 51.5% was in the low and very low risk zones and 49.5% was in the medium to very high risk zones. The river route extracted by processing satellite images using NDWI technique for 26 years period (1991 to 2017) and fitting tangential circles showed a large change in the geometric parameters of the river in this period. The central angle, radius and curvature of the river had changed, as a result of which the increasing number of meanders from 46 to 56. This indicates that the river was becoming more meandering, so, there was an increase in lateral erosion in 2017 compared to 1991. Therefore, according to the research findings, it was suggested that the river is a meandering river, so development of settlements may be critical.

Keywords: Flood risk, Geometric parameters, Iran, Karkheh River, Lateral erosion.

1- Introduction

Rivers are one of the important geomorphic and ecological landscapes (Moghimi, 2009). Rivers have played a significant role in development of civilizations and human societies. Floods typically kill about 2,000 people each year and affect 75 million of the world's population (Negaresh, 2003). This danger is increasing due to the physical development of urban areas; therefore, one of the most important considerations is to identify high-risk and low-risk areas. So, the development of human settlements can be managed in the desired direction and reduce the risks of floods. In this regard, paying attention to hydrogeomorphological conditions in identifying and separating suitable and unsuitable zones in the development of man-made structures adjacent to rivers is necessary (Abedini, 2011).

Increasing population has made the physical development of cities and villages inevitable. In this context, the development of settlements adjacent to major rivers is very important, because the river is dynamically active. Karkheh River along the rivers Karun and Dez is considered as of the main rivers of Iran. Considering that the Karkheh River runs through villages and towns along its path, during their rapid physical growth; any unmanaged development can increase the potential of flood damage to the cities and villages. (Arnaud-Fassetta et al., 2005) identified and determined Hydro-geomorphic hazards and impact of man-made structures during the catastrophic flood of June 2000 in the Upper Guil catchment. (Yang et al., 1999) evaluated Remote Sensing and GIS for the Analysis of Channel Migration Changes in the Active Yellow River Delta in China. (Tehrany et al., 2013) examined spatial prediction of flood susceptible areas using rule based decision tree (DT) and a novel ensemble bivariate and multivariate statistical models in GIS. (Fuller et al., 2003) studied Quantifying Channel Development and Sediment Transfer Following Chute-Off in a Wandering Gravel-Bed River. (Ghorbani Nejad et al., 2017) investigated the delineation of groundwater potential zones using remote sensing and GIS-based data-driven models. (Kummu et al., 2008) studied riverbank Changes along the Mekong River using Remote Sensing.

This study aimed to prepare flood zonation map using AHP method and consider lateral erosion of the Karkheh River for understanding effects of flood and river lateral erosion on settlement setting of cities and villages located along the river path.

2- Study area

Karkheh riverside, southwest of Iran (Fig. 1) is one of most important rivers that historic civilization developed near it. The study area has a very low elevation, while about 85% of it is located in the altitude of 8 to 64 meters. Based on digital elevation data, the lowest and highest points of the study area are 8 and 232 meters high, indicating low altitude and flat topography. The higher regions are located in the northwest of the studied area. alluvial deposits are present in the north of Abdulkhan in the eastern part of the study area. Aghajari and Bakhtiari formations are extinct. The passage of two faults along the northwest-southeast direction is one of the other important geological features of the study area. One of these faults has crossed the river bed near Hamidiyeh; this issue and the active tectonic resulting from it can play a role in changing the river path, so caused to lateral erosion of river bank (Fatemi-Aghda et al., 2001).

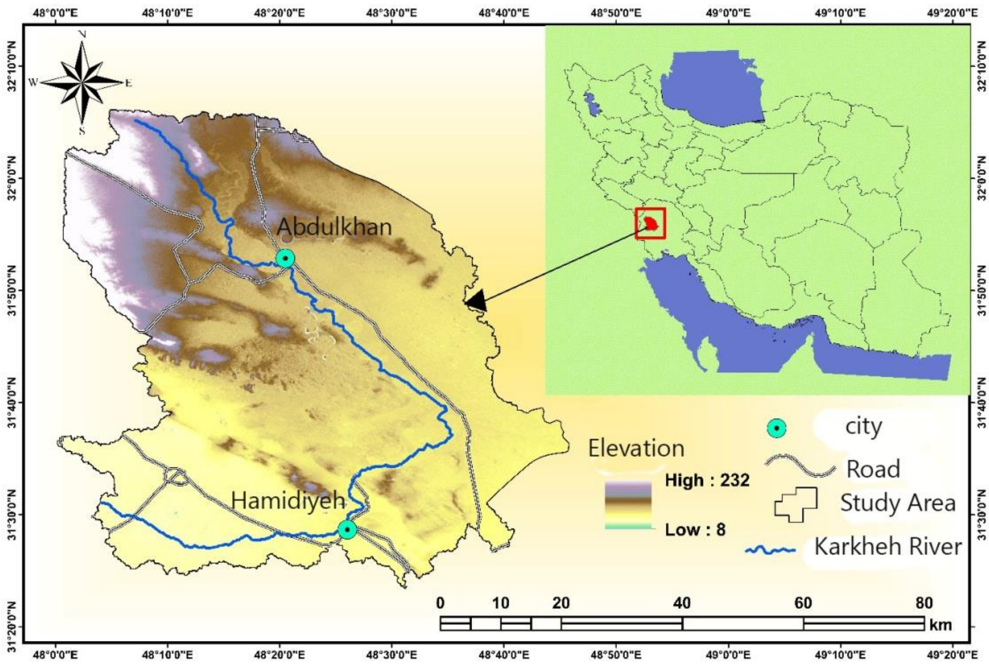

Figure 1- Map of the study area

3- Material and Methods

3-1-data

Landsat satellite images (TM and OLI sensors), the topographic map of the study area (scale 1: 250000), geologic map (scale 1: 100000), climatic data, hydrological data.

