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Economic damages of rice crop due to flood 2010 and its mitigations in Larkana division using geo-spatial tools

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ABSTRACT

This study was conducted to assess the crop damages due to flood and to develop flood risk maps in order to mitigate its future damages. For that purpose, field and satellite data was used to assess economic damages of Rice crop, prepare flood risk maps and to delineate possible flow paths for safe disposal of flood runoff in case of any future breach on the right side of the Indus river. For the current study, Landsat data for the years 2009 and 2011 along with ASTER Digital Elevation Model (DEM) were analyzed with ArcGIS 10.3, and ERDAS IMAGINE. The results of the study showed that about 247973.024 tons rice of worth 11.425 billion Pakistani rupees was damaged due to flood 2010 in Larkana Division. Moreover, the created flood risk map showed that most of the area of Larkana and Qamber-Shahdadkot has low elevation. Therefore, the risk of floods to these areas is high, while the Kashmore-Kandhkot district has a comparatively high altitude. Thus, the risk of flood is low in that district. The most prolonged flood flow path delineated from DEM using geospatial tools shows that the flow path starts from the southern part of Kashmore-Kandhkot, and then it enters Shikarpur and eventually disposes-off into Hamal Lake in Qamber-Shahdadkot which could be used for safe disposal in future flood scenarios to moderate the flood damages.

1. Introduction

Water is one of the most valuable resources on the earth's surface, without which life would not be possible - all living things depend on the availability of the water. But sometimes water causes major devastation in different ways like heavy floods and drought. Generally floods are considered as the natural disaster causing significant economic and social losses. Asia is the home for more than half of the world's population and its geographical area is approximately one-fifth of the earth's land as stated by Malloy et al. (2018). Due to several reasons Asian region is more vulnerable to flood-related losses in infrastructure and hamper the economic progress. Looking at the history from 1994 to 2004 alone, Asia has faced about one-third of 1562 floods worldwide and approximately 60,000 people lost lives reported by Arambepola and Iglesias (2009).

In Pakistan, 90% of the natural hazards are flood-related stated by Rehman et al. (2016). Pakistan being a flood-prone country, almost every year floods results in a massive economic and human loss. In 2010 super flood damage estimate goes up to 10000 US Dollar and 1985 people died. Indus River with its tributaries has caused extensive floods in the history of Pakistan. Thus, Pakistan has suffered almost 67 times from devastating floods since 1928, some of them are reported by Mustafa (1998), Mohammad et al. (2006), and Rahman (2010). It is reported by Sardar et al. (2008) from 1947 to 2008, due to floods in the Indus River Basin, more than 7,000 people are killed and massive infrastructure and crop loss occurred. The devastating flood of 1992 surpassed all previous record causing damages

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worth Rupees 50 billion as conveyed by Uddin et al. (2013).

During July 2010, above average monsoon rainfall events occurred in the Khyber Pakhtunkhwa, Gilgit-Baltistan, Kashmir, and Punjab causes devastating floods, which hits different parts of Pakistan. It inundated an area of about 60,000 km^2, displaced 15–20 million people (11 % of total population) and caused the death of about 2000 people as reported by Haq et al. (2012). Flows in River Indus further intensified when an unexpected cloudburst event occurred in Koh Suleman Range. Due to this event, Indus flow in Sindh at Guddu Barrage (1st barrage on Indus in Sindh province) crossed historic peaks. The flow of 1.14 million cusecs. Due to super flow in the river, a breach in protective bunds on the right bank of the river at Tori, district Kashmore occurred on August 07, 2010 which inundated vast areas of Jacobabad, Kambar-Shahdadkot, Shikarpur, Kashmore, and Dadu. The flood inundation started from Kashmore; advanced as per natural contour; after flooding Jacobabad, Shikarpur, Kambar-Shahdadkot, and Dadu districts, it eventually disposed of in Manchar Lake.

