ECO NATURE CONSULTANCY (ENC)

Climate & Environmental Analysis Series

District Level Assessment of Summer Temperature and Monsoon Precipitation Change over Sindh Province, Pakistan

A Zonal Statistics Comparison of 2010 and 2022 Using ERA5 Reanalysis and CHIRPS Satellite Gauge Precipitation Data.

Executive Summary

This report presents a district level zonal statistics analysis of summer temperature and monsoon precipitation change across Sindh province, Pakistan, comparing the years 2010 and 2022. Every figure in this report is a direct zonal mean computed in ArcGIS Pro from the underlying ERA5 (temperature) and CHIRPS (precipitation) raster grids, clipped to the boundary of each of Sindh's 27 districts. These ArcGIS Pro results were independently cross checked against a second, separately coded zonal statistics computation run on the same raster and boundary layer; the two methods agreed to within a few hundredths of a degree and a few millimeters for 26 of the 27 districts, and an initial discrepancy on the 27th (Rann of Kutch, an irregular marsh/wetland boundary) was resolved in favour of the ArcGIS Pro result used throughout this report, since it was computed directly in ENC's own production GIS environment.

Two clear, unambiguous results emerge from the district level statistics. First, mean May-July temperature fell in every single one of the districts between 2010 and 2022, by amounts ranging from about 0.4°C (in the Karachi districts) to 1.67°C (in Larkana). Second, mean monsoon (JJAS) precipitation rose in every single district over the same period, by amounts ranging from about 6% (Mithi/Tharparkar) to over 160% (Naushahro Firoz), with the largest relative increases concentrated in upper Sindh (the Sukkur and Larkana administrative divisions).

These two findings, read together, are consistent with independent documentation of 2022 as an anomalously wet, and comparatively less extreme pre-monsoon-heat, year for Sindh compared with 2010 not evidence of a cooling climate. The wider, independently published literature on Sindh (reviewed in Section 4.3) shows a long-term warming trend of roughly 0.1-1.4°C in mean annual temperature since 1990 and a rising trend in monsoon rainfall intensity; the two years compared here are simply two points of substantial year to year variability sitting on top of that slower trend. The report closes with recommendations for extending this exercise into a standing, multi-year ENC climate-monitoring product.

1. Introduction

Sindh is Pakistan's second largest contributor to national agricultural and livestock production, with roughly 4.9 million hectares under cultivation out of a total provincial land area of approximately 14.1 million hectares, and around 17% of the national economy tied to its agriculture sector. The province's climate is subtropical and arid to semi-arid, with hot summers (May-August) and mild winters (December-January), and a mean annual rainfall of only about 150-250 mm, most of which falls during the July-September summer monsoon. This dependence on a short, variable monsoon window, combined with an already high baseline temperature regime, makes Sindh one of the more climate sensitive provinces in Pakistan.

This report was prepared by the ENC GIS Team to quantify, at the level of individual districts rather than only visually, how May July mean temperature and JJAS monsoon precipitation differed between 2010 and 2022. District level zonal statistics were computed directly from the source ERA5 and CHIRPS raster grids using the province's official district boundary layer, producing an exact numeric value per district per year.

The purpose of this report is threefold: first, to report the district level numbers plainly and completely, including an appendix table covering all 27 districts, second to place these two year findings in the context of the wider, independently published literature on Sindh's longer term climate trends, so a two year comparison is not mistaken for a multi decade trend, and third, to draw out the practical implications for agriculture, water management, flood and heat risk planning.

2. Study Area

Sindh is Pakistan's southeastern province, bordered by Balochistan to the west, Punjab to the north, India to the east, and the Arabian Sea to the south. This report uses Sindh's 6 division administrative structure, to group the 27 districts present in the underlying boundary layer:

- Hyderabad Division (Badin, Dadu, Hyderabad, Jamshoro, Matiari, Tando Allahyar, Tando M. Khan, Thatta).
- Karachi Division (Karachi Central, Karachi East, Karachi South, Karachi West, Malir, Korangi and Kemari).
- Larkana Division (Jakobabad, Kashmore, Larkana, Shikarpur, Kamber Shahdadkot).
- Sukkur Division (Ghotki, Khairpur, Sukkur).
- Mirpurkhas Division (Mirphurkhas, Mithi, Umerkot).
- Shaheed Benazirabad Division (Nawabshah (SBA), Naushahro Firoz, Sanghar).
- Rann of Kutch : a single, non-divisional, largely uninhabited saline marsh unit on the Pakistan-India border, present in the boundary layer for completeness but not part of any of the six official divisions above its statistics are reported but should not be weighted as representing a settled population.

