Paper No. 170

USING MULTI-CRITERIA DECISION ANALYSIS (MCDA) TECHNIQUE TO IDENTIFY POTENTIAL FLOOD PRONE REGIONS ALONG THE INDUS BASIN FLOOD PLAINS (FP) AND HILL TORRENTS (HT) – MITIGATING THE IMPACTS OF CLIMATE CHANGE RELATED FLOODING IN PAKISTAN

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Abstract:

Flooding is a major socio-economic and environmental threat to any nation. Between 1998 – 2018, Pakistan has lost 9,989 lives and $3.8 billion due to flooding and climate change related disasters; making Pakistan 5th most vulnerable country to climate change according to an assessment conducted by German Watch in 2019. Flooding in Pakistan can broadly be classified into two categories: Flood Plains (FP) and Hill Torrents (HT). The main cause of flood prone disaster is the lack of capacity to identify critical flood prone regions and take site- or region-specific preparedness measures. If managed properly, the floodplains and hill torrents can provide a range of benefits for people and nature; for instance, improvements in water quality due to dilution, improved groundwater recharge, provision of excess water to indigenous wetlands, improved wildlife and ecological habitats, and availability of freshwater for agriculture and recreational activities are some of the advantages which a well-managed flood plain and hill torrent can offer. However, in order to succeed in seeking these advantages, it is important to first identify regions that are prone to high risk of flooding.

One of the ways this can be achieved is by employing GIS based Multi-Criteria Decision Analysis (MCDA) technique. MCDA is a common method employed in various spatial analysis studies, which relies on overlay of multiple layers of spatially processed GIS data. By assigning suitable score values (ranks and weights) to each layer, MCDA overlays each layer and evaluates overall score for a particular site or region under consideration. In case of this study, ten potential high flood risk sites/regions along the Indus River Basin were under consideration. For each of these sites/regions, three broad data types were spatially layered using the MCDA scoring method; 1. Bio-Physical 2. Socio-Economic and 3. Ecological Datasets. Least score indicated high vulnerability, versus high score indicated low vulnerability. It was determined that overall Haleji and Hadero were the most vulnerable sites due to ecological sensitivity, while Kaha

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Acknowledgements: Dr. Masood Arshad (Senior Director, Water, Food and Climate, WWF-Pakistan)

watershed and Chaker Lehri – sub basin was the least vulnerable among the group of sites/regions. Although almost all sites ranked equally in the category of flood risk vulnerability, ecological and socio-economic sensitivities were the key determining factors to cause variations in overall results.

Although this study is based on secondary sourced spatial data, the technique is found to be suitable to carry out preliminary flood risk assessment for a site. The data can further be built using real-time information to establish strong baselines to determine how different adaptive and mitigative measures could be implemented to reduce the level of vulnerability to the impacts of flooding.

Key Words: Remote Sensing (RS), Geographical Information System (GIS), Multi-Criteria Decision Analysis (MCDA), Flood Plain (FP), Hill Torrent (HT), Nature-based Solutions (NbS).

Introduction:

Overview: Floods are natural hazards that have severe adverse consequences on property, infrastructure, livelihood, livestock, human lives, human health, environment, cultural heritage, and economic activity [1]. Across the globe, annual flooding leads to a loss of about 20,000 lives and negatively impacts 20 million people annually [2], which is predicted to rise during the next decade as global warming increases [2]. Historically, floods have adversely a ected over 2.8 billion people since 1990 across the world [3]. The impact of floods can span from direct losses, such as loss of lives and property, or indirect impacts such as spread of disease, destruction of ecology and natural habitats etc. These direct and indirect losses occur largely due to inadequate structural, non-structural measures, and ineffective and ine cient policy responses [4,5].