3-2- Flood condition factors

In the present study, five conditioning factors were used to create the favorable thematic maps. These factors are elevation, land use/land cover, lithology, distance from the drainage network and slope.

3-2-1- Slope

The slope is one of the primary factors that causes flood occurrence (Shen, 1982). When the drainage density is high, the runoff rate is important (Çelik et al., 2012). Therefore, the flood hazard becomes higher. The slope map of the Karkheh riverside area was prepared using ArcGIS. In this study, this map was divided into five classes. The very high hazard class is characterized by a higher slope that is very highly affected by flood (Fig 7 and 8).

3-2-2- Distance from the drainage Network

The distance from the drainage network factor has a very important role in the identification of the flood risk region and evaluation of flood hazard index. (Fernández & Lutz, 2010) show that, the areas near the river network are highly affected by the flood hazard, whereas the effect of this parameter decreases progressively by moving away from the riverbed.

Distance from the drainage network in Karkheh riverside can be determined by imposing buffer zones around the drainage network information. The thematic map was classified into 4 classes, which are: high (176-232 m), Moderate (120 – 176 m), Low (64-120 m), Very low (8-64 m) (fig 13 and 14).

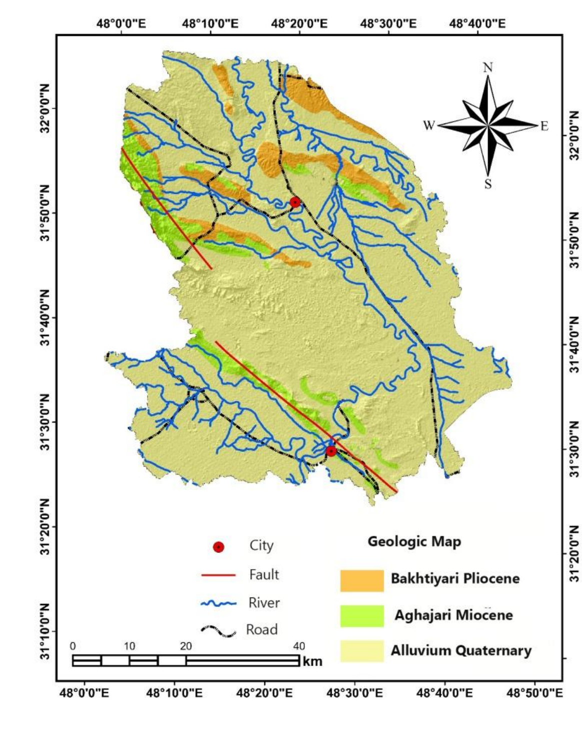

Figure 2- geology

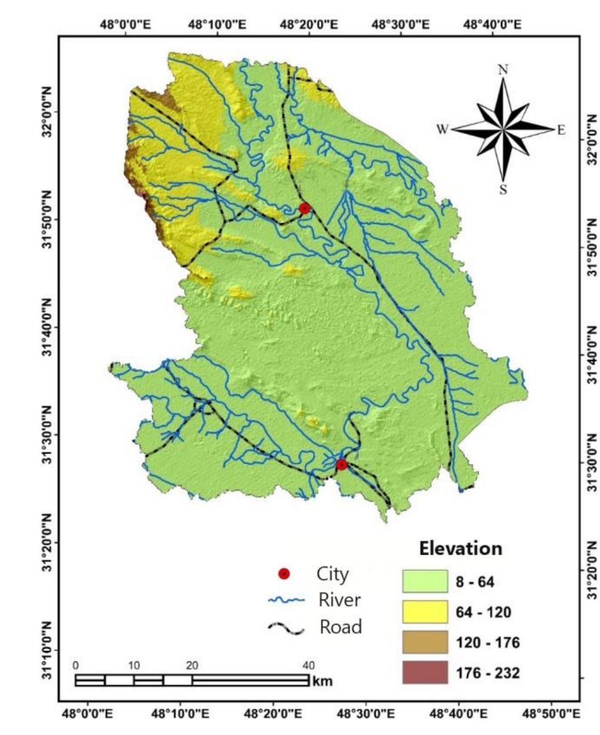

Figure 3- Elevation classification

3-2-3- Land use/Land cover

The Land use/Land cover is an important factor in the study of the flood hazard. This parameter influences the hydrological processes components such as runoff, infiltration, evaporation and evapotranspiration (Schumm, 1985). It includes the soil deposits, buildings distribution, streams, vegetation cover, bare land and roads (Shaban et al., 2006). The land use/land cover map of the study region was prepared using the processing of satellite images from Landsat 8. The selected image was of least clouds mainly from June to September. This image was processed by ENVI 5.1. The vegetation favors the infiltration rate and decrease the runoff rate. So they are considered to have a low potential on floods. On the other hand, the roads, the bare land, the rivers and the buildings increase the runoff rate (Çelik et al., 2012) since they are characterized by impervious surfaces (Fig. 9 and 10).

3-2-4- Lithology

The lithology is one of the major factors in the flood-prone areas identification. This is mainly considered as a critical factor to the spatiotemporal variations of hydrological processes (Gao, 1996). This factor is related to the permeability of soils that varies according to rock types (Gregory, 2006). The permeable formations (Coarse sand, conglomerats...), favor rainwater infiltration and subsequently decrease the flood hazard. On the other hand, the impermeable formations (marly, clay, gypsum...) increase runoff rate, which amplify the flood risk (Maghsoudi et al., 2010). The lithological map of the study area was obtained geological maps from National Iranian Oil Company on a 1/100000 scale (Fig 2, 11 and 12).

