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Extent and socio-economic impacts assessment of 2022 floods in Nushki, Pakistan, using Google Earth Engine, RS, and GIS

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ABSTRACT

Background: Floods are among the most common and devastating natural disasters worldwide, causing significant damage to people, the economy, and the environment. It is a recurrent phenomenon in Pakistan. The Nushki District of Balochistan also faced severe consequences from the 2022 floods.

Objectives: This study utilizes remote sensing (RS) data within a geographic information system (GIS) environment to map flooded areas and comprehensively analyze the socio-economic impacts of the 2022 floods in one of the most severely affected areas in Balochistan.

Methodology: The flood extent of the study area was prepared using Synthetic Aperture Radar (SAR) remote sensing data of Sentinel-1 through Google Earth Engine. Furthermore, the flood damage data is obtained from the National Disaster Management Authority (NDMA) and the Provincial Disaster Management Authority (PDMA). The collected data was further processed and analyzed using different software. ArcMap 10.8, Microsoft Excel, and CorelDRAW were used to generate maps, tables, and graphs for the present study area.

Results: The findings of the study reveal that floods in 2022 occurred more in the Daak sub-tehsil of the Nushki District. At least one male and three children lost their lives, and several injuries were recorded. A total of 2,229 livestock were lost in the study area because of the severe floods of 2022. The destroyed houses in the study area numbered 4,763, including 2,597 that were fully destroyed and 2,166 that were partially destroyed. The impacts in the agriculture sector include the loss of more than 2,783 acres of agricultural land in the study area.

Conclusion: The flood disasters in Balochistan have highlighted the region's inhabitants and infrastructure's extreme vulnerability. Future flood risk management in Balochistan must place a high priority on resilient rebuilding, enhanced early-warning systems, and sustainable drainage infrastructure. The generated flood extent maps will help policymakers to make preparedness plans and actions in the study area.

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1. INTRODUCTION

Floods are defined as when water runs through streams, submerging areas that are not usually affected by water flows (Intergovernmental Panel on Climate Change (IPCC), 2012). Flood is a transdisciplinary natural hazard whose dimensions and reach are expanded by its correlation with climate change (Waseem & Rana, 2023). The main causes of flood disasters are changing climatic conditions, such as drastic shifts in precipitation patterns and rising temperatures (Hussain et al., 2023). Floods are one of the most common natural disasters in the world, which cause significant damage to the economy, society, and human life (Allafta & Opp, 2021; N. Ullah et al., 2024). Floods have been worse during the last thirty years as a result of human activities, which alter the climate and land usage (Chakrabortty et al., 2022; Detrembleur et al., 2015). Some of the human activities that cause floods include land degradation, construction of properties in the flood zone, and deforestation in the upstream catchments.

Over 30% of natural disasters that happened in the past century were caused by floods, which also resulted in significant devastation, the loss of many lives, and the destruction of valuable property. Developing nations are more exposed to these threats because they lack the adaptive ability and proper infrastructure to handle natural disasters like floods (Shah et al., 2019). Although natural and climatic changes are primarily responsible for the rise in flood hazards in developing countries, human activities such as river encroachment also intensify the severity of flood impacts(Shah et al., 2017). Alongside conditions of drainage basins, including pre-existing river water levels, snow and ice cover, soil character and status (moisture content, permeability, and its vertical distribution), urbanization rate, and the existence of dikes, dams, and reservoirs, can also have an impact on floods (Kundzewicz et al., 2014). In large river basins, intense and long-lasting rainfall is the primary cause of river (fluvial) floods, while high-elevation regions are prone to snowmelt floods, which are sometimes boosted by ice jams or rain. Floods have a greater impact on South Asian countries during the summer monsoon season (June to September), due to more lives and livelihoods are being destroyed than in any other region on the globe (Almazroui et al., 2020). More than 1 billion people in South Asia have been impacted by floods in the last 20 years (EM-DAT, https://public.emdat.be/data). Extreme floods are becoming more common in South Asian countries (Mirza, 2011) and are expected to become more frequent in the future due to climate change (Alfieri et al., 2017; Hirabayashi et al., 2013). The South Asian Subcontinent, which includes the Great Himalaya Glaciers, is still at high risk. Although the rainy season is currently the main cause of flooding in the region, the region is still permanently threatened by the presence of glaciers and rising average temperatures. With a 40% occurrence rate, floods are the most frequent natural disaster in the area (Chaudhry Qamar Uz Zaman, 2017). In addition, 9.6 million people in Bangladesh, India, and Nepal have been impacted by urban floods brought on by poor solid waste management and a decline in urban vegetation, with 6.8 million of them affected in India alone.