Flood Impact in Pakistan: Between 1998 – 2018, Pakistan has faced direct losses in the form of loss of 9,989 lives and $3.8 billion due to flooding and climate change related disasters; making Pakistan 5th most vulnerable country to Climate Change according to an assessment conducted by German Watch in 2019 [6-9]. Pakistan is considered a flood-prone country as flows in Indus Basin increase due to melting of glaciers during summer seasons, and because of heavy torrential rainfalls during monsoon season and western currents in winters. Having a history of widespread and frequently occurring floods, loss of lives, substantial damage to property, infrastructure, loss of agricultural crops and livestocks, and land degradation are some of the common damages incurred to Pakistan each year, posing a great socio-economic challenge [12].

Flood Year	People Affected	Lives Lost	Reference/Source
2003	4376	484	Pakistan Weather Portal
2007	2 million	918	Pakistan Weather Portal
2010	20 million	<1781	Rehman et al., (2015) and Pakistan Weather Portal
2011	8.9 million	434	Pakistan Weather Portal
2015	2.5 million	367	Pakistan Weather Portal

Table-1. Incidence of floods in Pakistan during the last two decades (Ali, Akhter, 2020)

Table-1 shows list of major flood events between 2003 – 2015, with associated losses. It is noteworthy that the 2010 flooding was a major catastrophe faced by Pakistan, killing

more than 1700 people, while affecting over 20% of Pakistan's total land area and indirectly impacting approximately 20 million people. In addition it caused billions of dollars of loss through damages to infrastructure, housing, agriculture and livestock, and other family assets [14]. It destroyed more than two million homes, two million hectares of standing crops, and 1.2 million head of livestock. The overall loss of sugar cane, paddy, and cotton was estimated at 13.3 million MT [15].

The recent flood of September 2015 hit all of Pakistan, resulting in the deaths of 367 individuals. Over 2.5 million people were affected by the floods and rains, and 129,880 houses were partially damaged or entirely destroyed [16]. The agricultural sector was the most affected: around one million acres of standing crops were destroyed, and 250,000 farmers were affected [16]. As agriculture contributes approximately 21% to Pakistan's GDP, 43% to employment, and 60% of the export earnings [16], the adverse impact of flooding on the agricultural sector is likely to severely affect livelihoods, poverty and the economy of Pakistan.

However, if managed properly, the floodplains and hill torrents can provide a range of benefits for people and nature, for instance improvements in water quality due to dilution factors, groundwater recharge, provision of excess water storage in indigenous wetlands, improved wildlife and ecological habitat, availability of water for agriculture and recreational activities are some of the advantages that well managed flood plains and hill torrents can offer.

Flood Impact Assessment through GIS and Remote Sensing: Pakistan has two dominant types of floods in the system: riverine, i.e. Flood Plains (FP) and flash floods, i.e. Hill Torrents (HT). In order to succeed in seeking advantages of flooding, it is important to first identify regions that are prone to high risk due to floods. One of the ways this can be achieved is by employing GIS based Multi-Criteria Decision Analysis (MCDA) technique. MCDA is a common method employed in various spatial analysis studies, which relies on overlay of multiple layers of spatially processed GIS data. Remote Sensing (RS) and Geographical Information System (GIS) techniques are widely used to identify potential site for flood related disaster mitigation infrastructure and provide planning opportunity to develop evacuation, response, resource allocation, and evidence-based policy tools. In this study Multi-Criteria Decision Analysis (MCDA) is used to identify potential sites in Indus basin for the application of Nature-based Solutions (NbS) including restoration of indigenous wetlands to store excess flood water or divert it for alternate use.

Study Area:

Ten potential high flood risk sites/regions along the Indus River Basin were under consideration. These included Haleji, Hadero, Esakhel watershed, Lala Creek, Darya Khan-Ramak, (Nara, Chotiari and Deh Akro), Kaha watershed, Dera Ismail Khan, Chakar Lehri Sub Basin and Manchar Lake, as shown in Fig.-1 below.

