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Exploring the Nature-based Solution (NbS) to Flood Risk Reduction in the Punjab, Pakistan

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The history of floods in the province of Punjab is as old as the evolution of early human settlement in this "*land of five rivers*" named Harappa some five thousand years ago. The annual wet Monsoon brings rain, with changing climatic patterns. Similarly, the occurrence of floods in many parts of Pakistan has also shown a changing trend that has never been experienced before. This study aims to predict the flood prone area in Punjab. The study shows that 40.17% and 36.06 % of the population of Dera Ghazi Khan and Faisalabad divisions are at risk due to floods. District level Muzaffargarh 3318.4 square kilometers, Rajanpur 2293.93square kilometers (D.G Khan), and Jhang with 2170.63square kilometers (Faisalabad) are flood-prone areas in the Punjab. In recent years, the researcher's interest has increased in identifying and understanding the role of nature-based solutions (NbS) in reducing flood risk as well as their duration, magnitude, and frequency. In other words, NbS primarily aimed to reduce flood hazards by using indigenous knowledge of the local population, altering and managing land use, reservoir maintenance, and river channels. Further to this, the potential use of NbS can improve integrated water management, lessen the risk of floods and improve environmental governance in the region. The findings propose how to move forward with the influence of NbS for sustainable flood management strategies, which ultimately improve the well-being of millions of people living in flood-prone regions. This will also help formulate policies, and findings can be generalized for other similar parts of South Asia as well as other parts of the world.
Keywords: Flood Risk, Punjab, NbS, Environmental governance, Flood-prone regions

Introduction:

Floods are considered one of the most significant natural hazards, occurring at a rate 43% higher than other hazards worldwide. They are defined as events in which water overflows from rivers, streams, or other confined channels, inundating areas that are not usually affected under normal flow conditions [1] Torrential rainfall, topography, soil, and surface permeability are considered the key parameters for flooding [2][3]. Floods, being a regional and global phenomenon, and their intensity varies day by day across the globe. [4][5].

Globally, floods affected nearly 2 billion people between 1998 and 2017 [6]. In South Asia, 2/3 of the population is vulnerable to floods. Natural disasters and flooding are persistent threats in South Asia because of its geographical position [7]. In underdeveloped countries, climate change and environmental degradation are more critical in escalating the flood risk [8][9], instead of human-induced factors, e.g., encroachment in the riverbeds[10][7].

In the South Asian region, Pakistan is highly vulnerable to floods due to a changing climate, poor management, and inadequate supportive infrastructure[11]. The country is considered a key hotspot area for climate change impacts, mainly due to recurrent flood-related catastrophes [12]. Carbon emissions from Pakistan are insignificant, rather less than 1%, yet it faces severe climate change impacts. According to the Global Climate Risk Index (GCRI), it is ranked as the 7th most vulnerable and the 8th most affected country by climate change [13][14].Initially, it was considered a hazard associated with rural areas; however, it is now common in urban areas as well. In South Asia, the urban communities are more vulnerable due to urban growth along the floodplains and the changing climate. Urban flooding is a frequent phenomenon in Pakistan. The urban population has been massively affected by flooding (pluvial and fluvial) over the last decade. In 2010, the flood resulted in a monetary loss of more than 10 billion US dollars and damaged significant amounts of infrastructure across the country. Furthermore, in urban centers, pluvial flooding is known as a devastating hazard and recurring phenomenon every year due to excessive Monsoon rainfall [14].

The devastating effects of floods on social, economic, and ecological aspects are well understood at the individual and community levels[15][16]. However, in underdeveloped countries, the increase in flood vulnerability and risk is linked with multiple factors, e.g., climatic changes, human-induced factors. The encroachment onto the river also intensifies the extent and severity of flood effects [13].During the last decade, Pakistan experienced three major floods in 2010, 2011, and 2012. In the 2010 floods alone, approximately 70,000 km^2 of land were submerged, and about 0.9 million people were displaced. In 2011, a 21,000 km^2 area and 5.9 million people were affected with substantial infrastructure damage. In 2012, 22 districts of Pakistan suffered severe impacts, with substantial damage to infrastructure and loss of human life s[17][18][19][20].

In the past few decades, the country has experienced many frequent flooding events, which have triggered massive damage to livestock, industry, infrastructure, and human loss. The devastating effect of these floods in different sectors, e.g., livelihood, population, and the environment, is often intensified by a mix of insufficient resources, early warning systems, capacity constraints, and risk reduction strategies, and a high man-land ratio in flood-prone regions [21][13].From 1950 to 2014, the Punjab province experienced 22 devastating floods, which caused damage to property and loss of human and livestock [22][23]. Currently, the flood risk perception is identified as a key parameter in flood risk assessment [24][25].

