APPLYING SPATIAL ANALYSIS TO ASSESS CROP DAMAGE

A CASE STUDY OF THE PAKISTAN 2022 FLOODS

Takashi Yamano, Murali Krishna Gumma, Pranay Panjala, Nauman Ul Haq, Muhammad Fahad, Noriko Sato, Babur Wasim Arif, and Umer Saeed

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The series is a quick-disseminating, informal publication. The working papers may subsequently be revised and published elsewhere.

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ABBREVIATIONS

ADB	—	Asian Development Bank
CRS	—	crop reporting service
CY	—	crop year
FAO	—	Food and Agriculture Organization of the United Nations
GIS	—	geographic information system
ha	—	hectare
ICRISAT	—	International Crops Research Institute for the Semi-Arid Tropics
km^2	—	square kilometer
MODIS	—	Moderate Resolution Imaging Spectroradiometer
MVC	—	maximum-value composite
NDVI	—	Normalized Difference Vegetation Index
PDNA	—	Post-Disaster Needs Assessment

GLOSSARY

Ground truthing: Gathering information that is known to be real or true by direct observation and measurement as opposed to information provided by inference.

Maximum-value composite: A procedure used in satellite imaging, applied to vegetation studies. It requires that a series of multitemporal georeferenced satellite data be processed into normalized difference vegetation images.

Normalized Difference Vegetation Index: A measure of the amount and vigor of vegetation on the land surface; Normalized Difference Vegetation Index spatial composite images are developed to distinguish green vegetation from bare soils.

Spatial analysis: The process of examining, assessing, evaluating, and modeling spatial data features such as locations, attributes, and their relationships that reveal the geometric or geographic properties of data.

Spectral matching (for agriculture and forestry): Using remote sensing technology and algorithms to ascertain crop cover, type, health, and others.

EXECUTIVE SUMMARY

Pakistan is highly flood-prone and faces a growing risk of water-related disasters due to predicted impacts of climate change. From 1950 to 2021, each of the major floods claimed more than 400 lives in Pakistan, except the 1950 flood that claimed at least 2,000 lives. The latest flood in 2022 resulted in 1,678 deaths, which included 555 children. The Food and Agriculture Organization of the United Nations estimates that 55,000 square kilometers of land were flooded.

This report presents how spatial analysis could be used to assess flood damage to agricultural production by applying the analysis to the 2022 Pakistan floods. It recommends that spatial analysis capacity should be established within government agencies to ensure better preparedness for mitigating damages of future water-related disasters.

Using spatial analysis and a spectral mapping technique, the 2022 flood damage was assessed for four periods during June–September 2022 in Pakistan. The assessment conducted during the first half of September 2022 indicated that about 15% of crop areas were modestly or severely damaged. The accuracy of the technique was verified by cross-checking with data gathered at the actual locations on the ground. Subsequently, a monthly damage assessment system has been established and is circulating monthly reports to government agencies to help them prepare for future floods and other crop damage.

Spatial mapping can also be used to assess the impact of crop disease, pest infestations, drought, and others, and to inform policy makers and decision makers about situations pertinent to the national food supply, export earnings, and crop insurance. Spatial mapping can provide estimations of crop health for a wider area and do so faster than ground estimations, which require large amounts of resources, such as labor and transport, and are difficult to implement after floods or other natural hazards.

Key recommendations to facilitate the use of technology to enhance crop monitoring are as follows:

(i) increase the number of geographic information system and remote sensing specialists in relevant government agencies such as crop reporting services and statistics offices;
(ii) integrate the use of spatial analysis into statistical reporting systems to improve their accuracy and timeliness. The spatial analysis can provide preliminary results that can be verified by field observations;
(iii) familiarize policy makers with and enable them to interpret spatial analysis results to help them make more effective decisions. Circulate periodic spatial analysis reports among policy makers to earn their trust in the analysis; and
(iv) plan policy actions for early detection of crop damage, rapid field verifications, mobilization of adequate financial and material resources, and effective communications with affected populations. Images from spatial analysis can be released through media or posted on government websites.

I. INTRODUCTION

The glaciers of the western Himalaya act as a reservoir for the Indus basin, capturing snow and rainfall and releasing it into rivers that flow to the Indus River plains. Studies have long predicted that frequent and large floods would be caused by glacier melt due to rising temperatures, driven by climate change.[1] Intense heat waves that covered Pakistan in April and May 2022 led climate experts to be concerned that floods could ensue in the coming months because the warmer air could contain additional moisture that would enhance the monsoon rains and melt glaciers (Washington Post 2022).

Pakistan received more than three times its usual rainfall in August 2022, making it the wettest August since 1961 (Mallapaty 2022). The two southern provinces—Balochistan and Sindh—received eight and seven times their usual monthly rainfall, respectively. The Indus River burst its banks, and the intense rainfall also led to flash floods and landslides. The floods claimed at least 1,678 human lives, including 555 children. The Food and Agriculture Organization of the United Nations (FAO) estimates that 50,000 square kilometers of land were inundated (Mushtaq et al. 2022). The floods destroyed infrastructure and raised concerns about consequent impacts on human health (Bhamani 2022).

More than a year before the 2022 floods, the Asian Development Bank (ADB) started working with Pakistan government agencies and local consultants to provide them with spatial information technology skills and equipment so that they would be able to conduct crop damage assessments. The project started in April 2021 by establishing a consulting team working in a laboratory at Pakistan's Ministry of National Food Security and Research. Geographic information system (GIS) and remote sensing experts at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) provided training and continuing guidance as the consulting team conducted ground data collection, spatial analysis, and meetings to disseminate crop damage assessments. After the floods, the Post-Disaster Needs Assessment (PDNA) team was formed, comprising international agencies such as the FAO and the World Bank. The ADB project team shared the results of the spatial analysis with the PDNA team.

This report presents real-time crop damage assessments conducted by the ADB consulting team as the 2022 floods occurred in Pakistan, supplemented with subsequent monthly crop damage assessments in 2023. The crop damage assessments were generated with satellite data and analyzed with crop growth models that are supported with algorithms to improve the accuracy of the assessments. The project team conducted rapid field surveys to validate the findings of the spatial analysis ("ground truthing").

The crop stress assessment reports were shared with relevant government agencies as the floods occurred—a time when many sites could not be reached by land transport. Because such reports were new to the officers at the agencies, the reports were initially received with some skepticism. In addition, the assessments estimated the total crop damage, but the estimate was not disaggregated by crop because the spatial analysis still lacked sufficient data at the crop level to do so.[2]

In 2023, the project team started circulating monthly crop damage reports among relevant federal and provincial government agencies as well as international agencies. Examples of monthly reports are presented in Appendix 1. By circulating the monthly reports, the team hopes to clarify questions about the crop damage

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1 In the long run, after glacial reservoirs empty, simulation studies predict a large reduction of river flows because the glaciers would have melted. Rees and Collins. 2006. Regional differences in response of flow in glacier-fed Himalayan rivers to climatic warming. *Hydrological Process*. https://doi.org/10.1002/hyp.6209.

2 At the time of the 2022 floods, the ADB consulting team did not have adequate information to identify crop damage at the crop level. Subsequently, the team has been accumulating additional ground data and testing different machine learning algorithms to improve accuracy of the damage assessments at the crop level.

reports and gain relevant agencies' trust in the analysis. Furthermore, additional data are being collected to enable the project team to assess damage at the crop level in the coming agricultural seasons.

Climate change is expected to increase the frequency and magnitude of floods and other extreme weather events in the future. Thus, the Government of Pakistan needs to be prepared in advance to mitigate the damage. It is important to plan how to use real-time crop damage assessments such as spatial analysis to plan for immediate disaster assistance and recovery efforts.

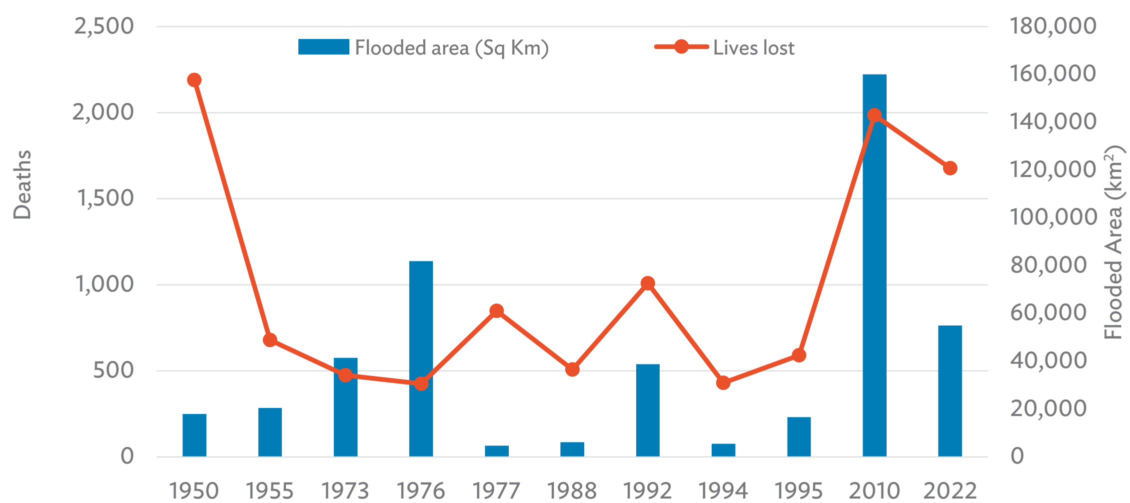
II. 2022 FLOODS IN PAKISTAN

A. Previous Floods in Pakistan

Pakistan is highly flood-prone and faces a growing risk of flood-related disasters. Each of the major floods listed in Figure 1 claimed more than 400 lives. The 1950 flood had the most casualties, claiming 2,190 lives, flooding an estimated 17,920 square kilometers and inundating 10,000 villages. The 1950 flood happened in a smaller geographic area compared to successive floods and affected many villages indicating that the flood occurred in highly populated areas.

The subsequent floods show no correlation between the extent of the flooded areas and the number of casualties. For example, the 1977 and 1988 floods affected smaller areas, but caused casualties equivalent to or even more than those of the 1973 and 1976 floods. These results suggest that the number of casualties depends on many factors, such as population density, topology of flooded areas, community preparedness, and post-flood assistance.

Figure 1: Selected Major Floods, 1950–2022



km^2 = square kilometer.

Note: More than 400 lives lost in the period of study.

Sources: H.N. Hashmi et al. 2012. A Critical Analysis of 2010 floods in Pakistan. *African Journal of Agricultural Research*. 7 (7): pp. 1054-1067; and F. Mushtaq et al. 2022. *A Rapid Geospatial Flood Impact Assessment in Pakistan, 2022.*

After the 1995 flood, Pakistan had no major floods for 15 years. Then in 2010, a flood affected the largest area since 1950, covering 160,000 square kilometers, inundating 17,553 villages, and claiming 1,985 lives—causing the country unprecedented devastation. The floods began in July 2010 following heavy monsoon rains in Balochistan, Khyber Pakhtunkhwa, lower Punjab, and Sindh. Balochistan and Khyber Pakhtunkhwa suffered predominantly from flash floods, while Punjab and Sindh experienced slow-rising riverine floods. After describing the damage caused by the 2010 floods, Hashmi et al. (2012) stated that the country "needs to do all it can to stop weather disasters becoming catastrophes and to protect people from future catastrophic flood disasters" and listed 13 recommendations, which include improving flood forecasting systems, developing flood management guidelines, and rehabilitating barrages to enhance their safe flood discharging capacities.

B. An Overview of Pakistan's 2022 Flood Assessment

Pakistan is ranked among the countries that are most vulnerable to climate change, especially to extreme weather events and natural hazards—the Global Climate Risk Index 2021 ranked Pakistan as the world's 8th most vulnerable country. The country is projected to experience warming surpassing the global average and an increase in the number of days with a heat index exceeding 35°C. Progressive warming and periodic heatwaves will accelerate glacial melting, increase the frequency and severity of droughts, and decrease water availability for agriculture. The observed spatial and temporal variability in monsoon rainfall has further exacerbated the uncertainty in water availability and implications on food insecurity. More than half of the country's population depends directly or indirectly on agriculture for its livelihood, and agriculture production is highly exposed to and dependent on climate and weather events (Eckstein et al. 2022). Climate warming will intensify the existing high water demand to 60% by 2047 compared to current levels, leading to a substantial decrease in crop and livestock productivity.

