Monsoon 2022 Floods and Its Impacts on Agriculture Land Using Geospatial Approaches: A Case Study of Khyber Pakhtunkhwa Province Pakistan.

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Pakistan lies among the most vulnerable countries facing severe episodes of climate change-induced hydro-climatic disasters, including heatwaves, floods, droughts, and rainfall-induced landslides. These disasters have major impacts on agriculture, soil health, groundwater, and the socioeconomic conditions of the region. In 2022, Pakistan experienced the biggest natural disaster in its history caused by several hydrometeorological anomalies. An extreme heat in May 2022 was followed by a devastating flood disaster in August 2022. Such natural hazards have hampered national socioeconomic conditions. Floods usually affected the whole province of Khyber Pakhtunkhwa (KPK) Pakistan; however, its nine districts were severely affected by the Monsoon-2022 Flood. In southern parts of the province, Dera Ismail Khan (DI Khan) and Tank were severely affected by the floods. In the northern parts of the province, Swat, Dir Lower, Dir Upper, and some areas of the Chitral region were affected. In the central parts, areas of Nowshera, Charsadda, and Peshawar were affected by the recent floods. Field data were collected and processed using geo-spatial techniques and verified the damages of floods in 2022. The results revealed that the recent monsoon spell damaged 1377.54 km^2 cropped area in the DI Khan region, and 270.15 km^2 cropped area fully or partially damaged in the District Tank region. Croplands with sugarcane and maize crops (117.56 km^2) were severely damaged in District Charsadda. While, a total cropland of 467.75 km^2 and 30.08 km^2 was damaged in District Nowshera and Peshawar, respectively. In the northern part of the province, District Swat was mostly affected by this flood where 122.00 km^2 of land with various crops and orchards were damaged. Similarly, 63.60 km^2, 15.15 km^2, and 575.68 km^2 of agricultural land were affected in District Dir Lower, Dir Upper, and Chitral, respectively. The outcome of the present study will help the government and other organizations mitigate the adverse effects of such floods in the future and will assist in rainwater conservation strategies/planning.

Keywords: Monsoon; GIS; RS; Disaster; Climate Change.

Introduction:

The abrupt positive trend in climate has caused uncertain weather phenomena around the globe [1] [2] [3] [4] [5] [6]. Developing countries specifically the South Asian region are affected drastically by the highest uncertain weather conditions due to maximum risk and their exposure [7] [8]. Each catastrophic event drives those countries into a downward spiral in their development [9] [10] [11] [12] [13] [14]. The southern region of the Asian continent is highly affected by extreme monsoon precipitation, which affects most of the livelihood in comparison to other regions of the globe [15]. According to Emdat (EM-DAT, https://public.emdat.be/data), approximately 1000 million persons have been victims of intense floods for the last 20 years. Expansion in endmost cloudbursts is observed in South Asian nations [16] and drastic climate changes will lead the region to be more exposed to such uneven disasters [17] [18]. Hence the South Asian stakeholders should take mitigative measures to overcome the floods. The southern provinces of Pakistan were severely impacted by an extreme heatwave in May, followed by a devastating flood disaster in August 2022 [19] [20]. This disaster put one-third of the country's population at risk, leading to the migration of nearly 32 million people across the nation. Tragically, 1,486 casualties were reported, including 530 children.

The disaster also resulted in a staggering $30 billion in financial losses [20] [4]. The agriculture sector is highly affected and chances of disease spread are expected to be maximum for the people surviving in shelters [21]. The causes of the flood that happened in Pakistan in 2022 is due to many factors including severe precipitation, glacial melting, and the formation of a low-pressure system above the ground due to heatwaves [22] [23]. In June 2022 Pakistan was hit by severe precipitation catalyzed due to the least pressure pattern [23]. Pakistan faces heightened risks due to climate change, including glacial melting, intense rainfall, floods, droughts, and rising sea levels [24] [25] [26] [27]. In addition, Pakistan is present in the world's first ten countries in the global climate risk index due to the drastic changes in climate patterns observed from 2000-2019 which indicates the risk for maximum disasters [28]. To build resilience, all factors associated with the August 2022 floods must be thoroughly analyzed and addressed.

This analysis focused on the adverse effects of floods on agricultural fields. Pakistan has experienced numerous disasters in recent years, including a powerful earthquake with a magnitude of around 7.6 between 2010 and 2014. Additionally, in 2022, the country was severely impacted by widespread floods. These events have significantly harmed the nation's economy. The agro-based sector in Pakistan contributes 21% to our GDP, provides employment up to 45%, and also acts as a backbone in exports up to 60%. Recent floods have a dynamic role in the destruction of crops including 2.5 million tons of rice, 7.5 million tons of sugarcane, 0.7 million tons of cotton, and 0.3 million tons of maze. The Prime objective of the study is to find out the impact of monsoon floods in 2022 on the prime agricultural land of the Khyber Pakhtunkhwa Province by utilizing remote sensing and filed-based data for mitigation and future planning.

Material and methods:

Study area:

In August 2022, floods affected the entire province of Khyber Pakhtunkhwa, Pakistan, with nine districts suffering severe impacts from the monsoon deluge. In southern districts, DI Khan (Dera Ismail Khan) and Tank district were severely affected by the floods. In northern districts swat, Dir Lower, Dir Upper, and some areas of District Chitral were affected. In the central Division District Nowshera, Charsadda, and Peshawar were affected by the recent floods. District DI Khan is located on the west bank of the Indus River where the District tank borders DI Khan on the northwest side. The cultural values and climatic conditions of both the districts are almost the same. However, Swat, Dir Lower, Dir Upper, and Chitral are

located in the Malakand division of the Khyber Pakhtunkhwa Province. Malakand Division is the largest division by area of the province where River Chitral from Chitral originates and Mirkany is diverted to Afghanistan. River Panjkora originates from beautiful Kumrat Valley upper Dir, flows downward to lower Dir, and then joins the Swat River which originates in Kalam Valley at the point of Chakdara. Districts Charsadda, Nowshera, and Peshawar are the central districts of the province where river Swat and river Kabul flow. All the 09 districts were severely affected by the recent monsoon spell in the region. Figure 1A shows the study area map and 1B shows the North south and Central Khyber Pakhtunkhwa.