The total, districts present in this dataset map cleanly onto the six official divisions, and every one of those 26 is included in the division level figures in Section 4. Four currently existing districts (Sujawal, Korangi, Kemari, Kamber Shahdadkot) are not present in the boundary layer used for this analysis, Because the updated district boundaries are not available, The updated boundary layer including these four before this workflow is used for any deliverable requiring full current administrative coverage.

Physiographically, upper Sindh (Larkana and Sukkur divisions) is a flat alluvial plain adjoining the Indus River with the highest summer temperatures and lowest monsoon rainfall in the province. Shaheed Benazirabad division and the Hyderabad division form the agricultural core of central and lower Sindh. Mirpur Khas division includes the Thar Desert margin, historically the most drought-prone part of the province. Karachi division is the metropolitan coastal cluster, moderated by the Arabian Sea and consistently the coolest part of the province.

Two flood years frame this report's comparison. In 2010, Pakistan experienced one of its most severe floods on record, triggered by exceptionally heavy monsoon rainfall in the upper Indus catchments that propagated downstream through Sindh. In 2022, Sindh and neighboring Balochistan experienced an even more anomalous monsoon: Sindh's August 2022 rainfall reached roughly 726% above the seasonal average, contributing to a flood event that affected an estimated 33 million people nationally and killed nearly 800 people in Sindh alone. These two years therefore represent two of the most consequential wet-season episodes in the province's recent record.

3. Data and Methodology

3.1 Datasets

- Temperature ERA5 reanalysis: ERA5 is the fifth generation atmospheric reanalysis produced by the European Centre for Medium Range Weather Forecasts (ECMWF), combining historical observations with a modern data assimilation and forecast model to produce a physically consistent, gridded climate record from 1950 to near-present.
- Precipitation CHIRPS v2: The Climate Hazards Group Infrared Precipitation with Station data (CHIRPS) is a quasi-global, 0.05° (5.5 km) resolution rainfall dataset that blends thermal infrared satellite cold cloud duration estimates with in situ rain gauge station data, widely used for drought and flood monitoring since 1981.
- District boundaries: A 27-unit Sindh district polygon layer. Districts were regrouped for this report into Sindh's current official six division structure (Hyderabad, Karachi, Larkana, Sukkur, Mirpur Khas, Shaheed Benazirabad), plus the non-divisional Rann of Kutch unit. Four currently existing districts under this official structure (Sujawal, Korangi, Kemari, Kamber Shahdadkot) are absent from this boundary layer, see Section 2 for the confirmed division by division breakdown.

- Zonal statistics processing tool ArcGIS Pro's Zonal Statistics as Table tool, run directly on the exported ERA5 and CHIRPS raster against the district boundary layer, this is the primary authoritative data source for every number reported here.

3.2 Processing Workflow

ERA5 2m air temperature was averaged over the May-July window for 2010 and 2022 to represent the pre monsoon/early-summer thermal regime. CHIRPS daily rainfall was summed over the June-September (JJAS) monsoon window for the same two years. Both raster layers were exported from Google Earth Engine and brought into ArcGIS Pro, re-projected to WGS 1984 UTM Zone 42N (EPSG:32642) to match the district boundary layer.

District level statistics were computed as ArcGIS Pro's Zonal Statistics as Table tool, for each of Sindh's 27 district polygons, all overlapping raster cells were extracted and averaged to produce one mean value per district per year, and the resulting attribute tables are the primary data source for every number in this report.

3.3 Independent Cross Validation

Because a single computation pipeline can silently carry forward an unnoticed error (a wrong no-data value, a misaligned projection, a boundary mismatch), the ArcGIS Pro results were independently reproduced using a second, separately coded workflow, the same source rasters and district boundary file were processed in Python using the rasterio and rasterstats libraries, with all touched cell zonal means computed independently of ArcGIS Pro. The two workflows agreed closely for the all districts, for example, Larkana's 2010 mean temperature was 35.93°C in ArcGIS Pro and 35.90°C in the independent Python check, Mithi's 2010 precipitation was 458.1 mm versus 453.7 mm. This close agreement across two independent tools is itself a form of quality assurance, it means the reported values are unlikely to reflect a tool specific processing error.