During June–August 2022, torrential rains and a combination of riverine, urban, and flash flooding led to an unprecedented disaster in Pakistan. The National Disaster Management Authority estimated that 33 million people—one in seven Pakistanis—had been affected by the floods, including nearly 8 million who were displaced and more than 1,700 people who died, one-third of them children. Rain-induced floods, accelerated glacial melt, and resulting landslides devastated millions of homes and key infrastructure, submerging entire villages and destroying livelihoods. Ninety-four districts in Pakistan (about 55% of all districts) were declared to be "calamity hit." The majority were in Balochistan, Khyber Pakhtunkhwa, and Sindh.

After the flood, the government conducted a PDNA with the support of ADB, the European Union, United Nations agencies, and the World Bank. National and international experts across 17 sectors have collaborated closely with federal and provincial ministries, departments, and agencies to collect data from the 94 calamity-hit districts. Partner agencies have supported the government in applying the PDNA methodology and analyzing data received from provincial and federal agencies, ministries, and departments. The PDNA report supports the prioritization and targeting of resources through multisector recovery planning, which is generally undertaken as part of developing a disaster recovery framework. Such a framework is the first step on the journey to climate-resilient, inclusive, and people-centered recovery. Given the ongoing nature of the disaster and the lack of access to inundated areas when the PDNA report was published, remotely sourced data were triangulated and validated where possible against ground-based information obtained from the government, local agencies, and international partners.

The PDNA report estimates the overall economic losses from the 2022 floods at $14.9 billion. The report highlights the significant impact of the floods on the country's agriculture sector, which is a major contributor to Pakistan's economy. The report notes that the floods damaged 1.8 million hectares (ha) of cropland, which resulted in a loss of $3.7 billion. The data in the PDNA report are provided by the provincial crop reporting services (CRSs) using field surveys. Because CRS employees could gather only limited information on the flood extent and crop damage, PDNA partners helped validate the data using remote sensing technology. Authenticating the data on crop damage was important and was accomplished by comparing the data derived from remote sensing with data gathered on the ground in accessible areas.

ADB's remote sensing team estimated crop damage by monitoring the health of crops over a period of time. The other organizations (FAO, World Food Programme, and others) used the extent of the flood (Table 1) as a proxy for crop damage. This proxy can be inaccurate because some crops may survive floods undamaged. In light of this, the ADB team initiated creating crop stress maps that indicated crop stress levels in terms of crop health. Information on crop stress, in the form of maps and reports, was generated every 2 weeks to continue monitoring the health of crops and evaluate whether they had been impacted by flood and if they had recovered over time. The crop stress maps identified crop damage more accurately than the other methods.

Table 1: Accuracy of Asian Development Bank, Food and Agriculture Organization, and World Bank Methodologies of Determining Crop Health

<table>
<tr><th colspan="2">Criteria</th><th>ADB</th><th>FAO</th><th>World Bank</th></tr>
<tr><td rowspan="2">Dataset used for Analysis</td><td>Flood Extent</td><td>Pre- and post-flood Sentinel-1 SAR and Sentinel-2 imageries</td><td>Sentinel-1 SAR imagery (month of August)</td><td>Pre- and post-flood Sentinel-1 SAR imageries</td></tr>
<tr><td>Crop Damage</td><td>MODIS/MOD09GQ.061</td><td>Sentinel-2, vegetation cover and rice area (a) (Mushtaq et al. 2022)</td><td>Sentinel-2, cropland (b) and cropland classes from ESA (c)</td></tr>
<tr><td colspan="2">Methodology</td><td>Time series crop stress monitoring is conducted using SMT, and stress levels are categorized from no stress to severe to identify damage</td><td colspan="2">Overlaid Sentinel-2 data over Sentinel-1 SAR data to estimate flood-damaged crops</td></tr>
<tr><td colspan="2">Ground Truthing Performed</td><td>Balochistan, Khyber Pakhtunkhwa, Punjab, and Sindh</td><td colspan="2">No ground data collected</td></tr>
</table>

ADB = Asian Development Bank, ESA = European Space Agency, FAO = Food and Agriculture Organization of the United Nations, MODIS = Moderate Resolution Imaging Spectroradiometer, SAR = Synthetic Aperture Radar, SMT = Spectral Matching Technique.

Sources: (a) F. Mushtaq et al. 2022. A Rapid Geospatial Flood Impact Assessment in Pakistan, 2022. (b) WorldCover Data; and (c) GFSAD1000: Cropland Extent 1km Multi-Study Crop Mask, Global Food-Support Analysis Data.

Floods generally occur during Pakistan's *kharif* (rainy) season from June to October, when four major crops are cultivated (Table 2). Rice occupies the largest area, at 3.5 million ha, followed by cotton on 2 million ha and sugarcane on 1.3 million ha. Maize is grown on less than 500,000 ha, and mostly in southern Punjab. Wheat is the country's most popular cereal crop, but it is grown in *rabi* (winter) season and was not directly damaged by the 2022 floods.

Table 2: Major *Kharif* Crop Areas in Pakistan, by Province
(hectare)

Province	Rice	Cotton	Sugarcane	Maize
Balochistan[a]	161,417	63,725	–	–
Khyber-Pakhtunkhwa[a]	62,286	–	110,991	467,979
Punjab[b]	2,555,241	1,279,239	869,284	–
Sindh[a]	750,500	636,600	320,500	–
Total	**3,529,443**	**1,979,564**	**1,300,774**	**467,979**

– = none or negligible.

Note: Livestock constitutes 60.6% of agricultural production value and 11.7% of the overall economy. It is difficult to assess damage to livestock from the satellite images obtained as the analysis relies on a vegetation index based on pixel color, as discussed in the next section.

[a] Rice grown outside of Punjab is non-Basmati long grain rice.

[b] Rice grown in Punjab is mostly Basmati rice, which has a high value and is a major export crop.

Source: Pakistan Bureau of Statistics. 2020. Population Census, 2017. Islamabad.

III. METHODOLOGY

Crop damage was estimated by mapping the crop extent (Gumma et al. 2022b), crop stress (Gumma, Nelson, and Yamano 2019), and the flood extent (Gumma et al. 2022a).

The maximum possible extent of croplands in crop years (CY) 2019–2020 was derived from a previously published South Asia cropland paper and multiple crop products. The map included all major crops with a classification accuracy of 80% and a 90% agreement with rice areas from district statistics. The CY2016 map was the most detailed publicly available map of cropland extent in South Asia. One main hypothesis was that there would be a slight change in the area that could be planted to crops between CY2020 and CY2022, and that most of the changes were attributable to water availability.

Assessing and mapping crop stress and changes in cropland areas due to rainfall relied on geospatial datasets in the public domain, such as the Normalized Difference Vegetation Index (NDVI) and Land and Surface Water Index. The latter used the shortwave infrared and the near-infrared regions of the electromagnetic spectrum that are sensitive to the total amount of liquid water in vegetation and its soil background.

The NDVI, which uses the visible (red band) and near-infrared bands, is the ideal indicator to employ when attempting to determine the vegetation on the ground through the use of remote sensing. The use of the two bands serves the aim of determining their relation to the absorption and reflection of radiation in accordance with the amount of chlorophyll present. Because chlorophyll in the leaf is capable of absorbing infrared light while simultaneously reflecting near-infrared radiation, this indicator is the superior choice for examining vegetation (Gumma, Nelson, and Yamano 2019).

To evaluate crop stress, the Moderate Resolution Imaging Spectroradiometer (MODIS) dataset (MODIS/MOD09GQ.061) was utilized, in which the NDVI was calculated from the near-infrared and red bands of each scene using Equation (1) and ranged from −1 to 1:

$$NDVI = \frac{NIR - Red}{NIR + Red} \quad \text{-------------} \quad (1)$$

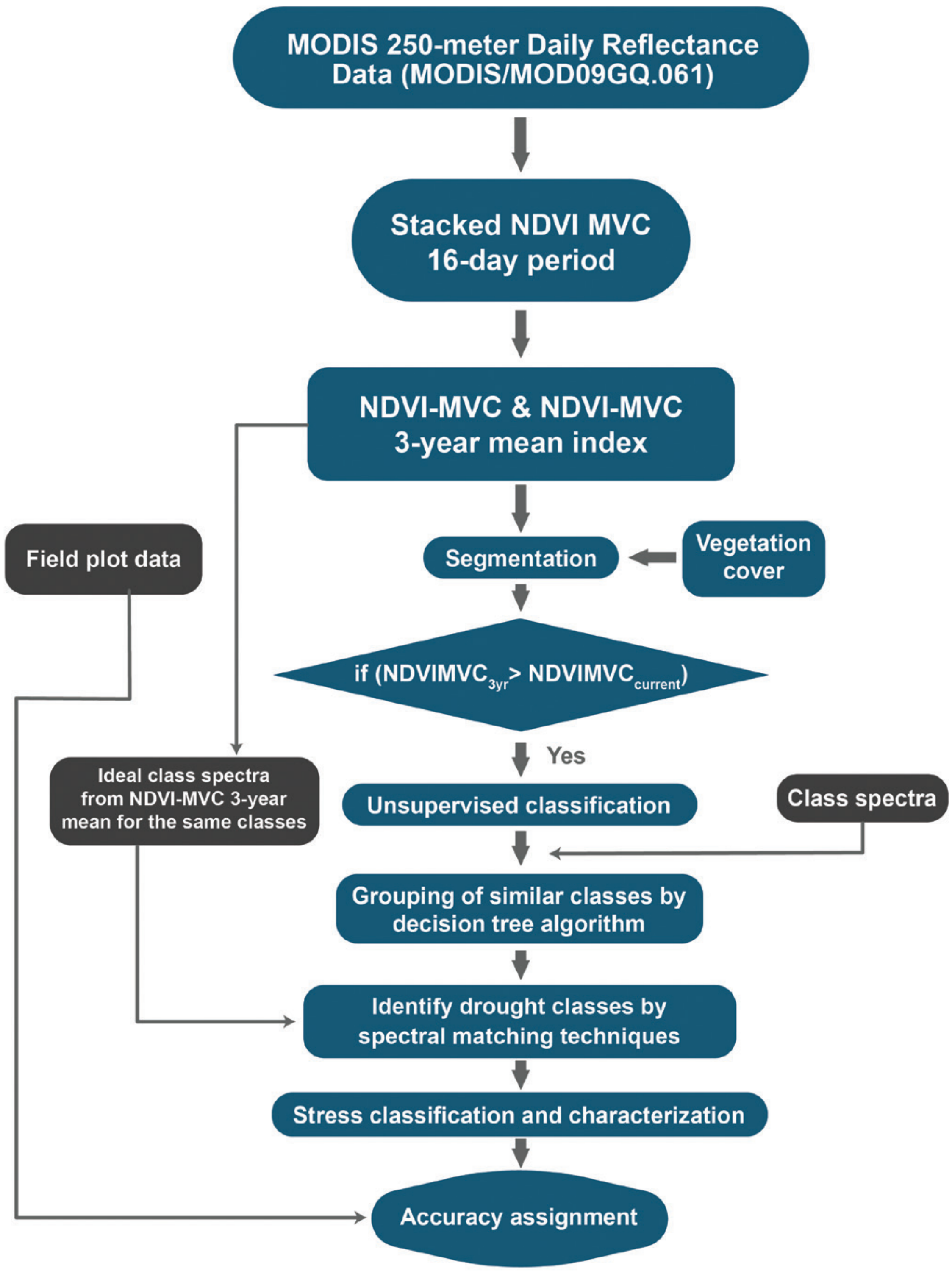
This product is derived from the MOD09GQ.061 Terra Surface Reflectance Daily Global 250m with a temporal resolution of 1 day, which means that we receive new images for analysis every day.

Depending on the meteorological conditions in the area of interest, the time series dataset must be a composite of either 8 or 16 days to perform the agricultural stress analysis. If the weather remains cloudy for an extended time, up to 16 days of maximum value composites may be required to get cloud-free imagery using composite imagery. Estimation must be made at the district level to identify daily changes in the land to determine crop status.

When the findings have been obtained, they should be validated by collecting data from the fields to determine the satellite data's accuracy. A spectral matching technique was used to measure crop stress and create maps for the Agriculture Department's CRSs.

Figure 2 provides an overview of the methodology.

Figure 2: Crop Stress Monitoring Methodology



MODIS = Moderate Resolution Imaging Spectroradiometer, MVC = maximum-value composite, NDVI = Normalized Difference Vegetation Index.