The heavy rainfall generates a huge amount of runoff water, which flows from upstream to downstream and causes flood. The floods rank top in natural disasters, therefore, the occurrence of floods is a top priority in natural hazards and hydrological studies. Borga et al. (2011) testified from the previous trend of floods that, it can be forecasted that due to climate change induced glacier melting; the river flows expected higher peaks as compared to the averages. Dinh et al. (2012) predicted that the frequency and intensity of floods will be increased in many regions of the world. Therefore, the problems experienced from floods need to be addressed, and it is highly recommended that an accurate flood risk mapping, using an integrated methodology of GIS and remote sensing data, for the quick response of floods.

The advancement in satellite technology and GIS provides enormous advantages for assessing and mapping the flood risks. It is clear that the natural disaster in terms of globally affected people and their individual fatalities can be managed properly by using GIS techniques based on remote sensing data as used by Coppock (1995). Hausmann and Weber (1988) and Clark (1998) stated that the use of GIS for flood management serves two main purposes; it generates a visualization of flooding and also creates potential to further analyse this product to estimate probable damage due to flood.

A number of studies were conducted to map the flood risk areas using digital elevation models (DEM) data and GIS techniques like Uddin et al. (2013), presented a simple and competent procedure for describing area under flood, flood hazard area and suitable area for flood shelters to reduce the impact of floods. With the help of ArcGIS Model Builder, they modelled the probable limit of flooding and they mapped for Sindh province. Isma'il and Saanyol (2013) used remote sensing and GIS to develop flood risk maps for the middle course of the river Kaduna, Nigeria. Based on DEM data, they developed a flow accumulation model which showed low risk, moderate risk and high-risk zones, using an equal interval for separation, based on the elevation of the area. Smith (1997) reviewed the application of remote sensing for determining river discharge, inundation, and stage. Since then, the focus in this direction is shifting from flood boundary delineation to risk and damage assessment.

The similar approach of GIS and remote sensing is used in this study for flood management. The objective of this study was to determine the rice crop damage assessment due to the 2010 flood event and its impact on NDVI. Beyond that this study was also conducted to develop flood risk map for Larkana division and to generate feasible flow paths for safe disposal of any future flood event.

2. Materials and methods

2.1. Study area

The Larkana Division is a secondary administrative unit in Pakistan, while it is a primary administrative unit of Sindh Province, Pakistan. It is situated in the Northwest part of Sindh Province at longitude 67° 11' 6" E and 69° 48' 40" E, and Latitude 27° 7' 56" N and 28° 29' 12" N. It comprises five districts i.e. Larkana, Jacobabad, Kashmore, Shikarpur, and Qamber-Shahdadkot, as shown in Fig. 1. The total area of the division is about 15,491 km^2. The Indus River flows along the eastern border of the division. The climate of Larkana Division is hot, during summer, and in winter it is dry and cold. Larkana Division is an arid region with mean annual precipitation of about 160 mm. The major Kharif crop grown in Larkana is rice, while wheat is a major Rabi crop. Agricultural lands of the division are irrigated from the network of canals that receive water from Guddu and Sukkur Barrages.

The data used in this study was: ASTER global digital elevation model (ASTER DEM) of 30-meter resolution, acquired from earth explorer. The Landsat7 imagery of September 2009, 2010 and 2011, acquired from golvis.usgs.gov using path 152 and row 40, 41. The ERDAS imagine and ArcGIS tool was used to pre-process and analyze the remote sensing data respectively.

2.2. Crop damages

The Landsat images of WRS-2 path 152, row 40 and 41, processing level 1T was acquired from United States Geological Survey (USGS) portal before and after the flood, for the years 2009 and 2011. The Landsat images of September were only taken for analysis.

Coppin et al. (2002) specified that The Landsat data needs to be pre-processed before analyzing for change detection, in order to develop a clear relationship between biophysical and available data.

Therefore, the data was pre-processed in ERDAS imagine for gap fill and also for geo-referencing the data.