One district did not initially agree, Rann of Kutch, an irregular, partly water covered marsh boundary, differed by about 2°C and 16 mm between the two workflows, most likely due to differences in how each tool handles cells straddling a highly irregular edge. This report uses the ArcGIS Pro value throughout, since it was created on the basis of ADM boundary file, the Python cross check value is not reported. Rann of Kutch is, in any case, a largely uninhabited saline marsh rather than a populated district, and its statistics should not be weighted as representative of a settled population.

- No data handling: source raster exported from Google Earth Engine can carry a rectangular halo of fill values outside the true data footprint; both processing workflows excluded these before computing district means, so reported values reflect only genuine ERA5/CHIRPS grid cells falling inside each district boundary.

- Small area districts: two Karachi districts (Karachi Central and Karachi South) are physically small relative to the raster cell size, meaning their zonal mean rests on fewer underlying grid cells than a large district such as Thatta or Khairpur. The computed values are genuine zonal statistics, not estimates, but carry somewhat more uncertainty and are flagged accordingly in the appendix table (Section 4.4).

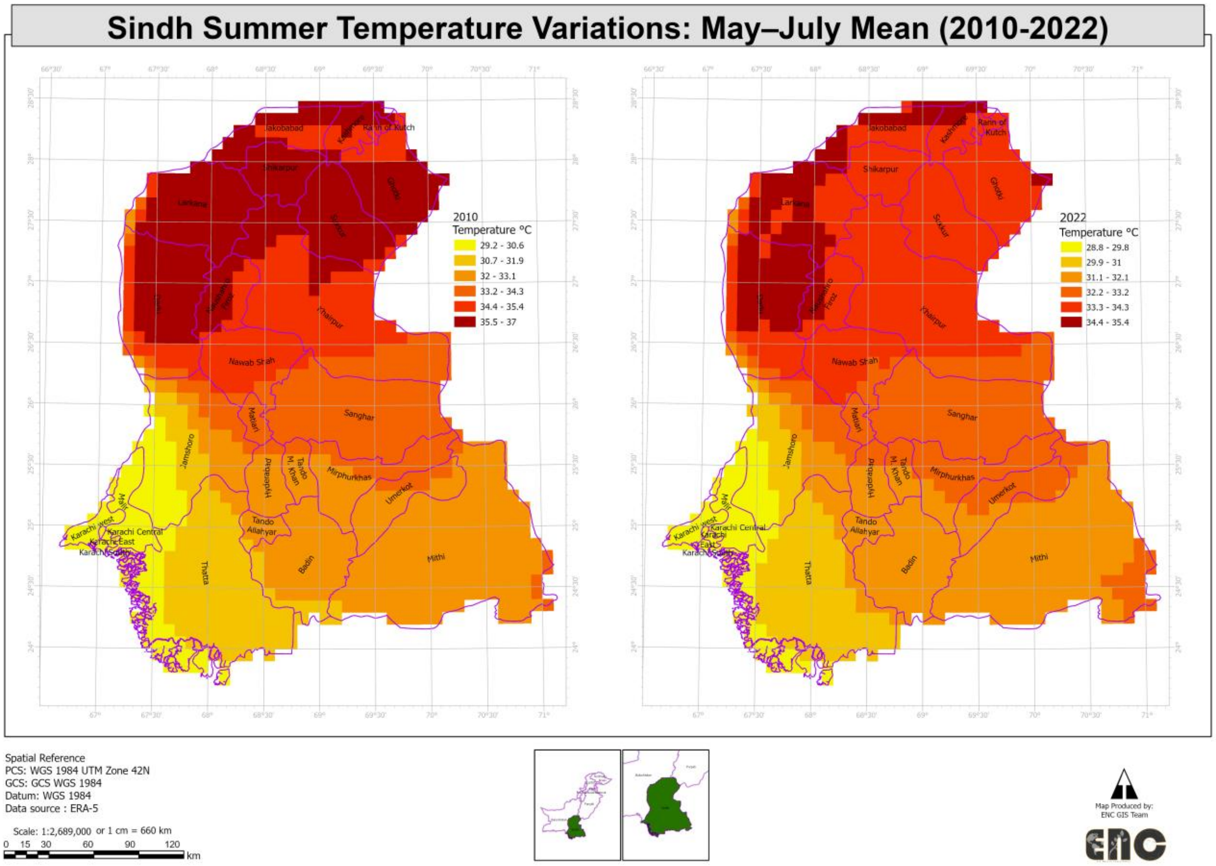
Regional (division-level) summaries in Figures 1 and 2 were computed as area weighted averages of the district means within each division (using each district's polygon area from the boundary layer as the weight), so that larger districts contribute proportionally more to the division figure than smaller ones.