3-2-5- Elevation

Elevations play a dominant role for the identification of the areas that risk to be submerged by flooding. This factor has a major effect on the flooding spread and mainly in the flow direction control and the flood depth (Miller et al., 1990). Elevation in Karkheh riverside can be determined using Digital Elevation Model (DEM). The thematic map was classified into 4 classes, which are: high (176-232 m), Moderate (120 – 176 m), Low (64-120 m), Very low (8-64 m) (fig 3, 5 and 6).

3-3- AHP

The adopted methodology for the present research is summarized. Present research integrating Remote sensing (RS) and GIS techniques for identification and delimitation of flood zones by applying the AHP. Hierarchical Analytic Process (AHP) is one of the most comprehensive systems designed for decision making with multiple criteria, since this technique allows formulating the problem in a hierarchical manner and also allows for considering different quantitative and qualitative criteria in the problem (Ghodsipour, 2005; Saaty, 1980). This method is one of the most effective techniques in spatial decision making using GIS [23].In order to identify the flood hazard area, a multi-parametric dataset containing satellite data and other conventional data including maps were considered for the determination of flood zones. These data are prepared using Geographic Information System (GIS), and evaluated by the weights assigned from expert choice. The mapping flood hazard areas were based on the overlaying of five thematic layers. Weights were assigned to different classes in each theme based on their relative importance towards floods in Karkheh riverside by applying the analytical hierarchy process (AHP). Then, the flooded zones were delineated by overlaying all the thematic layers of the weighted overlay method using the spatial analysis tool in ArcGIS.

For flood zoning in the present study, the Hierarchical Analytic Model (AHP) has been used. This model was proposed by Saaty in 1970 and is one of the many known techniques of decision making that makes decision making. According to the principle of correlation in AHP, the elements of each level depend only on higher-level elements, that is, the coefficients of the importance of the elements of each level are necessarily determined by the higher level, whereas at most there are between the choices of decision and the criteria for decision-making, relations and correlation (Malczewski, 1999; Saaty, 1999; Yang & Lee, 1997).

3-4- Applying NDWI index

For identifying and detecting surface water sources from satellite imagery indices has been provided named as "water extraction indices". In the present study, the NDWIF index has been used to identify the bed of the river. Modified NDWI index is calculated as defined by (McFeeters, 1996):

$$\text{NDWI Index} = (\text{Green}-\text{SWIR}) / (\text{Green} + \text{SWIR}) \quad (1)$$

Landsat satellite images have been used to calculate NDWI. Considering river route plan to calculate geometric parameters, using satellite imagery and measuring techniques this route was extracted for two different periods (1991-2017). The geometric parameters of the river such as: wavelength, curvature, central angle of the meanders, radius of the meanders and length of the valley were calculated in the AutoCAD software:

3-5- Curvature (sinuosity)

Using dividing the arc length is achieved by half the wavelength (Goswami et al., 1999). (Equation 2)

$$S = L / (\gamma / 2) \quad (2)$$

3-6- Centered Angel

This angle will be obtained after drawing tangible lines in AutoCAD software (Li et al., 2007). Thus, from the center of each circle tangent to the arches, two lines were drawn to the turning points of the circles with the valley (Equation 3).

$$A=180/ R\pi \quad (3)$$

3-7- Wavelength and valley length

In order to obtain these two parameters, first, the turning points of the river axis were determined, then both the turning points of one arc connected to each other and the length of the segment was obtained by using AutoCAD software (Mani et al., 2003). In the following, the wavelength for each arc was calculated for the river (Morisawa, 1968). To obtain the length of the valley, the turning point of an arc was determined to the next turning point along the river route axis and measured in AutoCAD (Fig. 4).

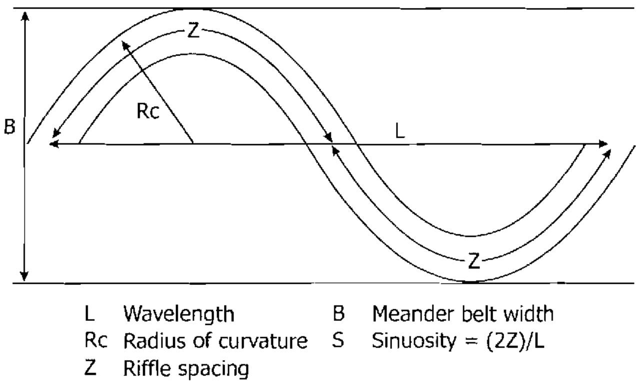

Fig 4- geometric parameters of the river meander

4- Results

4-1- Flood zonation using the AHP model

Performing paired comparisons Analysis of experts' opinions suggests that among the selected criteria, the attribute of flow accumulation with the score of 317 is the highest. Landuse with a score of 0.227 and a distance from the water with a score of 21.77 have earned the second and third positions, respectively. In contrast to the geological criterion, with a score of 0.047, it had the lowest impact on the occurrence of flood in the studied area. Weights are obtained based on expert's opinions.

After assignment of the weights related to each criteria in the GIS environment, all the factors were converted from vector to raster. Finally, multiplied by using the Raster calculator in ArcGIS, and ultimately the final map is obtained (Fig. 16)

Based on the map obtained from the AHP model, the study area is divided into five classes: very high risk areas, high risk, medium risk, low risk, very low risk, due to the potential of flooding. According to the map, most of the flood plains are located in the northwest and west parts. Also, parts of the East and the South are also at high risk. Northeast areas as well as parts of the central basin are also vulnerable areas. Based on the obtained map, about 51.5% of the range is in the low and very low risk zone and 49.5% in the medium to very high risk zone (Fig. 15).