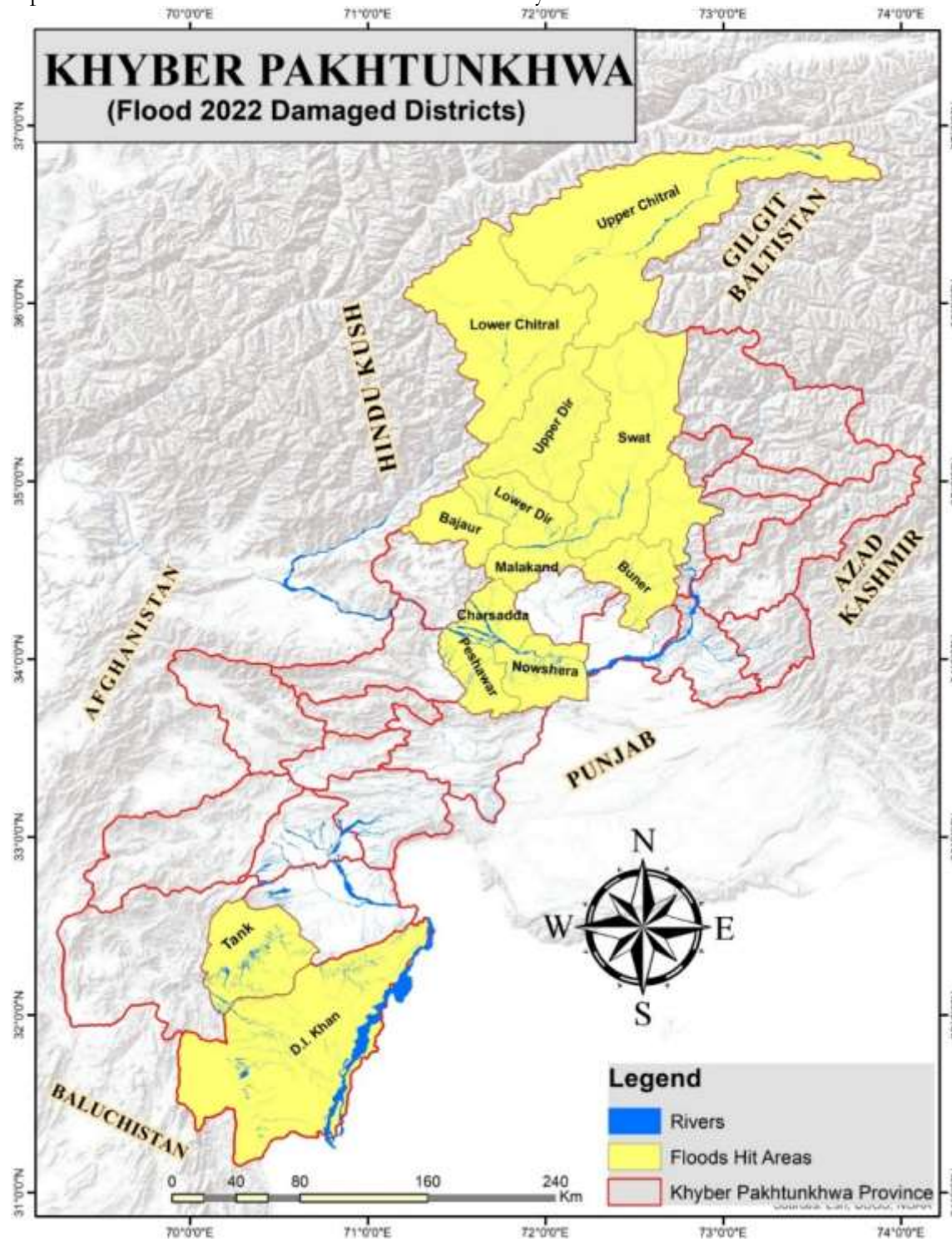

Figure 1A. The study area.