Source: M.K. Gumma, A. Nelson, and T. Yamano. 2019. Mapping Drought-Induced Changes in Rice Area in India. *International Journal of Remote Sensing*. 40(21). pp. 8146–8173

This method employs a stack of MODIS NDVI imagery that is compiled every 2 weeks by calculating the maximum-value composite (MVC) of the NDVI from before the flood dates (June 2022) to after the flood dates (August 2022) and then monitoring crop stress every 2 weeks to determine the change in crop health. This monthly NDVI MVC from June to August depicts the monthly status of the vegetation during the *kharif* season in 2022. Then, the dynamic Land Cover map at 100-meter resolution (Copernicus Global Land Cover Layers: CGLS-LC100 Collection 3) was used as a mask to produce proportionate estimates for vegetation/ground cover for land cover categories across Pakistan (Buchhorn et al. 2020). This mask excludes all other land cover properties: to compute crop stress, we selected solely vegetation cover. The monthly average MODIS NDVI MVC for the *kharif* season during the 3 years 2019–2021 is then used to determine an indication of the crops' optimal state ("signature"), which is then compared with the same time period of the 2022 *kharif* season.[3]

During the comparison, the first step was to identify crop regions in 2022 that had a lower NDVI value ("signature") than the typical year to use just the resulting pixels that show the crop regions are under stress. The *kharif* seasons of 2019–2021 are typical in this scenario. This calculation was carried using Equation (2):

$$Change\left(stress\right)=\left(NDVIMVC\right)_{3YR\ average}>\left(NDVIMVC\right)_{current} \quad \text{-------} \quad (2)$$

After the segmentation was completed and the crop area to be classified was obtained, based on the spectral similarities, the findings were grouped and classified as having "no stress," "mild stress," "moderate stress," and "severe stress," using a decision tree approach and ideal spectral signatures.

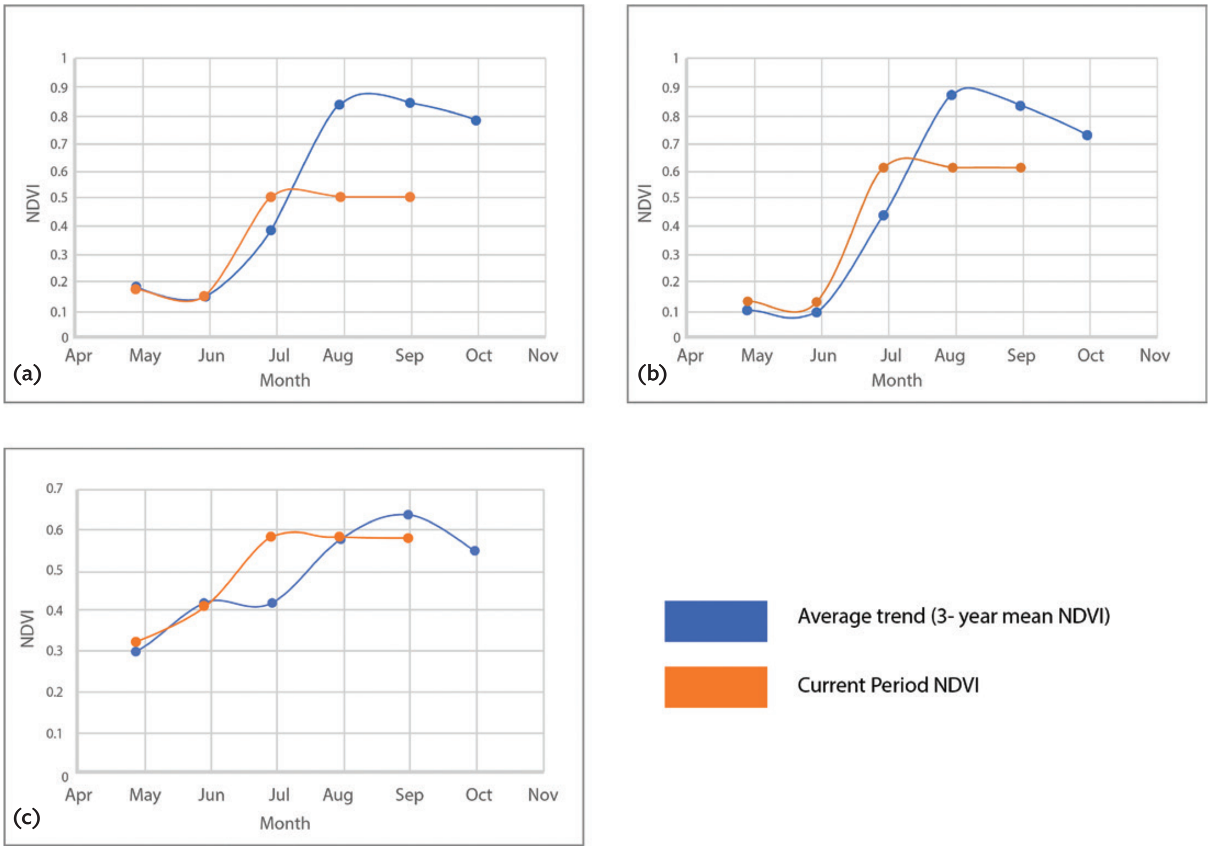
When the spectral signatures (classifications) for the 2022 *kharif* season (current period) and for the selected 3 years (the historical period) were developed,[4] then the two spectral signatures (current and historical) were compared with each other to capture the similarities and the differences. The crop stress level was ascertained keeping in mind the maximum NDVI threshold value of the crop for a particular month and comparing it with the *kharif* season 2022.

The analysis of the spectral signatures showed that an NDVI value in August and September with a difference of more than 0.3 with the 3-year average NDVI during the same months could be classified as severe stress, a difference of 0.15–0.20 could be classified as moderate stress, and a difference of 0.10–0.15 could be classified as mild stress. Figure 3 illustrates the disparity in spectral signatures between the NDVI MVC average of the preceding 3 years and that of 2022. Figure 3(a) depicts severe crop stress, as the difference between the 3-year average value of NDVI and the current year value during August (the flood month) is greater than 0.3 (NDVI range). Figure 3(b) depicts moderate crop stress with the difference being less than 0.3, but greater than 0.2, and Figure 3(c) depicts mild or no crop stress with a negligible difference or a nearly equal value of the NDVI for the current year and preceding 3-year average.

[3] The 3-year period was chosen to mitigate the effects of changes in cropping patterns as a form of crop stress. A longer historical reference period would be subjected to changes in the cropping pattern in Pakistan.

[4] In this case, 3 normal cropping years (2019, 2020, 2021) from the past 5 years were chosen as a baseline for NDVI and are considered to represent normal conditions.

Figure 3: Spectral Signature Comparison of 3-Year Average Normalized Difference Vegetation Index in Pakistan: (a) Severe Stress, (b) Moderate Stress, and (c) Mild Stress



NDVI = Normalized Difference Vegetation Index.

Source: Authors.

After the findings were obtained, a field survey (i.e., "ground truthing": checking the data physically at the sites) was conducted to examine the correlation of the analyzed crop stress raster representing stress severity (no, mild, moderate, and severe crop stress) with the reality on the ground. An android application (Locus Map) was used by overlaying the crop stress raster as a base map. During the survey, 223 ground points were captured from the districts with information about the crop and its condition (Table 3). This established that the results of our spatial analysis were aligned with the observations on the ground, i.e., severely stressed locations on the ground were in fact severely damaged crops, mostly rice.

Table 3: List of Ground Data Points

Province	District	Field Survey Points
Punjab	Layyah	27
Punjab	Attock	19
Punjab	Bhakkar	21
Punjab	Dera Ghazi Khan	41
Punjab	Muzaffargarh	16
Punjab	Rajanpur	37
Khyber Pakhtunkhwa	Dera Ismail Khan	24
Sindh	Jacobabad	7
Sindh	Shikarpur	5
Sindh	Khairpur	7
Balochistan	Nasirabad	10
Balochistan	Sohbatpur	9
	Total	**223**

Source: Authors.

Ground data collection is very crucial for interpreting satellite imagery regarding ground-level phenomena as well as for validation, especially in the identification of specific crops, land-use land cover, damage assessments, and others. To validate the flood and crop stress maps, a few locations were identified based on the intensity of crop stress obtained from preliminary classification for ground data collection.[5] During ground collection, significant information such as geographical information about the plot, crops sown, date of sowing, damage date, intensity of damage, and others is collected with farmer interviews, if available.

The accuracy of the maps was assessed based on validation data collected during the ground visits, as shown in the images in Appendix 2. For this purpose, we created a confusion matrix in which the columns represented the data points of the field plots and the rows represented the results of the classified maps (Congalton 1991). The confusion matrix contains the corresponding class changes in a multidimensional table. This statistical approach to accuracy assessment shows multivariate statistical analyses such as Kappa to relate the results of different classifications and regions (Cohen 1960); the degree of agreement between the user and reference ground data is indicated by a score of homogeneity or consensus. The accuracy assessments showed that the classified map from the remote sensing aligned with the ground truthing validation data with 91% accuracy.

[5] Field surveys were conducted exclusively in districts where crops experienced significant damage and were identified as being under severe stress in flooded areas, as well as in a limited number of districts, those were along rivers in Punjab. In those selected districts, 223 ground points were collected for validation purposes.

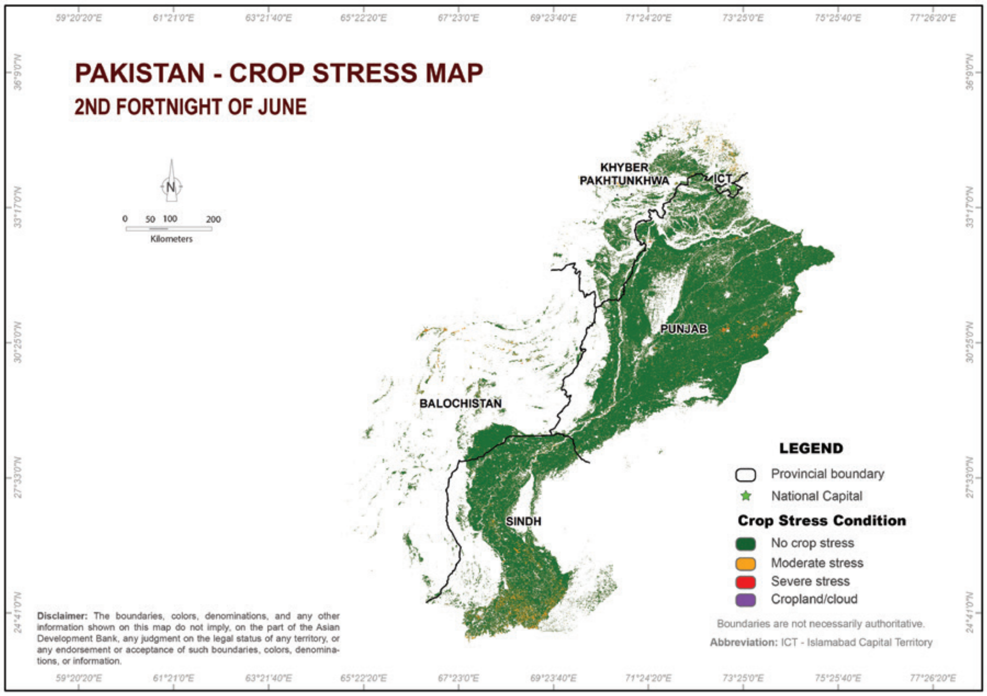
IV. MAIN RESULTS OF THE 2022 FLOODS: CROP STRESS

Figure 4 contains maps showing the distribution of crop stress in Pakistan during four periods in 2022: 16–30 June, 16–31 July, 16–31 August, and 1–15 September. Crop stress is categorized as no, mild, moderate, and severe stress. As can be seen in the maps, clouds can limit the analysis. Moreover, crops can recover from stress in their early growth stages, whereas crop stress in late growth stages can directly result in production losses. Moderate and severe stress during a late growth stage can cause complete crop losses, and mild stress can reduce harvests.

The 2022 *kharif* season started with little crop stress in June (Figure 4[a]). However, the crop stress intensified starting in early July as heavy rains and floods occurred (Figure 4[b]). About 21% of the crop fields were found to have moderate or severe crop stress in late July; 7% were under cloud so could not be assessed. In the third period (16–31 August, Figure 4[c]), the total area with crop stress declined. However, the stress maps in Figure 4(b) and 4(c) suggest that crops in lower Punjab and upper Sindh continued to suffer from moderate and severe stresses. These are the areas where heavy rain and flooding damaged the fields. In the last period (1–15 September, Figure 4[d])), the analysis identified that about 15% of the fields had moderately or severely stressed crops and were likely to incur significant or complete production losses.