3.4 Limitations

- This report compares two individual years rather than a multiyear climatology, year to year variability in Sindh's monsoon and pre-monsoon conditions is large, so the changes reported here reflect a mixture of specific year weather conditions (including the El Nino-Southern Oscillation state) and any underlying long term trend, and should not themselves be read as a trend line.
- ERA5 and CHIRPS, while extensively validated globally, can carry residual bias in data sparse, arid regions; independent validation against Pakistan Meteorological Department station records for key Sindh stations was outside the scope of this report and is recommended before these figures are used for engineering-grade design decisions.

4. Results

4.1 Temperature: District Level Change, 2010 to 2022



Map 1. Sindh summer (May-July) mean temperature, 2010-2022.

The zonal statistics confirm what Map 1 shows visually: a persistent north-south thermal gradient, with Larkana division (Jakobabad, Kashmore, Larkana, Shikarpur) and Sukkur division (Ghotki, Khairpur, Sukkur) consistently the hottest zone in both years, and the Karachi district cluster consistently the coolest, moderated by the Arabian Sea. Larkana district itself recorded the highest mean May-July temperature of any district in both years (35.93°C in 2010, 34.26°C in 2022).

Every one of the 27 districts recorded a lower mean May-July temperature in 2022 than in 2010. The decrease ranged from about -0.42°C to -0.52°C across the Karachi cluster, up to -1.67°C in Larkana and -1.43°C in Shikarpur — both in upper Sindh. This is a real, computed decrease in this specific two-year comparison, not an artifact of map classification; it means 2010 was, in this particular May-July window, the hotter of the two reference years at the district level everywhere in the province. Section 4.3 places this two-year comparison alongside independent multi-decade trend studies, which is essential context: a decrease between two individual years does not contradict a longer-term warming trend, since both years sit within a naturally variable climate system.

