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Original Research Article

Detection and analysis of cyclonic events through satellite-based remote sensing techniques for coastal areas of Pakistan

Muzzamil Bilal*

Department of Space Science, Institute of Space Technology, Islamabad, Pakistan.

* Corresponding Author Email: muzzamil098765@gmail.com

Abstract: This study reviews the unusual lifecycle and reach of Cyclone Asna (August–September 2024) over the North Arabian Sea with special focus on its inland re-intensification after landfall, a behavior not typically seen in that region. Remote sensing satellite platforms combined with geographic information systems (GIS) allow a multi-parameter assessment of Asna's track, rain patterns, flood extents, and resulting damage across Pakistan's coastal belt and deeper inland areas. Sentinel's 2 NDWI images map surface water changes before and after the storm, while integrated IMERG rainfall estimates and time-stamped damage reports identify high-risk areas and illuminate the cyclone's social and economic costs. Karachi and adjacent coastal towns recorded isolated totals above 266 mm, sparking extensive urban floods, power outages, and collapse of key transport links, all driven by Asna's slow forward motion and prolonged onshore presence. Asna's inland intensification was caused by a rare overlap of monsoon moisture feeding in from both the Arabian Sea and Bay of Bengal, upper-level divergence, saturated soils, high surface heat flux, and persistent mid- to upper-level cyclonic vorticity factors that together sustained the storm's vertical structure far beyond normal landfall limits. Broadly speaking, both the warmer Arabian Sea and its greater moisture-holding capacity are driving a recent increase in hybrid cyclone systems across the region. This study confirms that trend and points to satellite monitoring as an invaluable tool for bettering disaster preparedness and adaptive planning. As the case of cyclone Asna shows, predictive models and urban resilience plans must now be revised to reflect unusual cyclone behavior strengthened by evolving climate dynamics.

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1. Introduction

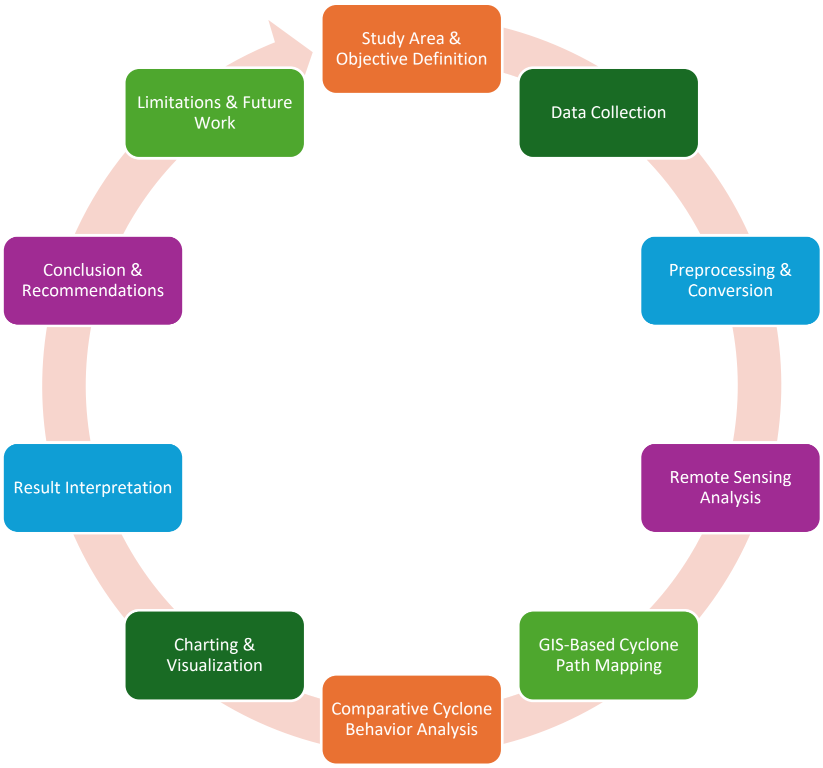
Tropical cyclones are considered one of the worst natural catastrophes in the world due to the destruction they bring with their strong winds, heavy rainfall, coastal floods and storm surges. South Asia, particularly the low-lying coastal regions, bears the brunt of the side impacts because of the high population density paired with weak infrastructure. Doing little to improve these conditions is Karachi, Pakistan's most populous city and economic center as it faces unplanned urban development and severe coastal climate risks (Emanuel, 2005; Ali et al., 2023). Supported with extensive evidence of increasing surface temperatures and climate change, the frequency and intensity of cyclones in North Arabian Sea has been rising consistently which is quite worrisome. Webster et al. (2005) and Murakami et al. (2020) were able to provide explanations for this intensification by stating it has been caused by the heating of water bodies due to climate change resulting in greater energy for cyclone formation and maintenance. For Pakistan which previously experienced very few cyclonic events, the trend indicates a heightened risk of these events which severely undermines us in planning infrastructure and formulating efficient response strategies. The effects of cyclonic storms go far beyond the damage they cause. These storms can halt economic activity, force human migration, disrupt lifeline systems and worsen environmental impacts IPCC, 2021.

The challenge of cyclone forecasting is compounded by a lack of real-time situational ground-level monitoring and limited cyclone detection capabilities which create a need for more advanced technological systems that can understand cyclones over wide areas. Remote sensing coupled with GIS are emerging as powerful tools in this field. Satellite-based systems are no longer constrained by traditional meteorological models and ground based observation observations, as they are capable of offering high-resolution continuous coverage over land and oceanic phenomena. Critical storm-related data is collected from region, such as the dynamics of storm clouds, sea surface temperature, wind speed, certain pressure anomalies and precipitation by instruments like Sentinel-1 SAR, Sentinel-2 MSI, GPM IMERG and MODIS Giri et al., 2021; Chaturvedi et al., 2023. These instruments allow for dynamic spatial analysis in GIS which enable the identification of cyclone paths, flood extents, and infrastructural vulnerabilities. The study aims to identify and analyze cyclone Asna which occurred in August to September 2024. It is one of the fastest and one of the rarest cyclonic systems that developed over the sea and hit the coastal regions of Pakistan, particularly the city of Karachi and southwestern Balochistan.

This research has been carried out using multi-temporal satellite imagery as well as meteorological data from IMD and PMD and flood and storm impact assessment as well as risk modeling were done using Python based GIS to analyze the behavior of the storms, assess the floods' impacts and map the risks induced by the cyclones. Moreover, this research provides a more comprehensive and multi-dimensional view of cyclone impacts within urban and peri-urban areas by integrating rainfall intensity mapping, detection of floods using NDWI, evaluation of infrastructural and Population vulnerability to these floods and mapping cyclonic risks. Also, it assesses the anthropogenic and environmental factors causing changing environmental conditions and the risks associated with disasters in the Arabian sea due to shifting climate. Given the current situation of devastating weather conditions influenced by climate change, particularly on Pakistan's coastline, it is crucial to embrace new technologies for tracking cyclones, forecasting their impact and communicating risks effectively. Through this research, I hope to aid in the development of precise and science-based climate-resilient urban planning while enhancing early warning systems and informing the national disaster risk reduction (DRR) policy frameworks.

2. Methodology

The work combines multi-source satellite data, meteorological records and GIS based analysis to assess the formation, path and effects of Cyclone Asna (2024) as well as a comparison of its traits with other significant Arabian Sea cyclones from 2007–2021. The approach has been crafted for spatial accuracy as well as time resolution in Python based geospatial workflows validated meteorological reports and visual analytics.



2.1. Data Collection and Preprocessing

Asna's cyclone track data (August–September 2024) were obtained from India Meteorological Department (IMD) and Pakistan Meteorological Department (PMD). It comprised time stamped latitude and longitude, wind speed converted from knots to km/h and central pressure in hPa. For comparative analysis historical cyclone data Gonu (2007), Phet (2010), Nilofar (2014), Vayu (2019) and Tauktae (2021) were retrieved from the IMD Cyclone Reports and the NOAA IBTrACS archive ensuring consistent spatial and temporal formats.

Preprocessing involved cleaning the data, interpolating missing values and restructuring the datasets into standardized CSV and Python dictionary formats for use in spatial plotting and statistical analysis. Rainfall measurements for Karachi and other coastal regions were compiled from PMD bulletins, validated media reports and GPM IMERG V07 satellite rainfall products for the monsoon period.

2.2. Cyclone Path Visualization and Interactive Mapping

Cyclone tracks were mapped geospatially with Folium, an interactive Python mapping library. Each cyclone path was color-coded and layered with pop-up markers showing wind speed and pressure at each time point. These points Flooded zones, Infrastructure damage, Rainfall intensity was validated using geolocated incident reports and rainfall station data These points were validated using geolocated incident reports and rainfall station data. A user-friendly layer control system was implemented, allowing toggling between individual cyclones with an interactive legend and embedded summary table for comparative meteorological parameters. To enhance readability for static output points were selectively filtered in dense areas retaining origin, peak intensity and final dissipation stages while avoiding visual clutter and overlap.

2.3. NDWI-Based Flood Detection and Analysis

The Normalized Difference Water Index (NDWI) was calculated to delineate the flood extent from Sentinel-2 images. Pre and post cyclone NDWI maps were created in Python with the help of Rasterio, Matplotlib and Cartopy. A difference map gave a strong indication of how much Flooded area there is in the coastal areas of Pakistan. Pixel wise statistics were also extracted to quantify the net change in surface water. The NDWI results were compared with reported on the ground flood zones to validate what the satellite observed as flooding. Statistical summaries (such as total increase in water pixels, mean NDWI change) were created to provide concrete measurable evidence of how much the floods intensified.