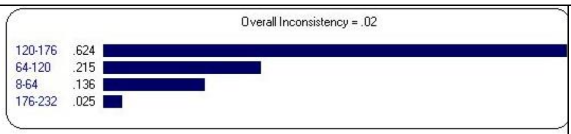

Fig 5- Elevation value weight and its incompatibility rate

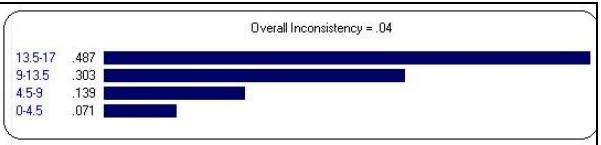

Fig 7- Slope value weight and its incompatibility rate

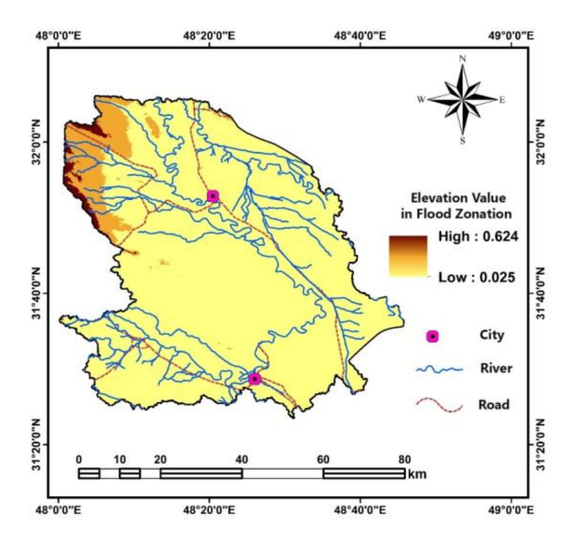

Fig 6- Elevation weighted value in Flood zonation

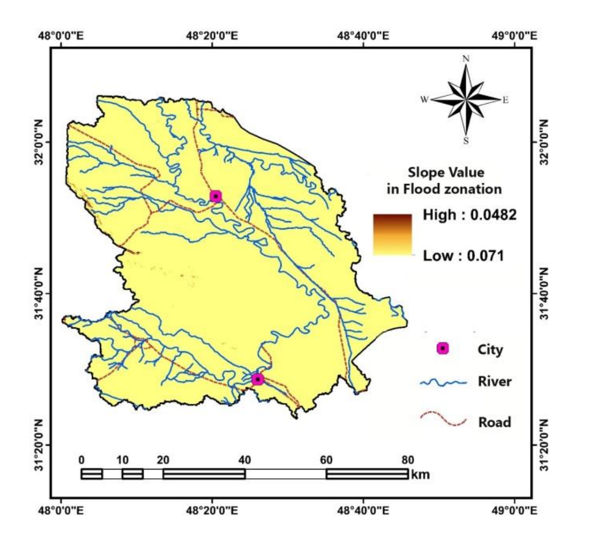

Fig 8- Slope weighted value in Flood zonation

4-2- Number of meanders and length of river

The number of meanders of the Karkheh River has increased in the 26 years period from 46 in 1991 to 56 meanders in 2017. The increase in the number of meanders is a sign of the intensity of lateral erosion in this period that the river is expanding its meanders due to flowing on the erodible alluvial formations in which it flows. The study of the length of the river during this period shows that the length of the river has increased from 105 km in 1991 to 108 km in 2017. Changes in the length of the Karkheh River over a spatial period of 3 km over a period of 26 years indicate changes in its marginal lands. Increasing the length of the river can also be evidence of the increase of more meandering along the river.