1.1. Background and theoretical foundations of research

In Pakistan, millions of people are impacted by floods each year, making the country one of the most vulnerable to floods. Nearly 30 million people reside in regions that are completely vulnerable to flooding (Shakeel Mahmood et al., 2024). In Pakistan, floods are a common occurrence that are mostly caused by high precipitation during the summer monsoon season and infrequently by tropical cyclones. Pakistan has been severely affected by floods since its creation, i.e., the 1950s, 1960s, 1970s, 1980s, 1990s, and most recently in 2022. The 2010 flood was the worst in the country’s history. It affected 45 of the 135 districts and lasted for six months, with an estimated damage of 9.7 billion US dollars, 20 million displaced people, 1.1 million destroyed homes, and 432 damaged healthcare facilities (Alderman et al., 2012). The flood of 2022 impacted over 30 million people in different areas of Pakistan, and it also caused significant damage valued at nearly 30 billion US dollars (Khan et al., 2021). One of Pakistan's major provinces, Balochistan, also suffered significant damage to houses, agriculture, and infrastructure during the 2022 flood. In August 2022, Balochistan province received 590% more rainfall since 1961 (Pakistan Meteorological Department (PMD), 2022). According to the National Disaster Management Authority (NDMA), in Balochistan, the flood of 2022 killed 336 people, injured 187 others, and destroyed 400,000 livestock in 32 of the 34 districts, and there have been damages to 2,222 kilometers of roads, 214,659 homes, and 58 bridges (National Disaster Management Authority (NDMA), 2022). A resilient infrastructure, better urban design, and proper disaster management strategies are needed to reduce the danger of floods in Balochistan. There is a lack of research work regarding the extent of the 2002 floods and their socio-economic impacts in the Nushki district of Balochistan based on Remote Sensing and Geographic Information System (GIS). By utilizing remote sensing (RS) data in a geographic information system (GIS) environment, this study is an attempt to map flooded areas and comprehensively analyze the socio-economic impacts of the 2022 floods in one of the most severely affected districts (Nushki) of Balochistan. This study provides unique data and insightful findings that are helpful for disaster management and future policy-making in Balochistan.

2. METHODOLOGY

2.1. Study Area

Balochistan is the largest province in terms of area, with an extent of 347,190 km2, or 43.6% of Pakistan's total land area (S. Ullah, Ullah, Tariq, Panezai, et al., 2025). Quetta is the provincial capital and most populous district of the province, with an area of 3,447 km² (S. Ullah, Ullah, Tariq, Kasi, et al., 2025). The provincial capital (Quetta) has an arid to semi-arid climate with hot summers and cold winters. Nushki District is chosen as the study area for the current research study (Figure 1). District Nushki is located in the west of Quetta and bordered by Afghanistan through the Pak-Afghan border to the north, Mastung in the east, Kalat and Kharan in the south, and Chaghi district in the west. The district is located between longitudes 65°07'42" and 66°18'45" East and latitudes 29°01'51" and 29°52'37" North (Government of Balochistan (GoB), 2011). The total area of the Nushki District is 5,797 km2, and according to the 7th Population and Housing Census, the population of the district is 207,834 people, with an average household size of 6.6 (PBS, 2024).