2.4. Time Series and Statistical Charting

Meteorological time series, including central pressure and wind speed were plotted using Matplotlib to analyze the temporal evolution of Cyclone Asna. Comparative graphs between 2023 and 2024 monsoon seasons were created using GPM rainfall data, with overlays of PMD's 30-year normal rainfall for Pakistan as a climatological reference. Key observations such as pressure drops during intensification phases and wind direction reversals were identified and interpreted in the context of cyclone dynamics.

2.5. Comparative Analysis with Other Arabian Sea Cyclones

A comprehensive comparison was made between Cyclone Asna and five other Arabian Sea cyclones (2007–2021) using metrics such as: Peak wind speed (km/h), Minimum central pressure (hPa)Rainfall over Pakistan, Landfall or offshore dissipation, Inland re-intensification behavior. This analysis was supported by a dedicated multi-cyclone map displaying spatial tracks and a color-coded summary table embedded in the output. Unlike Gonu, Phet or Tauktae, Asna displayed unusual inland re-intensification over East Rajasthan and Madhya Pradesh, later progressing to coastal Pakistan a behavior linked to anomalous monsoon inflow favorable vorticity and high antecedent soil moisture.

2.6. Risk Mapping and Geospatial Impact Assessment

Using validated hazard points (infrastructure damage, flood zones, rainfall hotspots) a Cyclone Risk Impact Map was generated. It included Cyclone path and wind category color scale, Coastal and inland rainfall markers, Damage incidents linked to geolocated sources, Regional sub-maps for Karachi and Makran coast. The result was a layered visualization of meteorological impact, spatial hazard distribution and population exposure suitable for risk communication and planning.

Karachi has been chosen as the study site because its coastline is facing more cyclones and, therefore, the city needs better disaster plans right now. Observations show that the Arabian Sea is producing more storms lately a trend linked to warmer surface waters. As a result, Karachi the biggest port city in Pakistan now sits in the storm belt and must prepare for heavy rain, strong gusts and destructive surges. Urban boom and poorly managed waterfront building make the situation worse. A crowded metropolis, a busy port and sprawling unplanned housing all expose Karachi to climate threats more than ever. Weak drains, low roads and aging bridges turn heavy showers into city wide floods that disrupt transportation and emergency responses.

Storms like Gonu in 2007 and Phet in 2010 along with Asna in 2024 have shown the same painful lesson year after year. Karachi is vulnerable and lacks the resilient plans needed to protect life and property. These repeated hits to homes to docks and to the economy push. The motivation behind this is to grasp the changing hazards so they can shield Karachi’s coastal people. Karachi fast moving and often unpredictable urban landscape provides an ideal proving ground for advanced observational and analytical tools like satellite remote sensing, Geographic Information Systems (GIS), and machine-learning algorithms. When combined these technologies can refine cyclone detection, enable evidence-led risk assessments and inform more agile urban-resilience and disaster-management plans for the city and other areas facing similar hazards.

3. Study Area

Karachi the largest metropolis in Pakistan lies along the southern coast of the Arabian Sea, roughly between 24.8607 N and 67.0011 E. Covering about 3,780 square kilometers it functions as the nation’s busiest economic and logistical center. The city hosts the two principal sea-ports Karachi Port and Port Qasim well as the international gateway Jinnah Airport. Its lengthy coastline exposes Karachi to a range of marine and atmospheric hazards including tropical cyclones that form over the North Indian Ocean and the adjacent Arabian Sea. Under the Köppen classification Karachi displays a hot arid climate (BWh) marked by scorching summers, mild winters and very little yearly rainfall. Average monthly temperatures sit between 25°C and 35°C during peak summer days the mercury often climbs past 40°C.

Annually the city collects about 250 mm of rain almost all of it falling between July and September during the southwest monsoon. Because the shoreline lies only a few kilometers from the heart of the city. Humidity frequently surpasses 70 percent especially in summer. Karachi s exposed coast also leaves it open to tropical cyclones, which bring storm surges, heavy rain and widespread flooding in urban areas. Cyclone Asna which crossed the region in 2024 caused extensive damage along Karachi seafront as well as in the districts of Thatta and Badin eroding beaches and destroying infrastructure. Scientists worry that higher sea-surface temperatures and changing atmospheric patterns will generate more intense storms over time making the metropolis a strategic site for remote-sensing and GIS studies of cyclonic risk.

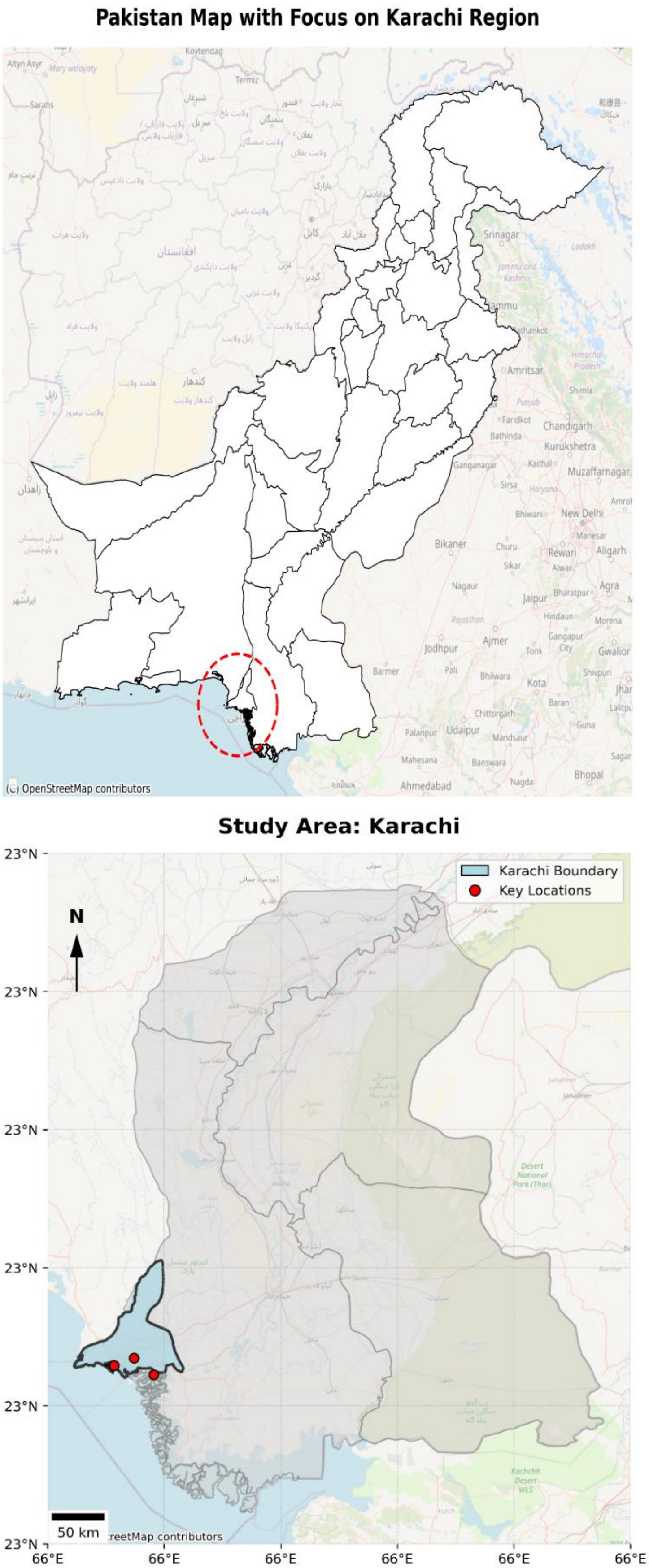


Figure 1: Pakistan map focusing on Karachi and 2nd map showing Boundaries of Karachi

4. Results and discussion

As in Table 1 the evolution of cyclone Asna over the North Arabian Sea and adjacent land regions from 25 August to 2 September 2024 has been accompanied by changes in the storm's timeline, wind speed, central pressure and classification. The information was extracted exactly from high-resolution satellite images and checked with ground meteorological station data considering time (IST), location (lat/long), maximum sustained wind speed (km/h), central pressure (hPa) and the cyclone category assigned by the India Meteorological Department. Because observations were taken every six hours the dataset allows researchers to track Asna's intensification, movement and eventual decay with good precision. Each entry provides the storms latitude and longitude plotting its steady drift from interior India toward the heart of the Arabian Sea. These readings trace the system's full life cycle beginning as a loose low-pressure area strengthening first into a Deep Depression and later a fully developed cyclone and finally weakening again. The close pairing of wind speed, central pressure and changing classification thus serves as an Official record that sits comfortably within global tropical cyclone monitoring standards. Cyclone Asna peaked between August 30 and September 1 with wind speed reaching 74.1 km/h and central pressure falling to 990 hPa. This level of consistency across independent observation sites points to a stable strengthening phase probably supported by warm sea surface temperatures and light vertical shear. Such fine-grained information feeds directly into hazard maps showing expected tracks vulnerable coastal areas and the broad footprint of impact. The table is more than a list arranged by time or date, but it serves as an analytical reference that simplifies the science, timing and behavior of cyclone Asna. The record illustrates how satellite data merged with standard meteorological measurements can illuminate storm dynamics and guide timely early-warning systems, evacuation plans and stronger coastal infrastructure.