Besides this, the GIS tool was used for mosaicking and also for extracting the area of interest. After pre-processing the data, the ArcGIS map was used for classifying the Landsat images. The coordinates from the various rice fields were collected from the whole study area. Supervised classification was used to categorize different classes such as barren land, vegetation, water body, and rice. Moreover, the classified images were then converted into vector data set to calculate the areas. The damages assessment was based on the area covered by each class, which was calculated from the attribute table of the vector datasets. The procedure was repeated for all the images of the year 2009 and 2011. Hence, the comparison of areas under each class gives the extent of crop damages due to the 2010 flood.

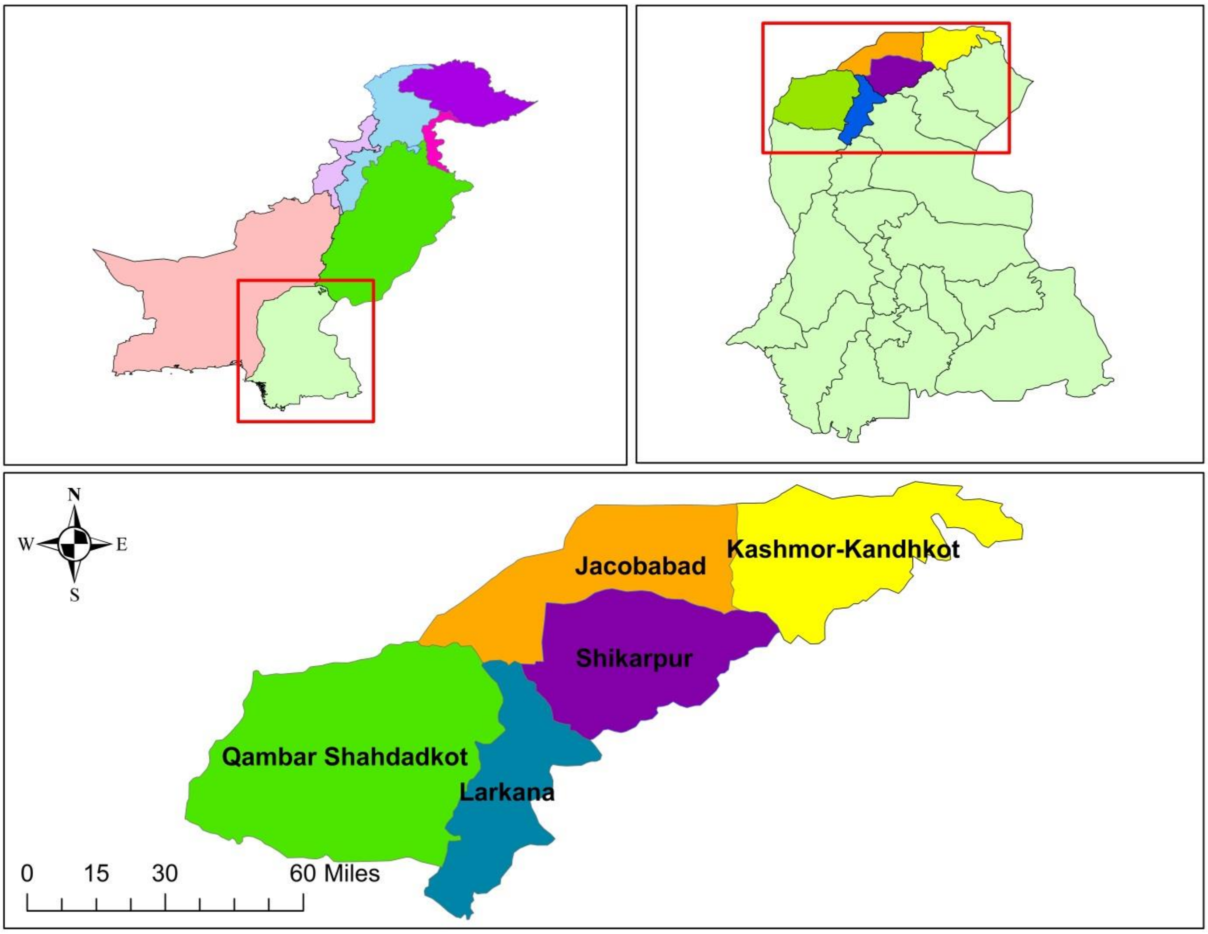

Fig. 1: Study area

The same imageries, which was used in calculating crop damages, was taken for NDVI calculation for determination of NDVI range the red and near-infrared bands (band 3 and band 4) of Landsat 7 imagery were used. The window analysis tool was used to develop NDVI maps for the month of September 2009 and 2011 as shown in Fig. 2.