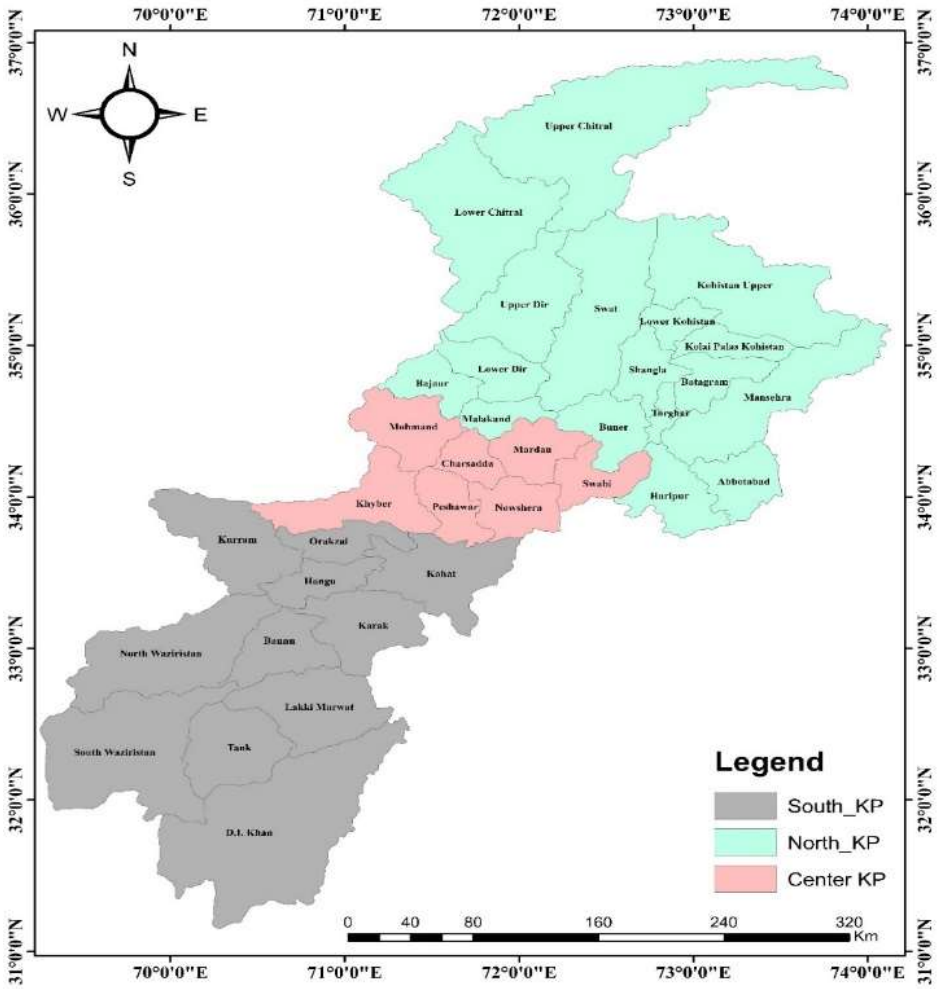

Figure 1B. The Zones of the study area.

Data collection:

The data for this study was collected from both primary and secondary sources. The secondary sources included newspapers, rainfall data, published research papers, and reports from different organizations regarding flood mitigation. The primary source includes Satellite images of Post and pre-flood Scenario. The Images were downloaded from the ESA NASA website using Google Earth Engine. The study also utilized supervised classification method in ARC GIS software to collect data.The Digital elevation model of ALOS PALSOR 12.5 meters spatial resolution was also downloaded from the same link of ESA using scripting. The Soil data were collected From the Soil Survey of Khyber Pakhtunkhwa. The rainfall data was downloaded from GPM for the September 2021 to September 2022 year.

Methodology:

Recent floods have resulted in the most alarming situation in the country, especially in the province, which is already grappling with severe economic conditions amid political and economic instability. The province faces significant financial challenges, and government organizations have halted all developmental projects. The floods have had a devastating impact on both people and livestock. This study mainly focused on the impact of floods on agricultural land and how much agricultural land was badly damaged in the 09 districts of the province. The methodology was followed as

Initially, the data were collected and brought to Geospatial format for further analysis and then physically verified the damages of floods in 2022. The rainfall data were downloaded and the most affected districts were selected for the study.

In the second step, Satellite images were classified. The supervised classification technique was used to generate the Land use and land cover layer where we can easily identify the agriculture or Cropland. After classification, the cropland was extracted in separate layers because the study was mainly focused on agricultural land damages. Script used for downloading the Sentinel 2b images from Google Earth Engine is given below:

```
Variable Flood affected areas as AOI
var Flood affected areas = ee.Geometry.shp;
Defined the start and end data for data downloading
var startDate = '2022-08-28';
var endDate = '2022-09-04';
var sentinel2 = ee.ImageCollection('COPERNICUS/S2_SR')
filterBounds(Flood effected areas)
filterDate(startDate, endDate)
filter(ee.Filter.lt('CLOUDY_PIXEL_PERCENTAGE', 20));
function maskClouds(image) {
var cloudMask = ee.Image(image.select('QA60').not());
return image.updateMask(cloudMask);
}
Applied cloud masking to the Image Collection
var sentinel2CloudMasked = sentinel2.map(maskClouds);
var rgbVis = {
bands: ['B4', 'B3', 'B2'],
min: 0,
max: 3000,
gamma: 1.4
};
For Display the Map
Map.centerObject(Flood effected areas, 10);
Map.addLayer(sentinel2CloudMasked.median(), rgbVis, 'Sentinel-2 RGB');
For Export to Drive
Export.image.toDrive({
image: sentinel2CloudMasked.median().clip(aoi),
description: 'Sentinel2B_ Flood effected areas ',
scale: 10,
region: Flood effected areas,
maxPixels: 1e9
});
```

In the next step, the rivers, canals, and streams were extracted and digitized from Google Earth and Alos Palsar DEM 12.5-meter resolution for both Pre and post-flood scenarios and brought into the GIS platform using Conversion tools.

The Script for downloading the Digital elevation Model using GEE is given below

```
Define the area of interest (flood affected areas)
var a Flood affected areas = Flood affected areas;
var dem = ee.Image('JAXA/ALOS/AW3D30/V3_2').select('DSM');
var dem_clipped = dem.clip(Flood affected areas);
For Display the DEM on the map
Map.centerObject(Flood affected areas, 10); Map.addLayer(dem_clipped, {min: 0,
max: 3000, palette: ['0000ff', '00ffff', 'ffff00', 'ff0000', 'ffffff']}, 'ALOS PALSAR
DEM');
For Export the DEM to Google Drive
```

```
Export.image.toDrive({
image: dem_clipped,
description: 'ALOS_PALSAR_DEM_12_5m',
scale: 12.5,
region: Flood affected areas,
maxPixels: 1e9,
fileFormat: 'GeoTIFF'
});
```

1. The field survey was done using a RUKU brand Drone along with a DGPS system where identify the river extent and damages done by floods in 2022 in 09 districts of Khyber Pakhtunkhwa province of Pakistan.
2. After the calculation of the river extension, the geo-processing techniques such as buffer analysis were operated to generate the buffer zone at the specified extent of floods in 2022.
3. Later on, affected areas were measured using ARC GIS.
4. Results were displayed in the form of tables and Maps