Table 1: Cyclone Asna table (25 august- 2 September)2024

Date	Time (IST)	Latitude (°N)	Longitude (°E)	Maximum Sustained Wind Speed (km/h)	Central Pressure (hPa)	Classification
August 25, 2024	00:00	24.5	77.3	37.0	997	Low Pressure / Not classified
August 25, 2024	03:00	24.6	76.9	37.0	997	Low Pressure / Not classified
August 25, 2024	06:00	24.6	76.5	37.0	996	Low Pressure / Not classified
August 25, 2024	12:00	24.4	75.6	46.3	996	Depression
August 25, 2024	18:00	24.3	74.7	55.6	995	Deep Depression
August 26, 2024	00:00	24.2	74.2	55.6	995	Deep Depression
August 26, 2024	06:00	23.8	73.6	55.6	995	Deep Depression
August 26, 2024	12:00	23.8	73.0	55.6	995	Deep Depression
August 26, 2024	18:00	23.8	72.4	55.6	995	Deep Depression
August 27, 2024	00:00	23.8	72.2	55.6	995	Deep Depression
August 27, 2024	06:00	23.7	71.7	55.6	995	Deep Depression

August 27, 2024	12:00	23.7	71.0	55.6	995	Deep Depression
August 27, 2024	18:00	23.7	70.6	55.6	995	Deep Depression
August 28, 2024	00:00	23.7	70.0	55.6	995	Deep Depression
August 28, 2024	06:00	23.7	69.7	55.6	994	Deep Depression
August 29, 2024	00:00	23.7	69.5	55.6	994	Deep Depression
August 29, 2024	12:00	23.6	69.2	55.6	994	Deep Depression
August 30, 2024	00:00	23.5	68.4	55.6	994	Deep Depression
August 30, 2024	06:00	23.5	67.9	64.8	992	Cyclonic Storm
August 30, 2024	12:00	23.5	67.2	64.8	992	Cyclonic Storm
August 30, 2024	18:00	23.6	66.4	64.8	991	Cyclonic Storm
August 31, 2024	00:00	23.6	65.8	74.1	990	Cyclonic Storm
August 31, 2024	06:00	23.6	64.9	74.1	990	Cyclonic Storm
August 31, 2024	12:00	23.6	64.4	74.1	990	Cyclonic Storm
August 31, 2024	18:00	23.5	63.7	74.1	990	Cyclonic Storm
September 1, 2024	00:00	23.2	62.6	74.1	990	Cyclonic Storm
September 1, 2024	06:00	22.7	62.0	64.8	994	Cyclonic Storm
September 1, 2024	12:00	22.2	61.7	55.6	996	Deep Depression
September 1, 2024	18:00	21.7	61.5	55.6	997	Deep Depression
September 2, 2024	00:00	21.2	61.3	37.0	998	Low Pressure / Not classified
September 2, 2024	03:00	20.9	61.2	37.0	999	Low Pressure / Not classified

4.1. Track and Evolution of Cyclonic Storm Asna from Formation to Dissipation (August–September 2024)

Figure 2 show the track and evolution from 16 august 2024 to 2 September 2024.The land-based origin of cyclone Asna and its westward movement towards the Arabian Sea is unique. On the morning of 16 August 2024, a low-pressure area (LPA) developed over Northwest Bay of Bengal and West Bengal-Bangladesh region. Over the next few days, it slowly moved westward while retaining its cyclonic form which is quite unusual for South Asian monsoon systems. The LPA remained over southern and central Bangladesh from 16 to 19 August. It was centered over central Bangladesh on 20 August and then drifted north towards northern Bangladesh on 21-22 August. By 23 August, the system moved into West Bengal and adjoining northeast Jharkhand marking the onset of classical westward monsoonal low movement. A Well-Marked Low-Pressure Area (WML) was formed over southeast Uttar Pradesh and northeast Madhya Pradesh on 24 August morning.

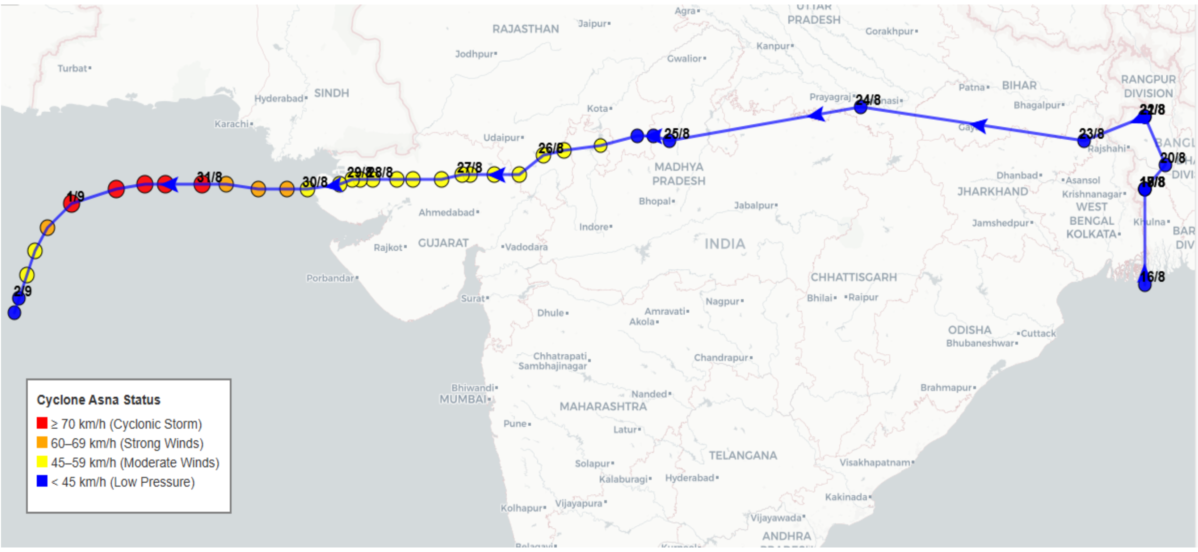


Figure 2: Track and Evolution of Cyclonic Storm Asna from Formation to Dissipation

It further developed into a Depression over northwest Madhya Pradesh by the morning of 25 August and by night of the same day had Deep Depression over eastern Rajasthan and western Madhya Pradesh. Deep Depression moved toward west southwest and by the evening of 26 August entered the north Gujarat region, maintaining the core structure of the system and proof to the system's strong internal circulatory processes. From 27 through 29 August the system’s center was located over mean coastline of Gujarat moving westward towards the coastline. On the morning of 30 August, it emerged into the Northeast Arabian Sea off the Karachi coast and adjacent Pakistan coastline**.** By midday on 30 august it intensified into a cyclonic storm and was officially named "Cyclone Asna”**.** On August 31, the cyclone was still centered over the northeastern part of the Arabian sea, but the winds were a bit stronger than before. Marked in red on the map are the observed winds during this period which were more than 70km/h. Asna's system started to weaken into a Deep Depression on 1 September (evening) while still moving south southwestward over the northwest Arabian Sea. By the morning of 2 September Asna had further weakened into a Depression and subsequently a Well-Marked Low-Pressure Area by afternoon. The final weakening into a Low-Pressure Area occurred over the west central and adjoining northwest Arabian Sea on 3 September.

4.2. Individual cyclones track images with wind barbs

Figure 3 shows the daily images mark the exact location of cyclone Asna while overlaying it onto a basemap of the area. These images incorporate wind barbs which are specialized meteorological symbols used to indicate both wind speed and direction at each location. The barbs denote wind speed and their direction denotes airflow. The images highlight not only the position but also the intensity and trajectory changes throughout the resolved period of time. This gradual approach provides structural understanding of the cyclone including rapid intensification and weakening and directional shifts. Understanding these nuances step by step is critical for comprehensive understanding of storms and forecasting future cyclones.