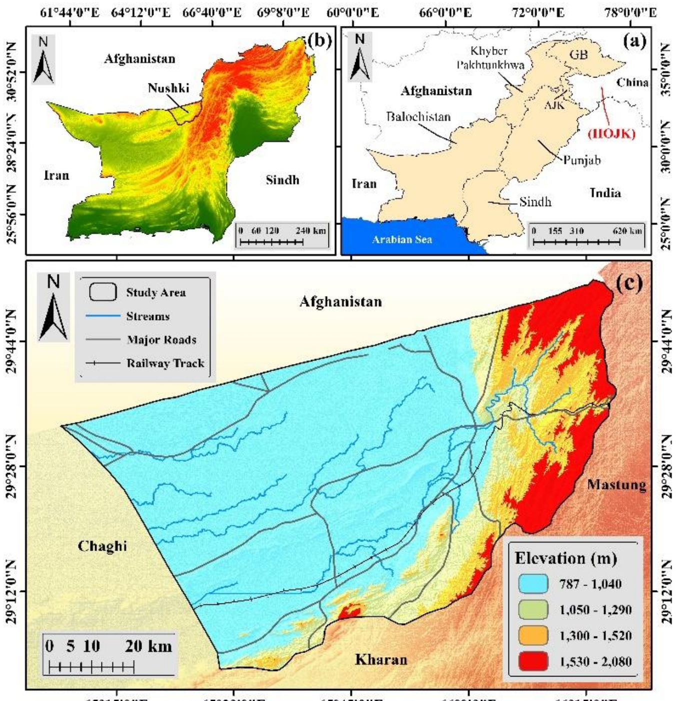

Fig 1. (a) National and provincial boundaries of Pakistan, along with association with neighboring countries, (b) Balochistan map with focus on the study area, and (c) the district boundary map along with elevation, major roads, streams, and railway track.

The annual average growth rate of the district from 2017 to 2023 is 2.53. The average elevation of the Nushki district is about 880 meters above sea level, and in the northern region of the district, there is a desert called Registan (Raig), which extends into Helmand province of Afghanistan (Rehman et al., 2019). The district's economy is based mostly on agriculture and the raising of livestock. The beds of perennial streams are home to the vegetation. Since the area is outside of the monsoon range, the 124 mm of annual rainfall largely falls during the winter. The long-term drought conditions in the district, which are marked by irregular rainfall and a drying karez irrigation system, have a significant negative impact on rural livelihoods. As a result, households have been forced to sell their assets, migrate, intake less food, and look for alternative sources of income rather than diversifying their cropping strategies (Tehmoor Rehman et al., 2019).

2.2. Data collection

Secondary data used in the present study were obtained from different sources. The national, provincial, and district boundary map, along with major roads, streams, and railway track, is obtained from the Spatial Decision Support System Lab (SDSSL). Shuttle Radar Topography Mission (SRTM) Digital Elevation Model (DEM) 30 × 30 used to identify the elevation of the study area is obtained from the United States Geological Survey-USGS Earth Explorer (Table 1). Rainfall data for the study area are acquired using CHIRPS (Climate Hazards Group Infra-Red Precipitation with Stations) with a spatial resolution of 5.3 km through online sources. The flood extent of the study area was prepared using Synthetic Aperture Radar (SAR) data of Sentinel-1. Furthermore, the flood damage data is obtained from the National Disaster Management Authority (NDMA) and the Provincial Disaster Management Authority (PDMA).

Table 1. Data type, description, and sources used in the present study.

