

Using Remote Sensing for Identifying Suitable Areas for Flood Shelter: A Case Study of Thatta, Sindh Pakistan

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Abstract: The most recurring type of disaster in the world these days is flood because of the spread and extent of its effect on people, among all-natural disasters of the world. Human activities have paved the way for many of these flood behavior to change as they used to be in the past. Pakistan experienced one of the most devastating natural disasters in its history all across the country in 2010, but Thatta district in southern part got severely affected during this flood. For the research, a simple yet efficient methodology Normalized Difference Vegetation Index (NDVI) by using remote sensing images for identifying flood hazard areas was utilized. Geographic Information Systems (GIS) helps in finding shelter areas with a minimum effect of floods. It is essential to realize the importance of mapped results in consideration of manual flood management in future. The method used in this study is robust enough to explain the flood hazard for suggesting suitable shelter sites in case of flooding events. This would help disaster management bodies and other related agencies to formulate the development plans while keeping the hazard areas, which are unsuitable for development due to flood risk in the future.

Keywords: Floods, remote sensing, NDVI analysis, disaster management.

Introduction

The most important for flood disaster management is a monitoring system that needs to be done in real-time, especially for the early response, designing and planning for both short and long-term mitigation strategies (Wang, 2004). Widespread flood analysis is significant, considering the socioeconomic status and environmental consequences (Markantonis et al., 2013). Remote sensing data and repetitive combination with Geographic Information Systems (GIS) technique have made its implication possible for flood mapping and monitoring in real-time. The availability of sensors with the properties to provide multiple ranges of the electromagnetic spectrum has enabled us to answer cost-effectively about the flooding range and its estimation (Smith 1997; Sanyal and Lu 2004). In the flood-prone river, Kosi in north Bihar, India, the utilization of remote sensing and GIS technique showed an integrated approach for flood risk mapping by utilizing land-use, land cover, topography, geomorphology, and population density (Bapalu and Sinha 2005; Sinha 2008). Others have focused on more theoretical approach using Multiple Criteria Decision Analysis (MCDA), analytical hierarchy process (AHP) model, Frequency Ratio (FR) model, remote sensing (RS) Normalized Difference Vegetation Index (NDVI) model and GIS techniques which are instrumental, reliable and provide accurate information as well analysis for flood-prone zones. The efficiency of the MCDA approach is its application when there is lack of data for some areas, therefore, local planners use it for flood mitigation. The analytical hierarchy process (AHP) model is suitable for China in making flood

diversion plans (Zou et al., 2013). However, the limitation of the AHP model was a correlation to its subjugation on the provision of information by experts (Chen et al., 2011). Additionally, FR is an understandable way to assess flood risk analysis and mapping for future management (Liao and Carin, 2009). Using remote sensing (RS) and Normalized Difference Vegetation Index NDVI to detect the smog and temperature values reflect the impact of urban development areas (Jahan et al., 2019). In terms of functioning, all models produce similar and comparable results for flood mapping.

Pakistan is one of the most disaster-prone countries in the world (Ahmed, 2013). It is among few countries blessed with very diverse topography, consisting of both highlands like northern parts and lowland areas in the southern region. Pakistan experienced the worst natural disaster in terms of the number of people affected in 2010. During the monsoon season, heavy rainfall caused flooding in the northern region of Pakistan. This rainfall, when reached Khyber Pakhtunkhwa region of Pakistan, the Indus river, started to breach from the embankments and canals along the river course, which resulted in massive destruction in most parts. Flooding initiated in mid-July 2010 and continued until early September. Its effect was all over affecting more than 20 million people (Table 1). Flooding in the Indus river caused a massive loss of more than 2113 lives and an economic loss of US \$ 9,500, 000 (EM-DAT, 2019). According to United Nations estimates in 2010 flooding, the humanitarian loss alone was the largest among the three worst natural disasters in the past decade

including the Asian tsunami, earthquakes in Kashmir and Haiti combined. The frequency of floods has increased considerably, especially in South Asia with large scale human and economic loss. These losses have forced governments and international think tanks to formulate the policies about river management strategies and other ways to tackle the problem (Ajmal, 2019).