Floods can reverse the growth in terms of poverty alleviation, socioeconomic uplift, and economic growth in the country. They have severe and adverse impacts on both the socioeconomic well-being and ecological environment of affected individuals and communities. Nature-based solutions (NbS) provide a practical substitute that minimizes the likelihood of flooding while conferring other advantages. [26][27][28]. NBS helps societies, their economy, and the environment by incorporating biophilic infrastructure, natural characteristics, and approaches into city landscapes and river stream management systems [29].

The impacts of floods profoundly depend on site, magnitude, duration, volume, intensity, degree, and susceptibility [13]. The present study is an effort to identify and use NbS to reduce the risk of floods in Punjab, the largest province of Pakistan in terms of population size, and millions of its inhabitants depend on agriculture, which remains at risk due to the occurrence of floods.

The study is designed to evaluate the existing flood risk profile of the province of Punjab, keeping in view the hydro-climatic parameters, land use patterns, as well as the socio-cultural vulnerability of the population. It further investigated the nature-based solutions to reduce the risk of ravine floods in the study area and suggested nature-based solutions to reduce the flood risk, which is a frequent norm in the province. The study of this nature has not been conducted in this part of South Asia and is novel among studies of this nature conducted elsewhere in the world.

Materials and Methodology:

Study Area-the Punjab:

Punjab province is located in a subtropical region in the southern part of Asia, between 27.42° and 34.02° N latitude and 69.81° and 75.23° E longitude. Punjab is known as the "Land of Five Rivers" because five rivers flow through it. It is the most populous province in Pakistan, with approximately 127.7 million residents. Punjab has a population density of 621.8 people per km² [30]. The province's climate ranges from arid to semi-arid, with average maximum temperatures between 29°C and 31°C and minimum temperatures ranging from 16°C to 18°C. Punjab re-experiences maximum rainfall in the summer season due to monsoon rainfall and winter rainfall from western depressions. The rainfall pattern is decreasing from north to south. Punjab province is significant as it is more vulnerable to floods compared to the other provinces. The total area of Punjab is only 26% but highly populated, sharing 56 % of the total population of the country [31]. Figure 1 depicts the study area map.

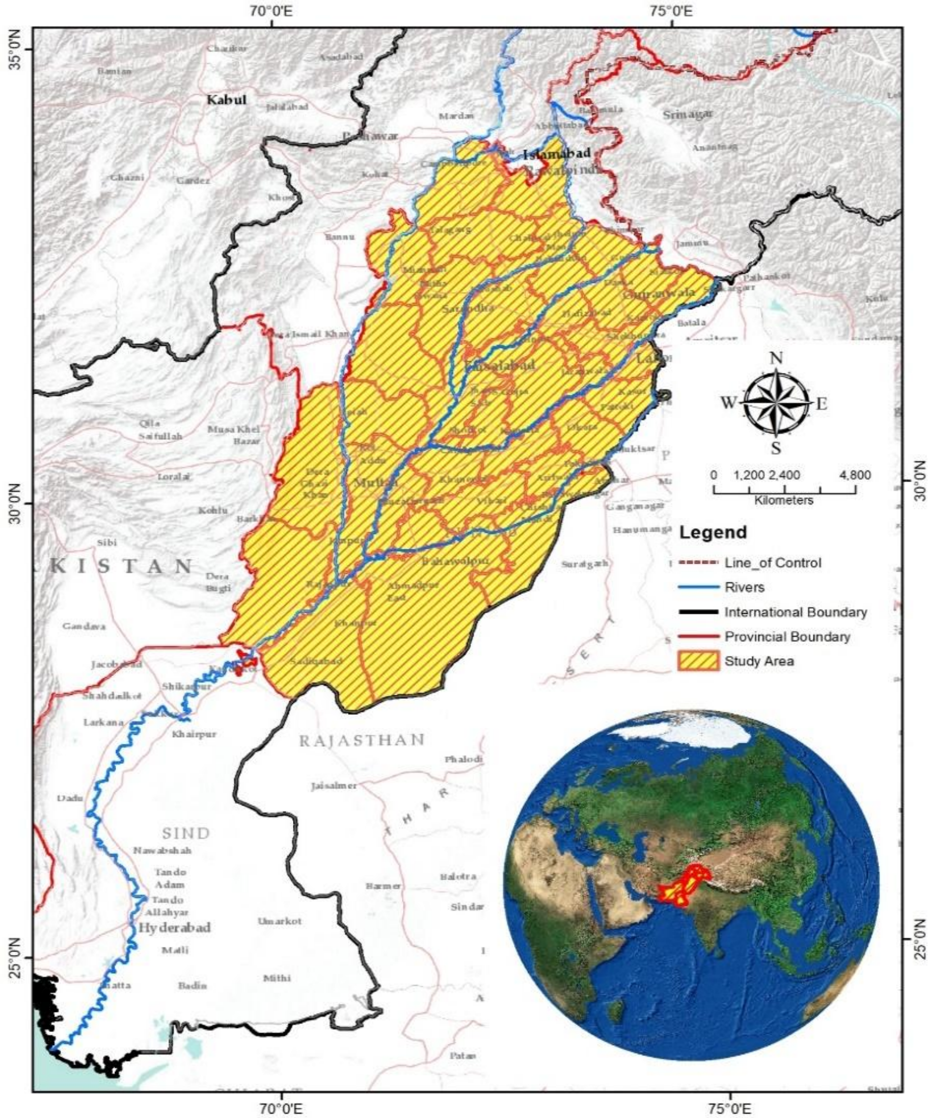

Figure 1. The study area Map

Data Acquisition:

In this study, for the flood extent mapping, the MODIS product "MOD09GA version 6.1 band 1-7 daily surface reflectance resolution was 50 and 1km [[32]. Flood-prone areas were identified, followed by a field survey based on random sampling to collect information on the disaster. The MODIS (https://modis.gsfc.nasa.gov/data/)products were downloaded, and different filters and correction techniques were applied to the dataset to estimate the flood-prone areas of the Punjab [33]. Eq. 1

Spatial Analyst > Raster Calculator

Con ("QA_Layer" = 0, "Band_to_Analyze", No Data) = Resultant

QA_Layer = Cloud Mask Layer

Band_to_Analyze = MODIS Band (1)

The MOD09GA product provides surface reflectance data corrected for atmospheric effects using algorithms that account for aerosols, water vapor, and other atmospheric factors. In this study, the MODIS Bands were used for analysis and extraction [33]Image analysis was performed, and layer stacking was applied using bands 7, 2, and 1. A true color-based image was used for image stacking for the identification of the Water spread[34].

Preprocessing:

The Modified Normalized Difference Water Index (MNDWI) was calculated by using the raster calculator. The MNDWI is calculated by following Eq. (2)

$$MNDWI = \frac{(Green - SWIR)}{(Green + SWIR)}$$

$$MNDWI = \frac{Band\ 4 + Band\ 7}{Band\ 4 - Band\ 7}$$

Supervised classification in ArcGIS systematically categorizes raster data into distinct classes using labeled training data. Training samples were marked on the analyzed image then after classification method (Maximum Likelihood) was used to classify the image [35]. The chosen classification algorithm was applied to the entire raster dataset using the training samples as a reference. After classification, accuracy assessment was performed, which can be done using tools [36]. After the OBI-based machine learning process, data transformation and conversion analysis were applied to the resultant raster for processing the data and results [35][36].After this, conversion from raster to polygon was done to apply zonal statistics for area calculation[37].

Zonal Statistics:

The overlay analysis technique was applied after zonal statistics for area calculations [37]. Zones were divided based on the divisional boundary of the Punjab. Table 1 shows the zonal statistics and overlay analysis.

Table 1. Zonal Statistics and Overlay Analysis

S. No	Division	Area sq./km	Flood-prone Area
1	Bahawalpur	40612.52	1509.07
2	Dera Ghazi Khan	23934.95	8123.67
3	Faisalabad	15286.21	3446.69
4	Gujranwala	14800.95	958.17
5	Gujrat	10735.08	1338.91
6	Lahore	21068.90	951.62
7	Multan	12597.06	1565.30
8	Rawalpindi	31039.44	419.09
9	Sahiwal	22042.82	1135.09
10	Sargodha	13927.52	2580.49

Flood Risk Assessment:

After completing all analyses, tabular data were prepared from the layers generated in the earlier section. Flood risk analysis of all vulnerable areas was calculated by the integration of tabular data and Google Earth Pro data. Google Earth Pro provides high-resolution, complete data regarding the existing settlements in flood-prone areas. Layers of flood-prone areas were converted into a Google Earth file and imported into Google Earth Pro to calculate the settlements located within these flood-prone zones [38]. The number of villages falls in the flood-prone area, secondly, the flood-prone area / total district Area, and lastly, the built-up area mapping of flood-prone areas. Flood risk was assessed through spatial analysis of various factors using GIS. Flood risk Analysis was calculated through the spatial analysis of different aspects using GIS.