#	Data type	Description	Spatial resolution	Source
1	Shapefiles (.shp)	Shapefiles were used for the study area mapping.	--	SDSSL https://ncgsa.org.pk/spatial-decision-support-system-lab-sdssl/
2	SRTM DEM	DEM is used to prepare the elevation of the study area.	30 m	USGS Earth Explorer https://earthexplorer.usgs.gov/
3	Rainfall	CHIRPS monthly data is used to prepare the rainfall graphs.	5.3 km	CHIRPS https://www.chc.ucsb.edu/data/chirps
4	Flood extent	Sentinel-1 SAR data is used for flood extent mapping	10-20m	Sentinel-1 SAR https://www.earthdata.nasa.gov/data/instruments/sentinel-1-c-sar
5	Flood damages	Flood damage assessment	--	NDMA https://www.ndma.gov.pk/
6	Flood damages	Flood damage assessment	--	PDMA https://www.pdma.gob.pk/

2.2. Data processing and analysis

Along with flood extent mapping, the present study examines the existing literature on the 2022 floods in the Nushki district of Balochistan. The collected data was further processed and analyzed using different software. Microsoft Excel and CorelDRAW were used to generate attractive tables and graphs for the present study area. Google Earth Engine (GEE) was employed to assess the flooded areas in the Nushki district using remote sensing data. The flood extent was further exported to a geographic information system (GIS) environment for map-making. Finally, maps were produced using ArcMap 10.8.2. The detailed methodological framework followed for the present study is shown in Figure 2.

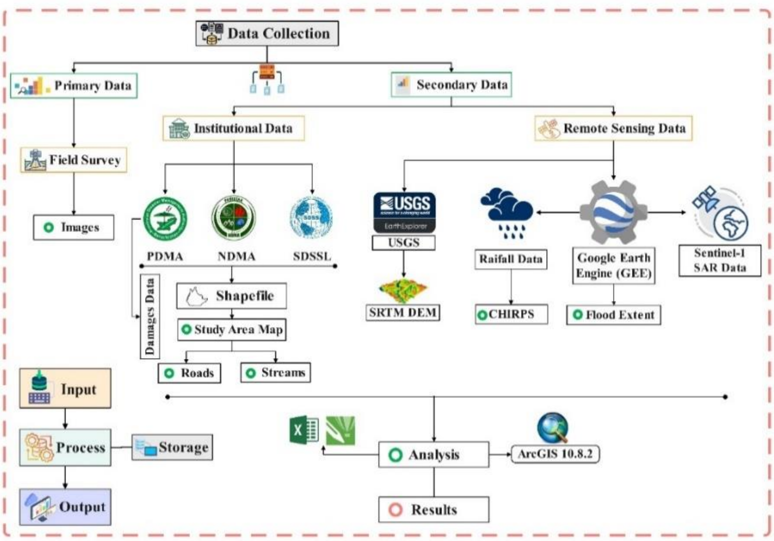

Fig 2. The detailed methodological framework is followed for the present study.

3. Results and Discussion

3.1. Rainfall distribution

Rivers overflow or surface flooding occurs when rainfall volume or intensity surpasses drainage capacity. In small catchments such as mountain torrents, intense rainstorms can cause unexpected floods. Flood production is primarily driven by rainfall intensity and other characteristics, such as duration, spatial distribution, and frequency; however, hydrological responses also substantially depend on land cover, soil moisture, watershed antecedent conditions, and catchment geometry (Sharma et al., 2018). Uncertain increases in rainfall extremes can result in disproportionately large floods in some dry catchments, whereas there is a roughly linear connection between rainfall and runoff in wet catchments with saturated soils (Breinl et al., 2021; Sharma et al., 2018). The consequences of climate change are more severe and far-reaching, compared to a few decades ago. Pakistan is most vulnerable to flooding (Shakeel Mahmood et al., 2024). The annual rainfall distribution of 2022 for Pakistan was obtained from CHIRPS (Climate Hazards Group Infra-Red Precipitation with Stations) through Google Earth Engine (GEE) (Figure 3). The maps in Figure 3 clearly show that District Nushki received less rainfall compared to the north and north-eastern parts of Balochistan. The total rainfall, maximum rainfall, and rainy days of 2022 in the Nushki district are shown in Figure 4. District Nushki, including other parts of Balochistan, receives very little rainfall in its regular pattern. However, in the months of June-August, the number of rainy days increased in 2022 (Figure 4). This led to catastrophic floods in Nushki and its adjoining areas in 2022. These floods have disrupted roads, communication lines, and crops.