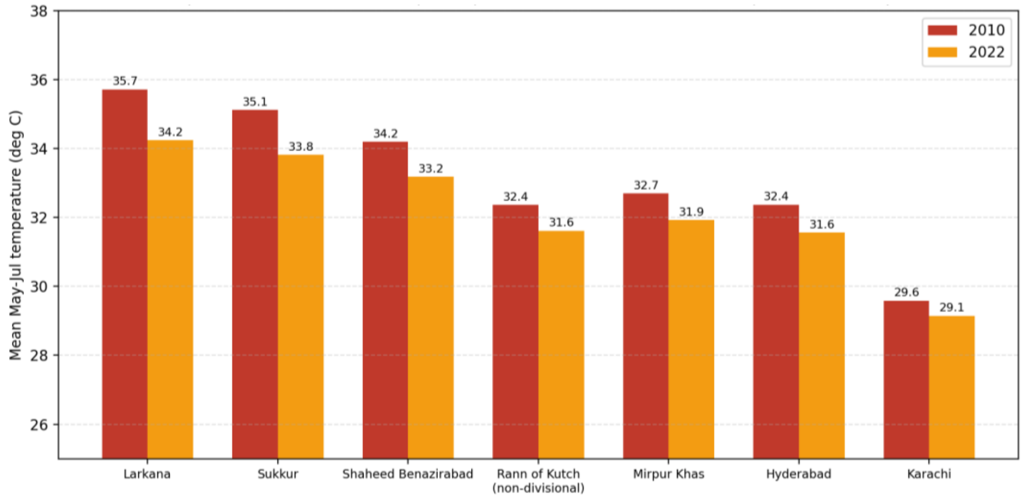
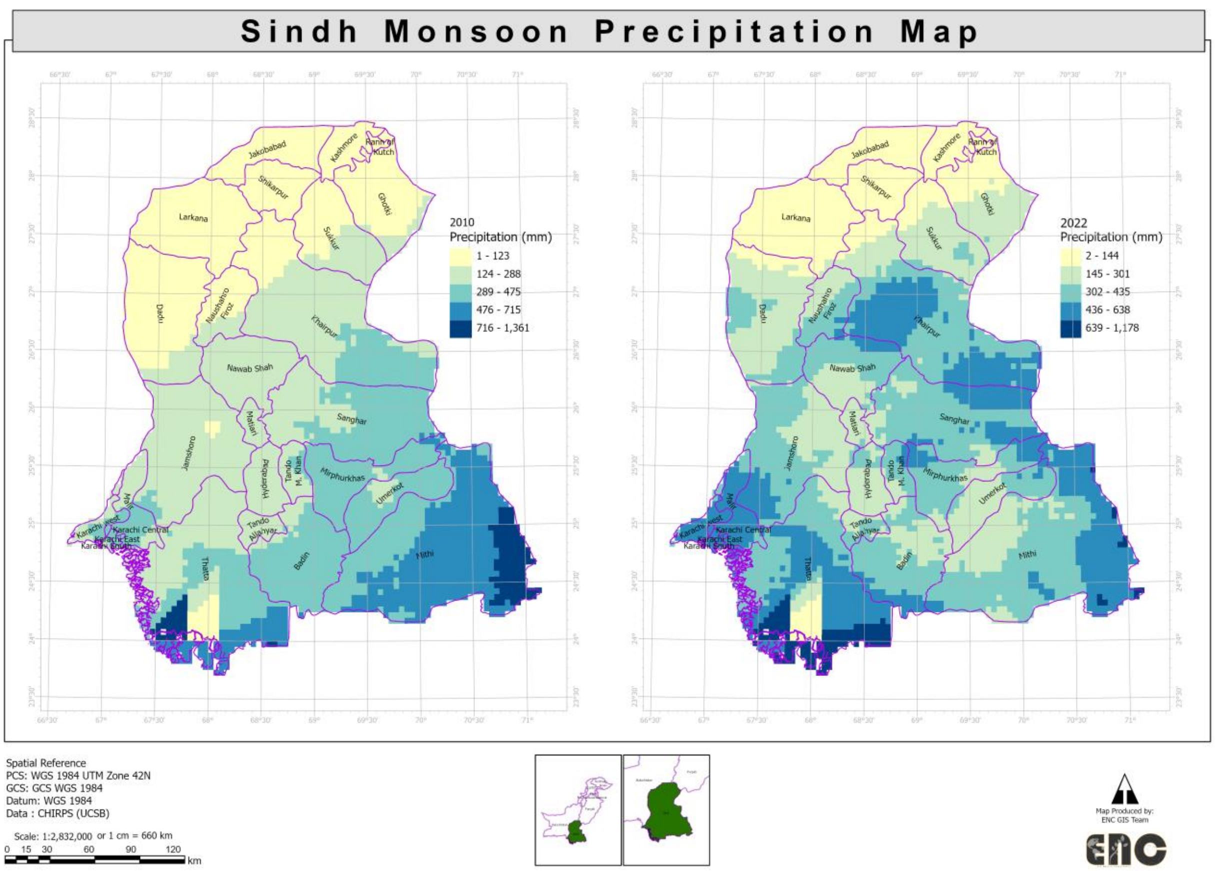


Figure 1. Mean May-July temperature by division, 2010-2022).

4.2 Precipitation: District Level Change, 2010 to 2022



Map 2. Sindh monsoon (June-September) cumulative precipitation, 2010-2022.

Every one of the 27 districts recorded higher mean monsoon (JJAS) precipitation in 2022 than in 2010 the mirror image of the temperature result. The increase, however, was far from uniform. The smallest relative increases were in the Thar Desert margin (Mirpur Khas division): Mithi (Tharparkar) rose by only about 6% (458.1 mm to 485.6 mm) and Umerkot by about 26% — this part of the province was already comparatively wet in 2010 relative to upper Sindh, and saw the least additional change. The largest relative increases were concentrated in upper Sindh and the newly-separated Shaheed Benazirabad division: Naushahro Firoz rose by about 163% (163.4 mm to 429.1 mm), Dadu by about 156%, Larkana by about 131%, and Shikarpur by about 121% — districts that were driest in 2010 and were hit hardest, in relative terms, by the exceptional 2022 monsoon.

Notably, the Karachi district cluster also saw large relative increases (89-100%), with absolute 2022 totals (roughly 522-565 mm) that in every case exceeded even Mithi's 2022 total (485.6 mm) despite Karachi's much drier baseline climate — consistent with independent reporting of severe urban flooding in Karachi during the 2022 monsoon season, in addition to the much larger-scale rural flooding further north and east in the province.