Flood Risk on Human = Total Number of Villages * Population / Flood prone area

Flood Risk on Agriculture = Total Green Area / Flood Prone Area

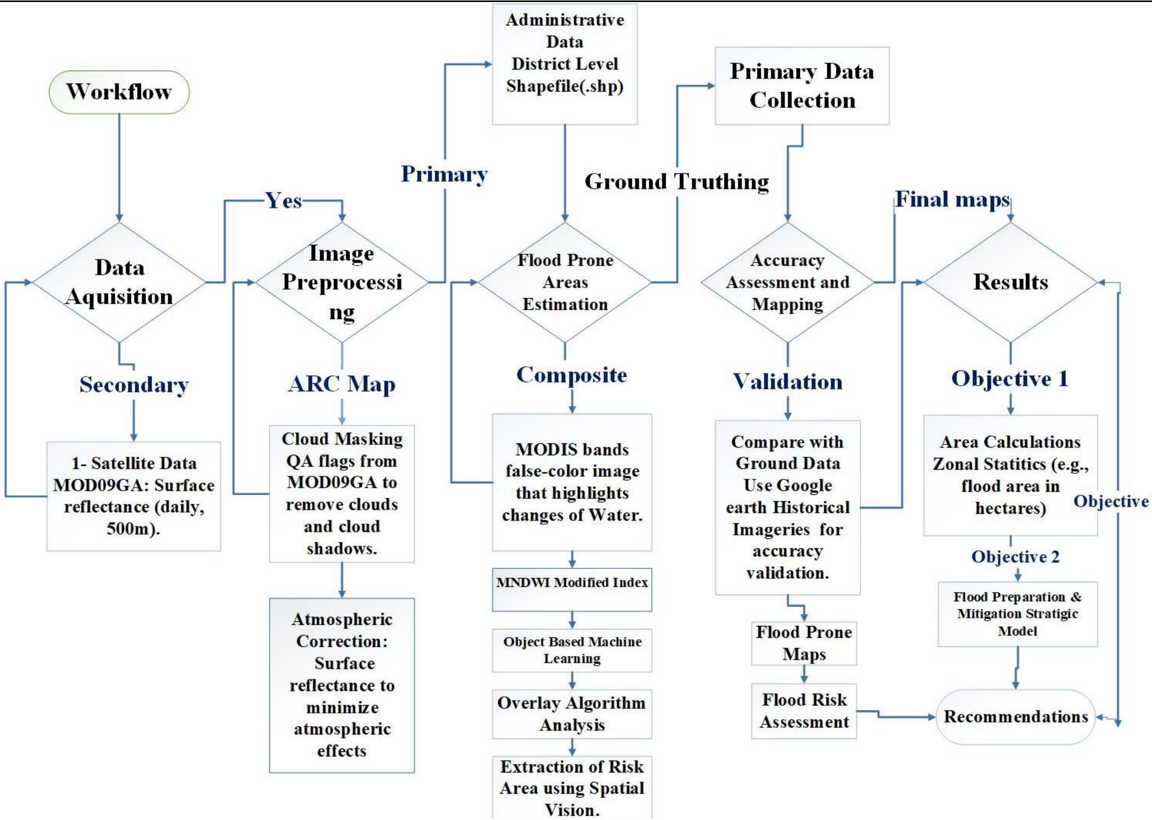

Figure 2. Research Workflow

Validation:

GIS-based platforms, including Google Earth, along with other high-resolution satellite images, were used to verify the accuracy of the results. The prepared data were then overlaid on Landsat 8 imagery for validation [35]. The results show that 95% of the data corresponded with Landsat imagery across different areas. Further validation of the data can be conducted through field surveys in flood-prone regions. [38][37]. Furthermore, all layers were imported into the new ArcGIS environment for the preparation of the maps. The desired layers were added to the GIS for mapping. Table 2 indicates the Accuracy and validation of the data.

Table 2. Accuracy and Validation of Data.

Sr. No	Class	Samples Marked from Google Earth	Sample Marked on Classified Map	Sample Matched	Accuracy
1	Water	100	100	95	95%
2	Urban	100	100	90	90%
3	Vegetation	100	100	91	91%
4	Desert	20	20	19	99%

Results:

Punjab province is more susceptible to these types of flood risk, e.g., flash floods, riverine floods, and urban floods. These floods frequently occur every year and bring a lot of damage in terms of property and human lives. The twelve districts are classified as higher-risk flood-prone districts in Punjab province. Flash floods are experienced in three districts e.g., such as Mianwali, Dera Ghazi Khan, and Rajanpur, as adjacent to hilly terrain, with storms of high velocity leading to fast flooding, often crossing through the narrow water channels. Figure 4 depicts the flood-prone areas and associated flood risks across different divisions of Punjab, Pakistan. Using key metrics such as area size and extent of flood-prone regions, affected villages, and potential flood risk to the population, this analysis identifies the divisions most vulnerable to floods. It highlights the need for targeted flood management and mitigation efforts.

Table 3 shows the flood risk division-wise rank in Punjab province. The Bahawalpur division encompasses an extensive area of 40,612.52 square kilometers but has a relatively small flood-prone region of 1,509.07 square kilometers that contains 359 affected villages, with flood risk impact on 23.79% of the population. In contrast, the Dera Ghazi Khan division exhibits the highest flood susceptibility in Punjab. Of its 23,934.95 km² area, approximately 8,123.67 km² are considered at risk. This division harbors 3,263 flood-prone villages, endangering 40.17% of its population. Faisalabad division, one of the country's important centers of industry and commerce, has an area of 15,286.21 square kilometers, out of which 3,446.69 square kilometers are flood vulnerable. This also affects 1,243 villages and 36.06% of the population.

While the Gujranwala division has a smaller flood-prone area, 958.17 square kilometers out of a total area of 14,800.95 square kilometers, it possesses very high flood risk vulnerability on account of exacerbating population density, with 279 villages impacted and 29.12% population risk. The Gujrat division has a population of 32.64%, with 1,338.91 km² of its total 10,735.08 km² classified as moderately flood-prone, and 437 villages are affected by flooding. Lahore division has an area of 21,068.90 square kilometers, within which 951.62 square kilometers is flood-prone; 293 villages are submerged, and 32.89% of the population is endangered.