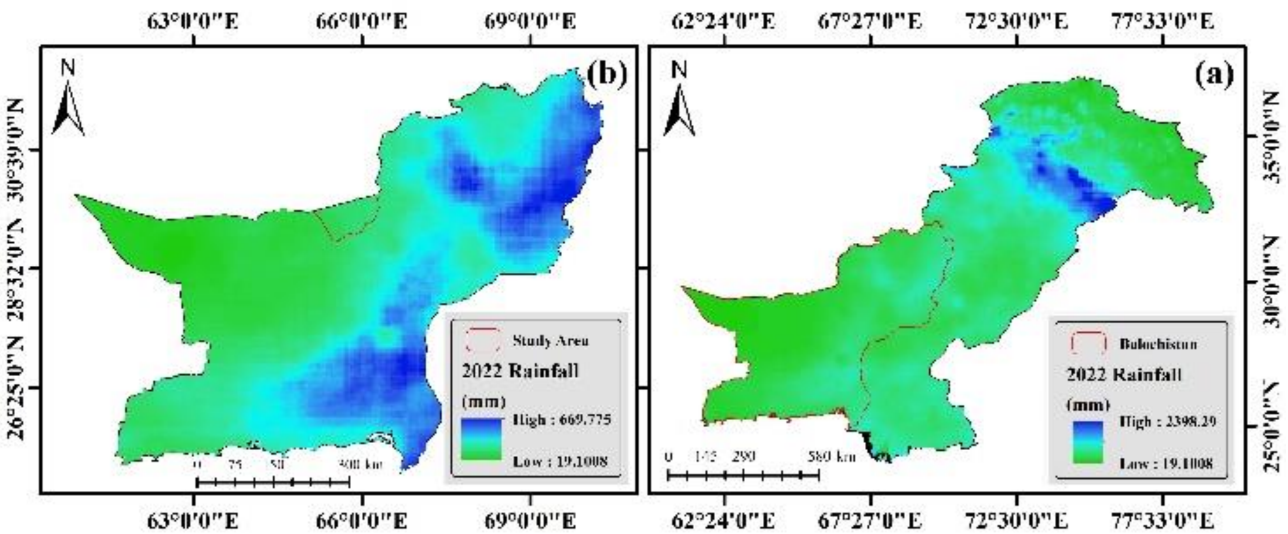

Fig 3. (a) 2022 rainfall distribution in Pakistan, (b) rainfall distribution in Balochistan with focus on the study area.