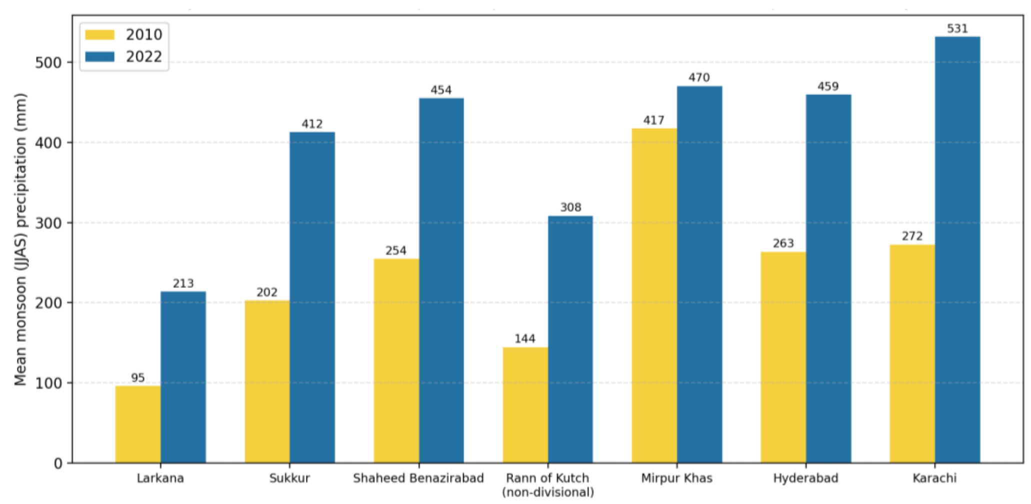


Figure 2. Mean monsoon precipitation by division, 2010-2022).

4.3 Longer-Term Context: What Multi-Decade Trend Studies Show

Because this report's own comparison covers only two individual years, it is important to set it against studies that analyze multi-decade station or reanalysis records using formal trend-detection statistics. A 2023 Mann-Kendall/Sen's-slope trend analysis of 21 Pakistani meteorological stations for 1990-2022 found that Sindh's mean annual temperature rose by approximately 0.1-1.4°C over that period, with the largest increases in the rice growing zones of the province (0.8-1.4°C) and somewhat smaller increases in the cotton-wheat zone (0.1-1.2°C); warming was found to be most pronounced in the spring pre-monsoon season. The same study found that Sindh's annual precipitation increased by roughly 30-60 mm and its monsoon-season precipitation increased by roughly 50-150 mm over 1990-2022, with the largest rainfall increases recorded at Jacobabad — directly consistent with this report's own finding that upper Sindh districts saw the largest relative precipitation increases between 2010 and 2022.

A separate 2024 climate projection study using Bayesian Model Averaging of multiple global climate models for Sindh projected a further rise of up to 1.3°C in maximum temperature and 0.5°C in minimum temperature by 2044 relative to a recent baseline, with winter warming projected to be disproportionately larger than summer warming. Pakistan's Meteorological Department has separately documented a rising frequency of multi-day heatwave events (temperatures at or above 40°C and 45°C for five, seven, and ten consecutive days) across Sindh since the 1990s a trend distinct from, but consistent with, the general warming signal reported above, and a reminder that this report's finding of lower May-July means in 2022 than 2010 reflects those two specific years, not a reversal of the heatwave-frequency trend.