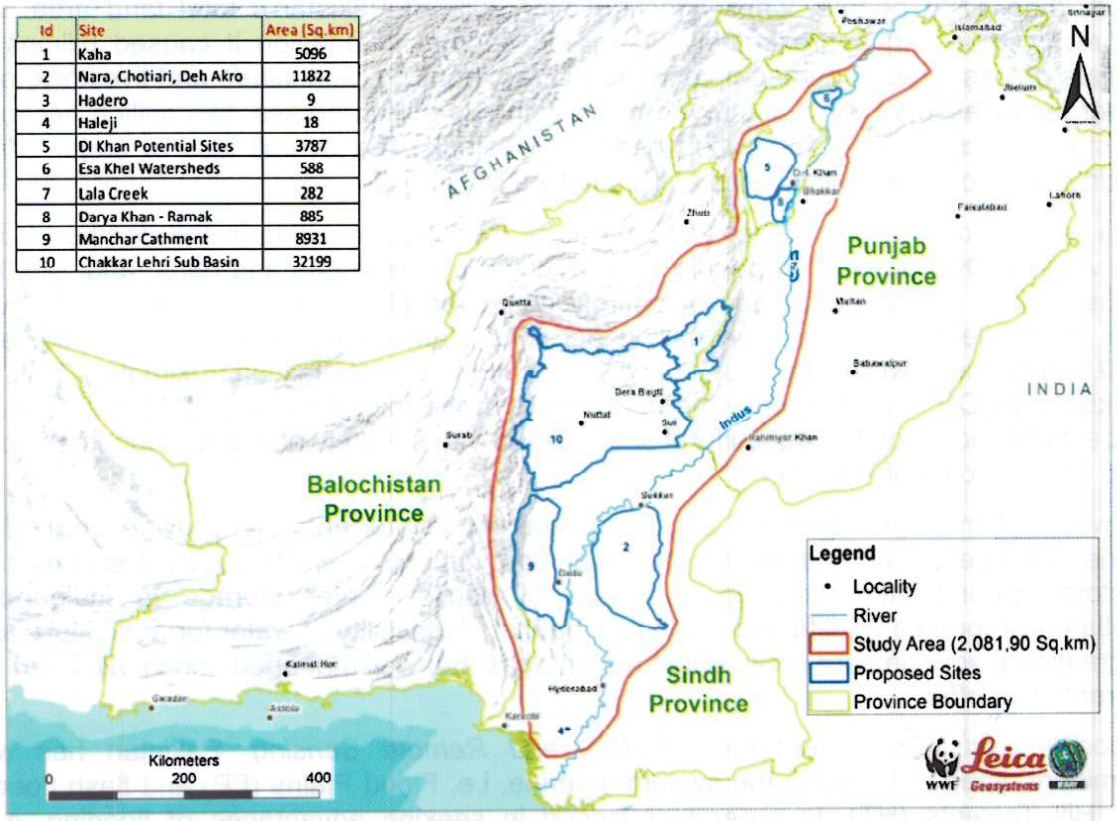


Fig.-1: Map highlighting Study Area and identified sites and regions

The reason for choice of these sites was due to frequently reported high flood impacts in the reports by Federal Flood Commission (FFC) and National Disaster Risk Management Authority (NDMA). In addition, consultations were carried out with FFC, NDMA and related water authorities and experts to finalize the choice of these sites for the purpose of initial investigation.

Methodology:

To initiate determining which sites are most affected by floods, a list of datasets was prepared. The datasets were categorized according to the type of risk they represented the best, i.e. Hazard, Exposure or Vulnerability. For example, flood frequency was categorized a type of risk that reflects the level of hazard while temperature variations and precipitation data depicted the scale of exposure. Similarly, groundwater levels and topographic features indicated vulnerability of a certain region. Detail of each dataset and their associated category is presented in Table-2 below.