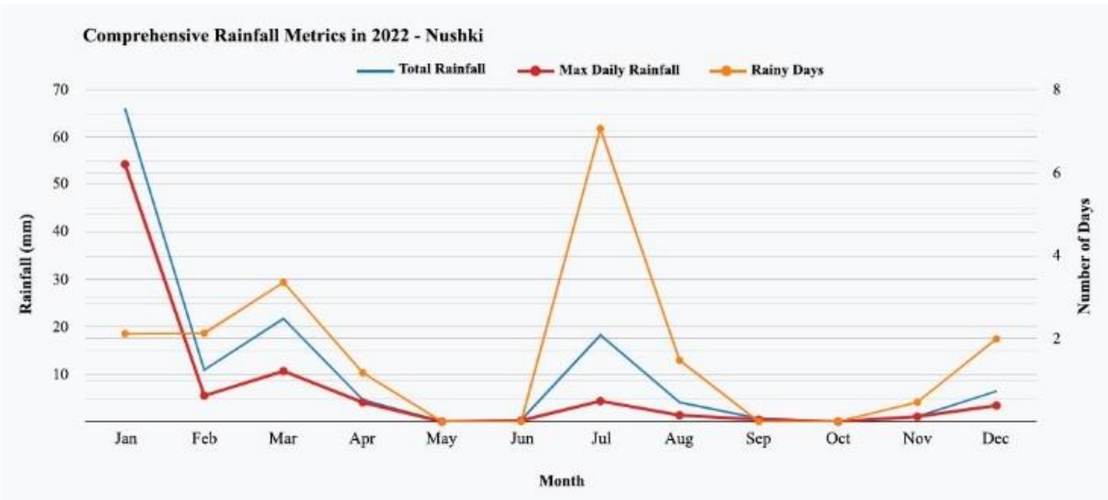

Fig 4. The total rainfall, maximum rainfall, and rainy days of 2022 in the Nushki district.

3.2. Rainfall distribution

Sentinel-1 satellite data were used for the flood extent mapping in 2022 for the study area. The flood extent mapping has been performed on Google Earth Engine (GEE), a cloud-based platform. Sentinel-1 SAR imagery is used because of its cloud-penetrating capabilities and suitability for flood mapping in all weather conditions. The resulting flood extent was visualized over the shapefile (.shp) of the study area. The flood extent raster was exported to Google Drive at 10-meter spatial resolution for further analysis in ArcMap 10.8.2 software. The flood extent in the study area is depicted with red color (Figure 5). Flood extent in the study area is shown by red color and is mostly found in the Daak Sub-Tehsil areas of the study area, which is reliable. This may be because the elevation of the whole Daak sub-Tehsil is low (800 meters) as compared to the Nushki sub-Tehsil.

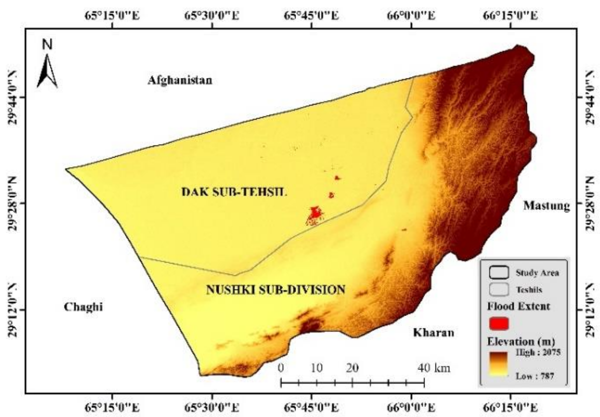

Fig 5. 2022-Flood extent in the study area.

3.3. 2022-Flood Impacts Assessment in Nushki

3.3.1. Impacts on Human Life

Flash floods occurred in Nushki District in July 2022, resulting in at least one male and three children losing their lives, and several injuries being recorded in other areas. The flooding also caused severe damage to the infrastructure (Table 2) (Provincial Disaster Management Authority (PDMA), 2022a). The Provincial Disaster Management Authority (PDMA) surveyed the study area from 12-17 August 2022 and assessed 62 flood-affected villages, where 31% of the human population was affected by the 2022 floods (Provincial Disaster Management Authority (PDMA), 2022b). Flooding turns short-lived water inundation events into long-lasting human crises that undermine social cohesion, economic stability, health, and well-being. This emphasizes how urgently vulnerable areas like the study area require coordinated disaster preparedness and recovery plans.

Table 2. Human casualties in the study area.