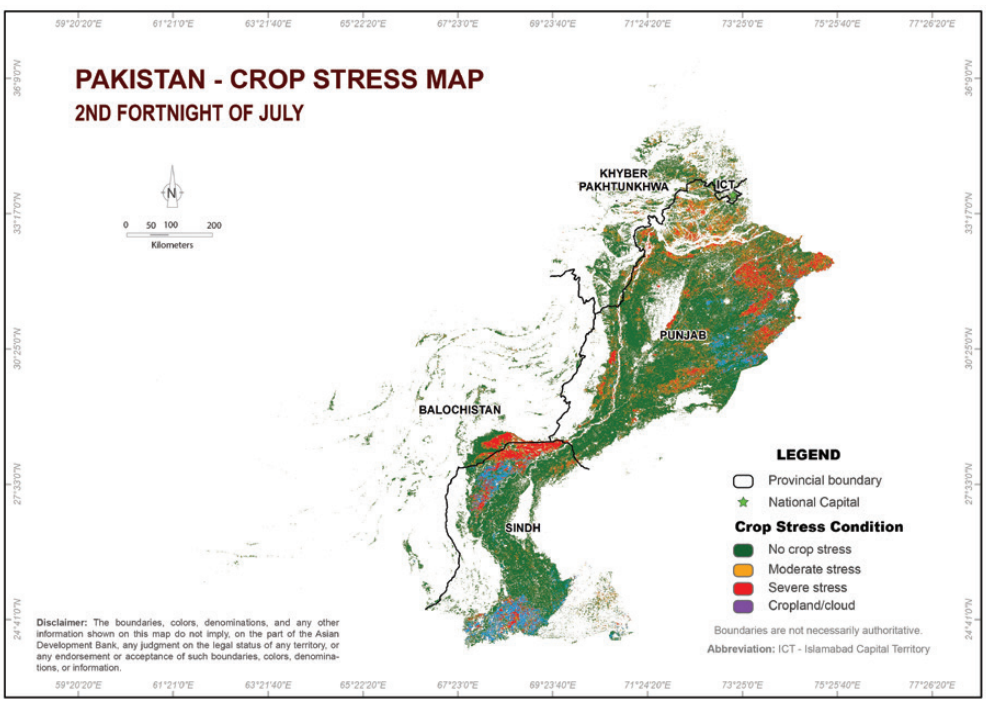
Figure 4: Crop Stress Maps, Pakistan

Figure 4(a): Second Half of June 2022



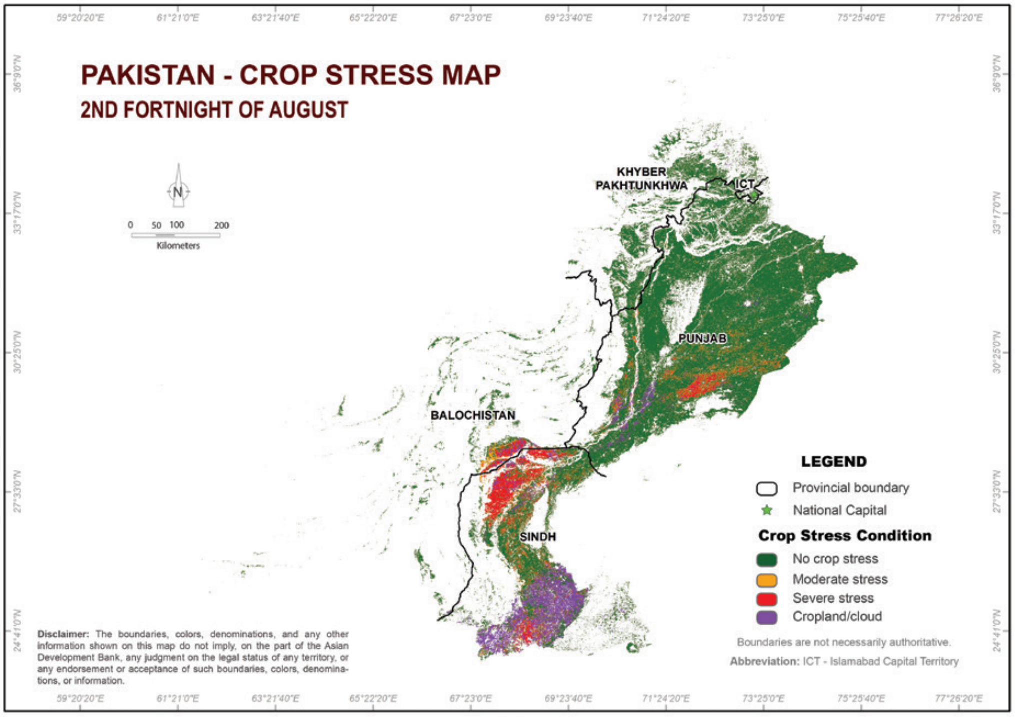
Source: Authors.

Figure 4(b): Second Half of July 2022



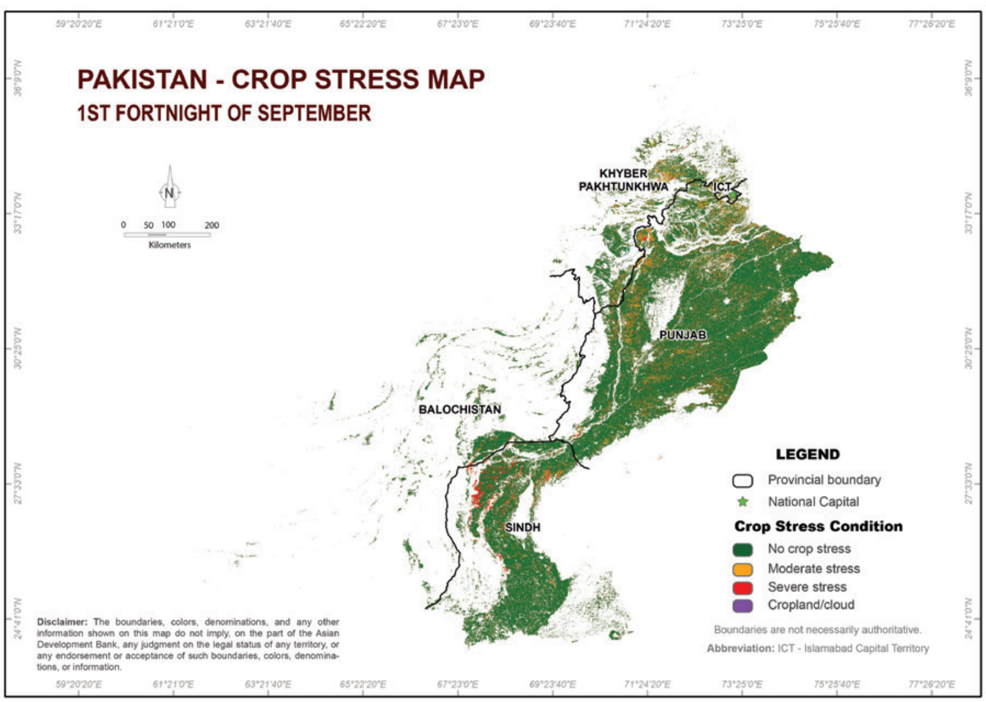
Source: Authors.

Figure 4(c): Second Half of August 2022



Source: Authors.

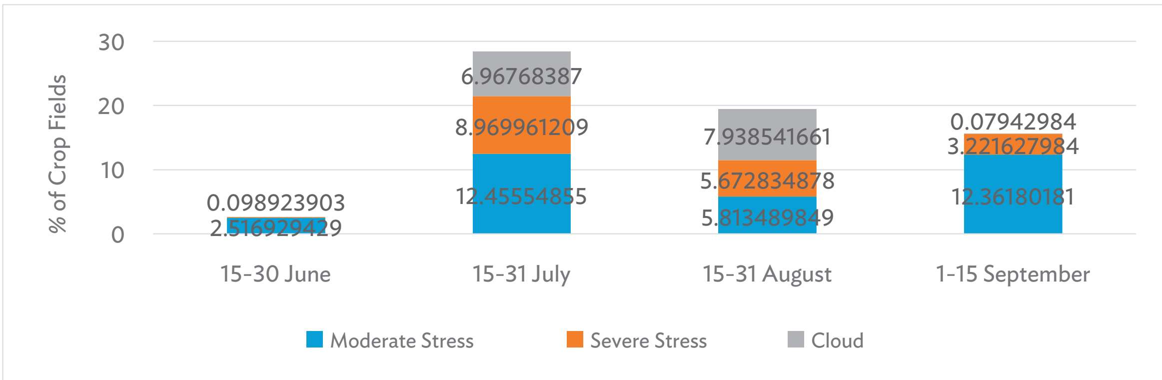
Figure 4(d): First Half of September 2022



Source: Authors.

In summary, Figure 5 estimates the shares of moderate or severe crop stress in the four crop growth periods. Mild crop stress was excluded because it is difficult to link with production losses, as crops may recover from mild stress in early growth periods, or fallow crop fields could be mistaken for mild crop stress. Careful ground verifications were needed for the analysis, but were unavailable for this report.

Figure 5: Crop Stress in Four Periods during *Kharif* 2022
(%)



Source: Authors' assessment using spatial analysis.

Table 4 shows crop stress areas by province in the last period, 1–15 September. The analysis found that about 16% of the crop fields of the four provinces, i.e., 3.3 million ha, suffered from moderate or severe crop stress. This suggests that about 700,000 ha would incur severe crop losses and another 2.6 million ha would have moderate crop losses. Moderate or severe crop stress was found in about 15% of fields in Balochistan (148,000 ha), 18% in Khyber Pakhtunkhwa (287,000 ha), 13% in Punjab (1.8 million ha), and 21% in Sindh (1.1 million ha).

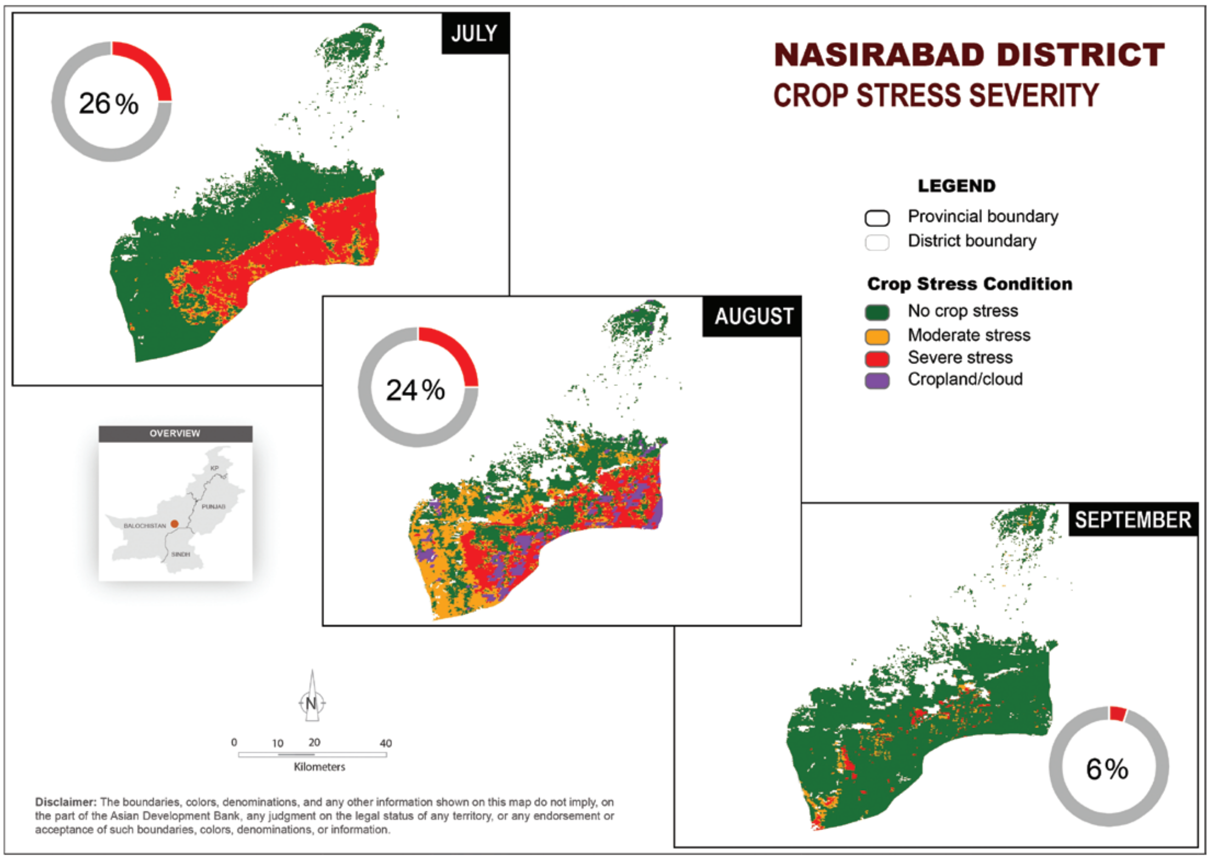
Table 4: Crop Stress on Crop Fields, by Province, 1–15 September 2022