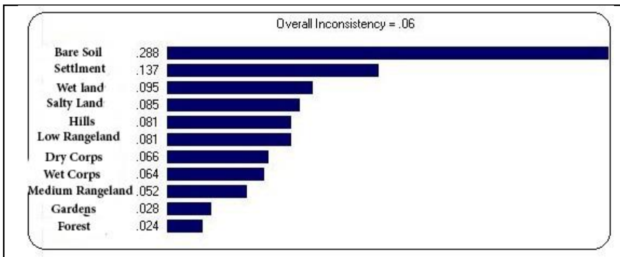

Fig 9- Landuse/Landcover value weight and its incompatibility rate

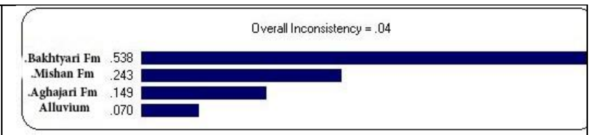

Fig 11- Lithology value weight and its incompatibility rate

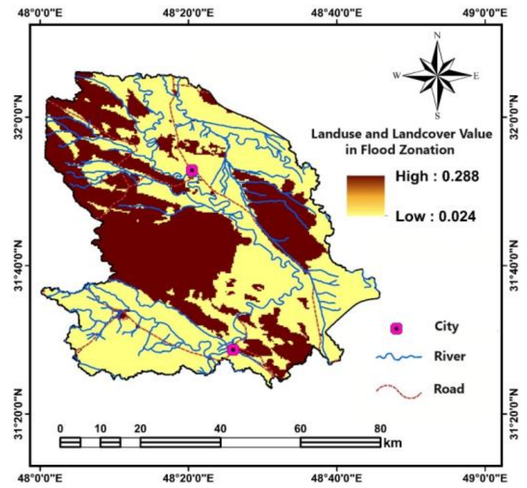

Fig 10- Landuse/Landcover weighted value in Flood zonation

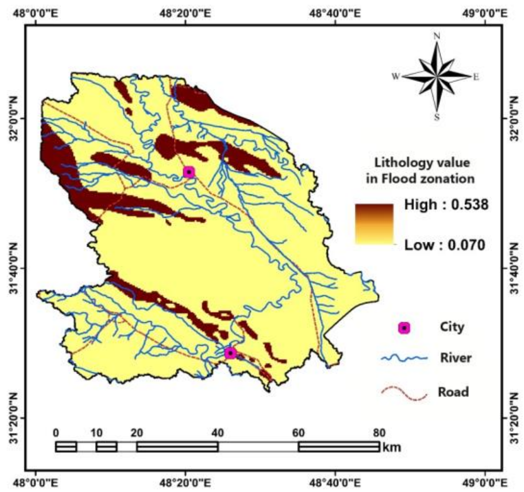

Fig 12- Lithology weighted value in Flood zonation

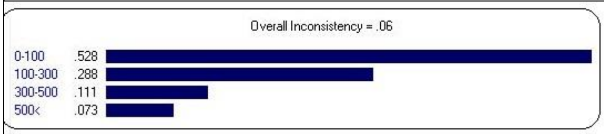

Fig 13- Distance to river value weight and its incompatibility rate

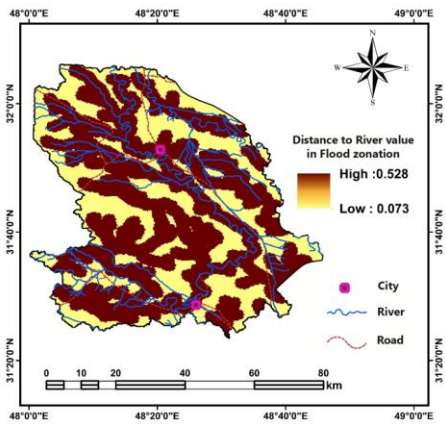

Fig 14- Distance to river weighted value in Flood zonation

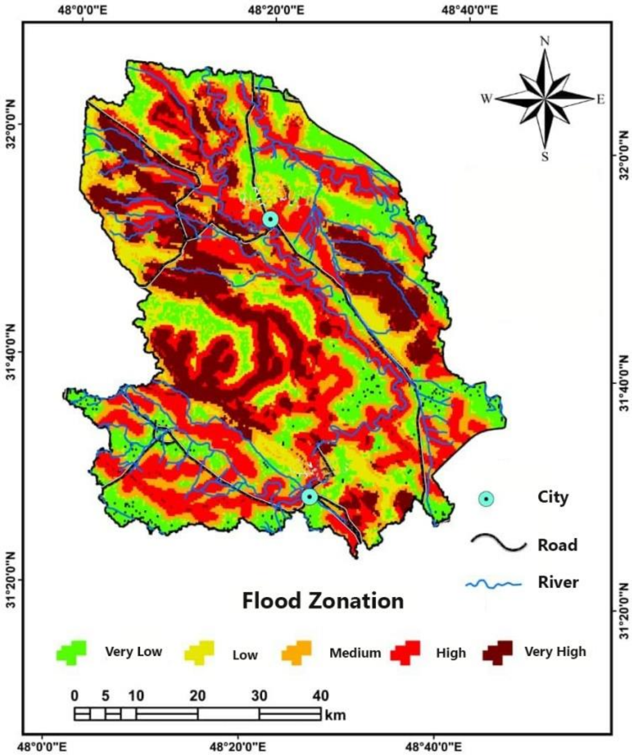

Fig 15- Flood zonation Map of the study area

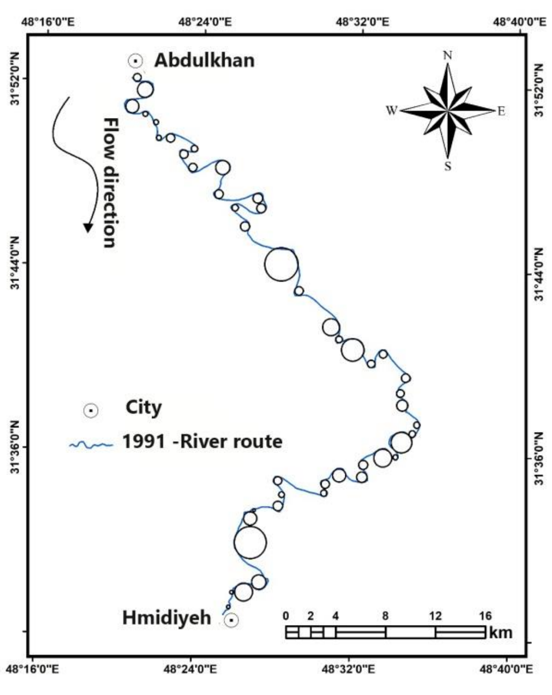	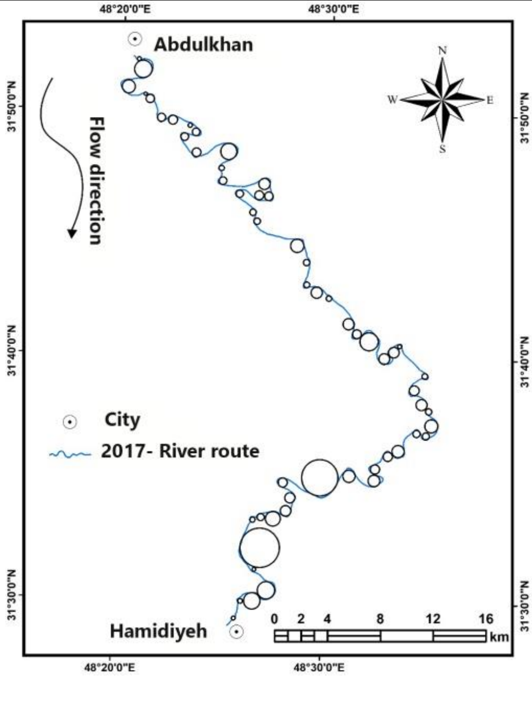
Fig 16- River route path in 1991 and tangenting circles	Fig 17- River route path in 2017 and tangenting circles