Table 3. Division-wise results

Sr. No	Division Name	Area Sq/km	Flood Prone Area Sq/Km	No of Villages Affected	Flood Risk on Population
1	Bahawalpur	40612.52	1509.07	359	23.79
2	Dera Ghazi Khan	23934.95	8123.67	3263	40.17
3	Faisalabad	15286.21	3446.69	1243	36.06
4	Gujranwala	14800.95	958.17	279	29.12
5	Gujrat	10735.08	1338.91	437	32.64
6	Lahore	21068.90	951.62	313	32.89
7	Multan	12597.06	1565.30	358	22.87
8	Rawalpindi	31039.44	419.09	79	18.85
9	Sahiwal	22042.82	1135.09	225	19.82
10	Sargodha	13927.52	2580.49	538	20.85

Table 4. Top 10 Flood-Prone Districts

Sr No	District Name	Division Name	Flood Prone Area Sq/Km	District Area
1	Muzaffargarh	Dera Ghazi Khan	3318.48	5681.27
2	Rajan Pur	Dera Ghazi Khan	2293.93	3513.35
3	Jhang	Faisalabad	2170.63	6273.68
4	Dera Ghazi Khan	Dera Ghazi Khan	1625.45	2601.70
5	Mianwali	Sargodha	1141.82	3252.85
6	Chiniot	Faisalabad	904.65	2967.70
7	Layyah	Dera Ghazi Khan	885.81	12138.64
8	Rahimyar Khan	Bahawalpur	846.87	8261.93
9	Sargodha	Sargodha	770.50	4410.80
10	Hafizabad	Gujrat	710.51	6094.64