Causalities			Injured		
Male	Female	Children	Male	Female	Children
01	-	03	02	-	03
04			05		

Source: PDMA (2022)

3.3.2. Impacts on the Livestock Sector

The livestock sector was badly disrupted by the floods in Pakistan in 2022, endangering food and economic security in the flood-affected areas. A total of 2,229 livestock were lost in the study area because of the severe floods of 2022 (Provincial Disaster Management Authority (PDMA), 2022a) (Figure 6). These losses resulted in permanent revenue decline, widespread food insecurity, and increasing poverty in rural and tribal areas where livestock is the main source of wealth and nutrition. The disaster thus qualifies as both an acute humanitarian emergency and a long-term livelihood crisis necessitating focused rehabilitation efforts, such as veterinary support, fodder provisioning, and restocking programs.

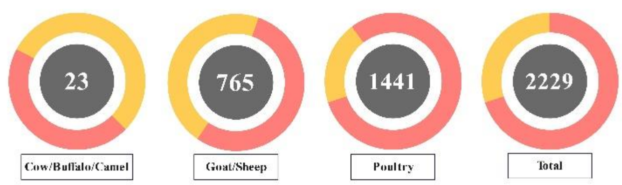

Fig 6. Livestock damages in the study area (PDMA, 2022)

3.3.3. Impacts on Infrastructure

The infrastructure sector was also damaged by the 2022 floods, isolating settlements and removing vehicle access tracks in the study area. Many locals were thus left temporarily without a place to live. Flash floods in the Qadir Abad area of the study area destroyed more than 40 mud-brick houses and damaged several more, forcing people to relocate and making houses uninhabitable (Saleem Shahid & Syed Irfan Raza, 2022). Other affected areas, where infrastructure was damaged, include Daak, Anam Bostan, Mengal Abad, and the Bazar areas (Figure 7). The floods of 2022 caused massive damage to houses in the study area, either completely or partially destroying them. The destroyed houses in the study area numbered 4,763, including 2,597 that were fully destroyed and 2,166 that were partially destroyed (Provincial Disaster Management Authority (PDMA), 2022a). Other damaged infrastructure in the study area includes 12 km of roads and 4 bridges.

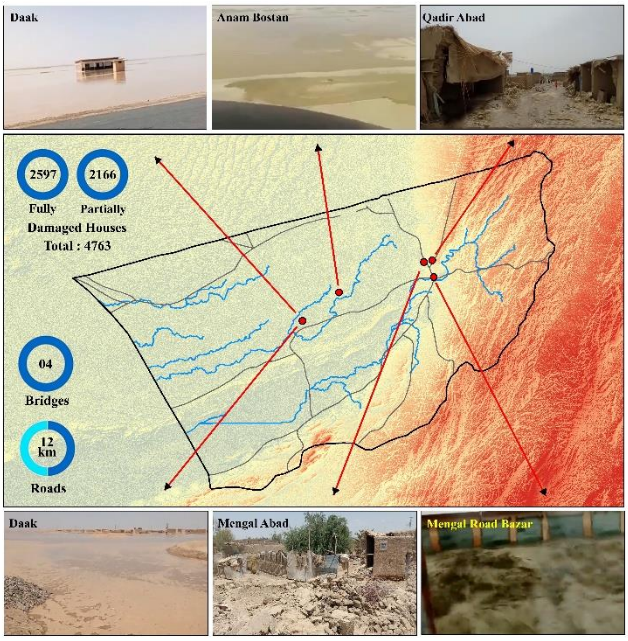

Fig 7. The infrastructure sector losses in the study area (PDMA, 2022)

3.3.4. Impacts on Agriculture

The agricultural sector was severely damaged by the floods in Pakistan in 2022, with long-term effects on food security, farmer livelihoods, and the overall rural economy. More than 200,800 acres (~81,200 hectares) of agriculture were destroyed in Balochistan, and the horticultural and orchard sector, which includes grapes, apples, peaches, and dates in the region, was also badly impacted. Particularly, in some places, losses in date orchards reached 90%. Estimates of the cost of provincial agricultural damage vary from Rs 4.9 billion Pkr to Rs 98 billion Pkr, indicating the extent of losses in districts such as Loralai, Washuk, and Nushki (Amin Ahmed, 2022). Nushki was one of the highest crop/vegetable damage districts in Balochistan. A total of 2,783 acres of agricultural land was affected by the 2022 floods in the study area, and solar panel losses were 25 (Provincial Disaster Management Authority (PDMA), 2022a).