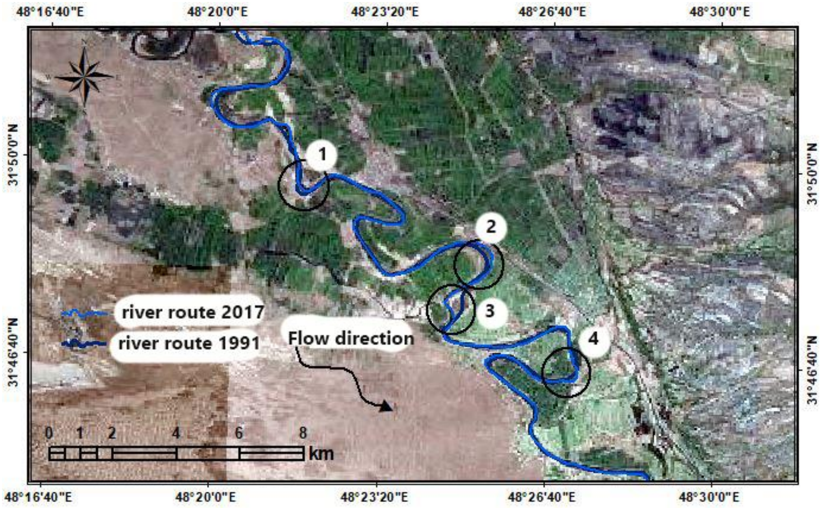

Fig 18- In points 1, 4 and 3 meanders are displaced in 26 years, and in point 2 a new meander is developed.

Table 1- Geometric Parameters for Karkheh River in 1991

Geometric Patameters	Radius (m)	Central Angle	Wavelength (m)	Valley length (m)	Curvature coefficient
Mean	280.32	108.45	214.42	593.2	1.6
Std. Dev.	269.56	89.34	198.53	290.49	0.4
Max	627	151	538.6	845	1.8
Min	29	30	171.1	269	1
Range	598	121	521.5	576	0.8
Range Coefficient	0.96	0.83	0.93	0.49	0.25

Table 2- Geometric Parameters for Karkheh River in 2017

Geometric Patameters	Radius (m)	Central Angle	Wavelength (m)	Valley length (m)	Curvature coefficient
Mean	207.65	112.35	175.56	471.05	1.7
Std. Dev.	190.46	95.48	139.41	199.08	0.3
Max	561	182	611.7	833	2
Min	1.8	18	18.7	193.4	1.4
Range	559.2	180.2	539	639.6	0.6
Range Coefficient	0.92	0.85	0.79	0.43	0.17

5- Discussion

The central angle is the index by which the river's meandering rate is measured (Tables 1 and 2). The average distance of the central angle is 108.45 for 1991 and 112.35 for 2017, so, Karkheh River in both periods can be considered as developing meander river. The central angle has increased by 93.3 degrees in 2017. Due to the morphology of the river, the reason for this was the increase in the number of meanders (Fig 16 and 17).

The curvature coefficient of the river was 1.6 in 1990 and 1.7 in 2015, which indicates an increase in the curvature coefficient of the river. The reason for this is an increase of 10 meanders over a 26-years period.

Width and valley length are two criteria for determining the bending coefficient of the river. The average length of the valley in 1991 was 214.42. The same parameters in 2017 indicate 175.56, which mean that about 18 percent of the river's wavelength and 12.6 percent of the length of the river valley were decreased in 2017 compared to 1991(fig. 18).

NDWI image is very useful in identifying the river bank line. While the shallow water channels have been considered the part of river, old and new soil/sand deposits at the river banks posed some ambiguity of interpretation as the river. A few of these soil/sand patches are at considerable distance from active water channel, but have dark tone on satellite image, indicating higher moisture (Aher et al., 2012; Rinaldi, 2003). On the other hand, several soil patches very close to the active water channel bear bright signature, an indication of low moisture. NDWI has been used in delineating the soil/sand areas which have higher moisture content. It has been observed that the areas with recent soil deposits have higher moisture in comparison to other areas adjacent to river bank, due to the river related activities associated with them. Either the river was flowing through that area in the recent past, or that area was submerged in water, when there was high flow in the river. These areas have been marked as a part of river. Thus the use of NDWI image helped in delineating the river bank line (Singh & Singh, 2011).