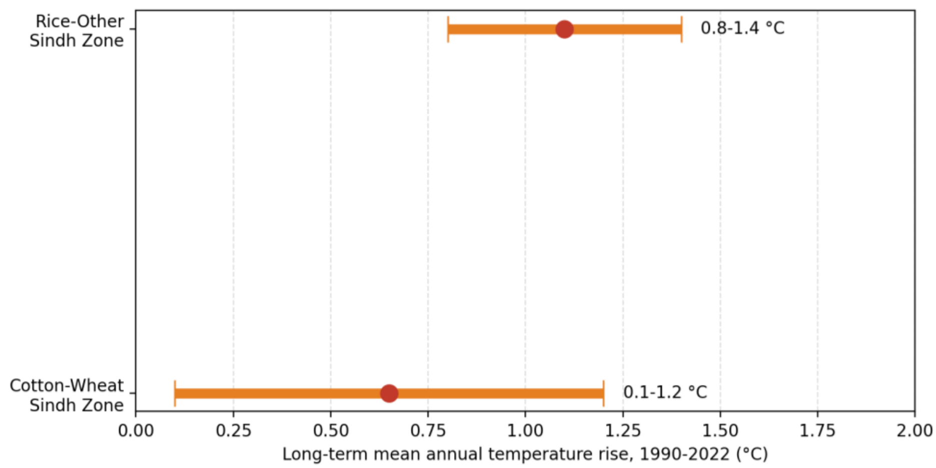


Figure 3. Published long term (1990-2022) warming trend ranges for Sindh's cotton, wheat and rice other agro climatic zones, based on Mann-Kendall/Sen's slope analysis of 21 PMD stations (Qureshi et al., 2023).

4.4 District Level Data Table

The ArcGIS Pro zonal statistics for all 27 districts is provided below for reference and reuse. Districts marked with an asterisk (*) are physically small relative to the raster cell size and should be treated with additional caution, the district marked with a dagger (†) is a largely uninhabited saline marsh.

District	Division	Temp 2010 (°C)	Temp 2022 (°C)	Change in Temp (°C)	Precip 2010 (mm)	Precip 2022 (mm)	Change in Precip (%)
Badin	Hyderabad	32.28	31.49	-0.79	321.5	447.6	+39.2%
Dadu	Hyderabad	35.59	34.17	-1.42	148.7	380.2	+155.7%
Ghotki	Sukkur	35.48	34.18	-1.31	149.1	317.8	+113.2%
Hyderabad	Hyderabad	32.68	31.85	-0.83	247.0	399.6	+61.8%
Jakobabad	Larkana	35.55	34.29	-1.26	105.8	231.1	+118.4%
Jamshoro	Hyderabad	31.57	31.03	-0.54	226.8	444.8	+96.2%
Karachi Central*	Karachi	29.74	29.28	-0.46	294.4	556.9	+89.2%
Karachi East	Karachi	29.96	29.44	-0.52	298.0	564.7	+89.5%
Karachi South*	Karachi	29.88	29.38	-0.50	281.8	544.4	+93.2%
Karachi West	Karachi	29.56	29.10	-0.46	274.2	547.6	+99.7%
Kashmore	Larkana	35.45	34.21	-1.24	104.5	217.6	+108.2%
Khairpur	Sukkur	34.85	33.59	-1.26	234.9	467.0	+98.8%
Larkana	Larkana	35.93	34.26	-1.67	88.5	204.4	+131.1%
Malir	Karachi	29.56	29.14	-0.42	269.4	521.9	+93.7%
Matiari	Hyderabad	33.72	32.85	-0.87	214.0	397.6	+85.8%
Mirphurkhas	Mirpur Khas	33.11	32.28	-0.84	318.1	457.6	+43.9%
Mithi	Mirpur Khas	32.55	31.80	-0.75	458.1	485.6	+6.0%
Naushahro Firoz	Shaheed Benazirabad	35.57	34.19	-1.38	163.4	429.1	+162.6%
Nawab Shah	Shaheed Benazirabad	34.62	33.47	-1.15	216.8	437.1	+101.6%
Rann of Kutch†	Non-divisional	32.37	31.62	-0.75	144.5	308.4	+113.4%
Sanghar	Shaheed Benazirabad	33.63	32.77	-0.86	297.5	470.6	+58.2%
Shikarpur	Larkana	35.58	34.15	-1.43	96.1	212.6	+121.2%
Sukkur	Sukkur	35.53	34.12	-1.41	166.4	354.9	+113.2%
Tando Allahyar	Hyderabad	32.10	31.30	-0.80	252.3	419.8	+66.4%
Tando M. Khan	Hyderabad	32.91	32.07	-0.84	271.0	443.2	+63.5%
Thatta	Hyderabad	31.01	30.37	-0.64	330.1	532.7	+61.4%
Umerkot	Mirpur Khas	32.99	32.15	-0.84	322.3	405.1	+25.7%

5. Discussion

The district level statistics computed for this report tell a consistent and, this time, fully quantified story, Sindh's strong north south thermal and rainfall gradient held in both 2010 and 2022, but 2010 was measurably the hotter year and 2022 was measurably, and in some upper Sindh districts dramatically, the wetter year. Read alongside the independently published multi decade literature, this is best understood as natural year to year variability superimposed on a genuine, slower warming and rainfall intensification trend, rather than evidence that the trend has reversed.