Study Area

The study area focused in this research is Thatta district, because its surroundings are facing problems of land degradation, soil erosion, loss of vegetation, overutilization of wood, water pollution, and rainy season flooding. Among all the environmental problems, flooding during monsoon season is one of the main issues faced by the people living in Thatta, especially near the river. High level of flooding, which is usually due to intensive rainfall in the northern uplands and around it. Thatta is a low lying area with low infiltration capacity of the ground surface, it is a significant threat to the people living down. The district lies in the downstream part of the Indus river (Fig. 1). Overflow of the Indus river frequently floods most of the districts around Thatta.

The study area comprises two districts of Thatta and Sajawal districts, which lie in the southernmost part of Sindh province, commonly called Thatta plateau and lies between the north latitude 23°43' to 25°26' and east longitude 67°05' to 68° 45'. It is one of most southern border districts of Sindh, Pakistan. For this study, we have to take Thatta as it was in the year 2010. It covered 12.3 percent area of the Sindh province, and in terms of Pakistan's total area, it is 2.18 percent. Thatta is divided administratively into 9 Talukas or commonly called Tehsils, 55 Union Councils, and the smaller unit is Mauzas/Dehs 652 (District at a glance Thatta | Pakistan Bureau of Statistics).

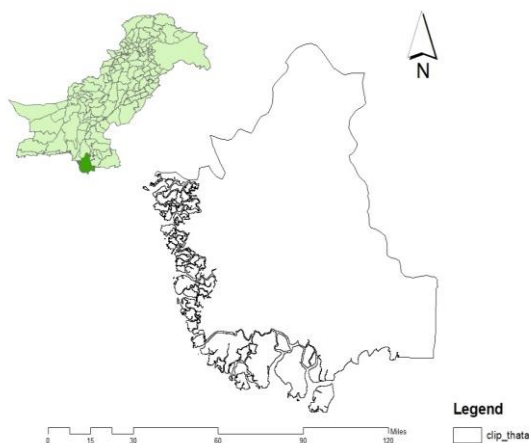


Fig. 1 District Thatta Source: Author extracted area.

Thatta lies in tropical to subtropical region, but in the summer season, it is hot and winter season is mild. The temperatures rises more than 45°C during the summer

season between May and August. The temperature in the winter season drops to a minimum average of 2°C during December and January each year. The average annual rainfall is about seven inches during the summer monsoons from mid-June to August. Thatta is mostly arid, like other parts of Sindh, with not much vegetation except in the area which has an irrigation system due to the Indus river. The annual average rainfall of the district is about 200 mm.

This study is based on analysis of the flooding in 2010, focusing on Thatta plateau that was devastated from July to September of 2010. Hydro-meteorological data coupled with satellite images and digital elevation in a systematic analysis had provided first-hand documentation for the series of events leading to this disaster. It is proposed that an integrated river basin approach is crucial for flood management of such rivers, and local engineering interventions cannot provide sustainable solutions.

Materials and Methods

For this study, moderate resolution imaging spectroradiometer (MODIS) Landsat 5 imagery was used to generate the desired flood inundation map. Topographic maps were used to extract different types of info-layers: administrative boundaries, roads, rivers, railway tracks, forests, lakes, natural reservoirs, while other land cover classes for Open Street Map were used to show the relationship. Moderate Resolution Imaging Spectro-radiometer (MODIS) onboard TERRA and AQUA images of 250 m resolution comprising bands 7, 2, and 1 were used to map the flood-affected areas. The MODIS images of the study area were provided by NASA and accessed from Earth-Explorer. ArcGIS 10.6.1 and eCognition software were used for processing and analysis.

Results and Discussion

To map the vegetation and water for the study, a remotely sensed normalized difference index was used firstly because the band ratios enhance the spectral signals by contrasting reflectance between different wavelengths. Secondly, it also reduces many multiplicative noises, such as individual topographic variations, atmospheric attenuation, cloud shadows and illumination differences. Lastly, it allows comparison among different images through time and space (Huete et al., 2002; Ji et al., 2009). Landsat and MODIS images underwent standard corrections for Rayleigh scattering, aerosols, and gases (Flood et al., 2013; Vermote and Wolfe, 2015). The drawback of using Landsat is the imperfect correction which in some cases affects the results when using time series data of remotely sensed images.