Province	Total Provincial Crop Area (hectares)	Crop Stress (hectares)			
		No/Mild	Moderate	Severe	Cloud
Balochistan	1,016,784	867,356	124,712	23,744	972
	(100%)	(85.3%)	(12.3%)	(2.3%)	(0.1%)
Khyber Pakhtunkhwa	1,561,806	1,260,470	249,019	38,458	13,860
	(100%)	(80.7%)	(15.9%)	(2.5%)	(0.9%)
Punjab	13,109,707	11,357,495	1,403,681	346,788	1,743
	(100%)	(86.6%)	(10.7%)	(2.6%)	(0.0%)
Sindh	5,179,402	4,113,900	802,212	263,290	0
	(100%)	(79.4%)	(15.5%)	(5.1%)	(0.0%)
Total	**20,867,699**	**17,599,221**	**2,579,624**	**672,280**	**16,575**
	(100%)	**(84.3%)**	**(12.4%)**	**(3.2%)**	**(0.1%)**

Source: Authors' assessment using spatial analysis.

Figures 6 and 7 are examples of district-level analysis of crop stress. Nasirabad, Balochistan is examined in depth (Figure 6). Nasirabad is one of the districts with the highest rice production in Balochistan and was damaged by flooding. In July and August 2022, when rainfall occurred in phases, floods caused 26% in July and 24% in August of severe crop stress. However, in September, crop stress had dropped to 6%, indicating that nearly 70% of the crop had almost recovered.

Figure 6: Crop Stress in Nasirabad, July–September 2022

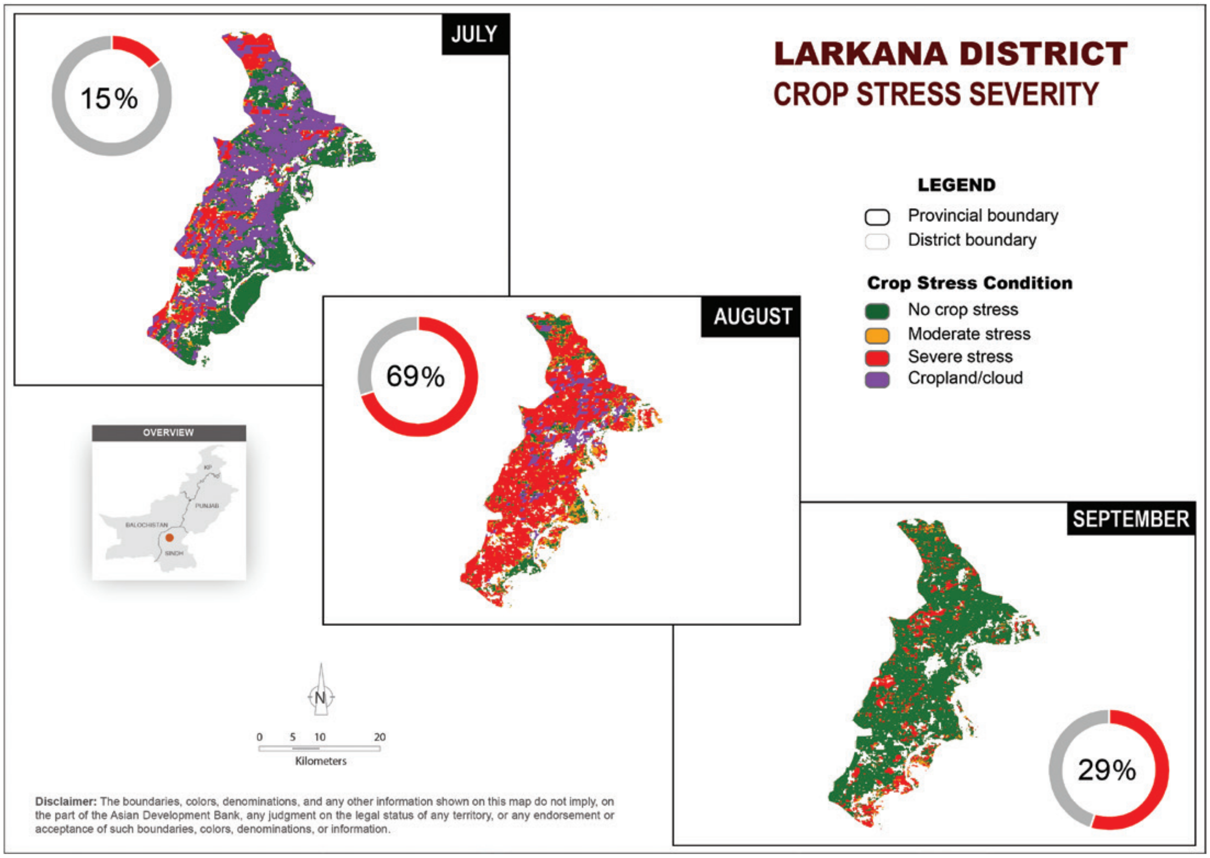


Source: Authors.

Severe flood also affected the rice-producing region of Sindh province. On Larkana's cropland, 69% of the crops had experienced significant stress in August, but 40% of that had recovered in September (Figure 7). Figure 7 shows that in September, 29% of the crop areas were still under severe stress. Spatial analysis can wrongly identify late-sowing areas as damaged areas. But, because crops in Pakistan are rarely sown after mid-July, the August and September figures are likely to show damaged crop fields, not late sowing.

Following the computations and analyses, the results were shared with provincial CRSs, which confirmed our data using their own statistical approach during their own field data collection. The CRSs found our results to be very close to the actual situation that they observed on the ground during crop damage estimation.

Figure 7: Crop Stress in Larkana, July–September 2022



Source: Authors.

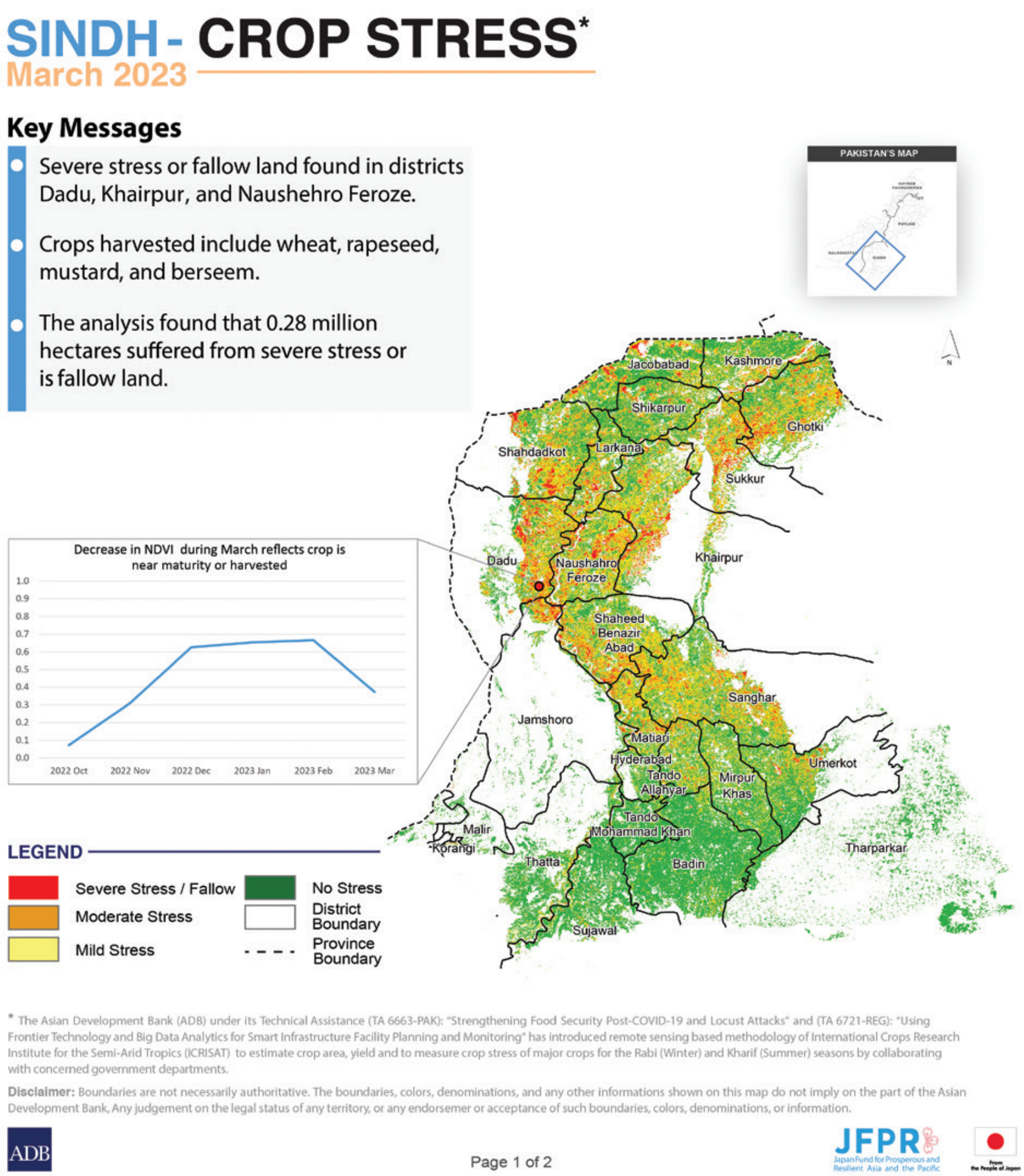
V. ESTABLISHMENT OF A MONTHLY CROP STRESS REPORTING SYSTEM

The crop stress maps of the 2022 floods were shared with the national and provincial ministries and international organizations. Such reports were a novelty to them, and were first received with skepticism and many questions. Their responses indicated (i) the importance of damage assessment per type of crop (rice, wheat, maize, pulses, and others) whereas the maps at the time were generic; and (ii) that the intended audience needed a better understanding of the system. Thus, it was important to establish a periodic crop damage reporting system to improve the accuracy and specificity of the crop damage assessment by assessing the analysis results with informed government officers, especially at the CRSs of the four provinces, and to gain government counterparts' confidence in the mapping system's results.

Establishing a reliable crop stress reporting system will help the government agencies to prepare for future floods. For this purpose, in February 2023, the project team started sharing monthly reports with relevant government agencies, which were asked to comment on the reports. Because agriculture policy is a province matter, monthly reports were developed for each province and shared with both the national and province government agencies.

Figure 8 is an example of the crop damage assessment. Analysis of this map found that 2.3 million ha of crop area in Sindh suffered from severe stress (or was fallowed land, possibly post-harvest).

Figure 8: Monthly Crop Damage Map: Sindh Province, March 2023



ADB = Asian Development Bank, JFPR = Japan Fund for Prosperous and Resilient Asia and the Pacific, NDVI = Normalized Difference Vegetation Index.

Source: Authors' assessment using spatial analysis.

VI. POLICY RECOMMENDATIONS AND DISCUSSIONS

Agriculture remains an important contributor to Pakistan's employment and its export industry. For effective and timely policy decision making, the provincial and federal governments need to have reliable data. Agriculture statistics and crop damage assessments depend on reports from provincial statistics offices and CRSs. However, their reporting services have inadequate financial and technical resources, potentially resulting in inaccurate and delayed reporting.

The use of advanced spatial analysis, i.e., GIS and remote sensing analysis, can help the statistics offices and CRSs by augmenting their field observations. Spatial analysis is useful to support and enhance reporting systems by providing estimated crop areas, production, and damage as satellite images become available. Spatial analysis results may need to be interpreted by experts based on local knowledge. The estimates need to be verified with ground observations.