4. DISCUSSION

The use of Geographic Information Systems and Remote Sensing enabled us to prepare the flood extent map for the study area. Regarding the extent of floods in 2022, the results of this study revealed that the floods in 2022 were more severe in the Daak sub-tehsil of the Nushki District. This may be because the Daak sub-tehsil is at a low elevation as compared to the Nushki sub-tehsil, which has high-elevation mountains. Therefore, the precipitation received during 2022 on the Nushki sub-tehsil area was drained quickly to the Daak sub-tehsil and affected the livelihoods of the people there. (Hussain et al., 2023) found that the people of district Nushki, which is near the borders of Afghanistan, have faced multiple natural hazards, including recurrent droughts and flash floods in 2022. Results of our study are in line with the study of (Shamshad Akhtar & Muhammad Rafique Dhanani, 2024), who found that Nushki was moderately affected by the 2022 floods.

Results also indicated that floods of 2022 had brought serious socio-economic impacts to the people living in District Nushki. The 2022 floods in Nushki brought about the deaths of about 3 children, and dozens of male and female were injured. A total of 2,229 livestock perished because of the 2022 floods. The floods also damaged 4,763 houses, either fully or partially. This may be because most of the people in District Nushki have used low-quality bricks, and muddy houses in the area were fully damaged because of the 2022 floods. Roads were severely disrupted by these floods. About 12 kilometers of roads were damaged to the extent that vehicles were unable to move on these roads. 4 bridges were also damaged as a result of these floods, which caused worry among the people to move to safer locations during floods. Floods had also damaged the crops and orchards, which were the mainstay of the majority of the farmers in the area.

Studies of Kiran & Jabbar (2022) also revealed that Nushki people faced serious concerns of food insecurity as a result of the 2002 floods. To make people safe and reduce the impacts of flood disasters in the future, there is a need for a proactive approach. Roads need to be elevated. Communication lines need to be strengthened. Evacuation shelter needs to be constructed to make sure the shelter for not only for human beings but also for livestock. These pre-disaster approaches will reduce the impacts of flood disasters in the future in the study area.

5. CONCLUSION

The floods of 2022 caused havoc in the whole of Pakistan and Balochistan, and especially the Nushki area was no exception to this phenomenon. The unusual increase in rainy days in 2022 resulted in severe flooding in the Nushki District. The low-lying sub-Tehsil of Daak was mostly affected because of its low elevation as compared to the Nushki sub-Tehsil. The floods affected the whole infrastructure, including damage to roads, buildings, electric poles, and other communication lines. These floods also affected the livestock and agriculture sector of the Nushki District. The floods also caused socio-economic impacts and affected the livelihoods of the communities through a shortage of daily food items. To safeguard the communities living in the vulnerable areas, the government authorities, including Disaster Management Authorities at the national level, provincial level, and district levels, need coordination among themselves. There is a need for planning and implementing pre-flood level management strategies that will make the communities resilient against flood disasters. Elevated shelter buildings need to be constructed to provide temporary shelter to the people in case of floods. These strategies, if fully implemented, will reduce the effects of future floods on the communities.

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Authors' Contribution: Niamat Ullah and Shafi Ullah led the idea, design, and supervision of the data analysis and editing. Said Qasim, Romana Ambreen, and Shazia: methodology, visualization, writing review, and editing. All the authors have made contributions to the paper and approved the submitted version of the manuscript.

Conflict of Interest: The authors declare that they have no conflicts of interest.

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Availability of Data and Materials: Data and materials for the present study will be available upon request from the corresponding author, Niamat Ullah (niamatullahza@gmail.com).

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