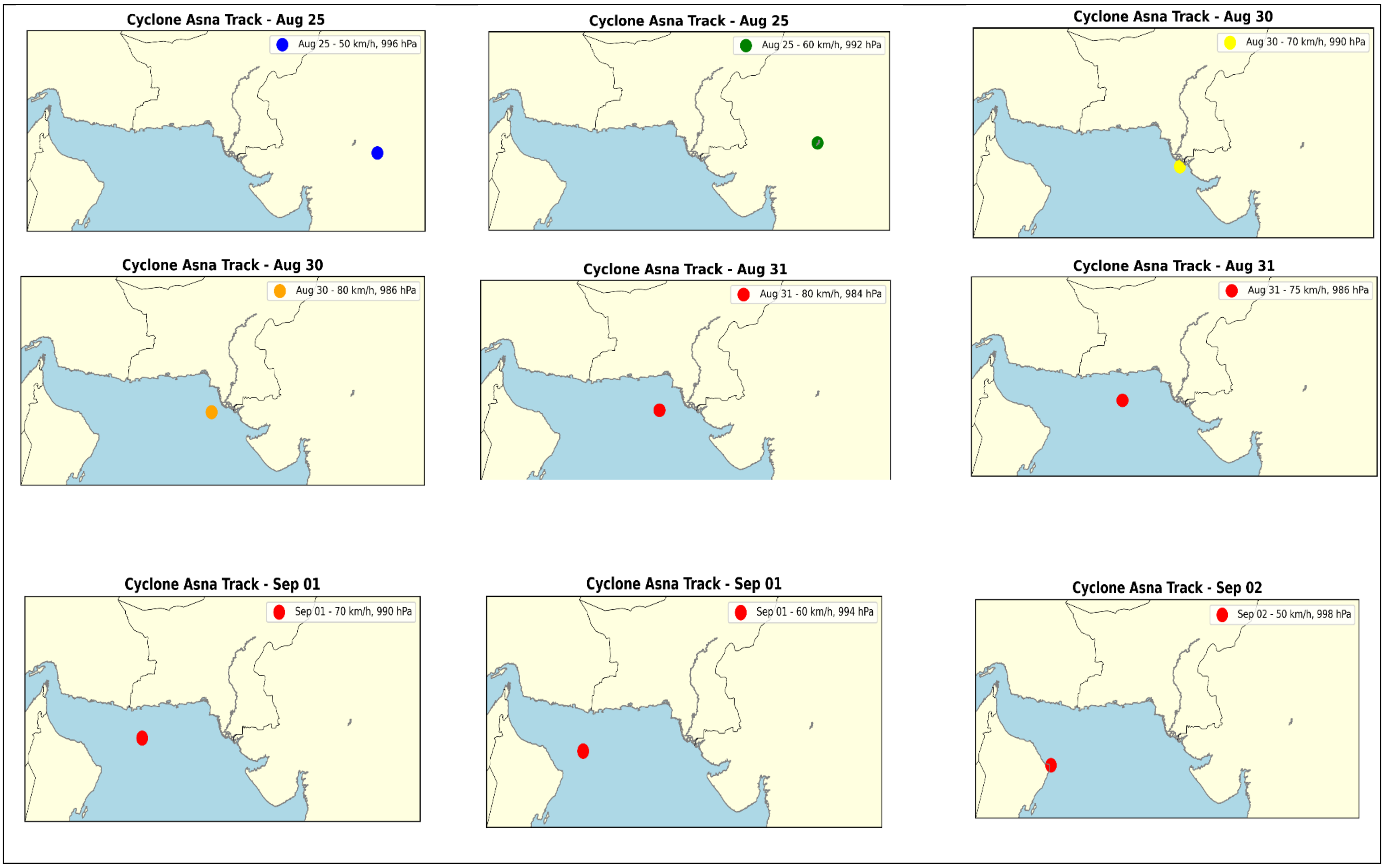


Figure 3: showing individual cyclone track images.

4.3. Cyclone ASNA Track and Intensity Analysis

Figure 4 shows its complete track From August 25 to September 2. Cyclone Asna traversed the Arabian Sea while changing in intensity. The trajectory illustrates the cyclone's progression from an origin ocean point as it traversed westward, gained strength, made landfall and subsequently weakened. The intensity of the cyclone is denoted through color coded markers depicting various cyclonic development stages which shift from green (initial stage) to yellow and orange (intensification) and then to yellow at the pre-landfall zone. Cyclonic activity post landfall is captured in blue signaling the final dissipated form termed as post-cyclonic weakness. Based on the spatial and temporal analysis of Asna Cyclone's development, the system originated over moderate fuel in the eastern Arabian Sea on August 25 and gradually progressed. The period between August 29 through September 1 was characterized by sudden rise in activity featuring strong winds and precipitation which supports what was previously assumed intensity peak period signified by orange-colored markers. The cyclone then rapidly weakened after landfall around September 2 due to the robust interactions with land as well as lower oceanic energetic supply. Such trajectory studies are extremely useful for understanding the dynamics of cyclones in the Arabian Sea and indicate a significant risk for the coast of Pakistan. Analyzing wind velocities, fluctuations in atmospheric pressure and rainfall distributions will yield a better understanding of the cyclone's comprehensive effects.

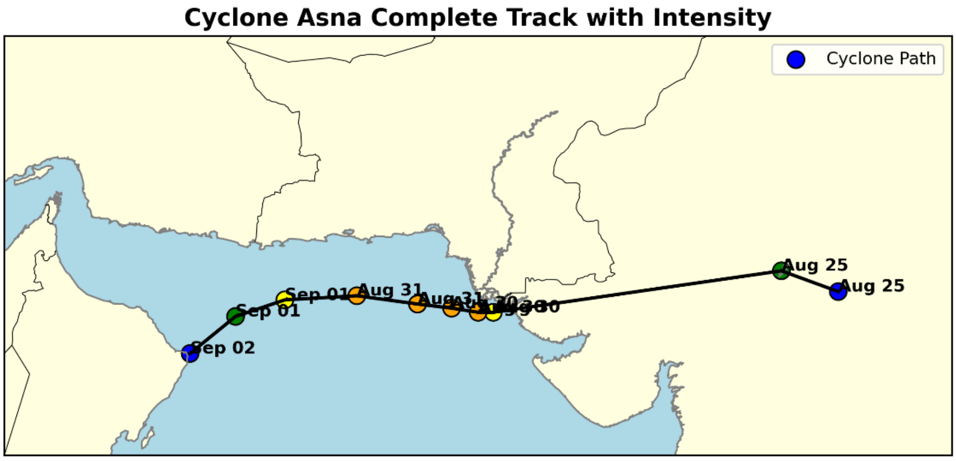


Figure 4: Cyclone Asna track with dates

4.4. Animated Cyclone Track (GIF)

As shown in Figure 5 the animation of Asna's cyclone displays a timelapse of its path over the Arabian Sea from 25 August 2024 to 02 September 2024. It is created by joining the daily positions of the cyclone so that the rapid change of the system is captured. One of the key benefits of this approach is that it shifts focus to visualizing the intensification phases as they occur. The movement speed and direction changes are crucial for detecting structural changes like expansion, dissipation or its comparing actual vs foreseen trajectories for evaluating the precision of the meteorological models in use. It is possible to analyze and pinpoint the most critical periods when certain factors like the sea surface temperature and wind shear contributed to destruction or intensification of the cyclone.

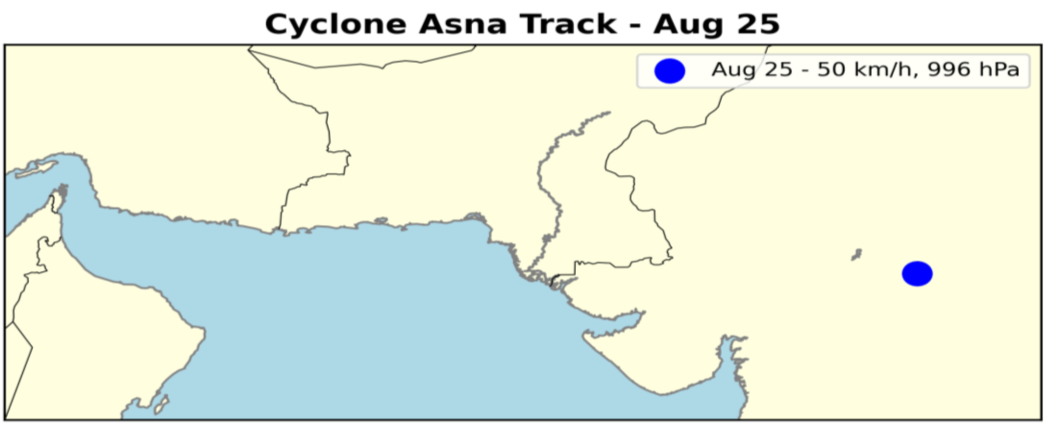


Figure 5: Animated cyclone track

4.5. Pressure and Wind Speed Trend Analysis

Figure 6 provides the relationship between central pressure and the maximum sustained wind speed during the lifecycle of the cyclone. It can be observed that both the factors have an inverse relationship. One of the variables central pressure (hPa) is represented in one axis and during the graph's duration it is observed to decline as the cyclone develops. The other variable maximum wind speed (km/h or knots) is plotted on the second axis and as it is observed it increases in value when the pressure decreases. Wind speed in the cyclic rapid intensification phases exhibits a steep rise within short spans of time which corresponds with steep declines in pressure. Weakening periods are also observable when pressure rises because of dry air, wind shear vertical changes or interplay with landfall. It can also be concluded that an environment which does not aid in intensification will lead to stagnation and the pressure remaining unchanged for many days. This kind of analysis helps in understanding the factors that contributed to the development and decay of cyclone Asna.

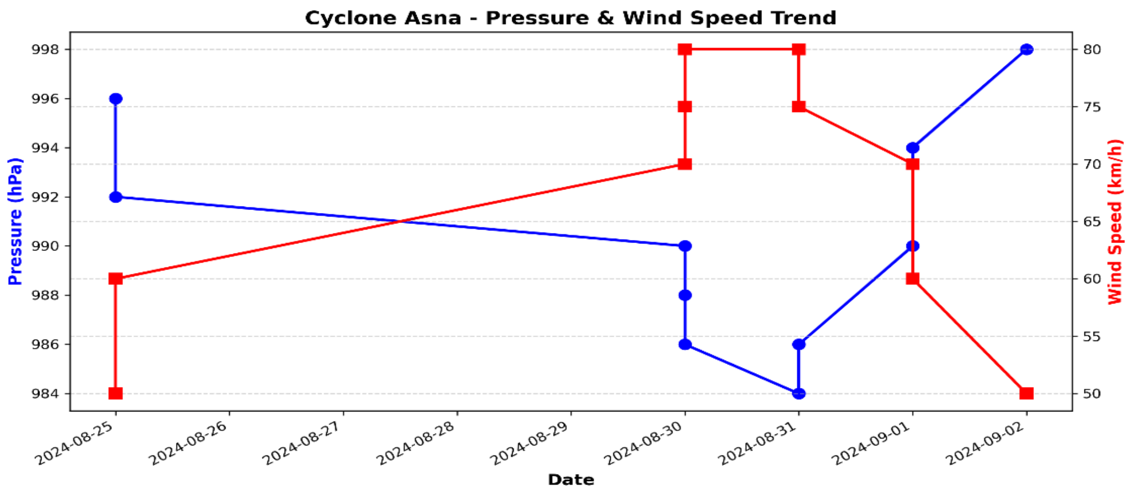


Figure 6: pressure and wind speed trends

4.6. Statistical Summary

A tabulated statistical summary gives an integrated glimpse of the most important meteorological parameters which presents a quick assessment of some general characteristics of the cyclone. The summary includes minimum central pressure recorded indicates peak intensity. Maximum wind speed observed defines the highest category reached by the cyclone. Average pressure and wind speed allows comparison of Asna with other regional cyclones. The time spent in the intensification and weakening stages reveals details regarding the storm's life cycle. Such quantitative approaches are useful for climate research, verification of forecasting models and assessment of potential impacts.