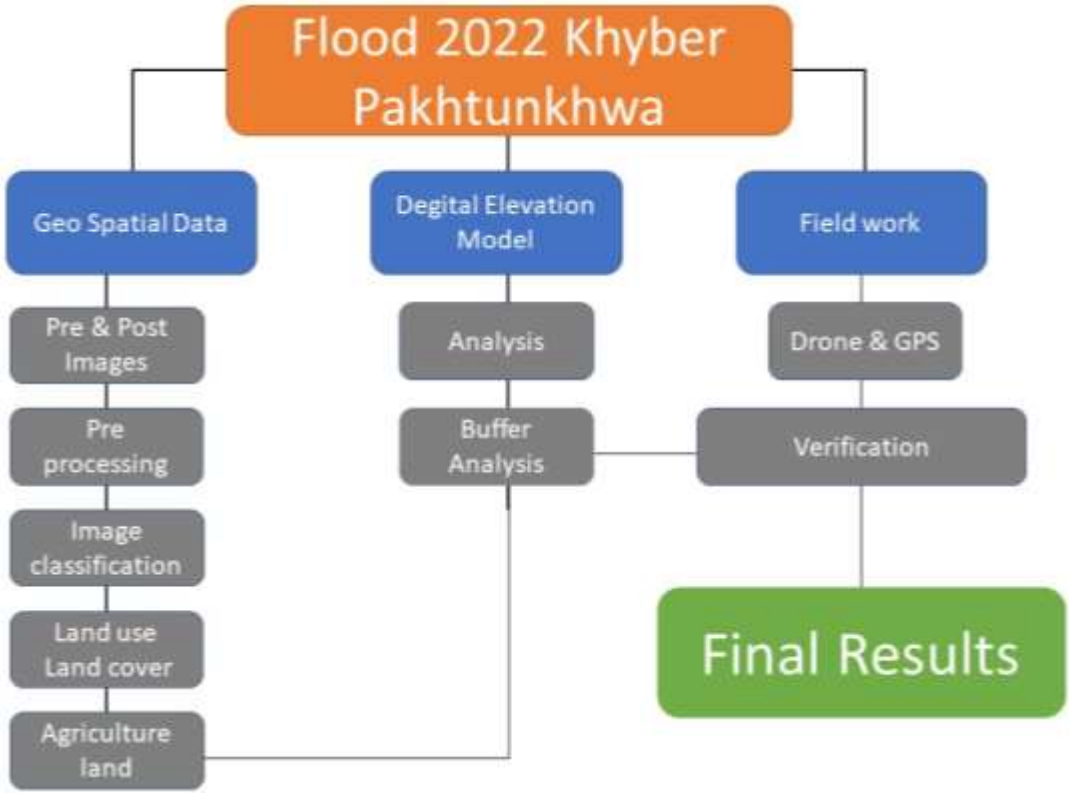

Figure 2. The flow diagram of Methodology.

Results and Discussion:

The current study revealed that the KPK received 22-246.22 mm annual rainfall from September 2021 to September 2022. Figure 3 shows the rainfall distribution in the province.

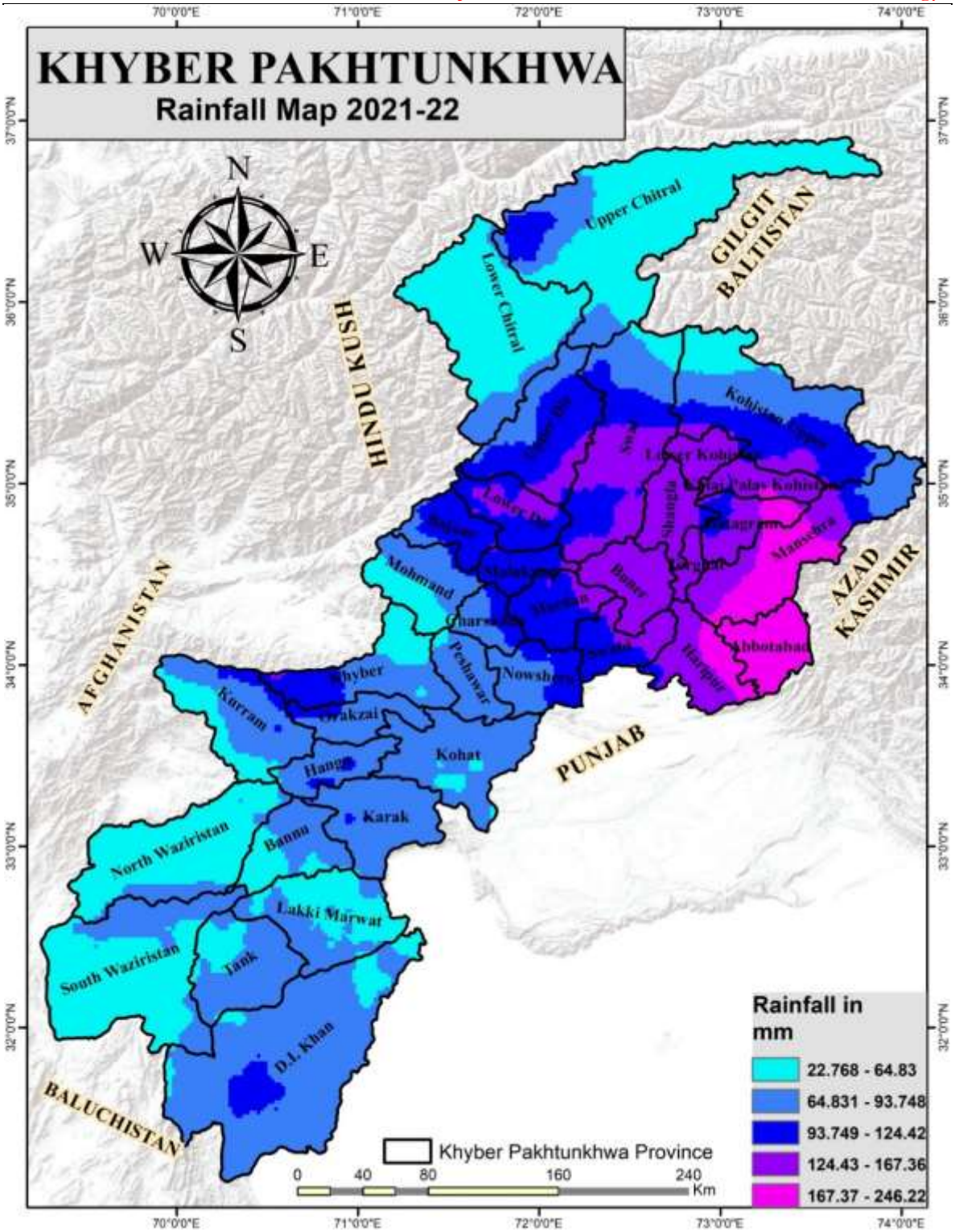

Figure 3. The rainfall distribution in the province.