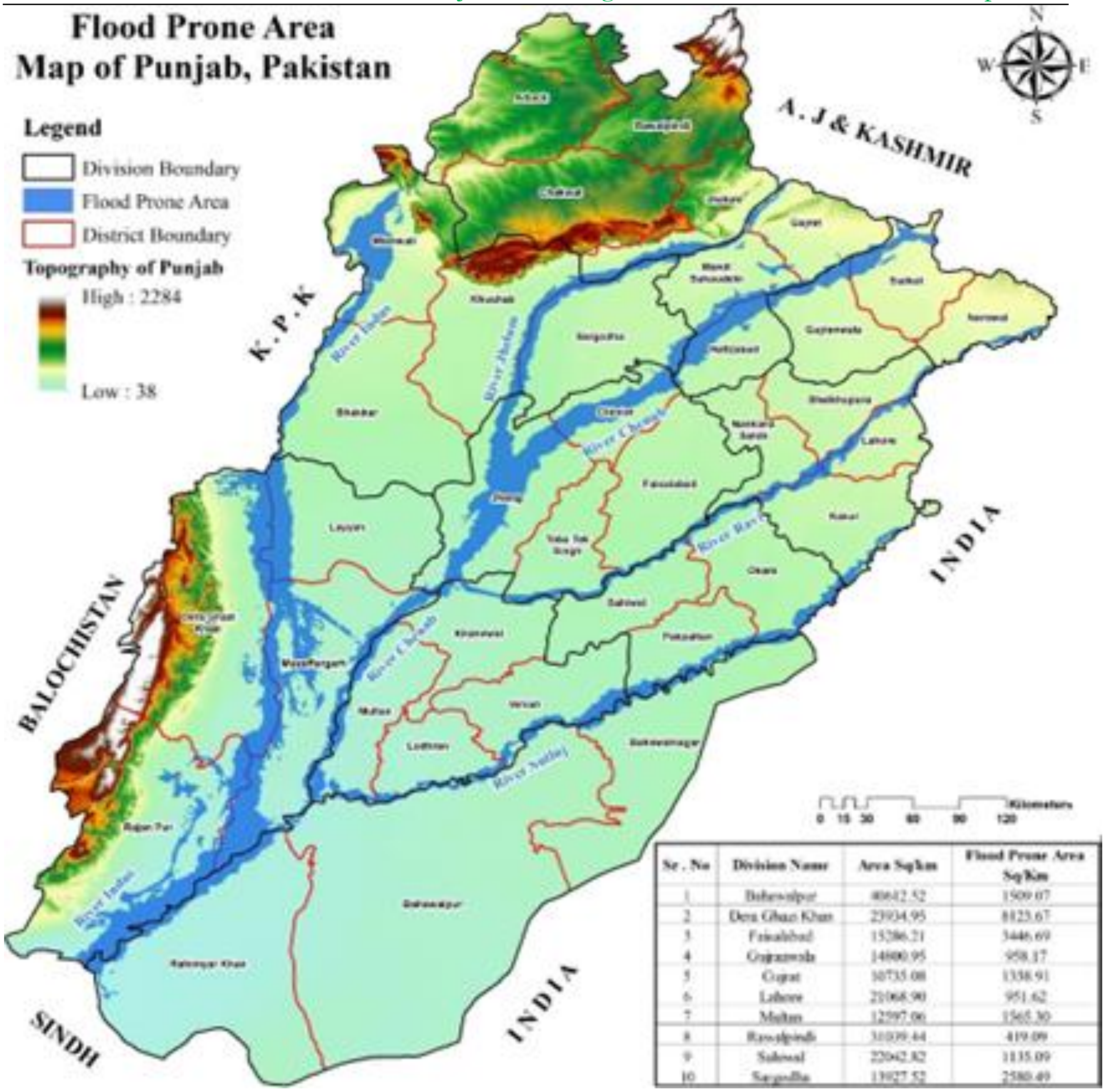

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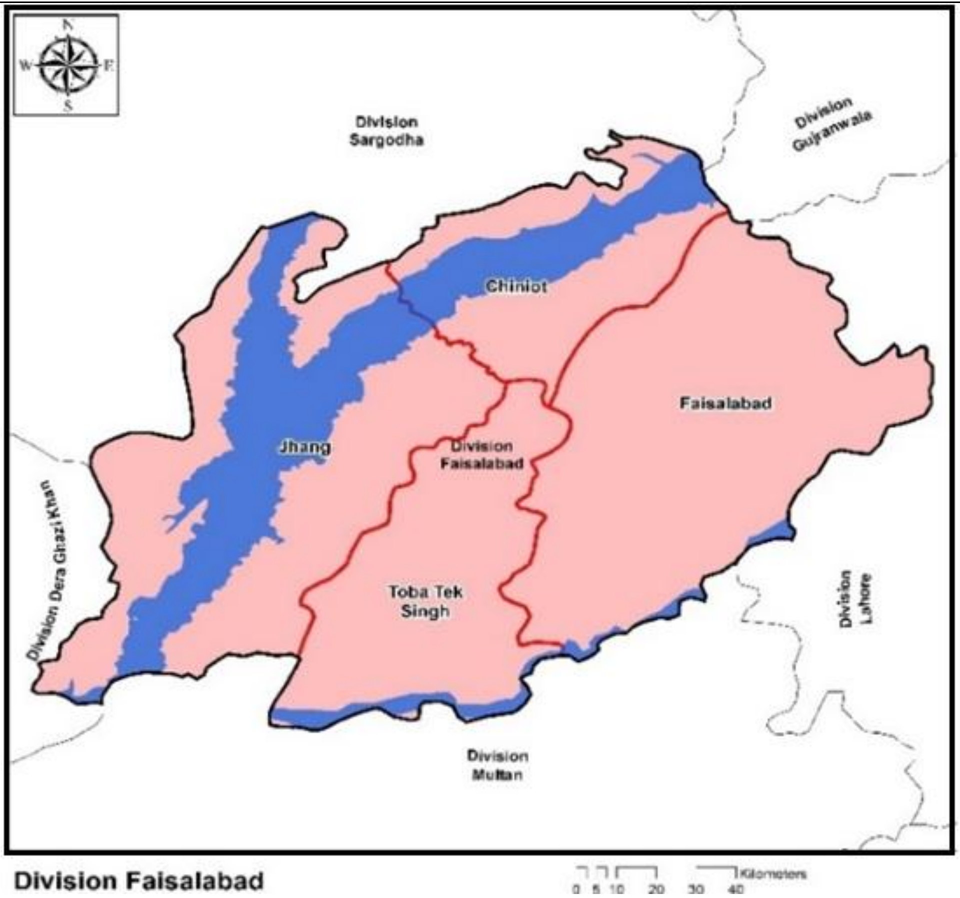