2.3. Flood risk map

The Digital Elevation Model (DEM), also known as a 3-D representation of terrain surface, can be used for several purposes, including water-flow modelling, soil-wetness modelling, and development of relief maps, satellite navigation, base mapping, and flight simulation. In this study, a DEM of 30 m resolution was used to map flood risk zones. The study area lies within different DEM tiles; therefore, to develop a single image, all DEMs were mosaicked. Moreover, the shapefile for Larkana division was used to extract the area of interest. The extracted image was then analyzed in ArcGIS to create flood-risk maps. The study area has varying elevations; therefore, depending on the elevation of the surface, the entire division was categorized as high, medium and low-risk zones through the GIS risk map.

2.4. Feasible flow paths

The application of remote sensing and GIS facilitates users for management of floods, in order to reduce its impacts. During the floods, the flow path generated from DEM data can be used for streamlining the flood water. The delineation of the flow path is based on the eight-direction (D8) flow model. However, Tarboton (1997) presented a new model, which is multiple flow direction model (D∞), in his model, he represented flow within a DEM instead of representing flow in eight possible directions. In this study, the GIS and remote sensing data are used to generate longest flow path based on eight-direction (D8) flow model, for that purpose, the SRTM DEM of 30 m resolution was taken. After completing all the steps, the longest flow path was created, by running the "drainage line" command. The generated longest-flow path meets the objective of creating a feasible flow path for the flood runoff waters in Larkana Division.