To strengthen the skills for and use of spatial analysis, we recommend the following action.

(i) First, government agencies should **increase the number of GIS and remote sensing specialists** at relevant offices. For this purpose, ADB has conducted nine training sessions during 2019–2023, training 80 specialists (Box). Externally funded projects should train government officers so that the technical expertise and skills are retained within government agencies so they can continue conducting project activities even after the project has ended.

(ii) Second, provincial agriculture statistics offices and CRSs should **consider integrating spatial analysis in their reporting process**. Spatial analysis can, for example, provide preliminary estimates of planted areas, crop damage, and expected harvests as an agricultural season progresses. The estimates could be reported to the public as predictions and could be verified by local offices prior to being published as final statistics. The spatial analysis can also leverage the NATCAT model (National Disaster Risk Management Fund) and the climate projections modeled by Global Climate-Change Impact Studies Center (Ministry of Climate Change) to assess risks to agricultural production systems under different climate scenarios and seasonal climate outlook.

(iii) Third, **enable agricultural policy makers to critically interpret spatial analysis results**. Spatial analysis can provide policy makers with estimated agriculture statistics such as the most recent estimated crop areas and production values. And it can provide estimated areas damaged or production lost after extreme climate events. Unless policy makers are familiar with spatial analysis and understand how to interpret the results, they are reluctant to use the analysis results for their decision making. Therefore, it is very important to familiarize key decision makers with the technique and to circulate and disseminate spatial analysis results among them. This is an important purpose of periodic reports, such as the monthly reports discussed in the previous section.

(iv) Fourth, **use spatial analysis to help plan effective policy actions**. For example, after spatial analysis detects crop damage (such as due to disease, insect attacks, and extreme weather events), local verification teams should be dispatched, financial and material resources mobilized, and government messages communicated to the affected farmers and communities. Financial and material resources should be reserved so that they can be mobilized immediately to minimize the damage.

Box: Capacity Building of Government Officers

Two technical assistance projects, (TA-6663 PAK and TA-6721 REG),[a] are being implemented for building the capacity of the Ministry of National Food Security and Research (MNFSR) and provincial crop reporting services (CRSs) for remote sensing and its application in agriculture. The emphasis is on delivering advanced-level training to analyze data for crop health monitoring and generating crop area and yield estimates on a regular basis using remote sensing technology. This type of analysis will eventually be used in the early warning systems, which will help agriculture extension to examine stressed locations and issue advisories accordingly and can be used for crop insurance purposes. Moreover, analysis of the data will permit decision makers to make improved decisions and policies regarding trade (import and export) of agriculture commodities.

For capacity building, a standard approach developed by the International Crop Research (ICRISAT) was introduced. Advanced training sessions were held to train CRS staff members to estimate crop area using spectral matching techniques, estimate yields using crop modeling, and monitor crop health during the growing seasons. To make the system sustainable, open-source platforms such as the Google Earth Engine were introduced for training, providing the access and parallel computing power for satellite imagery.

Punjab already had a Remote Sensing and GIS Unit working under its CRS. The unit served as a platform for developing the CRS's capacity to use advanced remote sensing technology to estimate crop area using the spectral matching technique, estimate yields using crop modeling, and monitor crop health. Sindh, however, lacked a GIS unit, but had skilled remote sensing personnel to whom the training was delivered.

Balochistan and Khyber Pakhtunkhwa did not have a GIS unit or trained remote sensing staff. To remedy this lack, remote sensing analysts were hired and deployed at CRS offices in Balochistan and Khyber Pakhtunkhwa, to teach the fundamentals of remote sensing and its application in agriculture. The ADB consultants then led an advanced session where they laid a strong foundation on computing the analysis to estimate crop area and yield, and to monitor crop health. A similar approach to that adopted in Balochistan and Khyber Pakhtunkhwa will be used to train more staff members in the Sindh CRS.

Extensive "ground truthing" (results verification in the field) training was also provided to the concerned government officials by engaging them in a month-long ground truthing survey.[b] The table lists the training delivered to the MNFSR and provincial CRSs.

Geographic Information System and Remote Sensing Training Provided for Government Officers

S.no.	Training On	Date	Training Duration (in days)	Government Staff Trained	Department	Province
1	Crop Area Estimation	27–29 Jul 2019	3	6	Crop Reporting Services	Punjab and Sindh
2	Crop Yield Estimation	15–17 Sep 2021	3	12	Crop Reporting Services	Punjab
3	Crop Yield Estimation	8–12 Nov 2021	5	12	Crop Reporting Services	Punjab
4	Introduction to Remote Sensing	21–23 Feb 2022	3	10	Crop Reporting Services	Khyber Pakhtunkhwa

Continued on next page

Box continued

S.no.	Training On	Date	Training Duration (in days)	Government Staff Trained	Department	Province
5	Crop Health Monitoring	18–20 Jul 2022	3	6	Crop Reporting Services	Punjab and Sindh
6	Crop Area Estimation	18–23 Dec 2022	5	6	Crop Reporting Services	Khyber Pakhtunkhwa
7	Crop Area Estimation	20–24 Feb 2023	4	12	Crop Reporting Services	Balochistan and Khyber Pakhtunkhwa
8	Ground Truthing Survey	25–28 Feb 2023	4	11	Crop Reporting Services	Balochistan and Khyber Pakhtunkhwa
9	Crop Health Monitoring	6 Feb 2023–present	22	5	Ministry of National Food Security and Research	Federal

[a] Using Frontier Technology and Big Data Analytics for Smart Infrastructure Facility Planning and Monitoring (TA 6721); and Strengthening Food Security Post-COVID-19 and Locust Attacks, Pakistan (TA 6663).
[b] Ground truthing survey was conducted to collect georeferenced data with a geographical positioning system for each crop type and other land use and land cover during *rabi* (winter) season crop year 2023.

Source: Authors.

VII. CONCLUSION

This report presents real-time crop assessments of floods that occurred in August 2022 in Pakistan and the aftermath of the flooding, describes the establishment of monthly crop damage assessment reports, and provides policy recommendations. The spatial analysis used in this report employed high-resolution satellite images and provided detailed crop stress maps. Satellite images in four periods from June to September 2022 were analyzed with crop growth models and artificial intelligence algorithms.

In early September 2022, the analysis identified that 15% of the cropped areas had severe damage that could lead to crop losses. The analysis reported crop damage at the district level so that government agencies could use the list for providing assistance to the affected districts after the floods. Spatial analyses could be used to assess crop damage from future stress events if government agencies are equipped to understand and conduct the spatial analysis process.

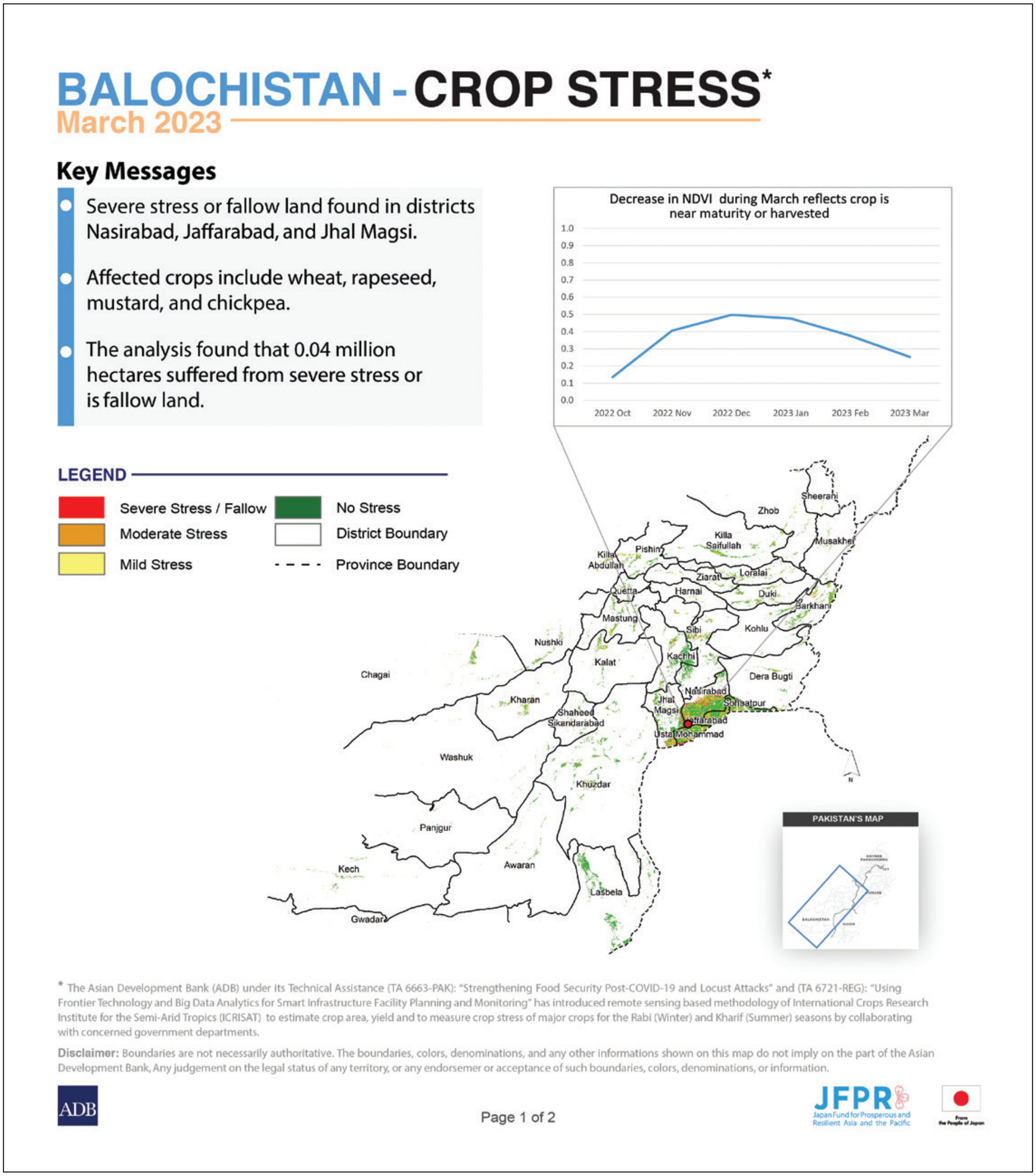
Section VI of the report provides four policy recommendations for adopting the assessment method: (i) increase the number of GIS and remote sensing specialists in relevant government offices, (ii) integrate the use of spatial analysis in statistical reporting systems to improve their accuracy and timeliness, (iii) familiarize agriculture policy makers with and enable them to interpret spatial analysis results, and (iv) plan effective policy actions in advance for events that spatial analysis can identify.

Early detection, rapid field verification, and timely resource mobilization can mitigate damage and help policy makers to plan for robust recoveries from crop damage. The experience of the 2022 floods highlights the importance of these preparations and the need for using visual presentations of spatial analysis to communicate with the public and affected communities.

APPENDIXES

Appendix 1: Monthly Reports

The following figures are examples of monthly reports of crop stress.



BALOCHISTAN - CROP STRESS*

March 2023

Key Messages

- Severe stress or fallow land found in districts Nasirabad, Jaffarabad, and Jhal Magsi.
- Affected crops include wheat, rapeseed, mustard, and chickpea.
- The analysis found that 0.04 million hectares suffered from severe stress or is fallow land.

* The Asian Development Bank (ADB) under its Technical Assistance (TA 6663-PAK): "Strengthening Food Security Post-COVID-19 and Locust Attacks" and (TA 6721-REG): "Using Frontier Technology and Big Data Analytics for Smart Infrastructure Facility Planning and Monitoring" has introduced remote sensing based methodology of International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) to estimate crop area, yield and to measure crop stress of major crops for the Rabi (Winter) and Kharif (Summer) seasons by collaborating with concerned government departments.