Landsat 5 images for two dates were retrieved (4th September 2010 and 7th November 2010) to find optimum index thresholds for standardizing flood mapping by using daily MODIS images. The first

selected date, 4th September 2010, occurred during the flooding event. Whereas the 7th November 2010 image was taken in order to compare it with the flooding, after four weeks time span. For that reason, combination images were used for water and vegetation floodplain response states could be identified for the accurate calibration of MODIS images. Due to limitations of the image extracted from the Earth Explorers, it does not cover all the areas of the Thatta district. These images have been used to provide the date as early September 2010 because, during these days, the study area had the maximum flooding, which was required for this analysis.

The Normalized Difference Vegetation Index (NDVI) (Rouse et al., 1974) and Normalized Difference Water Index (NDWI) (Gao, 1996) are used extensively to analyze biomass in dryland, flood plains and vegetation growth (Thapa et al., 2015). Therefore, it was used in this study to identify the dryland from the wetland. Normalized Difference Water Index (NDWI), along with NDVI are the most effective tool in terms of water-related content and perfect proxy for plant water stress. The Near-Infrared (NIR) and Short Wave Infrared (SWIR) channels are used to get the Normalized Difference Water Index (NDWI) and its satellite-derived index.

For the NDVI spectral index, was used for slope based Vegetation Index. The Geoprocessing-Imagery-Vegetation Index tool is used for visible Red band as spectral band 3 and visible near Infrared band as spectral band 4. The Landsat 4-5 TM, with a spatial resolution of 30 m, is used for generating the NDVI. Lastly, Landsat TM spectral Band 3 has a wavelength from 0.63 to 0.69 μm , and Band 4 has a wavelength from 0.76 to 0.90 μm . The NDVI spectral index equation by Rouse et al. (1973) is:

$$NDVI = \frac{(Near\ Infrared\ Band - Red\ Band)}{(Near\ Infrared\ Band + Red\ Band)} \quad (1)$$

NDWI has two channels which sense very different depths through vegetation canopies. The normalized difference water index (NDWI) is used for remote sensing, especially for the vegetation liquid water analysis. NDWI wavelength is 0.86 μm to 1.24 μm , the uniqueness of it is both 0.86- μm and the 1.24- μm channels fall in the high reflectance range of vegetation canopies. Gao (1996) explains the NDWI is as follows

$$NDWI = \frac{(Near\ Infrared\ Band)}{(Green\ Band)} \times 100 \quad (2)$$

Flood hazard mapping is based on many factors, like flood inundation and topography of the flooded area. In order to obtain the hazard maps, a few steps need to be taken to get the flood extended area map, (Fig. 2). The obtained MODIS reprojected to UTM, Zone 42. For making the object-based image analyses Pis (OBIA), eCognition Developer software was used. The

flow diagram explains as to how the object-based image analysis was used for flood extended mapping.

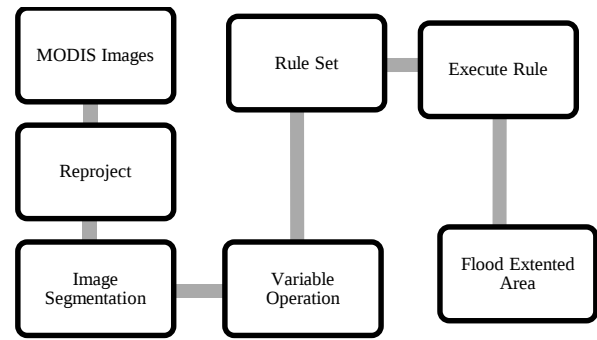


Fig. 2 Flow diagram for flood suitability area mapping.