In total fourteen spatial parameters, indicated in Table-2 above were used for geospatial database preparation. Using GIS tool, the thematic layers namely Ground Water Resources & Recharge, Flood Hazard Map, HDI, MPI, Population, Forest Cover, Vegetation Zones, Endemism, High Significant Wetlands, Birds Species Richness and

Mammal Species Richness datasets were prepared from different Sources mentioned in Table (Data Table). Ground Water Resources and Recharge Map was taken from IGRAC, 2015 and GIS tools used to develop thematic layer for analysis. CHIRPS satellite data of Annual mean Precipitation for the year of 2018 was processed. Similarly, Annual Mean Temperature Data from MOD11 A2 MODIS data utilized. Elevation Data Was extracted from SRTM 90m for year 2018. HDI and MPI Map of Pakistan were taken from United Nation Development Programme and digitized in ArcMap Environment to make thematic layers. Population thematic layer was developed using Pakistan Bureau of Statistics (PBS) Censes 2017 data.

	#	Criteria	Geospatial proxies / datasets		
			Bio-Physical Datasets	**Socio-Economic Datasets**	**Ecological Datasets**
Risk Criteria	1	**Hazard**	Flood frequency maps e.g. 1:1; 1:5; 1:10; 1:20; 1:50 (i.e. 100%, 20%, 10%, 5%, 2% probability in any one year) (FP)	N/A	Biodiversity Data (No. of IUCN red listed species etc.) (FP + HT) Endemism, Wetlands.
	2	**Exposure**	Hydrological / Watershed Maps (FP+HT) Surface Run Off /Precipitation Data (FP+HT) (CHIRPS, 2018) Temperature variation data (MODIS, 2017)	N/A	
	3	**Vulnerability**	Topographic information, e.g. contour maps (FP + HT) (STRM 90m) Slope index / contour maps (STRM 90m) Groundwater levels data (IGRAC 2015)	Multi-dimensional poverty index (MPI) (FP+ HT) (UNDP, 2015) Human Development Index (FP +HT) (UNDP, 2015) Population densities / settlements (Pakistan Bureau of Statistics, 2017)	Percentage Protected area under the influence of flood (FP + HT) Percentage vegetation / forested cover area (FP+HT) Migration routes and stop over sites for priority species (e.g. Indus Flyway) (FP+HT)

Table-2: Datasets used for overlay analysis

Once categorization was completed, each dataset was normalized and standardized by rescaling (ranking) between the values of 1 - 4, where value '1' would represent *'being most flood affected'*, while value '4' representing *'being least flood prone'*. Each dataset was then assigned a weight, based on its level of importance. In this case each dataset was considered equally important, thereby assigned an equal weightage. However, the level of importance can vary, and is dependent on the operator/system user to identify which dataset can have higher or lower weightage depending on the conditions of actual sites or regions under consideration.

A summary of data preparation method is presented in Table-3 below:

STAGES	STEPS
Data Development	Spatial / Non-Spatial data Acquisition from various Public / Private Organizations and online sources. Conversion of Non-Spatial data into GIS standardized format Data harmonization and preparation of map layers
Weighted Overlay	Map standardization i.e. classifying each layer with an equal distribution in four classes from 1 to 4 (where 1 stood for the Highest priority and 4 for the lowest priority) Assigning weights to each spatial layer Preparing an overall ranking map by overlaying weighted standardized criterion maps ("weighted overlay" analysis)
Score Assessment	Identifying the potential sites with highest scores of weighted criteria Final selection of potential sites based on Socio-economic, biophysical and Environmental parameters

Table-3: Stages of Data Preparation and GIS Analysis

Once the rankings and weightages were completed for each dataset, three sets of indices were then developed i.e. Bio-Physical Vulnerability Index, Socio-Economic Vulnerability Index and Ecological Vulnerability Index by adding the datasets for each type using the Multi-Criteria Decision Analysis (MCDA) on ArcGIS. Each dataset was overlaid one upon the other to develop a new dataset, referred to as vulnerability index. For example, in case of bio-physical vulnerability index, groundwater data was overlaid on temperature, precipitation and elevation datasets to calculate a new layer based upon the weighted averages.