Min Wind Speed(km/h)	Max Wind Speed(km/h)	Average Wind Speed (km/h)	Min Pressure (hPa)	Max Pressure (hPa)	Average Pressure (hPa)
50	80	68.18181818	984	998	989.8181818

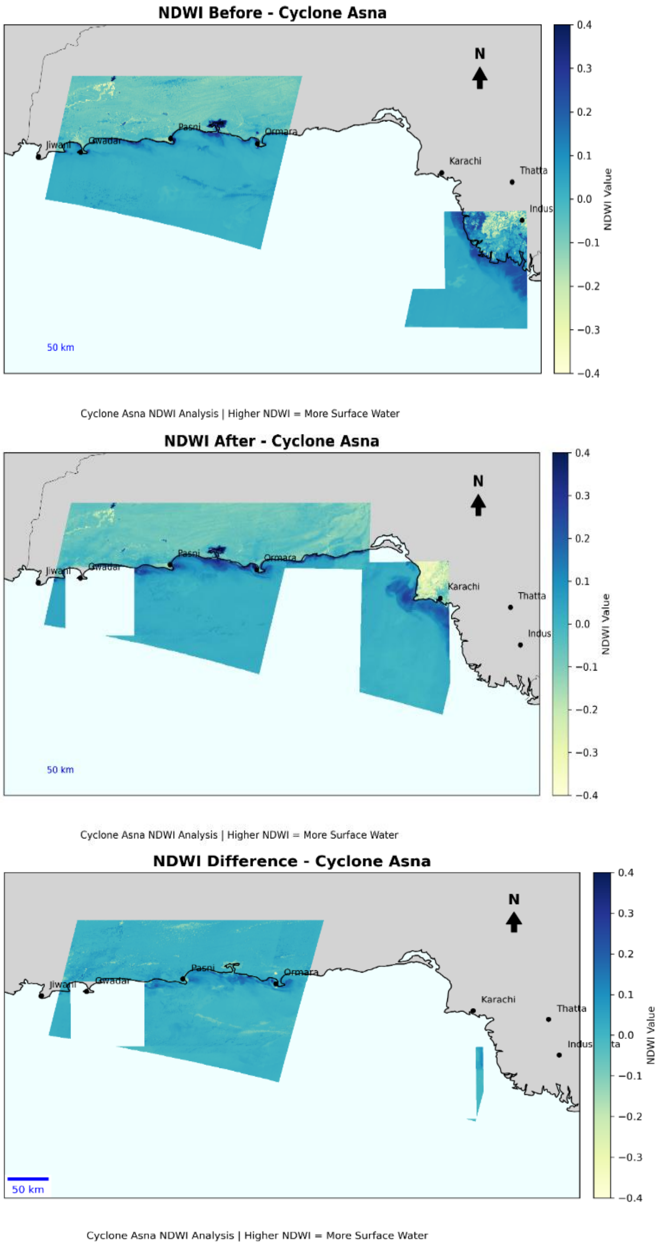
4.7. Comparison of daily weather parameters (2023 vs 2024) during Cyclone Asna

In 2023 both the zonal and meridional wind speeds remained positive suggesting stable wind conditions with a predominant eastward and northward flow. In 2024 wind patterns shifted dramatically both zonal and meridional winds became negative around August 27-28 signaling strong reversal (westward and southward) movement. This indicates stronger cyclonic circulation in 2024 compared to 2023. SLP in 2023 remained higher mostly above 99,200 Pa which indicate mostly calm atmosphere. In 2024 SLP dropped significantly below 98,800 Pa which indicates active deep low-pressure system typical of cyclonic activity. The steep pressure drops in (2024) coincides with stronger winds suggesting more intense cyclone formation in 2024.The extreme negative drop in (2024) sea level pressure correlates with extreme wind speed variation indicating high cyclone intensity. In 2023 the pressure and wind variation were milder, so the system was exhibiting less storm intensity. The evidence supporting the idea that cyclone Asna was stronger in 2024 than in 2023 includes the steep decline in pressure and the shift in cyclone winds. As a result, this suggests that the 2024 cyclone will have more powerful winds, storms, surges and rain than 2023 had.

Figure 7: Comparison of zonal wind, meridional wind and sea level pressure between 2023 and 2024

4.8. NDWI Based Flood Impact Analysis for Cyclone Asna

To enhance the visual interpretations, we conducted a pixel based NDWI pre and post cyclone raster comparison analysis. This gave insights quantitatively into the dynamics of the water surface during the cyclone event.



Figures 8: Normalized Difference Water Index (NDWI) of Cyclone Asna: Before, After and Change Detection

As indicated in Table 2 the total amount of water pixels increased by approximately 314,000 suggesting a concrete increase in surface water coverage which could be the result of flooding, storm surges or accumulation of coastal waters. The mean NDWI increased by 0.0113 which is a statistically significant change supports an increase in surface saturation of water. More than 1.67 million pixels recorded an increase in NDWI reinforcing the theory of hydrological intensification post cyclone. A smaller subset around 594,000 pixels displayed a decline in

NDWI which may indicate water withdrawal areas or regions of sediment deposition resulting from the preceding event.

NDWI Formula: NDWI= Green+NIR/Green−NIR

The cyclone's impact on the coastal hydrology of the region is clearly observable through the spatial and statistical analyses combined. Asna cyclones NDWI estimates show a baseline dispersion of water bodies, rivers and coastal areas. After the cyclone's impact the estimate depicts increased in flooded areas with no drainage especially within shallow coastal regions and delta. Difference mapping floods highlight area change detection and change localization while flood impacted areas appear in various shades of blue indicating NDWI surplus. This methodology provides enhanced automation capability and supports in assessed the flooded areas, disaster mapping and relief operation aid planning based on objective satellite image information. Findings from this study prove the applicability of NDWI remote sensing tool for impact monitoring on disasters. The images provided along with their accompanying statistics can be used in policy debates or as the basis of discussion outside the scientific community in climate resilience or emergency response strategies.

Table 2: NDWI pixel wise comparison table

Metric	Before Cyclone	After Cyclone	Change
Mean NDWI	0.0009	-0.0080	↓ 0.0113
Min NDWI	-0.7019	-0.5985	-
Max NDWI	0.7567	0.7942	-
NDWI > 0.1 (Water Pixels)	6,548,802	6,862,904	↑ 314,102
Pixels with Increase	-	-	1,677,084
Pixels with Decrease	-	-	594,823

4.9. Cumulative Monsoon Rainfall over Pakistan (Jul 1 – Sep 30, 2023 & 2024)

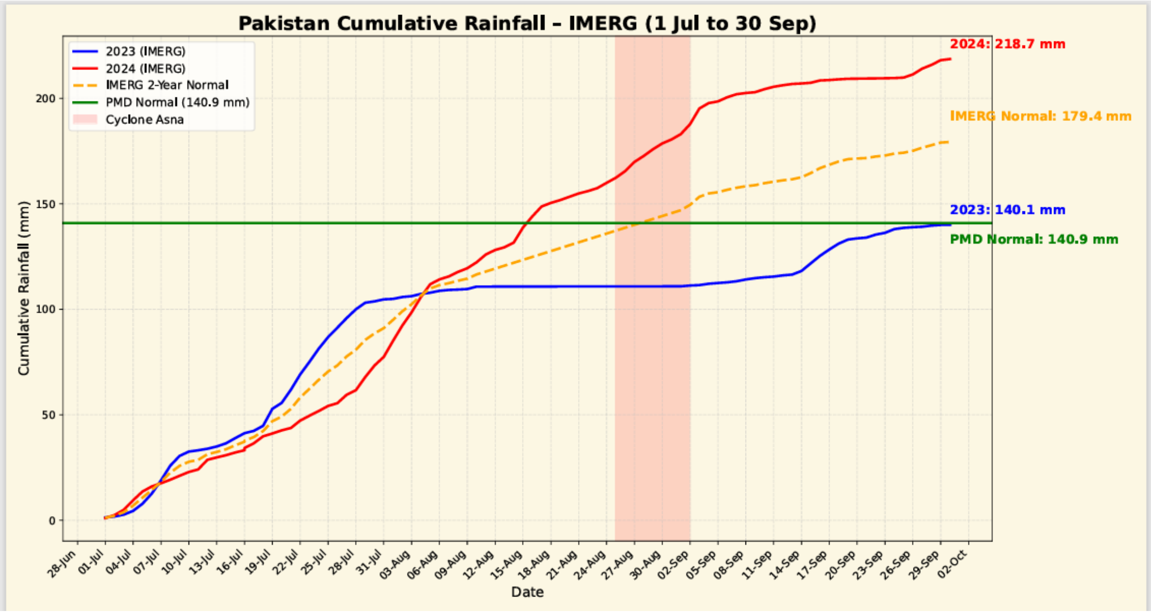


Figure 9: Cumulative Monsoon Rainfall over Pakistan (Jul 1 – Sep 30, 2023 & 2024)
Data Source: IMERG (GPM), Final Run V07; Region: Pakistan (Lat: 24°N–37°N, Lon: 60°E–77°E)

Figure 9 demonstrates the monsoon rainfall accumulation across Pakistan within the timeframe from 1st July to 30th September for the years 2023 and 2024, employing satellite-based daily precipitation data from IMERG (Integrated Multi-satellite Retrievals for GPM). Cumulative rainfall for the years 2023 and 2024 is represented by blue and red lines. These values were calculated using spatial averages over the geographic extent of Pakistan and then aggregated daily to capture seasonal accumulation. A clear contrast between the two years is observable. 2024 shows much greater rainfall primarily due to the intense rainfall events associated with cyclone Asna from August 25 to September 2. This period is marked in red to emphasize its impact on the overall seasonal total. For additional context two reference lines are added. IMERG 2 Year Normal (Dashed Orange) represents the arithmetic mean of 2023 and 2024 accumulated satellite rainfall. This serves as a relative baseline to mark interannual anomalies within the IMERG observation period. PMD 30-Year Normal (Solid Green) denotes a flat reference line at 140.9 mm which is the PMD's official climatological normal for the monsoon season based on ground station records depicting long-term averaged values. Final totals for accumulated rainfall are annotated at the end of each curve. Importantly the total for 2024 clearly exceeds both the 2023 curve and the PMD norm suggesting a season with anomalously excess rain caused by extreme weather events.