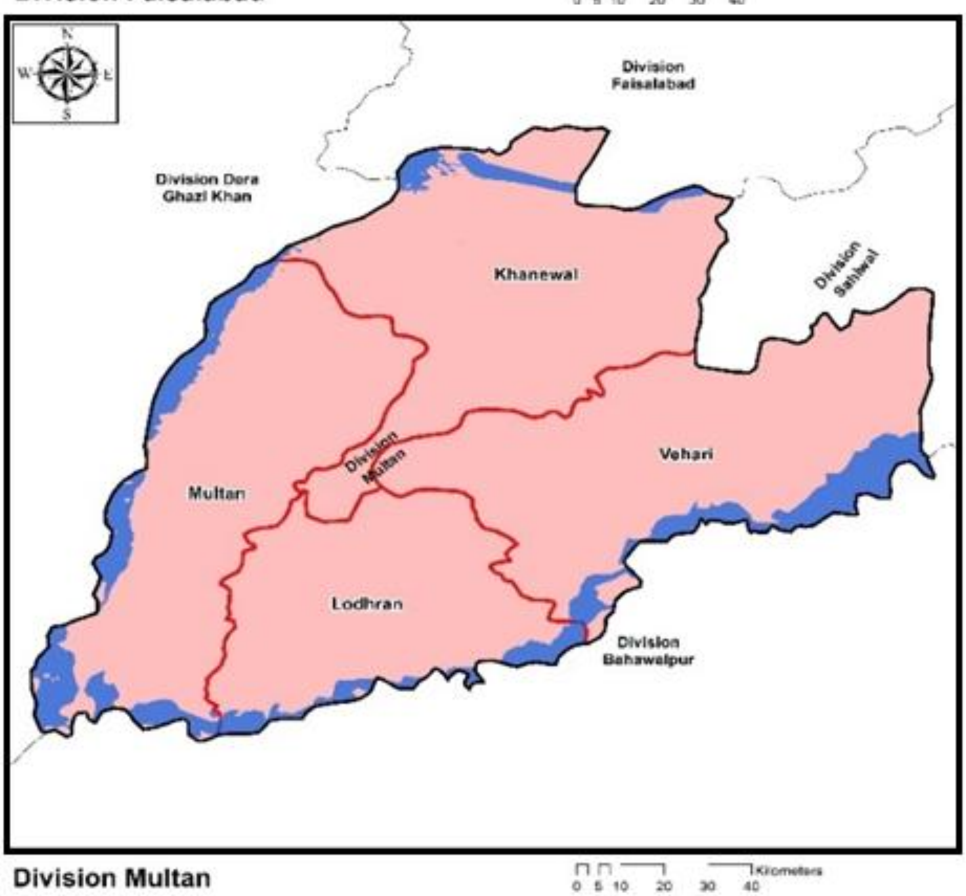
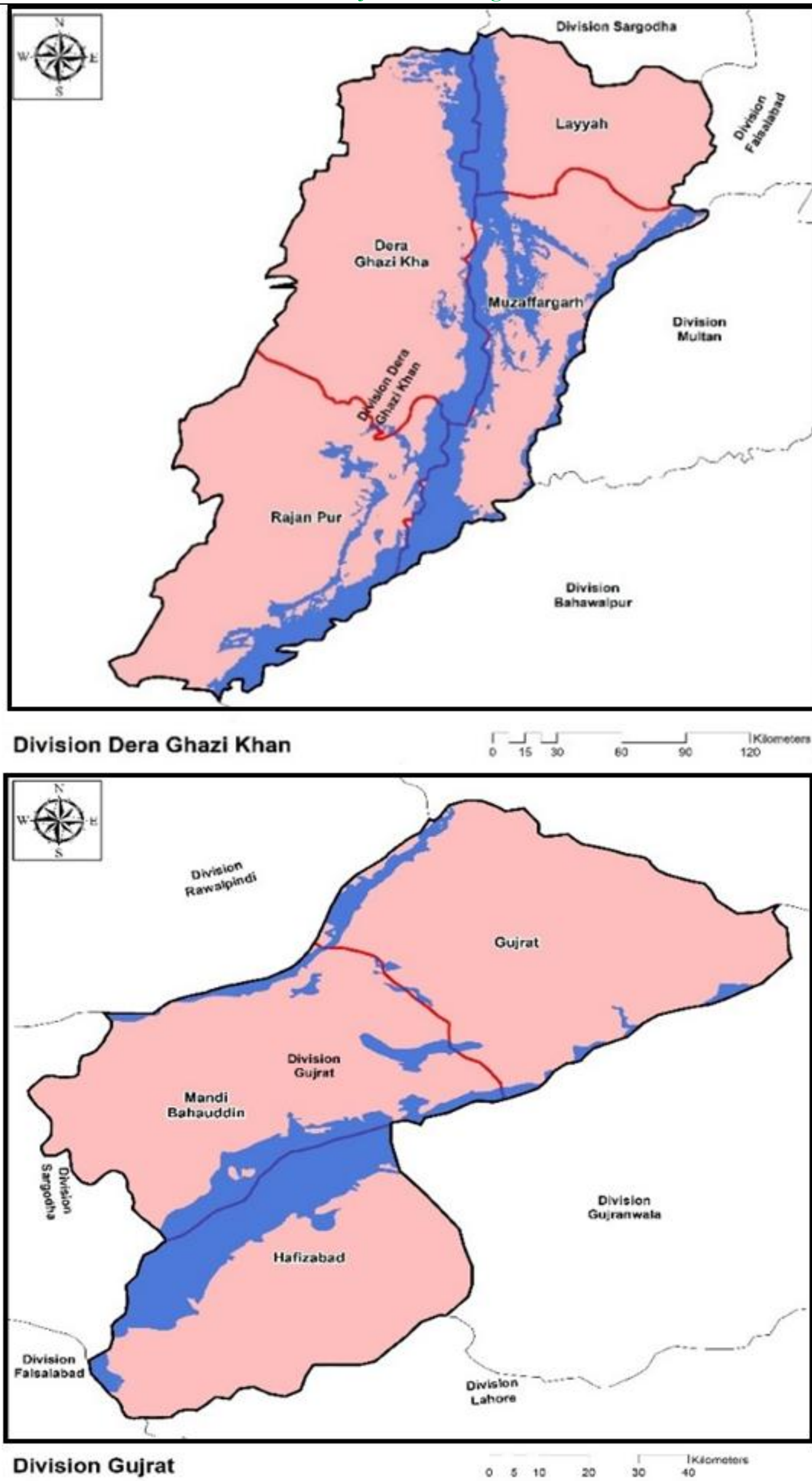
Figure 3. Flood Prone Area in Punjab