The description of calculation of each vulnerability index is given below:

Bio-Physical Vulnerability Index:

In order to calculate Bio-Physical Vulnerability Index due to Flood Hazards, weighted overlay analysis in ArcMap Environment was employed using Ground water recharge, Temperature, Precipitation, Elevation thematic Layers. Results of the index are shown in Table-4 below

Bio-Physical Overlay Analysis				
Layers	**Source**	**Values**	**Rank**	**Weightage (Influence %)**
Ground Water Resources & Recharge (mm/a)	IGRAC , 2015	Major Ground Water Basin Very Low (<2)	1	25
		Major Ground Water Basin Low (2 – 20)		
		Local & Shallow Aquifer Medium - Very Low (<100)	2	
		Major Ground Water Basin Medium (20 – 100)		
		Major Ground Water Basin Very High (>300)	3	
		Local & Shallow Aquifer Very High – High (>100)	4	
		Major Ground Water Basin High (100-300)		
Precipitation	Pakistan Meteorological Department	701---1600	1	25
		401---700	2	

	Department (PMD),2015	201---400	3	
		50---200	4	
Temperature	MODIS, 2017	26---40	1	25
		16---25	2	
		6---15	3	
		<5	4	
Elevation	SRTM 90m	0---500	1	25
		501---1000	2	
		1001---1500	3	
		>1500	4	

Table-4: Bio-physical Weighted Overlay Analysis Data

Socio-Economic Vulnerability Index:

Socio-Economic Vulnerability Index was determined through weighted overlay analysis in ArcMap Environment using Human Development Index (HDI), Multi-Dimensional Poverty Index (MPI) and population spatial datasets. Each dataset was initially pre-processed, standardized and assigned weight, as shown in Table-5 below:

Socio-Economic Vulnerability Index				
Layers	**Source**	**Value**	**Rank**	**Weightage (Influence %)**
Human Development Index (HDI)	United Nations Development Programme (UNDP), 2015	0----0.286	1	33
		0.287----0.510	2	
		0.511----0.698	3	
		>0.699	4	
Multidimensional Poverty Index (MPI)	United Nations Development Programme (UNDP), 2015	0.325---0.641	1	33
		0.248---0.324	2	
		0.119---0.247	3	
		0.13---0.118	4	
Population	Pakistan Bureau of Statistics (PBS), 2017	0----500000	4	34
		500001---2000000	3	
		2000001---5000000	2	
		> 5000001	1	

Table-5: Socio-economic Weighted Overlay Analysis Criteria Layers & Weights

Ecological Vulnerability Index:

To determine the ecological vulnerability, Indus flyway dataset prepared internally by WWF-Pakistan was used as a proxy to represent the overall ecological conditions. This was due to the limited external database available against the ecological parameters identified earlier. The ecological vulnerability score was, therefore, reflective of the dataset for Indus flyway.

Results (Flood Site/Region Score Calculation):

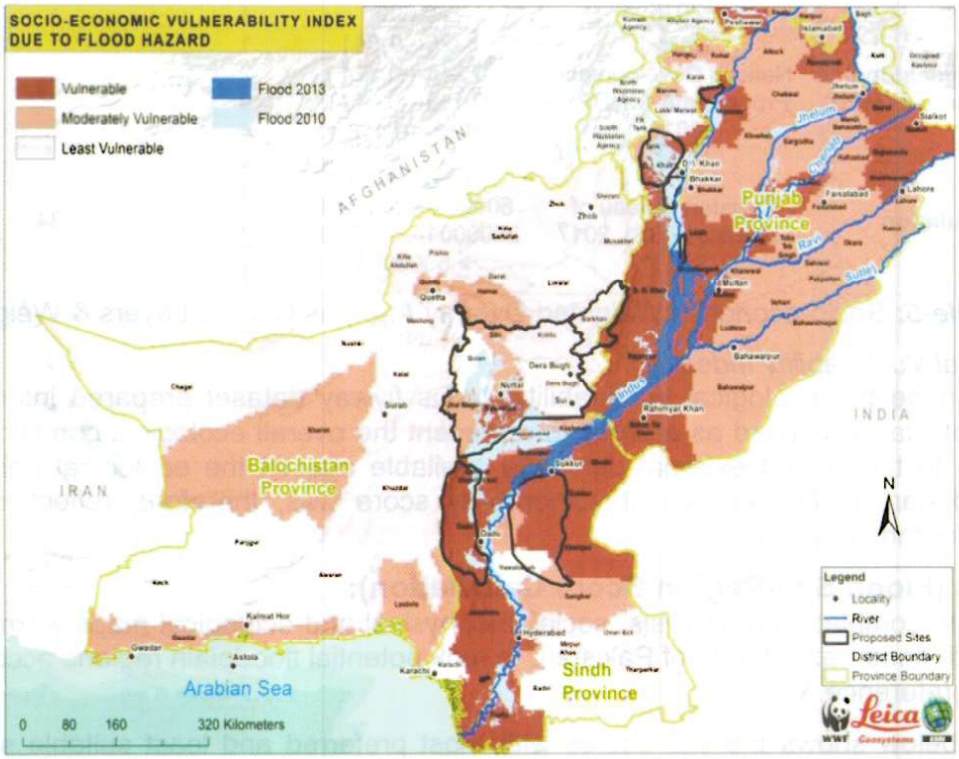
In order to complete the analysis, social, biophysical and ecological maps were scored, along with flood hazard map of Pakistan, to rank potential floodplain regions according to level of preference.