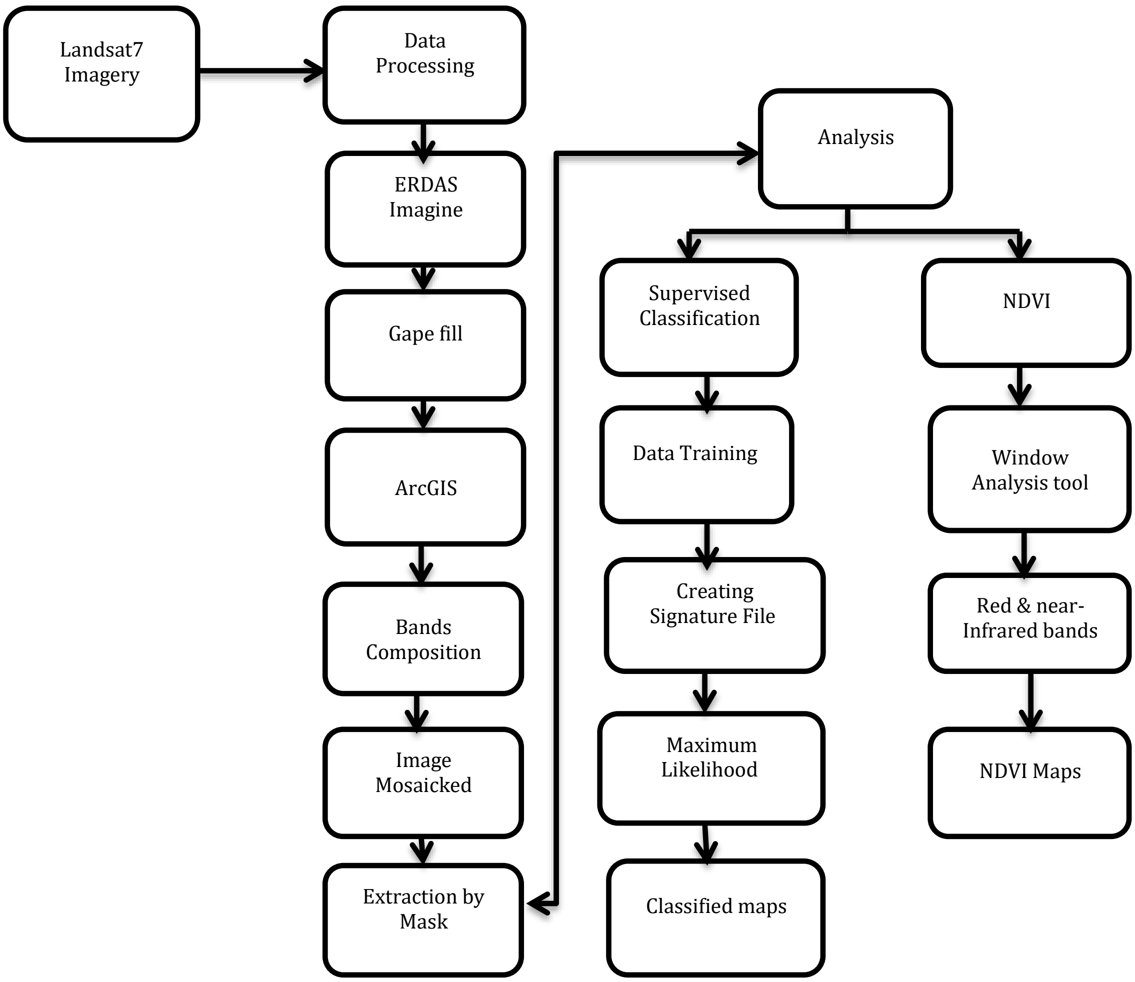

Fig. 2: Flow chart for classifying landsat data and developing NDVI maps

3. Results

3.1. Crop damages

A supervised classification was used to classify the two images of September for the years 2009 and 2011, and the results provide an overview of the land use changes in the Larkana division. The major land use covers were categorized into four main classes; these were Waterbody, Land (built-up areas and barren lands), Rice and Vegetation. The Figs. 3 and 4 illustrate the land use land cover in the study area for the month of September.

Table 1 shows the variation in each class in terms of areas from 2009 to 2010 for Landsat images of September. The area under water body has increased about 30554 hectors; as a result, the area of land has decreased from 758949 hectors in 2009 to 734421 hectors in 2011 showing 24528 hectors of land loss in 2 years. However, the area under Vegetation has decreased from 51416 hectors to 13117 hectors after the flood 2010. The results also show a significant change in the area under rice i.e. the area before flood 2010 was 607223 hectors, but after the flood, the area has reduced to 543508 hectors.

During the period of flood 2010, the major growing crop in Larkana division was Rice. According to Government of Sindh agricultural department, the main type of rice grown in Sindh is IRRI-6, and the average production of the rice in Larkana during 2008 and 2009 was 1.575 tons per acre while the average price of IRRI-6 rice in Larkana was approximately 45.35 rupees per kg or 46075.6 per tons. Since the total damage of rice crop due to flood 2010 was 63715 hectors (157443.19 Acres), therefore, the total loss of rice crop was about 247973.024 tons, which makes an estimated economic damage about 11.425 billion Pakistani rupees.

Furthermore, the analysis of Landsat images shows the decrease of NDVI value from 2009 to 2011 and this change in NDVI can be caused due to flood 2010. Sambah and Miura (2016) told that due to floods and Tsunami, the NDVI values decreases, on the other hand, normalized difference water index (NDWI) values increased. The NDVI value of

September 2009 was 0.70 and then it decreases to 0.64 in September 2011.