4.10. Cyclone Asna impact map for coastal areas of Pakistan

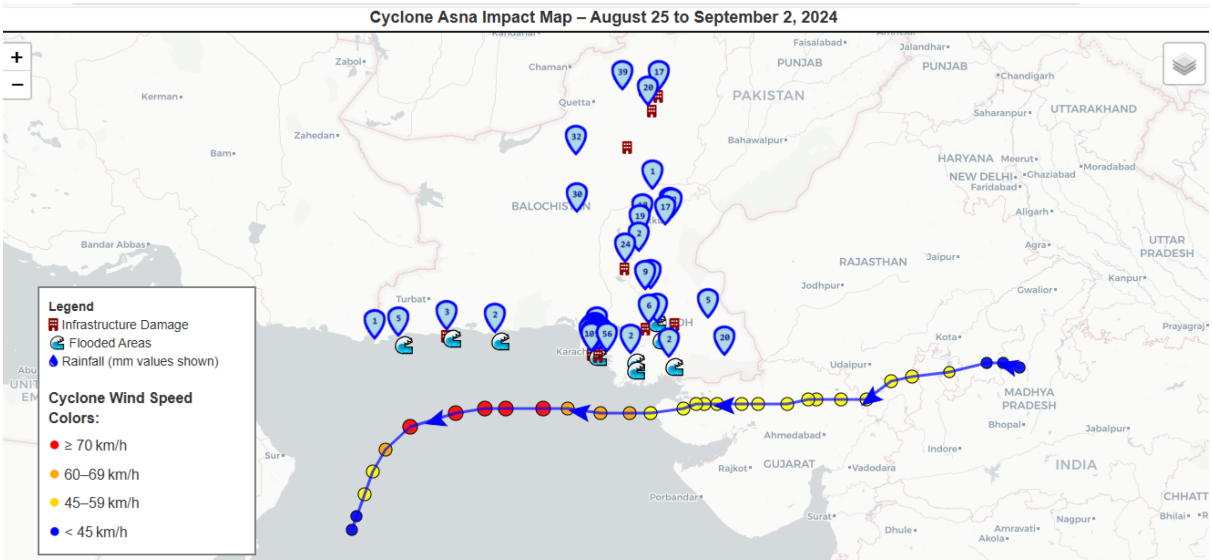


Figure 10: Cyclone Asna impact map

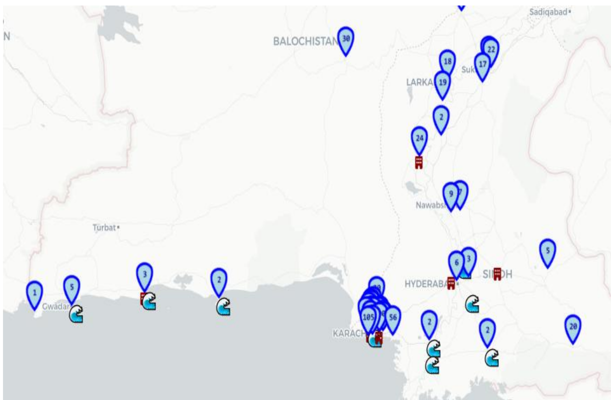


Figure 11: Pakistan coastal area rain points

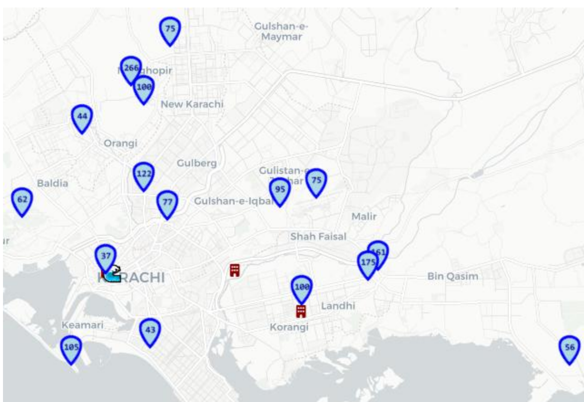


Figure 12: Karachi rainfall points.

The spatial analysis provided in Figures 10, 11 and 12 illustrates cyclone Asna's evolution, its geospatial trajectory and the meteorological impacts for Pakistan and the adjoining areas of the North Arabian Sea from August 25 to September 2, 2024. This framework integrates diverse datasets such as cyclone intensity, rainfall distribution, infrastructural damage and flooding within a GIS framework to provide a multiscale visualization of the phenomena. The purpose of these maps is to convey intuitively and extensively the cyclone's development, regional hydro-meteorological impacts and social and environmental impacts. The first map shows the complete trajectory of cyclone Asna starting with its rare formation over central India, drifting unusually westward into the Arabian Sea and then curving towards southern Pakistan. In the map cyclonic movement is timestamped and marked with circular symbols whose colors represent the intensity of winds at that point (measured in km/h). The color coding complies with international standards for cyclone intensity classification. Red (≥ 70 km/h) severe intensity, Orange (60–69 km/h) Moderate intensity, Yellow (45–59 km/h) Mild intensity, Blue (< 45 km/h) Weakening/depression stages. These notations indicate where and when the storm strengthened and weakened while moving from a partially terrestrial origin, underwent marine intensification and then transitioned to land interaction along the coastline of Pakistan.

To further enhance interpretation arrowheads along the cyclone's trajectory, denote the direction of motion which is Cyclone Asna's westward to northeastward turning motion during its life cycle. Markers themed blue clouds show the observed or estimated rainfall amounts in millimeters derived from PMD rainfall stations and some remote sensing datasets such as IMERG and GPM. Markers which contain actual rainfall numbers allow for quick spatial assessment and comparison supporting flood risk evaluation in aggravation and impact studies particularly for flood vulnerable regions. Verified disaster event points are superimposed based on official NDMA reports, respected media coverage (Dawn or Geo News) and satellite damage assessments. Since infrastructure damages comprise power failures, electrocutions, roof and building collapses (wind or flash flooding) and structure failures. Flooded areas comprise urban waterlogging, coastal inundation, breached flood barriers and crop submersion zones. Each point was captured through direct geospatial referencing which provides spatial coordinates and is accompanied by description through on-map tooltips for contextual explanation. The cyclone's effect on sea reached areas such as Gwadar, Ormara, Pasni and Jiwani which are highlighted in Figure 11 along with the rainfall over Balochistan and Sindh's coastal zones. The observed rainfall assists in identifying areas prone to storm surge flash floods. correlate the cyclone proximity with wind inflow and observed rainfall. Early precipitation impacts prior to landfall and the behavior of the storm need to be mapped and analyzed. Figure 12 depicts distinct areas of rainfall concentration across Karachi capturing Surjani Town (266 mm) and Gulshan-e-Hadeed (175 mm). Within the domain of Karachi rainfall data reveals a clear difference in precipitation exposing the city to urban flooding and high risk of disruption from storm surges.

Surjani and Quaidabad where anomalously high rainfall was recorded, urban flooding was just one outcome coupled city wide infrastructure collapse proving critical to disaster planning as well as responsive management. The depicted geospatial elements are not simply for exposition they are analytical in nature and support the understanding of the interplay between cyclone activity and associated risks. They accomplish several primary objectives for this research. Illustrate the degree of meteorological severity with wind and pressure measurements. Show presence and absence of rainfall using field and satellite data. Interaction of meteorological data and infrastructure with flood incidents is verified in the field. Assisting in constructing cyclone vulnerability indices and risk stratification for the coastal area of Pakistan. These maps complement other analyses as communications tools devoid of biases which planners, disaster management specialists and scientists need to make evidence-based decisions regarding the socio-political impacts of cyclones in South Asia. The PMD satellite rainfall retrievals, and local reports supplied the rainfall data. Position and wind speed of the cyclone are obtained from IMD storm bulletins (2024). Damage points were georeferenced from media and field observation reports. Below are the table of rainfall, flood and infrastructure damage points.