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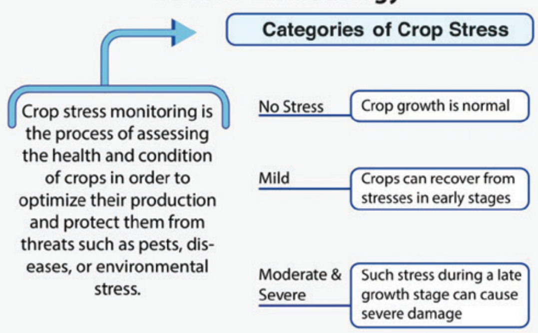
BALOCHISTAN - CROP STRESS
March 2023

The Asian Development Bank (ADB) under its Technical Assistance (TA 6663-PAK): "Strengthening Food Security Post-COVID-19 and Locust Attacks" and (TA 6721-REG): "Using Frontier Technology and Big Data Analytics for Smart Infrastructure Facility Planning and Monitoring" has introduced remote sensing based methodology of International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) to estimate crop area, yield and to measure crop stress of major crops for the Rabi (Winter) and Kharif (Summer) seasons by collaborating with concerned government departments.

ICRISAT Methodology



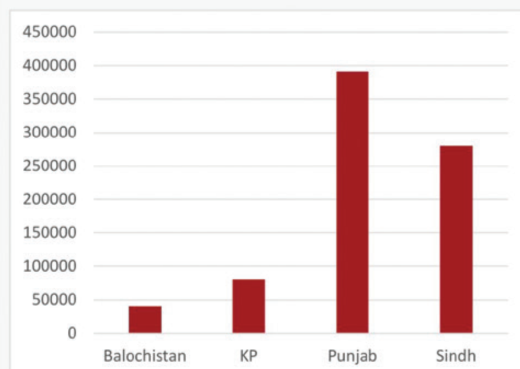
Crop stress is computed by comparing parameters obtained from the present satellite images with the historical averages of the same parameters. Range of difference between current year and historical NDVI is used to categorize the stress into different categories.

Nasirabad has the largest share in provincial agriculture. Wheat, rapeseed, mustard, coriander and chickpeas are the major crops of rabi season in the district. It is observed that Nasirabad is severly stressed. It could be due to poor wheat growth, harvesting of mustard and rapeseed or land is fallow.

District-wise severe stress (ha), Balochistan

Districts	Severe Stress (ha)	Districts	Severe Stress (ha)
Nasirabad	17171	Killa Saifullah	78
Jaffarabad	10353	Zhob	60
Jhal Magsi	6487	Mastung	56
Sibi	2402	Musakhel	53
Sohbatpur	1008	Nushki	49
Kachhi	730	Kech	44
Dera Bugti	438	Kalat	43
Khuzdar	268	Harnai	43
Killa Abdullah	200	Sheerani	30
Lasbela	123	Kharan	16
Loralai	118	Kohlu	16
Quetta	115	Ziarat	14
Barkhan	107	Gwadar	11
Duki	102	S. Sikandarabad	11
Chagai	100	Panjgur	0
Pishin	93	Washuk	0
Awaran	82		

Province-wise severe stress (ha), Pakistan



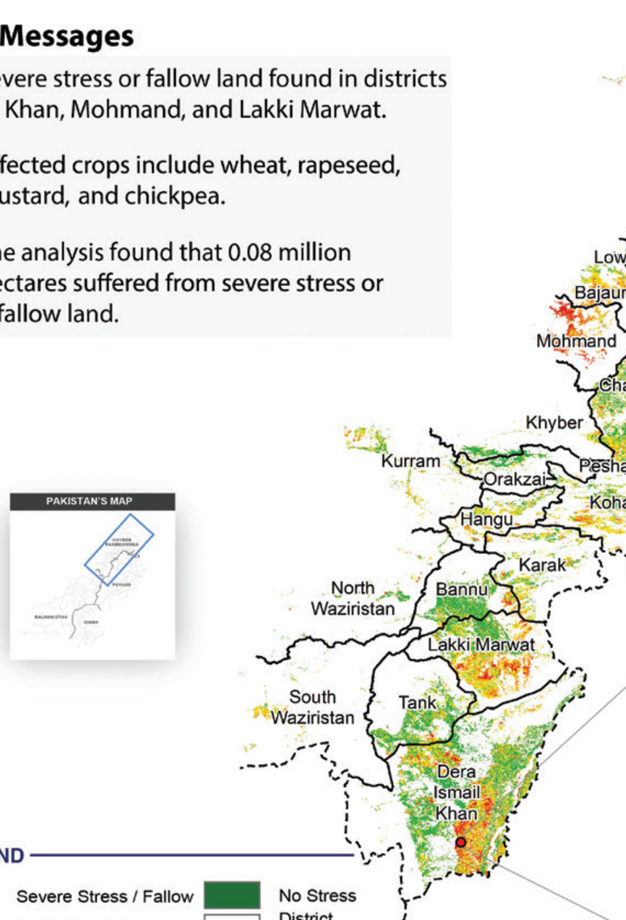
The analysis found that 0.12% area in Balochistan, 0.79% in KP, 1.91% in Punjab and 1.99% in Sindh is under severe stress / fallow land. The area mentioned under stress includes crops as well as other vegetation.

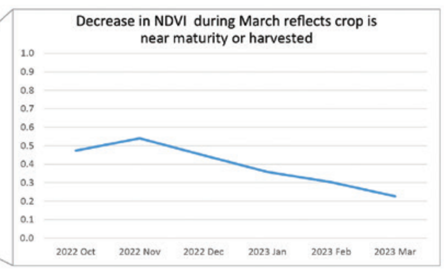
KHYBER PAKHTUNKHWA - CROP STRESS*

March 2023

Key Messages

- Severe stress or fallow land found in districts DI Khan, Mohmand, and Lakki Marwat.
- Affected crops include wheat, rapeseed, mustard, and chickpea.
- The analysis found that 0.08 million hectares suffered from severe stress or is fallow land.





LEGEND

- Severe Stress / Fallow
- Moderate Stress
- Mild Stress
- No Stress
- District Boundary
- Province Boundary

* The Asian Development Bank (ADB) under its Technical Assistance (TA 6663-PAK): "Strengthening Food Security Post-COVID-19 and Locust Attacks" and (TA 6721-REG): "Using Frontier Technology and Big Data Analytics for Smart Infrastructure Facility Planning and Monitoring" has introduced remote sensing based methodology of International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) to estimate crop area, yield and to measure crop stress of major crops for the Rabi (Winter) and Kharif (Summer) seasons by collaborating with concerned government departments.

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JFPR Japan Fund for Prosperous and Resilient Asia and the Pacific

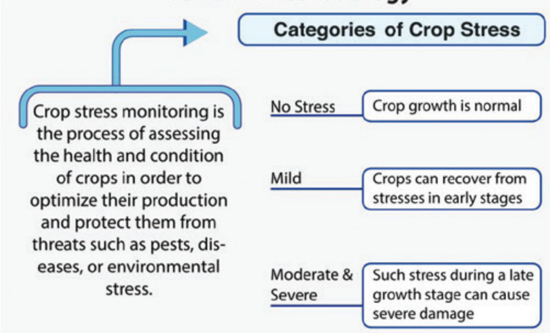
From the People of Japan

KHYBER PAKHTUNKHWA - CROP STRESS

March 2023

The Asian Development Bank (ADB) under its Technical Assistance (TA 6663-PAK): "Strengthening Food Security Post-COVID-19 and Locust Attacks" and (TA 6721-REG): "Using Frontier Technology and Big Data Analytics for Smart Infrastructure Facility Planning and Monitoring" has introduced remote sensing based methodology of International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) to estimate crop area, yield and to measure crop stress of major crops for the Rabi (Winter) and Kharif (Summer) seasons by collaborating with concerned government departments.

ICRISAT Methodology



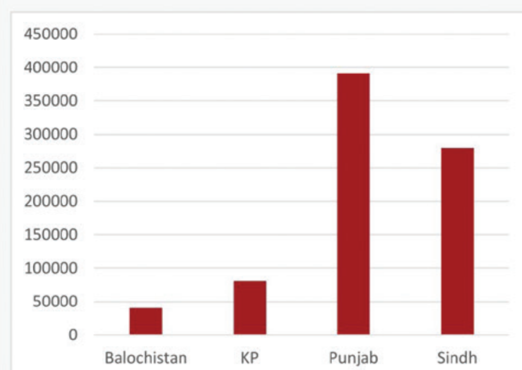
Crop stress is computed by comparing parameters obtained from the present satellite images with the historical averages of the same parameters. Range of difference between current year and historical NDVI is used to categorize the stress into different categories.

DI Khan has the largest share in provincial agriculture. Wheat, rapeseed, mustard, berseem (fodder), chickpea and sugarcane (annual) are the major crops of rabi season in the district. It is observed that Dera Ismail Khan is severly stressed. It could be due to harvesting of crops (sugarcane and rapeseed) or land is fallow for the next crop.

District-wise severe stress (ha), KP

Districts	Severe Stress (ha)	Districts	Severe Stress (ha)
DI Khan	32941	Malakand	151
Mohmand	16715	Lower Dir	144
Lakki Marwat	11044	Mardan	136
Bajaur	3276	FR Peshawar	114
Kohat	2741	FR Bannu	111
Nowshera	1824	Mansehra	110
Peshawar	1554	Tor Ghar	91
Bannu	1543	Orakzai	47
Haripur	1498	Swabi	44
Karak	1089	FR D.I.Khan	44
Hangu	1061	Shangla	42
Swat	1025	Upper Dir	38
Tank	921	FR Kohat	27
Kurram	710	Abbottabad	24
N. Waziristan	550	Batagram	22
Charsadda	460	FR Tank	17
S. Waziristan	236	Buner	10
Khyber	186	Kohistan	7
Chitral	176	FR Lakki Marwat	0

Province-wise severe stress (ha), Pakistan



The analysis found that 0.12% area in Balochistan, 0.79% in KP, 1.91% in Punjab and 1.99% in Sindh is under severe stress / fallow land. The area mentioned under stress includes crops as well as other vegetation.

ADB

JFPR Japan Fund for Prosperous and Resilient Asia and the Pacific

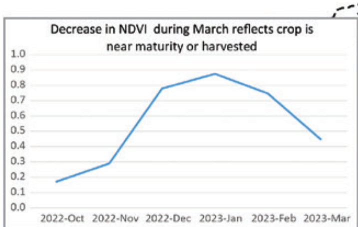
From the People of Japan

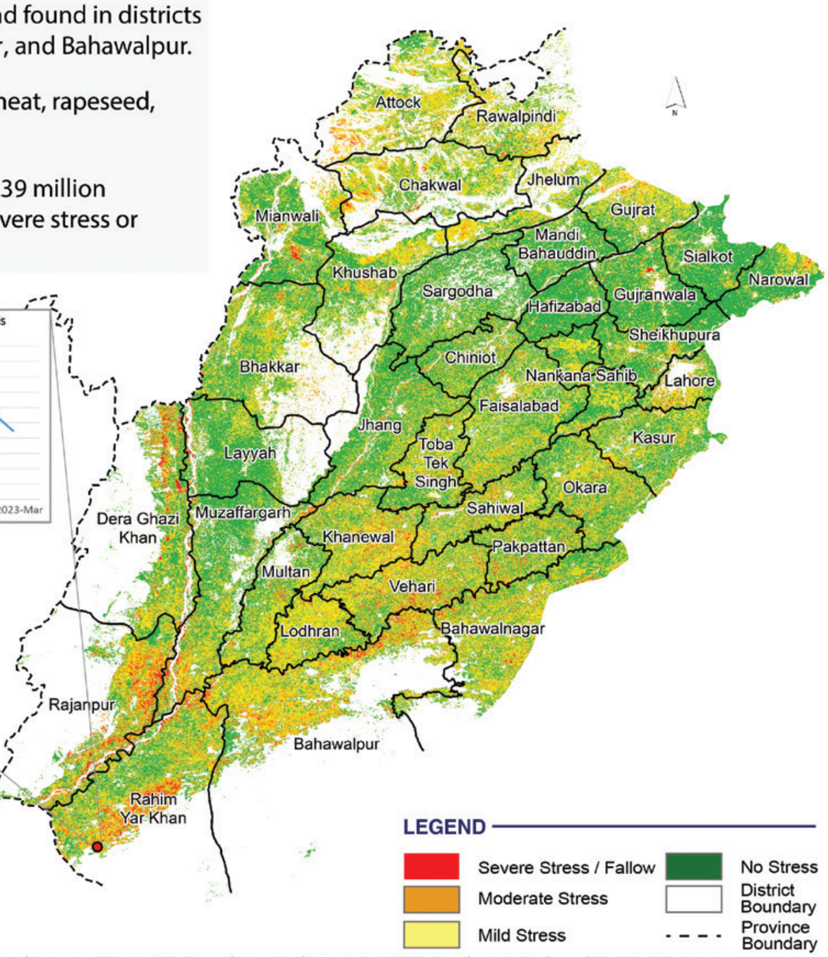
PUNJAB - CROP STRESS*

March 2023

Key Messages

- Severe stress or fallow land found in districts Rahim Yar Khan, Rajanpur, and Bahawalpur.
- Affected crops include wheat, rapeseed, mustard, and berseem.
- The analysis found that 0.39 million hectares suffered from severe stress or is fallow land.