In comparison to the pixel-based approach, the object-based image analysis (OBIA) shows better classification results with higher accuracy because this approach uses both spatial and spectral information (Civco et al., 2002; Gao et al., 2007; Blaschke, 2010). Firstly, the essential step in the image analysis approach is first the segmentation of the scene where information is aggregated into a homogenous image, which is earlier in single pixels. In the next step, the Multiresolution and Quadtree segmentations were applied for object-based image analysis with the help of eCognitions software, which is used in this study. For analysis, the images were grouped with respect to areas of similar area of interest into pixel values objects. Then separated it, as homogeneous areas result in larger ones and heterogeneous areas in smaller objects. Therefore, several segmentations were run in order to test different sets of parameters until the desired results were obtained. For each object and information, values of average spectral, land, water mask, and most importantly, average Normalized Difference Vegetation Index (NDVI) were generated. Secondly, in the pre-processing stage, an NDVI image was created using GIS software by applying NDVI (equation 1) indices values ranging from -1.0 to 1.0, which separate the non-vegetation area as a negative value (-1.0) and vegetation area like a forest, will have a positive value of 1.0 (Fig. 3). The Land and water mask index (equation 2) values can range from 0 to 255, whereas for water values usually, they range from 0 to 50, which were similar in our study as well. The information obtained from the above process was used to develop suitable classification algorithms for developing the flood inundation map for our case study.

The next step was to insert class and define the classes. The Image objects, class objects, and each classification link, created were stored by assigning them values of the image object, which were in the linked class. The classification was based on the user-defined rule for the Image objects. For simplification in analysis, the objects with smaller areas were identified, and a defined minimum mapping unit was merged with other objects. This classified map then

exported to shapefile format in order to do further processing for flood hazard mapping, flood shelters, and area location identification.

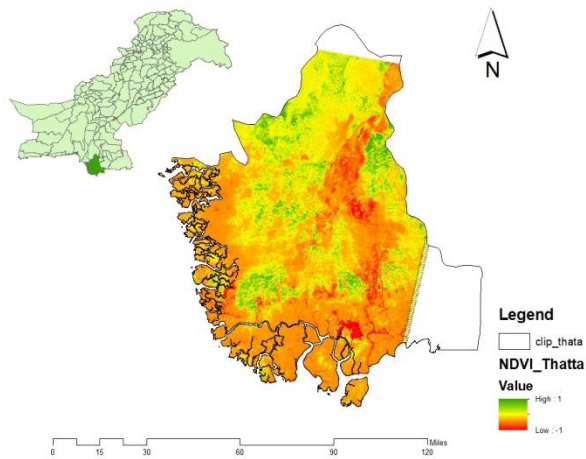


Fig. 3 NDVI and Euclidean analysis during flooding 2010.
Source: USGS EarthExplorer. Landsat 4-5 TM C1 (Level 2), Author created.

Several types of factors/parameters were required to do a flood hazard assessment. Acquired datasets comprise of attributes such as the land-use, digital elevation model, order of stream, water bodies, road network, railway route, and river. These datasets include all the data that a flood would have any effect due to it. One of these datasets is a slope. The slope is vital for understanding the topographic factor, which allows them to make flood potential into three-dimensional which includes the assessment of flood damages, in a specific time, and space. For that, the slope data layers were generated by using digital elevation modeling techniques for the study area.

The NDVI has been used because vegetation plays an essential role to restrain the threat of flooding, and reduces runoff by the flood. Euclidean allocation allows calculating the nearest source for each cell to get the Euclidean distance and calculating the direction based on the nearest source. Typically, all nearest source areas lie in the flooded areas, which are prone to flooding (Fig. 4). Euclidean distances of rivers and Euclidean allocation for stream order were generated to rank flood possibility.

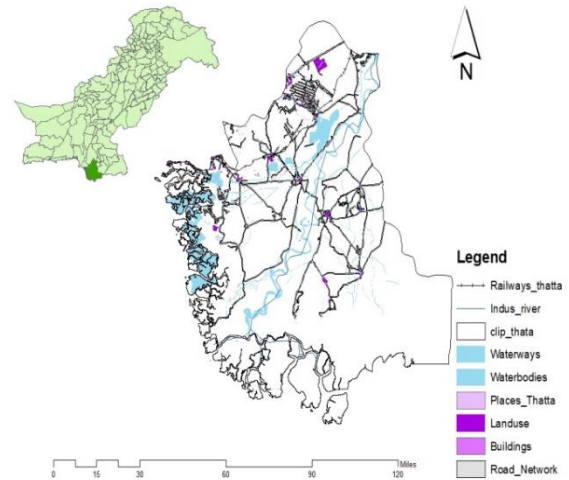


Fig. 4 Different raster layer combined.
Source: USGS EarthExplorer. Landsat 4-5 TM C1 (Level 2), Author created