Table 3: Rainfall observation during cyclone Asna

No.	Location	Latitude	Longitude	Rainfall (mm)
1	Surjani Town	24.9827	67.0206	266.0
2	Gulshan-e-Hadeed	24.8500	67.2000	175.0
3	Quaidabad	24.8572	67.2078	161.0
4	Nazimabad	24.9106	67.0304	122.0
5	Keamari	24.7922	66.9756	105.0
6	Korangi	24.8333	67.1500	100.5
7	North Karachi	24.9700	67.0300	100.2
8	PAF Faisal	24.9000	67.1333	95.0
9	Old Airport	24.8917	67.0481	77.5
10	Gulshan-e-Maymar	25.0100	67.0500	75.6
11	Jinnah Terminal	24.9065	67.1606	75.0
12	PAF Masroor	24.8931	66.9386	62.5
13	Bin Qasim	24.7924	67.3526	56.3
14	Orangi Town	24.9500	66.9833	44.3
15	DHA Phase II	24.8044	67.0350	43.0
16	Saddar	24.8544	67.0013	37.0
17	Gadap	25.1200	67.1000	30.0
18	Gwadar	25.1264	62.3220	5.0
19	Ormara	25.2084	64.6356	2.0
20	Pasni	25.2636	63.4696	3.0
21	Jiwani	25.0670	61.7450	1.5
22	Dadu	26.7324	67.7766	24.0
23	Sukkur	27.7052	68.8574	23.0
24	Rohri	27.6833	68.9000	22.0
25	Islamkot	24.6998	70.1796	20.0
26	Mohenjo Daro	27.3294	68.1386	19.0
27	Larkana	27.5589	68.2120	18.0
28	Khairpur	27.5295	68.7617	17.0
29	Sakrand	26.1389	68.2725	9.0
30	Shaheed Benazirabad	26.1530	68.4086	7.0
31	Hyderabad	25.3960	68.3578	6.0
32	Chhore	25.5226	69.7821	5.0
33	Tando Jam	25.4289	68.5451	3.0
34	Padidan	26.9650	68.1169	2.0
35	Thatta	24.7474	67.9235	2.0
36	Badin	24.6600	68.8383	2.0
37	Jacobabad	28.2810	68.4388	1.0
38	Ziarat	30.3818	67.7254	39.0
39	Kalat	29.0250	66.5900	32.0
40	Khuzdar	27.8000	66.6167	30.0
41	Muslim Bagh	30.0491	68.3439	20.0
42	Loralai	30.3700	68.5981	17.0

Table 4: Reported Flood Events and Infrastructure Damage During Cyclone Asna

No.	Location	Latitude	Longitude	Type	Description
1	Pasni	25.2639	63.4694	Flood	Coastal flooding
2	Ormara	25.2083	64.6355	Flood	Coastal flooding
3	Gwadar	25.1264	62.3220	Flood	Flooding
4	Karachi	24.8610	67.0023	Flood	Urban flooding
5	Badin	24.6500	68.8391	Flood	Low-lying crop inundation
6	Thatta	24.7474	67.9235	Flood	Coastal flood inundation
7	Sujawal	24.5700	67.9100	Flood	Urban flooding
8	Tando Muhammad Khan	25.2333	68.5333	Flood	Flash flooding
9	Matiari	25.6000	68.4167	Flood	Localized waterlogging
10	Pasni	25.2639	63.4694	Infrastructure	Structural damage
11	Korangi (Karachi)	24.8333	67.1500	Infrastructure	Power outage/tree damage
12	University Road, Karachi	24.8610	67.0023	Infrastructure	Fallen trees/electrocution fatality
13	Korangi, Karachi	24.8614	67.0996	Infrastructure	Electrocution fatality
14	Dadu	26.7324	67.7766	Infrastructure	Sewage breach/structural damage
15	Jamshoro	25.4300	68.2826	Infrastructure	Dyke breach/flash flooding
16	Mirpurkhas	25.5291	69.0000	Infrastructure	Electrocutions/building collapse
17	Upper Dir (KP)	35.1600	72.4200	Infrastructure	Landslide roof collapse, 13 killed
18	Loralai	30.3700	68.5981	Infrastructure	Flash flood swept people away
19	Duki	30.0600	68.4500	Infrastructure	Hill torrent flooding
20	Jhal Magsi	29.3000	67.8500	Infrastructure	Flash flood damage
21	Qila Saifullah	30.5000	68.2500	Infrastructure	Road/bridge damaged

4.11. Arabian Sea Cyclones (2007–2024)

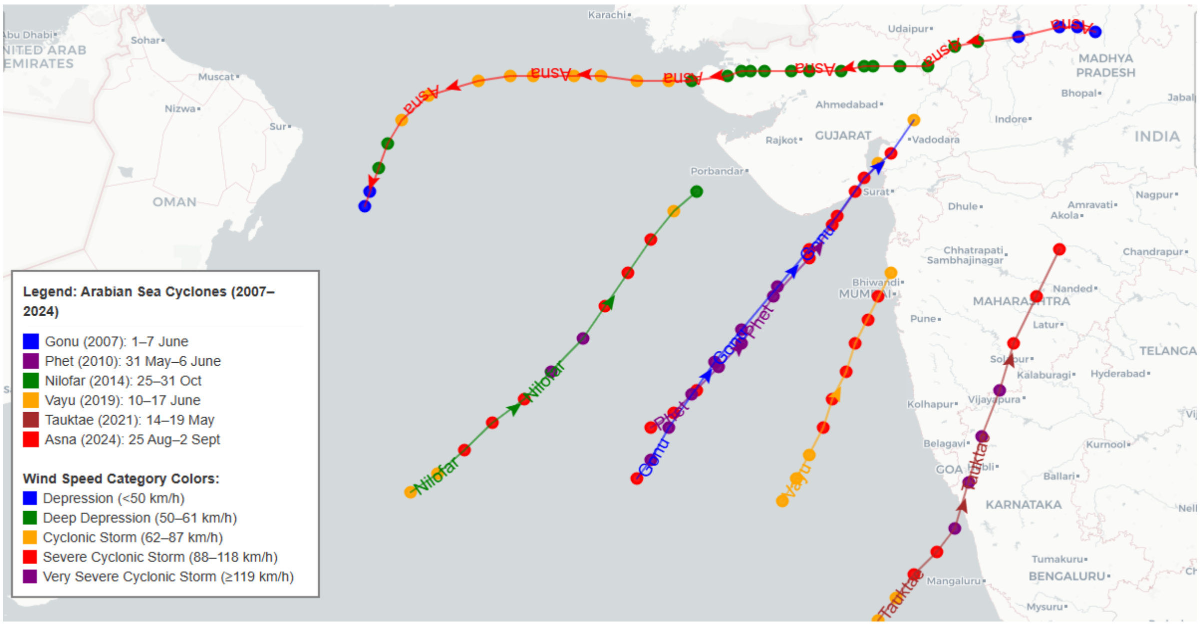


Figure 13: Arabian sea cyclones

The image above shows a comparative track map for six major cyclonic systems of the Arabian Sea region from 2007 to 2024. It depicts the spatial paths and wind intensity levels of Cyclones Gonu (2007), Phet (2010), Nilofar (2014), Vayu (2019), Tauktae (2021) and Asna (2024) along with color coding for consistency. This image is aimed at demonstrating how Asna's deviation from behavior patterns of earlier Arabian Sea cyclones was in terms of their land interaction and evolution processes. Unlike other cyclones in the dataset that weakened or fully dissolved after landfall because of the lack of oceanic heat and moisture, Asna showed an unusual over land re-intensification. Asna was originated from the northwest Bay of Bengal then moved over land only to re-intensify into a Deep Depression over East Rajasthan and West Madhya Pradesh by 25 August 2024 after losing contact with the sea. This phenomenon marked by the extended westerly track of Asna is completely unusual within the context of Arabian Sea cyclone history and very different from the offshore dissipation patterns of Nilofar and Vayu. Re-intensification of Cyclone Asna can be explained by a number of land surface and atmospheric conditions such as constant monsoonal moisture inflow from the Bay of Bengal and Arabian Sea. There is strong divergence on the upper levels and the mid troposphere has cyclonic vorticity (850–500 hPa). There are high levels of antecedent soil moisture and latent heat flux due to excessive rainfall during the monsoon. Warming in the backdrop climate enhances landward convection (Roxy et al., 2021; Patil et al., 2020; IMD, 2024). This type of behavior shows the increase in the number of hybrid cyclonic systems which creates a need to improve inland monitoring and forecast models as they bypass traditional ocean-land dynamics. The map serves a dual purpose of spatial reference and visual argument illustrating the causal climatological and meteorological anomalies which differentiate Asna from well-documented systems like Phet (2010) and Tauktae (2021) that decayed post-landfall. Thus, cyclone Asna joins a small group of systems labelled anomalous alongside Cyclone Daye (2018) and Shaheen (2021). These storms re-intensified far from the coast hundreds of kilometers offshore blending complex factors such as anomalously high soil moisture, vigorous upper-level divergence and persistent monsoonal inflow from adjacent oceans. Consequently, Asna disputes conventional paradigms in tropical cyclone modelling and highlights the critical need for more comprehensive longitudinal land ocean atmosphere monitoring systems for proactive alerting and risk mitigation of inland disasters.

4.12. Comparative Analysis of Key Meteorological Parameters for Arabian Sea Cyclones (2007–2024)

The figure 14 shows four critical meteorological indicators panels peak wind speed, minimum central pressure, peak wind gusts in Pakistan and Rainfall in Pakistan across six significant Arabian Sea cyclones that formed between 2007 and 2024. Specifically the storms examined are Gonu (2007), Phet (2010), Nilofar (2014), Vayu (2019), Tauktae (2021) and Asna (2024). The chart is designed to illustrate the overall strength of each cyclone and its associated hydrometeorological consequences over Pakistan land and waters. The first panel plots the maximum sustained wind speed recorded at any point at sea or onshore during each system's life. Both Gonu and Phet exceed 230 km/h classifying them as Super Cyclonic Storms under the India Meteorological Department's scale. Tauktae follows with a peak near 190 km/h while Nilofar and Vayu attain 135-140 km/h. By contrast Asna shows a maximum sustained speed of only 90 km/h, making it the weakest of the six according to standard intensity categories. Data are drawn from IMD RSMC Cyclone Reports 2007-2024, WMO Cyclone Summaries and JTWC Track Data. Panel 2 summarizes minimum central pressure a standard measure of tropical cyclone intensity. Asna posted the deepest reading at 920 hPa trailed by Phet at 940 hPa and Tauktae at 950 hPa. Asna with a central pressure of 990 hPa ranks last in strength matching its modest wind field. Yet Asna still caused substantial inland disruption hinting that its circulation behaved unlike typical ocean centered systems. Data are drawn from IMD Best Track and RSMC storm bulletins. The second panel maps peak wind gusts reported across Pakistan providing a focused regional snapshot.