The study shows that the total agriculture/crop land in DI khan is 4736 Sq.km, tank is 638.40 Sq.km, Peshawar is 666.00 Sq.km, Nowshera is 562.00 Sq.km, Charsadda is 644.00 Sq.km, Swat is 230.00 Sq.km, Dir lower is 180.10 Sq.km, Dir upper is 57.50 Sq.km, and Chitral contains 56.50 Sq.km area. Figure 4 shows the land cover land use status of the Khyber Pakhtunkhwa province. While Table 1 shows the total land use distribution.

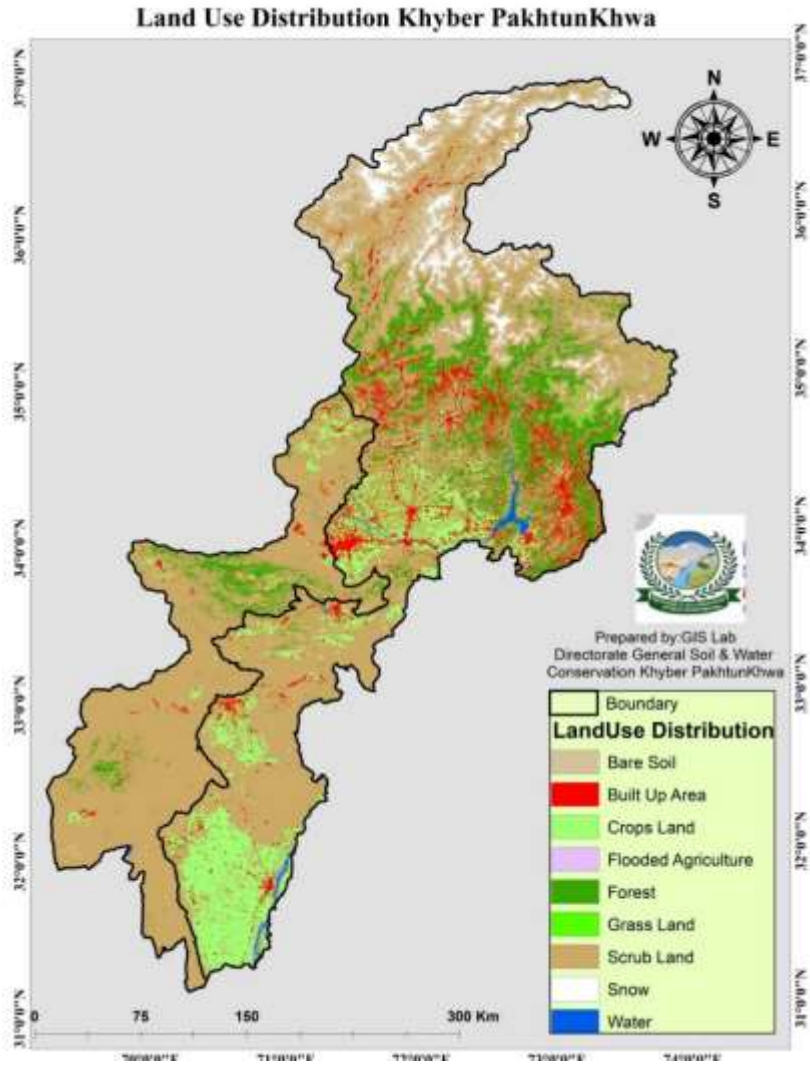

Figure 4. The land cover land use status of the province Khyber Pakhtunkhwa.

Table 1. Showing the total area of 09 Districts' Agriculture land

S. No	District	Land Use Land Cover		Total Area Sq. Km
		Land Type	Area Sq. Km	
1.	Peshawar	Bare Land	1.0147	1283.174
		Built-Up Land	426.4654	
		Crops Land	665.0014	
		Flood Agriculture	0.0001	
		Forest Land	9.9817	
		Grass Land	1.333	
		Scrub Land	168.7701	
		Water Bodies	10.6073	
2.	NOWSHERA	Bare Land	6.5562	1595.4343
		Built-Up Land	246.5457	
		Crops Land	561.7406	
		Flood Agriculture	0.0958	
		Forest Land	0.5834	
		Grass Land	0.5834	

		Scrub Land	750.3206	
		Water Bodies	29.0086	
3.	CHARSADDA	Bare Land	5.2201	977.3058
		Built-Up Land	244.637	
		Crops Land	643.4996	
		Flood Agriculture	0.4964	
		Forest Land	21.2811	
		Grass Land	0.1605	
		Scrub Land	41.7517	
		Water Bodies	20.2594	
4.	TANK	Bare Land	20.4939	1679.7357
		Built Up Land	100.6643	
		Crops Land	638.3319	
		Flood Agriculture	0.0357	
		Forest Land	13.5986	
		Grass Land	0.0332	
		Scrub Land	905.252	
		Water Bodies	1.3261	
5.	DERA ISMAIL KHAN	Bare Land	110.2977	9030.747
		Built Up Land	349.1376	
		Crops Land	4730.0653	
		Flood Agriculture	4.7011	
		Forest Land	31.2639	
		Grass Land	1.3815	
		Scrub Land	3620.6719	
		Water Bodies	183.2281	
6.	DIR LOWER	Bare Land	1.6172	1587.278
		Built-Up Land	416.596	
		Crops Land	179.1489	
		Forest Land	257.1992	
		Grass Land	1.986	
		Scrub Land	722.7733	
		Water Bodies	7.9574	
7.	DIR UPPER	Bare Land	181.4185	3726.961
		Built-Up Land	370.4916	
		Crops Land	43.6069	
		Flood Agriculture	0.0752	
		Forest Land	1241.909	
		Grass Land	13.9046	
		Scrub Land	1764.942	
		Snow Covered	94.8842	
		Water Bodies	15.729	
8.	CHITRAL	Bare Land	5884.365	14649.7726
		Built-Up Land	258.2575	
		Crops Land	55.0652	
		Flood Agriculture	0.6452	
		Forest Land	355.3922	
		Grass Land	1.828	