After getting all different datasets were combined, as they need to be on a standard scale analysis. Reclassification allows to rank the potential hazard locations for each dataset. Then reclassified data sets were made based on ranges from 1 to 7. All the reclassifications were done based on natural breaks and made into 7 classes, which were used to define the flood potential. Every raster was assigned ranks based on flood possibility or potential of a flood. As a result, they have ranked as '7' means with the most flood potential, and '1', least flood potential. After generating all the raster layers using the models developed, these were used to produce the flood hazard map, raster layers the overlaid together. The weighted layers were to reduce the number of inputs and to make the final weighted layers.

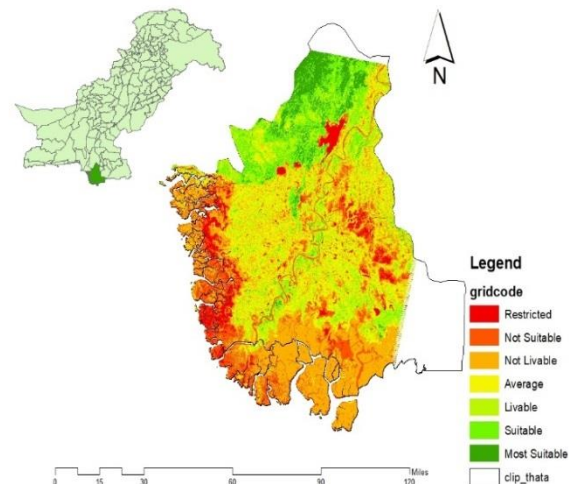


Fig. 5 Suitability Area Analysis, After Flooding in December 2010.
Source: USGS Earth Explorer. Landsat 4-5 TM C1 (Level 2), Author created.

The weighted layers were assigned an equal weight of 20 percent, to get flood possibility index. The result was verified with the flooding event in 2010. It is essential to find flood shelters in flood-affected areas

like in areas that are prone to flood. These flood shelter areas identification can provide not only shelter to keep people safe but also would be helpful for relief activities after flooding. In contract, roads, settlement, water bodies, land cover, and digital elevation models were used to make the suitability analysis for the flood shelter ideal location. To get the shelters' suitability, the settlement datasets were used for the point dataset, roads for Euclidean, elevation dataset for slope, and flooding events of 2010. The dataset was then reclassified using the same classifications ranges to rank the suitability of locations for flood shelter. In this scenario, the raster was assigned to reclassify, it in rank as `7` for restricted and `1` for the most suitable for flood shelters.

After having all four raster layers, they were overlaid together to get final map for flood shelters (Fig. 5). The suitable locations for the flood shelter map were produced after the raster layers were weighted according to a percentage of influence and combined. The flood shelter alternative sites were selected, and the optimum area is identified for the new flood shelter.

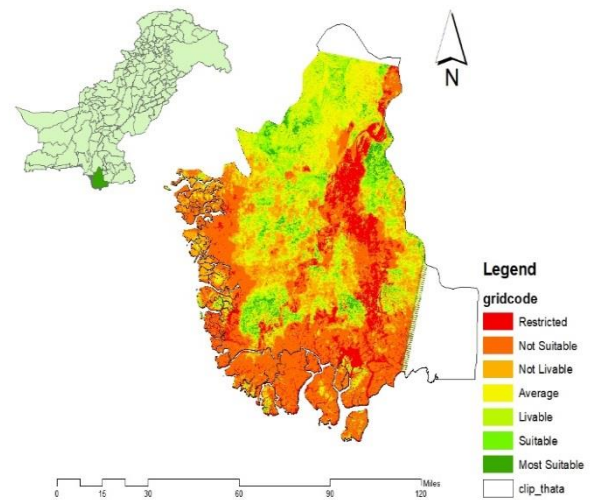


Fig. 6 Suitability Area Analysis, During Flooding September 2010
Source: USGS Earth Explorer. Landsat 4-5 TM C1 (Level 2), Author created.