Division Sargodha
Division Gujranwala
Chiniot
Faisalabad
Jhang
Division Faisalabad
Division Dera Ghazi Khan
Toba Tek Singh
Division Lahore
Division Multan
Division Faisalabad
0 5 10 20 30 40 Kilometers

(a)


Division Faisalabad
Division Dera Ghazi Khan
Khanewal
Division Sahiwal
Division Multan
Vehari
Multan
Lodhran
Division Bahawalpur
Division Multan
0 5 10 20 30 40 Kilometers

(b)



(c)

(d)

Figure 4. Flood-prone areas of the Punjab

Discussion:

Multan division has a total area of 12,597.06 square kilometers and contains a flood-prone area of 1,565.30 square kilometers where 358 villages are located with a population risk of 22.87%. Rawalpindi division was reported to have the smallest flood-prone area of 419.09 square kilometers out of 31,039.44 square kilometers, with only 79 villages affected and an 18.85% population risk. This high flood risk is largely due to the region's topographical conditions. Nevertheless, managing flash floods and monitoring river basins remain priorities. Covering 22,042.82 km², the Sahiwal Division has 1,135.09 km² prone to flooding, affecting 225 villages and placing 19.82% of its population at risk. The Sargodha division has a total area of 13,927.52 square kilometers with a flood-prone zone of 2,580.49 square kilometers, which includes 538 adversely affected villages and 20.85% of its population. Table 4 shows the district-wise flood-prone area in Punjab province. Districts in southern Punjab are more severely affected by floods. Muzaffargarh and Rajanpur, located in the Dera Ghazi Khan division, are particularly flood-prone, while Jhang district in Faisalabad is also highly susceptible.

In D.G. Khan during September 2012, torrential monsoon rains created massive destruction in urban and rural areas. The floods mainly affected the districts of D.G Khan, Rajanpur, Muzaffargarh, and Rahim Yar Khan. As Rajanpur is in the vicinity of the riverbed, the eastern part of the district is mainly affected by inundation from the Indus River due to torrential rainfall in the monsoon season. The riverine flooding submerged the low-lying area along the river belt in all districts and subdivisions. The western part of the district is affected by flash floods due to the Suleman Range. Both these floods caused huge loss of livelihood and mud houses. 60 percent of the population of the area resides in approximately 80% of the land. The traditional nature-based solution (NbS) and the ways to control flood risk in the Punjab are floodplain restoration and strengthening the natural levees by the communities living along the banks and on active flood plains of the rivers flowing in the study area. Another way is to plant indigenous trees (kikar, ber,shisham, papal, bor, and dhraek) and native vegetation to provide a buffer against the floods. The wetlands also provide a natural way to absorb flood water and government may construct flood water wetlands to make ground water recharged to be utilized during dry seasons. The local governments and irrigation department must restore natural depressions in the floodplain areas and link them with the spillways or other nearby bay waterways to reduce the impacts of floodwater. The combination of green and \blue structures in urban landscapes is also a way to reduce the impact of floods in cities. The aforementioned NbS can contribute to regulating microclimates and the environment of the region.

Conclusion:

The impacts of floods are more devastating due to the changing climate and extreme weather events in Pakistan, as well as in the Punjab. In Punjab, Pakistan, floods have posed a significant threat to local communities since time immemorial. There is a dire need to evolve and develop strategies at the micro and macro levels among communities to reduce and mitigate flood risk. All the stakeholders should develop links at the community and institutional levels to lessen the impact of floods. The study shows that 40.17% and 36.06 % of the population of Dera Ghazi Khan and Faisalabad divisions are at risk due to floods. District level Muzaffargarh 3318.4 square kilometers and Rajanpur 2293.93square kilometers (D.G Khan), and Jhang with 2170.63square kilometers (Faisalabad) are flood-prone areas in the Punjab. The districts lying in South Punjab are more affected by floods. Muzaffargarh and Rajanpur lie in the Dera Ghazi Khan district, are more prone to floods. While Jhang district in Faisalabad is more susceptible to floods. To respond proactively to flood issues in Punjab, the strategies should be evolved, e.g., an early warning system, improved drainage, and embankments in higher-risk divisions. Advocacy for community preparedness and selfpreparedness education for people while residing in areas vulnerable to flooding. Nature-based Solutions (NbS) serve as an innovative and eco-friendly method for managing floods, leveraging ecosystems and natural processes not only to mitigate flood risks, but also to offer a plethora of ecological and social advantages.

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