Table-6 below shows the site scores with most preferred and least suitable sites that were identified. Scores to each site were allocated using the following scale; 1: Highly Suitable; 2: Suitable; 3: Moderately Suitable; 4: Least Suitable

The scores were assigned against the level of vulnerability measured on the socio-biophysical score map, ecological map and flood hazard maps shown in Figure-2. The selection of most preferred site was based on the least score obtained by a site or a region. The reason for low score was due to the standardization of each layer done earlier during the analysis.

Site Name	Socio-Biophysical Score	Ecological Score	Flood Hazard	Overall Score
Hadero	1	1	2	**4**
Haleji	1	1	2	**4**
Esa Khel Watersheds	1	2	2	**5**
Lala Creek	1	2	1	**4**
Darya Khan - Ramak	1	2	2	**5**
Manchar Catchment	1	1	1	**3**
Nara, Chotiari, Deh Akro	1	1	1	**3**
Dera Ismail Khan	1	1	3	**5**
Chakkar Lehri Sub Basin	2	2	2	**6**
Kaha Hill Torrent	2	3	2	**7**

Table-6: Scoring table for prioritization of sites



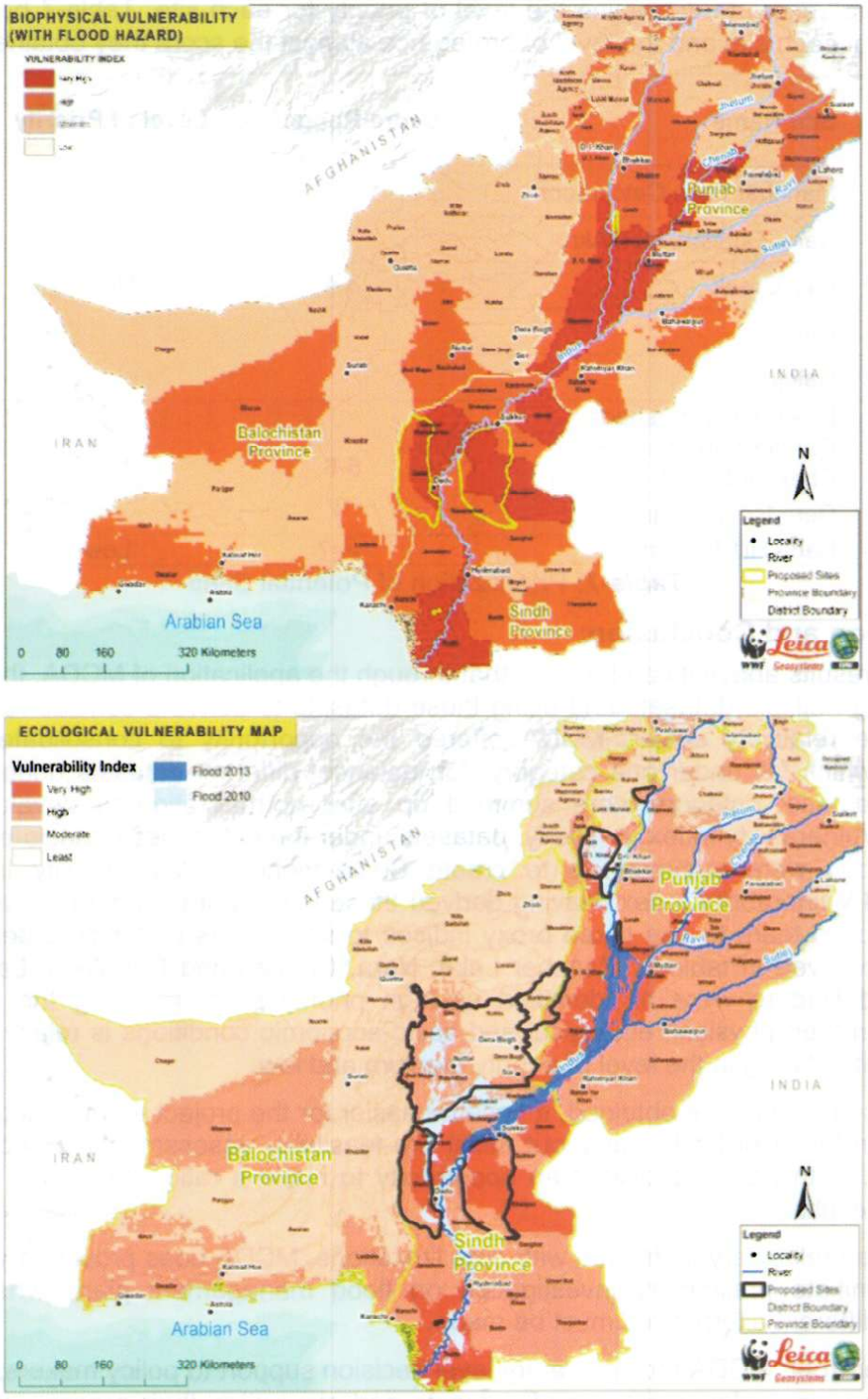


Figure-2: Socio-Economic, Bio-Physical and Ecological Vulnerability Index Maps

Using overall score to determine the level of priority for each site, Table-7 below gives summary of each site and the level of preference against the score they obtained.

Site ID *(As per map)*	Site Name	Score Range	Level of Priority