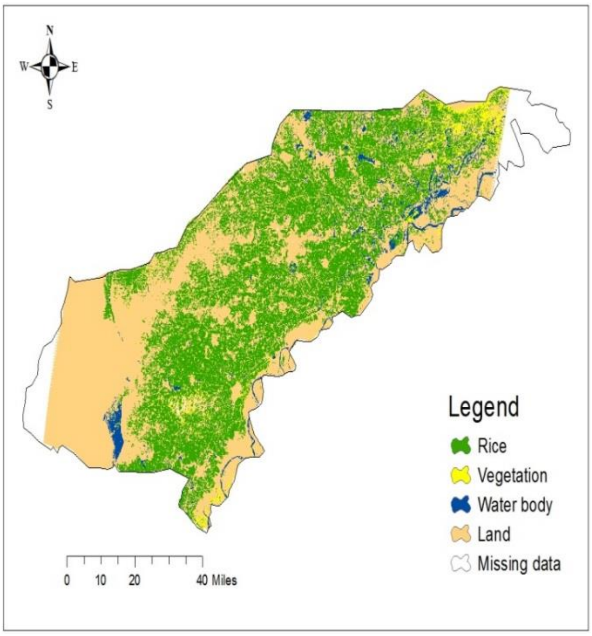

Fig. 3: Classified image of September 2009

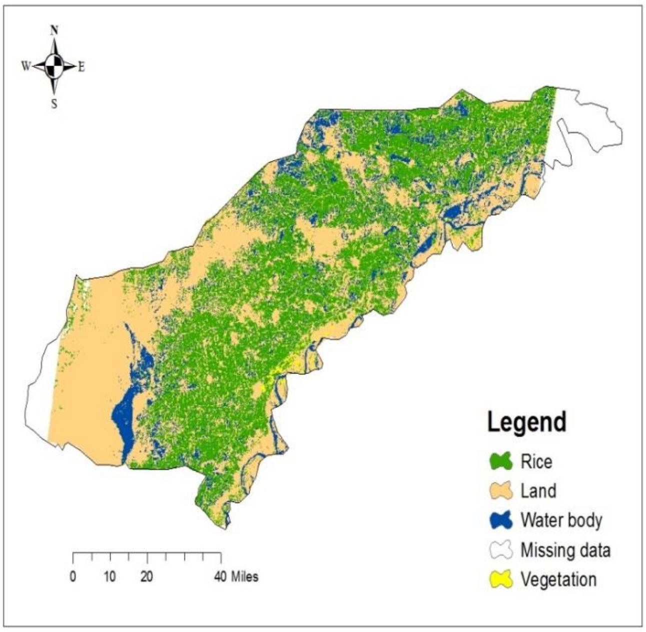

Fig. 4: Classified image of September 2011

Table 1: Change in the area from 2009 to 2011

	2009		2011		2009-2011	
Land cover Type	Area (Ha)	Area (%)	Area(Ha)	Area (%)	Increase in area (%)	Decrease in Area (%)
Water body	48203	3.288	176458	12	266.07	
Land	758949	51.777	734421	50.04		3.23
Rice	607223	41.426	543508	37.079		10.49
Vegetation	51416	3.407	13117	0.906		75.77

Wang et al. (2004) showed that the NDVI value is related to the photosynthetic activities, and its range is from 0.2 to 1, and those plants, which are in good condition, have NDVI value about 0.6. Therefore, based on the results of the analysis, it can be concluded that the crops were in good condition before the flood, but after the quick response of flood, the crops were damaged in September 2011. Figs. 5 and 6 show the change in NDVI range.