		Scrub Land	5545.326	
		Snow Covered	2502.424	
		Water Bodies	46.4695	
9.	SWAT	Bare Land	652.9306	5378.3059
		Built-Up Land	575.1739	
		Crops Land	196.6917	
		Flood Agriculture	0.0178	
		Forest Land	1083.926	
		Grass Land	34.278	
		Scrub Land	2340.658	
		Snow Covered	453.9344	
		Water Bodies	40.6955	

Flood Damages In Northern KPK:

The field survey revealed that the river expanded into various areas, directly impacting agricultural land. The agricultural land and orchards have been damaged by severe floods near Chaill, khwaza khela, and Matta. The Matta tehsil lies among the most affected areas in terms of agricultural land damages. Figure 5 shows the flood damages in the Malakand division.

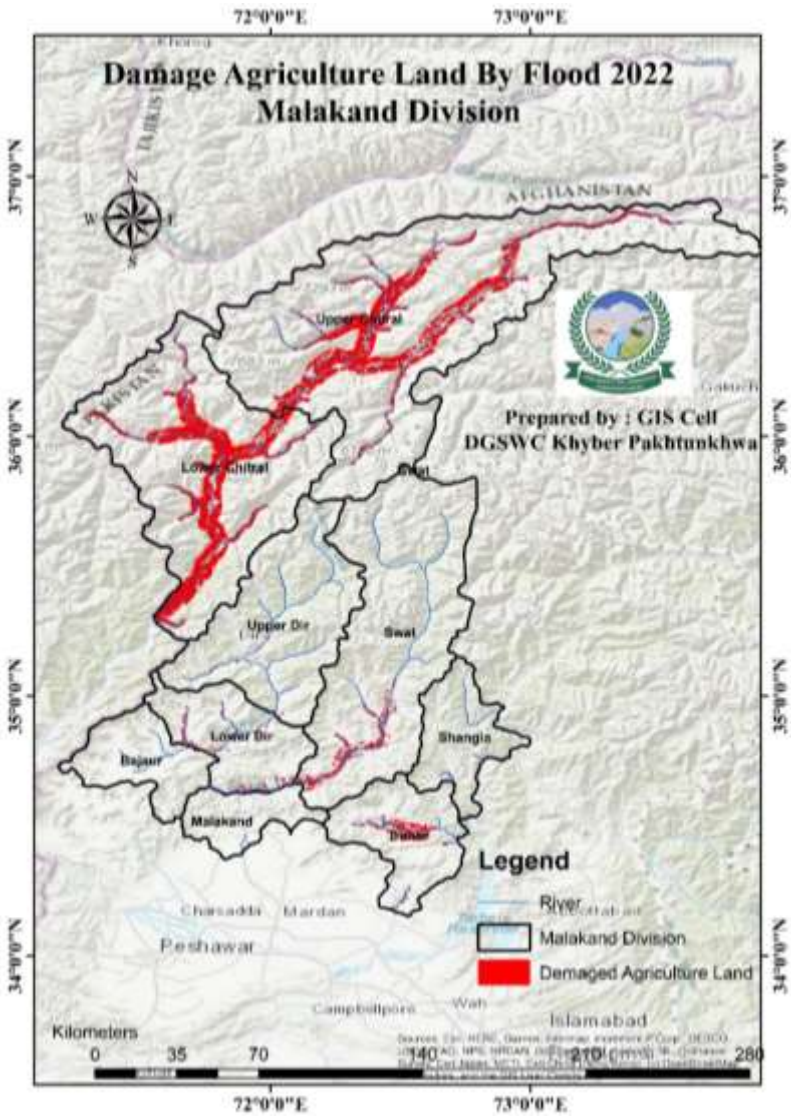

Figure 5. The flood damages in the Malakand division.

Flood damages in Central KPK:

In Peshawar, the agricultural areas that have been severely affected by recent floods include Gujjar, Jala Bela, Dalazak, Mamukhatakey, and Ghari Imran. Affected areas in Charsadda include Abazai, Sardar Garhi, Turlandai, Nahqi, Tarnab, and Hassan Zai. In Nowshera, the Khairabad, Jahangera, Misra Banda, Pirsabad, Tamangarh, Mohib Banda, Aman Kot, and Adham Zai agriculture lands have been damaged. Figure 6 shows the flood damages in Peshawar Division.

Figure 6. The flood damages in the Peshawar division.

Flood damages in South KPK:

The agricultural lands were hit by the Pirkach, Kiryani, Tikwara, Sidgi, and Tikwara streams. Different maps of these affected areas is presented in this study illustrating the distribution and extent of floods in 2022. Figure 7 shows the flood damages in the Di Khan division.