Study and research in the field of natural environment of cities is of special importance, because physical development is directly related to geomorphological features. In geomorphological studies, in many cases, the damage to the building is related to their incorrect location, which increases the cost of construction and repair of the building. This is very important. To control the development of the city, it seems useful to pay attention to environmental hazards (Rosgen, 2001; Surian, 1999). Zoning the risk and dividing the physical development areas of the city into very suitable parts (as the first priority), appropriate (as the second priority) and medium (as the third priority) and inappropriate and very inappropriate (as areas that should be The development of the city is avoided in that direction) is an initial step in reducing hazards. In this regard, due to the development of settlements along the Karkheh River, Iran, this area was studied in terms of flood risk zonation and morphological changes of the river, which is an important factor in flood occurrence. The zoning of the area was used by AHP model and the tangent circles fitting technique was used to derive the geometric parameters of the river. Based on the research findings in terms of flood risk zoning; in the very low class, have the best possible conditions in terms of flood resistance. This class occupied 708 square kilometers of the area, which is equivalent to 19% of the total area. In the low risk class; Which is of secondary importance in terms of flood risk zoning; It occupied about 102 square kilometers of the area, which in this regard, with 32.5% of the total area. Moderate risk class; which has the intermediate values for flood zoning, is scattered in most zones and the interface between the classes is high and low. This class was ranked second in terms of area with 822 square kilometers of total area, which is equivalent to 22 percent; High risk class; having high potential for flooding, it covers a large part of bare lands. The western and northwestern regions, which correspond to the high and steep regions of the range, are included in this class. This class has acquired 476 square kilometers, equivalent to 13% of the area. The very high risk class has the highest value in terms of flood potential by most criteria. This class corresponds to the floodplain unit and the river winding sites. This class with 495 square kilometers, which corresponds to 13.5% of the total area; Therefore, the research findings show that in terms of flood risk, the area is almost divided into two parts so that 51.5% of the total area is in the low and very low risk zone and 49.5% of the total area is in the medium to very high risk rang.

Extraction of geometric parameters of the river also indicated that due to the effects of various factors of the river, in 2017 compared to 1991, the situation of the river has become more twisting, which indicates the occurrence of more lateral erosion in the river and resulting in new meanders in the river. So, pixels with a high degree of flood risk are located along the river and flood potential of the river may greatly increase.

The present research using GIS and multi-date satellite data to reveal changes in fluvial land. The Karkheh River exhibits differential rate of erosion and deposition during 26 years (1991-2017). It is observed that the river has eroded both the banks throughout its route except at a few sites where its banks are preserved due to presence of rocks. Many reaches along the Karkheh River have been perceived as suffering from high erosion that endanger nearby settlements and infra-structure. There arises the need for in-depth study of interaction of geotectonic activities conjunctively with fluvial regime in the region to understand the complex physical processes completely for suggesting more practical result oriented river management interventions.

6- Conclusion

According to the research findings, periodic change of direction, lateral erosion is one of the main features of the Karkheh River. From the total area of 3709 square kilometers, 495 square kilometers is located in a very high risk zone (13.5%)., 81 square kilometers of hazard zones(16.5%)of this hazard zone, is located on the main tributary of Karkheh River and near the meanders. The importance of this number becomes clear when attention is paid to the fact that the movement path of the main branch of Karkheh River has a very small area. According to above, the riverside and the area of the meandering river is one of the very high risk areas for floods in the study area.

The area of highlands in the study area is very small. These areas are mostly located in the northwest and west of the area. Among the selected criteria, the height factor with a score of 0.055 has the lowest value compared to other influential factors. In the higher areas of the area, due to the influence of various factors, there is a less possibility of floods in the higher areas of the area.

Flood hazard susceptible zones mapping is a very useful technique that allows reducing flood hazard dangers in order to assist decision-makers and planners to have proper management over the prone areas, and this ensure proper and sustainable socio-economic development. The very high flood hazard area is characterized by the lowest elevation and slope, an urbanized zone, high rainfall intensity, an impermeable to semi permeable soil type and the distance from the drainage network is very near. The sensitivity analysis process of assigned weights to the different criteria by the ranking method and Single-parameter sensitivity analysis method allowed validating the effectiveness of the developed method. Therefore, the results obtained after the coupling of the AHP methods in the study area allowed giving authorities and the decision-makers a valuable tool for identifying flood hazard zones and assessing flood risk index which makes it easier to make decisions in order to reduce the flood risk.

References

Abedini, M. (2011). Investigating the structures of Sarein tourist city with emphasis on topography, tectonics and climate for optimal use of urban lands using GIS. *Journal of Geography and Environmental Planning, Payai*, *49*, 51-65.

Aher, S. P., Bairagi, S. I., Deshmukh, P. P., & Gaikwad, R. D. (2012). River change detection and bank erosion identification using topographical and remote sensing data. *Int J Appl Inf Syst*, *2*(3), 1-7.

Arnaud-Fassetta, G., Cossart, E., & Fort, M. (2005). Hydro-geomorphic hazards and impact of man-made structures during the catastrophic flood of June 2000 in the Upper Guil catchment (Queyras, Southern French Alps). *Geomorphology*, *66*(1-4), 41-67. https://doi.org/10.1016/j.geomorph.2004.03.014

Çelik, H. E., Coskun, G., Cigizoglu, H. K., Ağıralioğlu, N., Aydın, A., & Esin, A. I. (2012). The analysis of 2004 flood on Kozdere Stream in Istanbul. *Natural hazards*, *63*(2), 461-477. https://doi.org/10.1007/s11069-012-0165-x

Fatemi-Aghda, M Fayazi, F., & Alipour, D. (2001). Engineering geology of a part of Karkheh river (Abdulkhan village to Elhai village). *Journal of Tarbiyat Modares University*, *1*(6), 163-189.