Agricultural and water-resource implications

The published trend literature indicates that warming in Sindh has been most pronounced in spring, ahead of the kharif (summer) cropping season, and that this earlier and stronger pre monsoon heat can increase irrigation requirements, accelerate soil moisture desiccation, and induce heat stress in wheat, cotton, rice, and sugarcane Sindh's dominant crops. At the same time, this report's finding that upper Sindh districts (Naushahro Firoz, Dadu, Larkana, Shikarpur) recorded the largest relative precipitation increases between 2010 and 2022 is a double edged development, modestly higher and more reliable monsoon totals could, in principle, reduce reliance on groundwater and canal withdrawals for kharif crops, but when concentrated into short, intense bursts as in 2022 the same rainfall increase instead produces field inundation, waterlogging, and secondary soil salinization, particularly in the poorly-drained central and lower Sindh plains.

Flood risk and the 2022 event as a case study

The scale of the 2022 flood in Sindh illustrates why precipitation intensity, not just seasonal totals, deserves particular attention in future ENC risk products. Independent attribution research attributes a meaningful share of the extreme 2022 monsoon rainfall to the effect of global warming on regional atmospheric moisture and circulation, layered on top of a strong La Nina state that year. This report's finding that upper Sindh districts, historically the driest part of the province, recorded the largest relative rainfall increases suggests that drainage capacity, canal-bank protection, and flood-plain land-use planning in that zone may need re-evaluation against a wetter, more intense monsoon envelope than historical design norms assumed. The parallel finding of a sharp precipitation increase across the Karachi district cluster is consistent with independently reported severe urban flooding in Karachi during the 2022 monsoon, a distinct risk pathway from the rural/agricultural flooding further north.

Heat risk in upper Sindh and the Thar margin

Even though 2022 was as a cooler year than 2010 in the May-July window at every single district in this analysis, the independent PMD and peer-reviewed literature is clear that the frequency of extreme heat events has been rising in Sindh since the 1990s. Larkana, Shikarpur, Jakobabad, and the Sukkur corridor consistently recorded this report's highest district level temperatures in both reference years, confirming upper Sindh's status as the province's chronic heat risk zone regardless of which specific year is examined.

Uncertainty and interpretive caution

Three sources of uncertainty merit explicit acknowledgement. First, ERA5 and CHIRPS, while state of the art, are model and satellite based products rather than direct ground truth, and both can carry residual bias in arid, data sparse regions. Second, comparing only two years cannot separate a genuine climate trend from natural year to year variability driven by phenomena such as El Nino-Southern Oscillation. Third, two physically small Karachi districts (Karachi Central, Karachi South) draw on fewer underlying raster cells than Sindh's larger districts and their exact values should be treated with slightly more caution, though both were confirmed by independent cross validation.

6. Conclusion

This district level analysis of Sindh's summer temperature and monsoon rainfall confirms a pattern that matches what is already well known about the province. Upper Sindh is hot and dry, central Sindh is warmer with moderate rainfall and forms the province's farming heartland, the Thar margin is arid, and the coastal belt around Karachi stays cooler and wetter than the rest of Sindh. Looking at exact figures for all districts, two clear results stand out. Every single district was hotter in 2010 than in 2022 during the May-July period, and every single district was wetter in 2022 than in 2010 during the monsoon season. Upper Sindh saw the sharpest rise in rainfall, which fits with what is already known, 2022 was one of the most extreme monsoon years in Pakistan's history. These two years, however, are just two data points. Longer climate studies covering multiple decades in Sindh show a real, ongoing warming trend of about 0.1 to 1.4°C in average yearly temperature since 1990, along with more frequent heatwaves and a monsoon that is delivering more rain overall, but in a less predictable and sometimes more damaging way. So the results here should be read as two examples of this natural year to year swing, sitting on top of that slower long term shift, not as a sign that the climate is cooling or that flooding risk has faded.

For ENC's advisory work, this means clients in agriculture, water management, and disaster planning should not treat heat stress and monsoon flooding as two separate problems. They are connected risks that build on each other, and upper Sindh stands out as the area facing both the highest heat exposure and, based on this data, the biggest swings in monsoon rainfall from one year to the next.

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