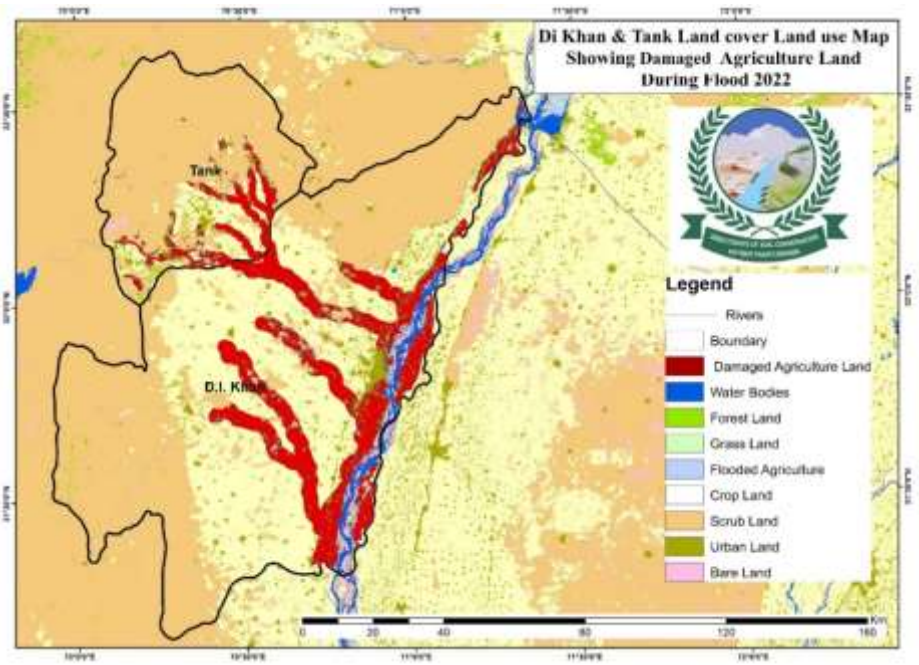

Figure 7. The flood damages in DI Khan division.

Following GIS analysis, the extent of flood-damaged areas was determined. The thematic layer of damaged land was transformed from a geographic coordinate system to a projected coordinate system, with the study area located in the 43-North zone.

Each district was individually converted to a projected coordinate system, and the damaged areas were assessed. The results indicated that in the DI Khan division, particularly in the district of DI Khan and its sub-division, the recent monsoon severely impacted a total of 1,377.54 square kilometers of agricultural land. Crops in this region have been either fully or partially damaged. However, In the district tank and sub-division tank, 270.146935 sq. km of cropland was damaged. In the Peshawar division, the agricultural land of District Charsadda was damaged where the sugarcane and maize crops were severely damaged. Using GIS, the affected area in district Charsadda was calculated to be 117.55 square kilometers, while in district Nowshera, it was 467.74 square kilometers. Additionally, 30.08 square kilometers of crop area were damaged in the district of Peshawar. The northern part of Khyber Pakhtunkhwa is mostly mountainous and the residents are dependent on agriculture practices and gardening. In the Malakand division district, swat was more affected by the current spell of Monsoon where 122.38 sq. km of main crops and orchards area was damaged. Similarly, 63.60 sq. km area of District Lower Dir, 15.14 sq. km area of Upper Dir, and 575.678 sq. km cropland of District Chitral were hit by the floods in 2022. Figure 8 displays the affected area maps for the nine districts.

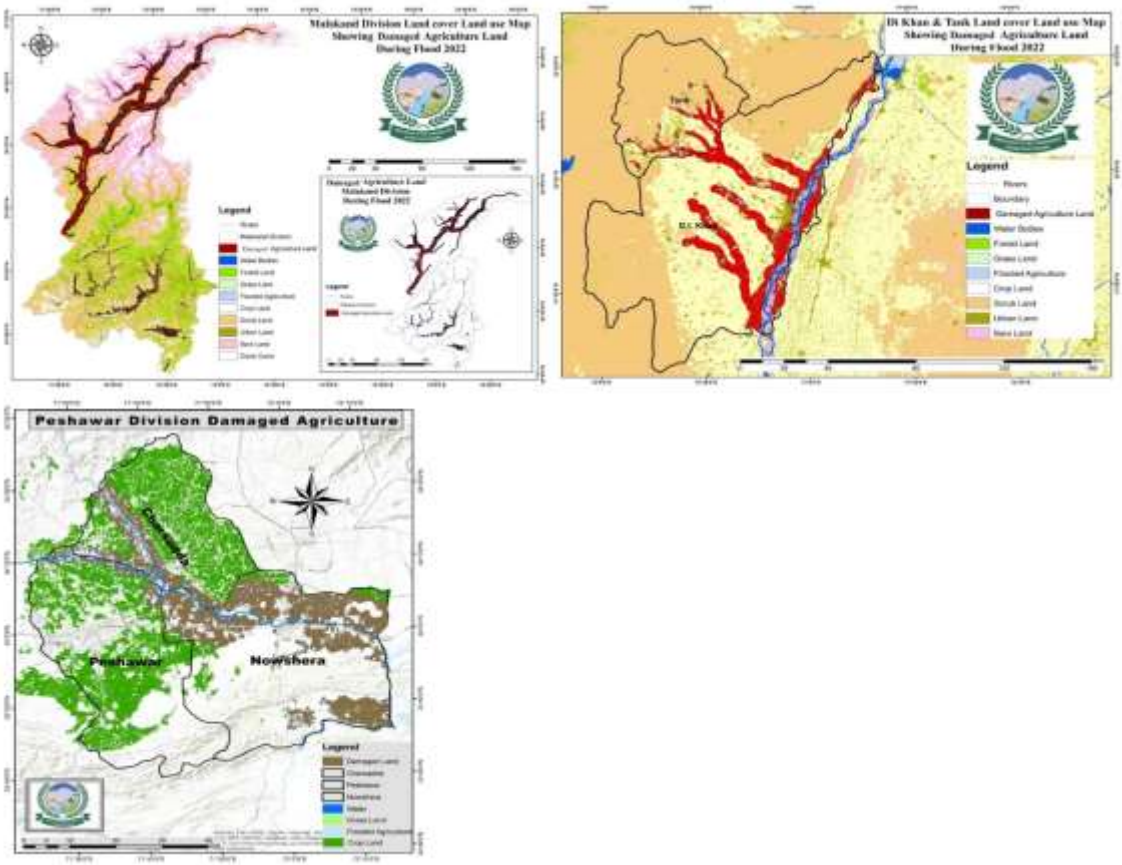

Figure 8. Spatial distribution of flood-affected areas of Khyber Pakhtunkhwa Province.