Fernández, D., & Lutz, M. A. (2010). Urban flood hazard zoning in Tucumán Province, Argentina, using GIS and multicriteria decision analysis. *Engineering Geology*, *111*(1-4), 90-98. https://doi.org/10.1016/j.enggeo.2009.12.006

Fuller, I. C., Large, A. R., & Milan, D. J. (2003). Quantifying channel development and sediment transfer following chute cutoff in a wandering gravel-bed river. *Geomorphology*, *54*(3-4), 307-323. https://doi.org/10.1016/S0169-555X(02)00374-4

Gao, B.-C. (1996). NDWI—A normalized difference water index for remote sensing of vegetation liquid water from space. *Remote sensing of environment*, *58*(3), 257-266. https://doi.org/10.1016/S0034-4257(96)00067-3

Ghorbani Nejad, S., Falah, F., Daneshfar, M., Haghizadeh, A., & Rahmati, O. (2017). Delineation of groundwater potential zones using remote sensing and GIS-based data-driven models. *Geocarto international*, *32*(2), 167-187. https://doi.org/10.1080/10106049.2015.1132481

Goswami, U., Sarma, J., & Patgiri, A. (1999). River channel changes of the Subansiri in Assam, India. *Geomorphology*, *30*(3), 227-244. https://doi.org/10.1016/S0169-555X(99)00032-X

Gregory, K. J. (2006). The human role in changing river channels. *Geomorphology*, *79*(3-4), 172-191. https://doi.org/10.1016/j.geomorph.2006.06.018

Kummu, M., Lu, X. X., Rasphone, A., Sarkkula, J., & Koponen, J. (2008). Riverbank changes along the Mekong River: Remote sensing detection in the Vientiane–Nong Khai area. *Quaternary International*, *186*(1), 100-112. https://doi.org/10.1016/j.quaint.2007.10.015

Li, L., Lu, X., & Chen, Z. (2007). River channel change during the last 50 years in the middle Yangtze River, the Jianli reach. *Geomorphology*, *85*(3-4), 185-196. https://doi.org/10.1016/j.geomorph.2006.03.035

Maghsoudi, M., Sharafi, S., & Maghami, Y. (2010). Trend of morphological pattern changes in Khorramabad River using RS, GIS and AutoCAD. *J Spat Plan*, *14*, 275-294.

Malczewski, J. (1999). *GIS and multicriteria decision analysis*. John wiley & sons.

Mani, P., Kumar, R., & Chatterjee, C. (2003). Erosion study of a part of Majuli River-Island using remote sensing data. *Journal of the Indian Society of Remote Sensing*, *31*(1), 12-18. https://doi.org/10.1007/BF03030747

McFeeters, S. K. (1996). The use of the Normalized Difference Water Index (NDWI) in the delineation of open water features. *International journal of remote sensing*, *17*(7), 1425-1432. https://doi.org/10.1080/01431169608948714

Miller, J. R., Ritter, D. F., & Kochel, R. C. (1990). Morphometric assessment of lithologic controls on drainage basin evolution in the Crawford Upland, south-central Indiana. *American Journal of Science*, *290*(5), 569-599.

Morisawa, M. (1968). Streams: their dynamics and morphology. *(No Title)*.

Negaresh, H. (2003). The Application of Geomorphology in the Localization of Cities and its Consequences.

Rinaldi, M. (2003). Recent channel adjustments in alluvial rivers of Tuscany, Central Italy. *Earth Surface Processes and Landforms: The Journal of the British*

Geomorphological Research Group, *28*(6), 587-608. https://doi.org/10.1002/esp.464

Rosgen, D. L. (2001). A stream channel stability assessment methodology. Proceedings of the seventh federal interagency sedimentation conference,

Saaty, T. L. (1999). Fundamentals of the Analytic Network Process, ISAHP. Kobe, Japan.

Schumm, S. A. (1985). Patterns of alluvial rivers. *Annual Review of Earth and Planetary Sciences, Vol. 13, p. 5*, *13*, 5.

Shaban, A., Khawlie, M., & Abdallah, C. (2006). Use of remote sensing and GIS to determine recharge potential zones: the case of Occidental Lebanon. *Hydrogeology Journal*, *14*(4), 433-443. https://doi.org/10.1007/s10040-005-0437-6

Shen, H. (1982). The wandering rivers. *Water International*, *7*(1), 10-17. https://doi.org/10.1080/02508068208685943

Singh, V., & Singh, U. (2011). Basin morphometry of Maingra River, district Gwalior, Madhya Pradesh, India. *International journal of Geomatics and Geosciences*, *1*(4), 891-902.

Surian, N. (1999). Channel changes due to river regulation: the case of the Piave River, Italy. *Earth Surface Processes and Landforms: The Journal of the British Geomorphological Research Group*, *24*(12), 1135-1151. https://doi.org/10.1002/(SICI)1096-9837(199911)24:12%3C1135::AID-ESP40%3E3.0.CO;2-F

Tehrany, M. S., Pradhan, B., & Jebur, M. N. (2013). Spatial prediction of flood susceptible areas using rule based decision tree (DT) and a novel ensemble bivariate and multivariate statistical models in GIS. *Journal of hydrology*, *504*, 69-79. https://doi.org/10.1016/j.jhydrol.2013.09.034

Yang, J., & Lee, H. (1997). An AHP decision model for facility location selection. *Facilities*, *15*(9/10), 241-254.

Yang, X., Damen, M. C., & van Zuidam, R. A. (1999). Télédétection par satellite et SIG pour l'analyse des déplacements des chenaux dans le delta actif de la Rivière Jaune en ChineTeledetección satelitária y SIG para analizar cambios en el desplazamiento de causes en el delta activo del Río Amarillo, China. *International Journal of Applied Earth Observation and Geoinformation*, *1*(2), 146-157. https://doi.org/10.1016/S0303-2434(99)85007-7