* The Asian Development Bank (ADB) under its Technical Assistance (TA 6663-PAK): "Strengthening Food Security Post-COVID-19 and Locust Attacks" and (TA 6721-REG): "Using Frontier Technology and Big Data Analytics for Smart Infrastructure Facility Planning and Monitoring" has introduced remote sensing based methodology of International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) to estimate crop area, yield and to measure crop stress of major crops for the Rabi (Winter) and Kharif (Summer) seasons by collaborating with concerned government departments.

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PUNJAB - CROP STRESS

March 2023

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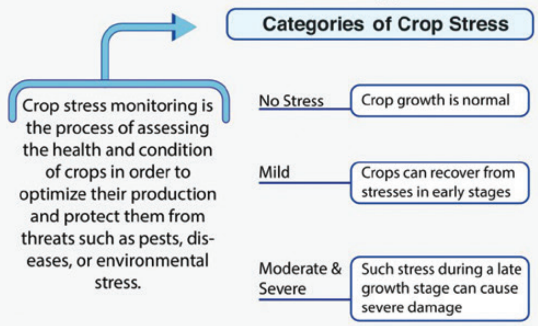


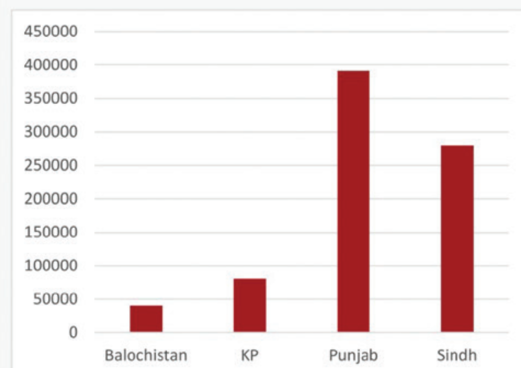
Crop stress is computed by comparing parameters obtained from the present satellite images with the historical averages of the same parameters. Range of difference between current year and historical NDVI is used to categorize the stress into different categories.

It is observed that Rahim Yar Khan and Rajanpur compared to other districts of the province are under severe stress. Wheat, rapeseed, mustard and berseem are major crops of rabi season in these districts. Majority of the rapeseed and mustard cultivated area may have been harvested or land is fallow.

District-wise severe stress (ha), Punjab

Districts	Severe Stress (ha)	Districts	Severe Stress (ha)
Rahim Yar Khan	51383	Lodhran	5386
Rajanpur	48876	Toba Tek Singh	5280
Bahawalpur	38227	Rawalpindi	5030
Dera Ghazi Khan	31772	Gujranwala	4965
Muzaffargarh	22593	Kasur	4958
Vehari	22034	Bhakkar	4798
Khanewal	19497	Chiniot	4541
Bahawalnagar	17941	Lahore	4534
Mianwali	9276	Sheikhupura	3866
Pakpattan	9011	Khushab	3740
Sahiwal	8261	Gujrat	3392
Jhang	7528	Sargodha	2334
Faisalabad	7494	Narowal	1918
Multan	7305	Jhelum	1907
Okara	7165	Sialkot	1832
Attock	6873	Nankana Sahib	1817
Layyah	6654	Hafizabad	1690
Chakwal	5907	Mandi Bahauddin	1611

Province-wise severe stress (ha), Pakistan



The analysis found that 0.12% area in Balochistan, 0.79% in KP, 1.91% in Punjab and 1.99% in Sindh is under severe stress / fallow land. The area mentioned under stress includes crops as well as other vegetation.

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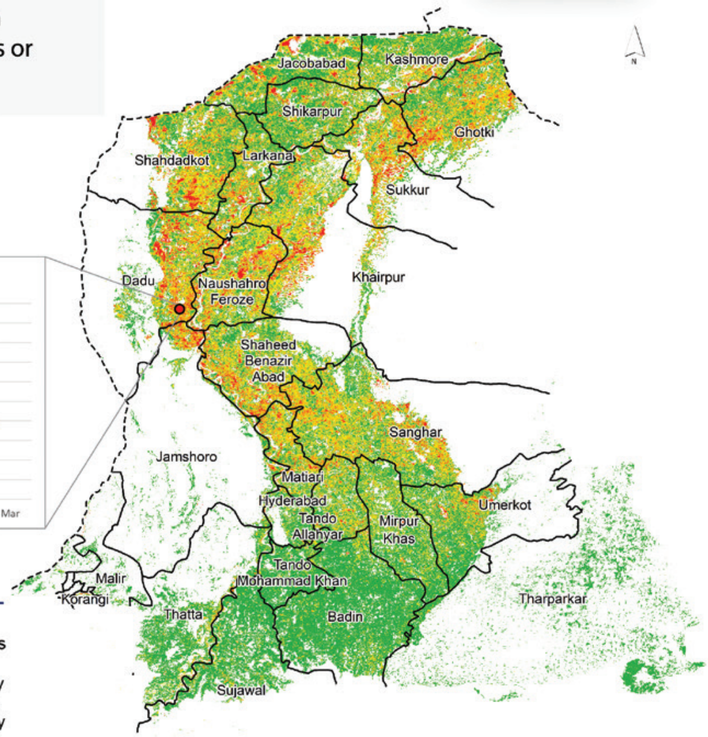
From the People of Japan

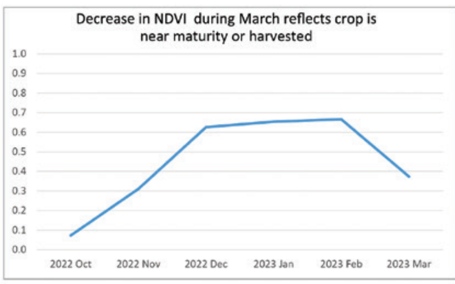
SINDH - CROP STRESS*

March 2023

Key Messages

- Severe stress or fallow land found in districts Dadu, Khairpur, and Naushehro Feroze.
- Crops harvested include wheat, rapeseed, mustard, and berseem.
- The analysis found that 0.28 million hectares suffered from severe stress or is fallow land.





LEGEND

- Severe Stress / Fallow
- Moderate Stress
- Mild Stress
- No Stress
- District Boundary
- Province Boundary

* The Asian Development Bank (ADB) under its Technical Assistance (TA 6663-PAK): "Strengthening Food Security Post-COVID-19 and Locust Attacks" and (TA 6721-REG): "Using Frontier Technology and Big Data Analytics for Smart Infrastructure Facility Planning and Monitoring" has introduced remote sensing based methodology of International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) to estimate crop area, yield and to measure crop stress of major crops for the Rabi (Winter) and Kharif (Summer) seasons by collaborating with concerned government departments.

Disclaimer: Boundaries are not necessarily authoritative. The boundaries, colors, denominations, and any other informations shown on this map do not imply on the part of the Asian Development Bank, Any judgement on the legal status of any territory, or any endorsemer or acceptance of such boundaries, colors, denominations, or information.

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SINDH - CROP STRESS
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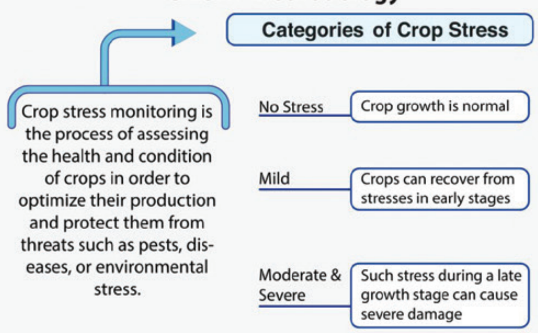
ICRISAT Methodology



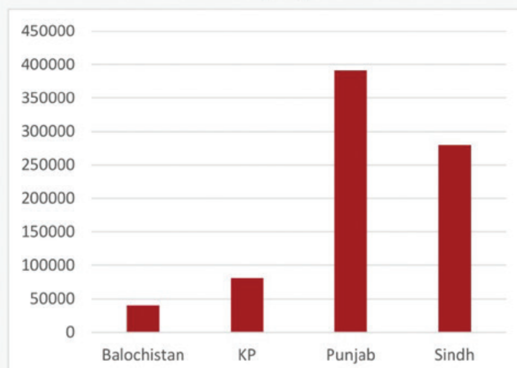
Crop stress is computed by comparing parameters obtained from the present satellite images with the historical averages of the same parameters. Range of difference between current year and historical NDVI is used to categorize the stress into different categories.

It is observed that Dadu, Khairpur and Naushero Feroze are severly stressed. It could be due to harvesting of crops (wheat, rapeseed and mustard) or land is fallow. Wheat, rapeseed, mustard and berseem are major crops of rabi season in these districts.

District-wise severe stress (ha), Sindh

Districts	Severe Stress (ha)	Districts	Severe Stress (ha)
Dadu	32111	Tando Allahyar	3262
Khairpur	30533	Thatta	1439
N. Feroze	29762	Mirpur Khas	1355
Shahdadkot	28672	Sujawal	1031
Ghotki	23507	Badin	908
Sanghar	22369	Hyderabad	482
Sukkur	20745	Tando M. Khan	225
S. Benazir Abad	19666	Korangi	214
Jacobabad	14137	Malir	131
Larkana	9529	Tharparkar	85
Jamshoro	9292	Karachi West	8
Kashmore	8689	Karachi East	0
Shikarpur	8320	Karachi Central	0
Matiari	7566	Karachi South	0
Umerkot	6010		

Province-wise severe stress (ha), Pakistan



The analysis found that 0.12% area in Balochistan, 0.79% in KP, 1.91% in Punjab and 1.99% in Sindh is under severe stress or land is fallow. The area mentioned under stress includes crops as well as other vegetation.

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Appendix 2: Photographs from Fields Taken during Data Collection or Validation on the Ground

Maize Crop Damage Resulting from Floods

Maize crop damage resulting from floods. Ground truthing efforts in Pakistan, conducted independently by Asian Development Bank funding, reveal extensive damage to maize crops in the aftermath of the 2022 floods (photo by Nauman Ul Haq).

Complete Crop Damage Resulting from Floods

Complete crop damage resulting from floods. Captured during ground truthing activity, this showcases the complete devastation of crop fields caused by the 2022 floods (photo by Hamza Saeed).

Stagnant Floodwater Remaining in Crop Field

Stagnant floodwater remaining in crop field. Persistent floodwater stagnation in crop fields is observed during ground truthing efforts following the 2022 floods (photo by Muhammad Fahad).

Appendix 3: Possible Wrong Identification of Crop Damage

Table A3: List of Possible Wrong Identifications for Crop Damage

Potential Mistake (as crop stress)	**Description**	**Mitigation and/or Improvements**
Cropping Pattern Change	In recent years, cropping patterns in Pakistan have shifted due to climate change with a notable transition from cotton to maize, sesame, and rice. In the spatial analysis, a major cropping pattern change could be reflected as a severe stress.	To reduce the risk of wrong identification arising from changing cropping patterns, a short timeframe, i.e., a 3-year period, has been chosen to mitigate the effects and reduce the impact of crop stress.
Late Sowing	Late sowing could be identified as mild crop stress.	This phenomenon occurs very rarely, as we consider the 16 days maximum value composite, so the late sowing problem is largely addressed within this framework.
Fallow Land Due to Previous Damage	Land could be left fallow due to previous damage (e.g., floods). This situation could be misidentified as severe crop stress.	To address this issue, ground-level verifications were conducted as much as possible after the analysis.

Source: Authors.

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Applying Spatial Analysis to Assess Crop Damage

A Case Study of the Pakistan 2022 Floods

Climate change is expected to increase the frequency and magnitude of extreme weather events in Pakistan. During and immediately after such events many locations are inaccessible, yet the government needs evidence-based data to help plan effective responses. This paper uses spatial analysis and spectral mapping to assess the agricultural damage from the 2022 floods in Pakistan. Spatial analysis could be a vital tool in assessing and verifying damage from disaster events. The paper emphasizes the need to build spatial analysis capacities in provincial crop reporting services and the Ministry of National Food Security and Research.

About the Asian Development Bank

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