9	Manchar Lake Catchment	3-4	High
2	Nara, Chotiari, Deh Akro		
7	Lala Creek		
3	Hadero		
4	Haleji		
6	Esa Khel Watersheds	5-6	Medium
8	Darya Khan - Ramak		
10	Chakkar Lehri Sub Basin		
5	Dera Ismail Khan		
1	Kaha Hill Torrent	>=7	Low

Table-7: Prioritization of Potential Sites

Discussion and Conclusion:

From the results above it can be seen that through the application of MCDA, the process of handling multiple datasets and using those datasets to derive a conclusive evidence was made relatively easier. MCDA offered the opportunity to consolidate different datasets which fall under one category, for instance, different datasets under the Bio-Physical dataset category were summed up after normalization to develop a Bio-Physical Vulnerability index. Similarly, datasets under the categories of socio-economics and Ecology were summed up to create Socio-economic Vulnerability Index and Ecological Vulnerability Index. Having derived these indices, it became relatively easier for the project team to use these proxy indices to score sites under consideration. As can be observed in table-7, Manchar Lake, Nara, Chotiari and Dek Akro, Lala Creek, Haleji and Hadero were all identified as high priority sites; meaning the impact of flooding on their physical, ecological and socio-economic conditions is relatively higher than the sites falling in the level of priority medium and low.