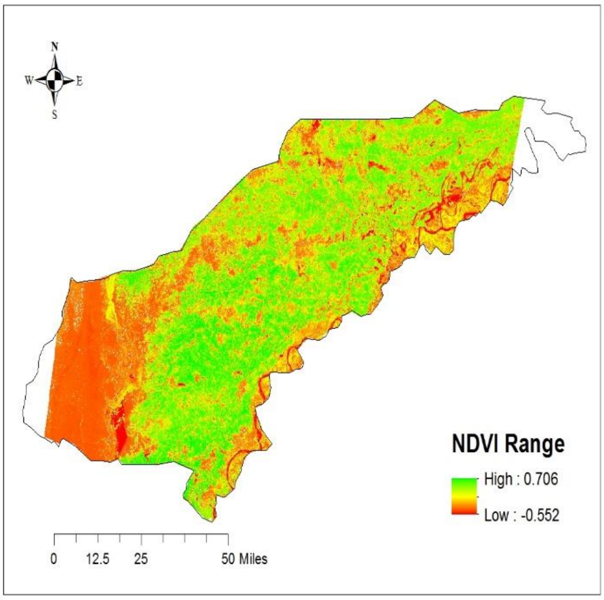

Fig. 5: NDVI map of September 2009

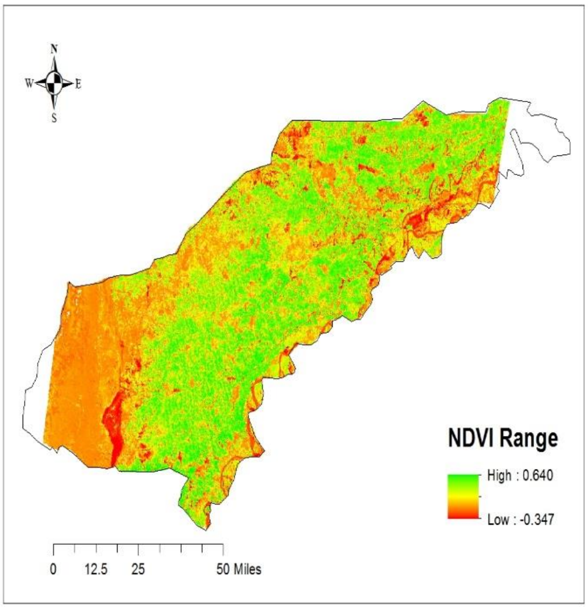

Fig. 6: NDVI map of September 2011

3.2. Flood risk map

A number of studies are conducted to map the flood risk areas using DEM data and GIS techniques. In this study, a simple method is used to prepare flood risk map. After analyzing the DEM data, the resulted flood risk map shows three different zones in terms of elevation of the study area. The risk of floods is classified as high risk 23-53 meters, medium risk 53- 68 meters and low risk 68-255 meters. The distance of the study area from the river was not taken during the analysis; however, the analysis was entirely based on the elevations, as the elevation is the main factor compared to distance regarding flood risks. For example, it is not necessary that the areas which are near to the river are always at high risk, as compared to the areas which are far away.

If the elevation of the area is low it might be in a high-risk zone even if the geographic position is far away from the river course. Isma'il and Saanyol (2013) used the same approach to study the risk of flood from river Kaduna, they considered the elevation only as a major factor for developing the flood risk map. The similar technique was used to map flood risk for Larkana division, and the results showed that most parts of the Qamber-Shahdadkot and Larkana are at high risk to floods as they have a low elevation, while Jacobabad and most parts of Shikarpur are at medium risk to floods. Besides this, the hilly area of Qamber and Kashmore-Kandkot are at low risk to floods as shown in Fig. 7.