Discussion:

The monsoon floods of 2022 had a profound and multifaceted impact on the agricultural landscape of Khyber Pakhtunkhwa (KP), revealing significant vulnerabilities within a sector crucial to both the regional economy and food security. Agriculture in KP is a cornerstone of the local economy, employing over 40% of the labor force and contributing

more than 20% to the province's GDP. This sector plays a pivotal role in poverty alleviation and food security, thus making its resilience against climatic shocks critical.

Our study reveals that the heavy monsoon rains led to widespread flooding across KP, affecting significant areas of agricultural land. This aligns with findings from [25], who documented severe agricultural impacts in flood-prone regions of Pakistan, noting similar patterns of land erosion and crop destruction due to intense rainfall. Our results indicate that in DI Khan, 1,377.54 square kilometers of agricultural land were severely impacted, while other districts such as Tank, Peshawar, Charsadda, and Nowshera also experienced significant damage. These findings are consistent with [28s] study, which highlighted that major river systems and their tributaries in Pakistan are highly susceptible to flooding, resulting in substantial agricultural losses. The analysis of the rainfall data from September 2021 to September 2022 indicates that KP experienced rainfall ranging from 22 to 246.22 mm, a substantial volume that contributed to widespread flooding. The severity of the floods was particularly pronounced in areas adjacent to major rivers and streams, where the convergence of several water bodies exacerbated the flooding. In Peshawar, the overflow of the Kabul River, intensified by its confluence with the Swat River, led to significant agricultural damage. Similarly, in Chitral, the merging of the Yarkhoon, Turikho, and Chitral Rivers resulted in extensive land loss along these river systems. The flooding impacted main rivers with widths of approximately 600 meters and local streams with widths of 100 to 150 meters, highlighting the extensive nature of the flood-related erosion and destruction.

The Panjkora River, which traverses Upper and Lower Dir, also experienced severe flooding, particularly affecting areas like Koto Haji Abad. These areas, renowned for their fertile lands and significant production of onions and rice, suffered extensive damage. The confluence of multiple streams with the Panjkora River exacerbated the flooding, resulting in severe destruction of agricultural fields and critical infrastructure, such as roads and bridges. In the DI Khan district, the Indus River's overflow caused considerable damage to agricultural lands along its left bank, with areas like Parora, DI Khan city, and Tank district experiencing significant impacts. Despite the proactive measures taken by the Soil & Water Conservation Department, which constructed over 3,000 soil and water conservation structures across the province, the scale of the rainfall and subsequent flooding proved overwhelming. These structures, designed to mitigate flood impacts, were partially damaged by the unprecedented rainfall, underscoring the need for enhanced flood management strategies and more resilient infrastructure.

The GIS analysis further elucidates the extent of damage across various districts. In Dera Ismail Khan, approximately 1,377.54 square kilometers of agricultural land were affected. The Tank district saw damage to 270.15 square kilometers of cropland. Similarly, Peshawar, Charsadda, and Nowshera experienced damage to 30.08 square kilometers, 117.55 square kilometers, and 467.74 square kilometers of agricultural land, respectively. The northern regions, including Swat, Lower Dir, Upper Dir, and Chitral, also faced significant damage, with reported impacts on 122.38 square kilometers, 63.60 square kilometers, 15.14 square kilometers, and 575.68 square kilometers of agricultural land, respectively. In summary, the 2022 monsoon floods have exposed the susceptibility of KP's agricultural sector to extreme weather events. The extensive damage to agricultural lands not only jeopardizes food security but also threatens the livelihoods of a significant portion of the population. This underscores the urgent need for more robust flood management strategies, improved soil conservation practices, and the development of resilient agricultural systems capable of withstanding future climate-related challenges. Addressing these issues will be crucial for safeguarding the agricultural sector and ensuring continued economic stability and food security in the region.

Conclusion:

The study concludes that Pakistan is an agrarian country, with the majority of its local population depending on agricultural production. The Department is working towards its future vision of addressing 21st-century challenges by fostering a dynamic agriculture sector that enhances value addition and enables access to international markets for agricultural products. Government Projects like water conservation in barani areas proved useful to mitigate disasters and conserve fertile agricultural land. The study also finds that geospatial techniques are valuable for efficiently collecting and analyzing geospatial data. Additionally, it reveals that the province frequently experiences various natural disasters, causing significant disruption to local communities. The 2022 monsoon floods particularly impacted agricultural land, severely affecting farmers who rely on these crops. In DI Khan and Tank, floodwaters persisted for extended periods, damaging standing crops. In Charsadda, sugarcane crops suffered substantial damage, while crops in Swat and Dir districts along the Swat and Panjkora rivers were also heavily affected.

Recommendations:

In the current study, we have analyzed the impact of floods on agricultural land. A series of natural disasters have hit Pakistan in recent years. In October 2005, there was a 7.6-magnitude earthquake. In 2010, 2011, 2012, 2013, 2014, and now 2022 we faced severe flooding events. These disasters have a massive cumulative effect in reducing the economy of Pakistan. Agriculture accounts for 21% of Pakistan's GDP, 45 % of employment and 60 % of exports. In this study, we also analyzed the interventions carried out by the Soil and Water Conservation Department to conserve the soil from floods and other disasters. The government should adopt long-term policies to conserve the fertile land. A maximum budget is required to mitigate these disasters in Khyber Pakhtunkhwa province. Moreover, advanced technology like Geographic Information Systems (GIS) and Remote Sensing (RS) should be applied in the agriculture sector so that GIS experts and planners can easily identify suitable sites, where the flood water can be diverted. Soil conservation practices like check dams, mini dams, water reservoirs, and protection bunds should be constructed in the prone areas.

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