Pakistan experiences frequent flooding, especially during the monsoon season from June to September. In 2010, it experienced the worst flooding in its history, in terms of deaths, people affected, and economic losses (EM-DAT, 2019). Sindh also suffered greatly due to it because flooding affected more than 7579 km² in Sindh province. The total area of Sindh is 46138 (km²), while our total area of the present study is 12532 km². The modeled result indicates a most hazard-prone area classified based on flood shelter, being restricted to 3832 km² (Table 2). In terms of the percentage, only 7.49% of the land of the case study area is most suitable for shelter, and 30.5 percent is a restricted area. The 938 km² is the city area, less flood hazard-prone and is the most suitable; it can be used for shelter, hospitals, schools, and all-important strategical infrastructures.

In the case of the flooding event in 2010, it shows that

Table 2. Suitability area analysis after the flood for flood shelter

S.no	Area Criteria	Ranking	Area Sq meter	Area Sq Km	Percentage
1	Most Suitable	1	938861623	938.86	7.49
2	Suitable	2	2073528356	2073.52	16.54
3	Livable	3	1177706644	1177.70	9.39
4	Average	4	2164762944	2164.76	17.27
5	Not Livable	5	787096337	787.09	6.28
6	Not Suitable	6	1559286628	1559.28	12.44
7	Restricted	7	3830797055	3830.79	30.56
Total			12532039589	12532.03	100

Notes: The area is calculated in square meter and then converted to a square kilometer
Source: USGS. Landsat 4-5 TM C1 (Level 2), Author calculated criteria analysis and area

Table 3. Suitability area analysis during flood 2010 for flood shelter.

S.no	Area Criteria	Ranking	Area Sq meter	Area Sq Km	Percentage
1	Most Suitable	1	38897695	388.97	3.10
2	Suitable	2	8590773295	859.07	6.85
3	Livable	3	161851218	1618.51	12.91
4	Average	4	2690376688	2690.37	21.46
5	Not Livable	5	7309617816	730.96	5.83
6	Not Suitable	6	4657008594	4657.01	37.16
7	Restricted	7	1587126067	1587.12	12.66
Total			12532039589	12532.03	100

Notes: The area is calculated in square meter and then converted to a square kilometer
Source: USGS. Landsat 4-5 TM C1 (Level 2), Author calculated criteria analysis and area

Thatta district has less area that is suitable for shelter places. The modeled result indicates a most hazard-prone area classified based on flood shelter as restricted 1587 km², not suitable 4657 km², not livable 730 km², average 2690 km², livable 1618 km², suitable 859 km² and most suitable 388 km² (Table 3). Firstly, in terms of the percentage, only 3.1% of the land of the case study area is most suitable for shelter as compared to post-flooding, which was 7.49%. Secondly, 12.66% area was identified as a restricted area as compared to post-disaster, which was 30.5%. In terms of the restricted area, there is a significant change in the area because after the flooding occurred, the breaches of river and canals caused the wide spreading of water, making the restricted areas less, but increasing the non-livable area of 37.16%. This also shows that the land which was non-livable expanded even more due to flooding, making 388.9 km² area less flood hazard-prone and most suitable for flood shelters. In short, there is a need to build dams and improve the irrigation system to make more land useable for human inhabitation or agriculture use.

Conclusion

The comprehensive flood hazard assessment is essential for better and targeted relief efforts. Suitable area analysis done by using ArcGIS can easily be used by any GIS user for making right and calculated decisions at any level. The object-based remote sensing technique and geographical information systems were used to classify the extent of floods. Real-time monitoring is essential in today's world when we have modern tools and techniques at our disposal, like using satellite data. These remote sensings have proved to be a more precise and practical approach to identify flooded hazard-prone areas. In this study, eCognition and GIS were used for identifying potential flood hazard maps and recommending suitable flood shelter areas using remote sensing images. The methodology used in this research is useful to carry out rapid damage assessment and damage need assessment, which is vital at the time of such disaster. The study shows, if created satellite images are processed then it be effortless just to overlay them to generate these hazard maps. The process used in this research will help save thousands of lives and minimize the economic losses that occur every year around the world due to flooding events.

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