Once these results were obtained, it became easier for the project team to decide which sites to prefer in order to carry out initial pre-feasibility assessments. Hence, MCDA technique, in this case, provided an opportunity to make a rational decision based on scientific results.

Although a preliminary technique with data limitations, MCDA does provide a valid entry point to initiate preliminary investigation on flood management plans when choice between different alternatives must be made.

On a wider front, MCDA provides entry level decision support to policy makers, and data experts to process large number of datasets and streamline their process of decision making. A long-term impact of this process can also be on streamlining of budgetary allocations for climate change resilience projects.

It can therefore be concluded that, MCDA provides a good basis to process flood risk related information and establish baselines for decisions on climate change resilience planning process.

References:

1. Ali, Akhter, and Dil Bahadur Rahut. "Localized Floods, Poverty and Food Security: Empirical Evidence from Rural Pakistan." Hydrology 7.1 (2020)
2. Kellens, W; Terpstra, T.; De Maeyer, P. Perception and communication of flood risks: A systematic review of empirical research. Risk Anal. Int. J. 2013, 33, 24–49. [CrossRef] [PubMed]
3. EM-DAT. EM-DAT The International Disaster Database. 2016. Available online: http://www.emdat.be/database (accessed on 25 November 2019).
4. Mustafa, D.; Wrathall, D. Indus basin floods of 2010: Souring of a Faustian bargain? Water Altern. 2011, 4,72–85.
5. Mall, R.; Srivastava, R. Sustainable flood management in changing climate. In SAARC Workshop on Flood Risk Management in South Asia; Mishra, O.P., Ghatak, M., Kamal, A., Eds.; SAARC Disaster Management Centre:New Delhi, India, 2012; pp. 49–66.
6. Davies, R. June 2013 Floods Summary. Floodlist. 2 July 2013. Available online: http://floodlist.com/summary/June-2013-Floods (accessed on 18 December 2019).
7. Field, C.B.; Barros, V.; Stocker, T.F.; Dahe, Q. Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation: Special Report of the Intergovernmental Panel on Climate Change; Cambridge University Press: Cambridge, UK, 2012.
8. Turner, A.G.; Annamalai, H. Climate change and the South Asian summer monsoon. Nat. Clim. Chang. 2012,2, 587. [CrossRef]
9. Tinh, D.Q.; Hang, P.T. Living with Floods in the Mekong River Delta of Vietnam; Department of Dike Management, Flood and Storm Control, Ministry of Agriculture and Rural Development: Hanoi, Vietnam, 2003.
10. Theron, M. Climate change and increasing floods in Africa: Implication for Africa's development, Consultancy Africa Intelligence/Africa Watch Newsletter 2007.
11. Kundzewicz, Z.W.; Kanae, S.; Seneviratne, S.I.; Handmer, J.; Nicholls, N.; Peduzzi, P.; Mechler, R.; Bouwer, L.M.; Arnell, N.; Mach, K. Flood risk and climate change: Global and regional perspectives. Hydrol. Sci. J. 2014, 59, 1–28. [CrossRef]
12. Sardar, M.S.; Tahir, M.A. and Zafar, M.I. Poverty in riverine areas: Vulnerabilities, social gaps and flood damages. Pak. J. Life Soc. Sci. 2008, 6, 25–31.
13. Tariq, M.; Hoes, O.; Van de Giesen, N. Development of a risk-based framework to integrate flood insurance.J. Flood Risk Manag. 2014, 7, 291–307. [CrossRef]

14. Government of Pakistan. Economic Survey of Pakistan; Ministry of Economic Affairs, Pak Secretariat: Islamabad, Pakistan, 2011.

15. Rehman, A.; Jingdong, L.; Du, Y.; Khatoon, R.; Wagan, S.A.; Nisar, S.K. Flood disaster in Pakistan and its impact on agriculture growth (a review). Environ. Dev. Econ. 2016, 6, 39–42.

16. Government of Pakistan. Economic Survey of Pakistan; Ministry of Economic Affairs, Pak Secretariat: Islamabad, Pakistan, 2015.