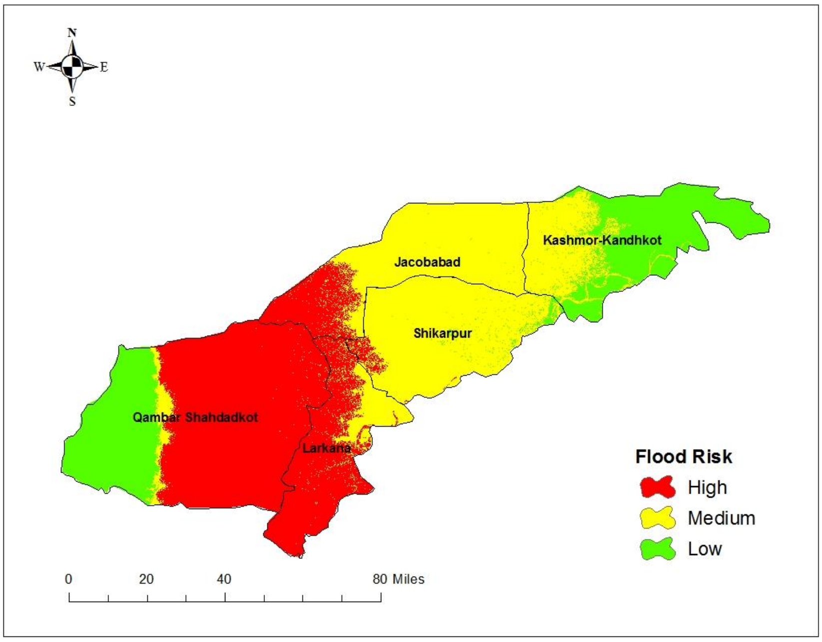

Fig. 7: Flood risk map

3.3. Longest flow path

The analysis of DEM data showed the various flow lines form different catchment areas. The results of the analysis showed that the longest flow path starts from Kashmore-Kandhkot and crosses through Shikarpur, Jacobabad and then disposed into Hamal Lake in Qamber-Shahdadkot. The generated longest flow path is shown in Fig. 8.

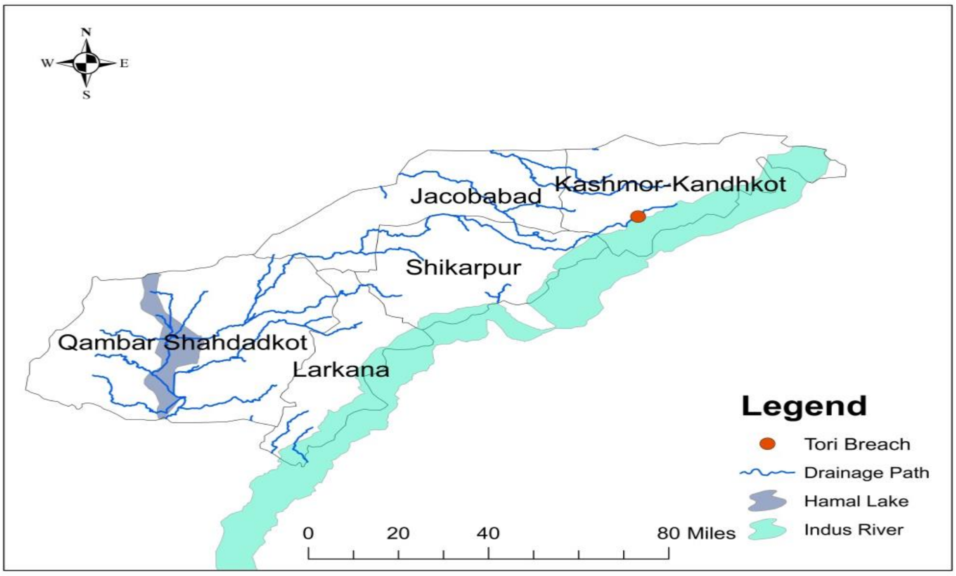

Fig. 8: A feasible flow path

4. Conclusion

To assess the flood damages and to mitigate its effects is a crucial task for natural disaster management authorities. The accurate analysis of flood risk areas requires comprehensive information about the conditions of the field. In this study, the simple technique of GIS and remote sensing data were used to develop the flood risk map, based on the elevation of the area, and to streamline the flood runoff water for a future flood event. The results of the study show the three different risk zones for whole Larkana division. These zones were categorized as low, medium and high-risk zones. Based on the resulted risk map, most parts of the Larkana and Qamber-Shahdadkot are in the high-risk zone to flood. The GIS and remote sensing technique were also used to determine the change in the area of vegetation in Larkana division and the result shows a decrease of 79323.496 hectors.

5. Recommendation

The application of GIS and remote sensing provides a satisfactory result; therefore, the approach should be applied in Pakistan for devising water resource planning and management, in order to develop flood protection strategies. The flood risk maps and flow paths developed in this study should be adopted in flood protection strategies in order to reduce the damages of the flood. For further studies, the Analytical hierarchy process (AHP) and Hydrological engineering center and river analysis system (HEC-RAS) techniques integrated with GIS should be used to make more accurate flood risk maps by considering various factors such as:

- type of soil
- slope and elevation
- distribution of annual rainfall
- information of land use land cover changes, and
- drainage density

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Compliance with ethical standards

Conflict of interest

The authors declare that they have no conflict of interest.

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