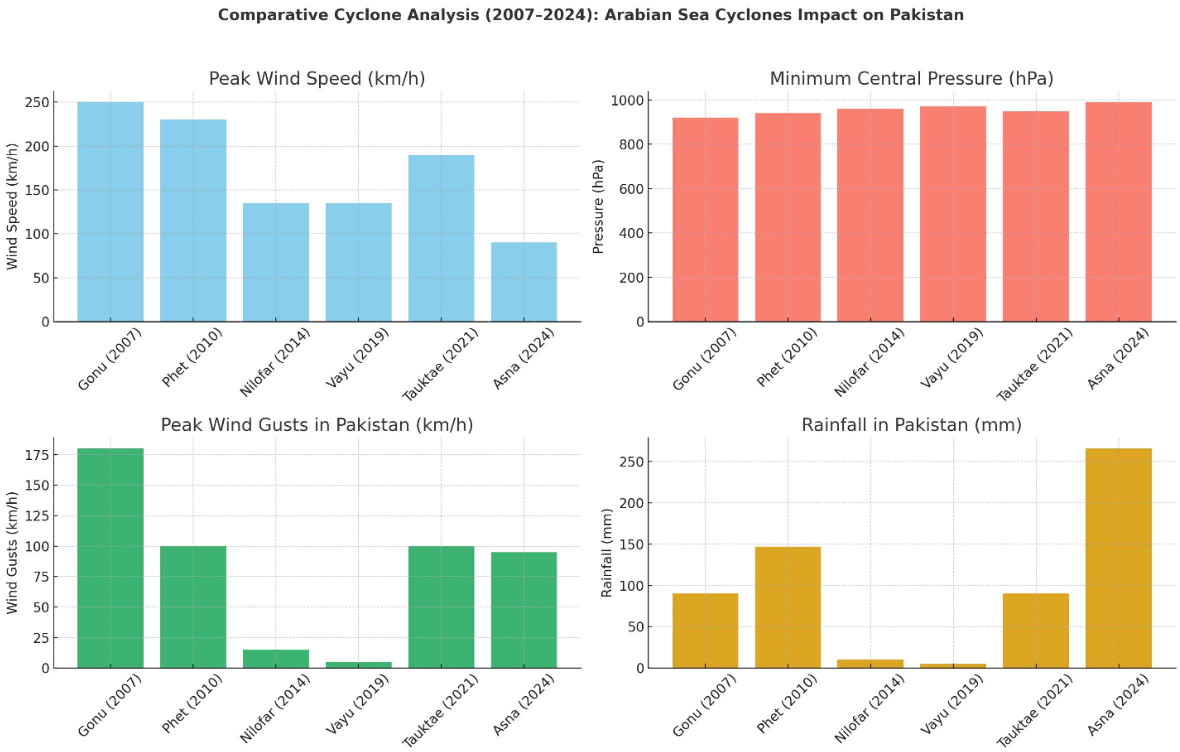


Figure 14: comparison of meteorological parameter of Arabian sea cyclone

In an unexpected twist Asna peaked at 95 km/h nearly the same as the far stronger Tauktae. Gonu despite missing a formal landfall whipped up gusts near 180 km/h along Balochistan coastal stretch. Phet affected Karachi and Makran with 100 km/h blasts. Nilofar and Vayu lasted offshore and together registered negligible gusts anywhere in Pakistan. Asna's powerful inland gusts arise from the blending of monsoon currents with regional wind convergence and upper-level divergence a phenomenon explained in the IMD 2024 report. Once over land the cyclone's structure lingered because high soil moisture, latent heat release and unusual land-based convection now appearing in hybrid sea land systems fed it. Data Sources are PMD Karachi Station Logs, IMD Technical Bulletins (2024), NDMA Reports. This panel quantifies total rainfall produced by each cyclone across Pakistan. Asna emerges as the record holder topping out at 266 mm in Surjani Town, Karachi and leaving broad swaths of coastal Sindh and southern Balochistan with 120-240 mm. Phet once thought the wettest dropped only 147 mm on Karachi in June 2010. Tauktae and Gonu brought 60-90 mm while Nilofar and Vayu stripped rainfall to less than 10 mm as those storms skirted the coast. Although Cyclone Asna ranked as a low-intensity system in terms of wind speed its anomalous track over land kept rain falling for several days across a wide area. Analysis from the India Meteorological Department (2024) and GPM-IMERG rainfall anomaly maps demonstrate that the storm coupled with an active monsoon trough and unusually high humidity produced flash floods in Karachi, Gwadar, Thatta and Dadu. Additional data from Pakistan Meteorological Department archive (2024), IMERG V07 Final Run and daily summary reports issued by the National Disaster Management Authority (NDMA) form the basis of this interpretation. Taken together the available charts show that cyclone intensity blended wind speeds and central pressure does not neatly map onto local impacts in Pakistan. Asna the weakest of the recent events by those same metrics delivered rainfall totals that matched or even exceeded those of stronger systems like Phet or Tauktae. Such outcomes highlight the emerging risk posed by hybrid cyclones that either form inland or regain strength over land a trend likely linked to rising regional temperatures, intensified moisture transport and broader climate variability. Comparative visuals of this kind are therefore vital when building more accurate site-specific hazard models for South Asian coastal cities such as Karachi where damaging rainfall tends to pose a greater threat than high winds.

4.13. Cyclone Asna Unusual Land Re-intensification reasons

In 2024 the South Asian monsoon entered an unusual phase characterized by a pronounced monsoon trough extending through northern and central India. This allowed the Asna remnant to receive moisture from both the Arabian Sea and the Bay of Bengal (IMD, 2024) keeping deep convection alive even after the system had moved inland. Mid and upper-level satellite analyses from 24 to 26 August show a well-organized pattern of strong upper level divergence and stable cyclonic vorticity between 850 and 500 hPa directly over Central India. This sustained vertical coherence in the circulation laid a solid foundation for the system to re-intensify after its initial inland crossing. Preceding weeks of heavy monsoon rain had left the soil saturated a condition that as documented by Patil et al. (2020) lowers ground friction and delays boundary layer stabilization thereby permitting cyclone like features to persist longer than usual. Concurrently warmer sea surface temperatures across the Arabian Sea and western Indian Ocean increase air humidity capacity and supply supplementary heat energy a trend flagged by WMO (2023). Together, these climatic factors raise the probability of land based re-intensification. Unlike historical Arabian Sea systems Gonu in 2007, Phet in 2010 or Nilofar in 2014 that steadily weakened over land. Asna demonstrates a hybrid behavior keeping intensity and driving destructive winds well after moving inland. Its trajectory thus strengthens the argument that future South Asian cyclones given adequate monsoon dynamics and upper-level support may routinely experience secondary intensification even after emerging over land. This pattern is distinctly different from that seen with earlier Arabian Sea cyclones such as Gonu and Phet, suggesting that forecasting models should be updated to include the possibility of land-driven strength recovery in a warming world (Roxy et al., 2021; WMO, 2023).

5. Conclusion

This study uses satellite data and remote sensing tools to map how Cyclone Asna formed moved inland and then affected both the coast and deeper land areas in Pakistan. By analyzing cloud imagery, the Normalized Difference Water Index (NDWI) rainfall estimates and damage maps we trace not only the storm's immediate destruction but also its wider weather and environmental fallout. In contrast to most Arabian Sea storms Asna strengthened after crossing the shore keeping deep clouds and strong winds for hours over land, a behavior rarely recorded in the region. Observations show that three overlapping factors made that unusual inland revival possible. First, the 2024 South Asian monsoon was strong enough to draw moist air from the Arabian Sea and Bay of Bengal, feeding clouds long after the cyclone left open water. Second high-altitude winds diverged sharply while mid-level cyclonic spin added uplift helping the weakened system stay vertically organized instead of collapsing. Finally wet land from earlier rains quickened heat transfer to the air and softening soil allowed less resistance to rising currents together lowering stability and letting the storm live longer inland. Long-term ocean-and-atmosphere trends in the Arabian sea warming water and moisture air likely intensified Cyclone Asna matched the rising occurrence of hybrid storm systems seen lately. By combining Sentinel-2 NDWI images taken before and after verified rain gauges which shows increase in water bodies. Negative wind patterns of both zonal and meridional winds in time of Cyclone Asna and SLP also decreasing significantly in the time of cyclone Asna. Whereas increase in rainfall after Cyclone Asna which leads to floods and infrastructure damage affecting Karachi regions. This research not only confirms Asna's odd behavior but also showcases satellite remote sensing and GIS as quick tools for early-warning, risk-assessment and event record work. The evidence points to an immediate need for revised cyclone models that treat inland re-intensification as routine especially in Pakistan where dense settlements fragile housing and weak infrastructure increase the risk. In that light Asna becomes more than a rare and unusual weather event. It is a demonstrable signal that climate driven changes in cyclone life cycles are now real, measurable and damaging. To build stronger futures, regional monitors must be upgraded data sharing across agencies and community level awareness, warning drills, evacuation routes, safe shelters made standard rather than optional.

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