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Spatio-Temporal Analysis of Aridity Trends and Shifts in Karnataka Over 63 Years (1958-2020): Insights into Climate Adaptation

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ABSTRACT

Understanding aridity trends is crucial for climate adaptation strategies. This study analyzes the spatial and temporal fluctuations in aridity across Karnataka, India, over 63 years from 1958 to 2020 using the Aridity Index (AI). Monthly, seasonal, and annual AI values were calculated using precipitation and potential evapotranspiration data sourced from TerraClimate. The results indicate that approximately 74% (142,464 sq. km) of Karnataka is classified as dryland, ranging from semi-arid to dry subhumid zones, while 26% (49,416 sq. km) falls under more humid non-dryland areas. The Malnad and coastal regions are more humid compared to the predominantly semi-arid northern inland Karnataka. Temporal analysis between the periods 1958–1990 and 1991–2020 revealed that 6.24% of the land area shifted from semi-arid to dry subhumid, indicating increased moisture availability, whereas 0.43% shifted from dry subhumid to semi-arid, suggesting localized aridification. During the post-monsoon season, 14.12% of dryland areas transitioned to non-dryland, with substantial improvements in moisture availability observed in districts such as Uttara Kannada (59.21%) and Mandya (82.97%). Conversely, 1.5% of non-dryland areas converted to dryland, indicating localized decreases in water resources. Seasonal analysis revealed that 99.92% of the summer aridity status remained constant, while during the monsoon season, only 2.42% of dryland areas changed to non-dryland, reflecting stable monsoonal rainfall patterns. These findings highlight the significant influence of topography, monsoonal patterns, and water management on aridity dynamics in Karnataka. The study provides valuable insights for developing policies on climate adaptation, sustainable agriculture, and regional water resource management. Addressing the increasing trends in aridity is essential to reduce desertification risks and enhance the State's resilience to climate change.

INTRODUCTION

Climate vulnerability is the propensity of human populations to be adversely affected by the consequences of climate change, taking into account exposure, sensitivity, and adaptive capability (Turner et al. 2003). The Aridity Index (AI) is a quantitative measure of the degree of dryness of climate in a particular region. The only study that meets the quantitative variables criteria and has a computation that correctly identifies the climatic condition in question. AI is often employed in studies regarding the detection of dry surfaces and a region's vulnerability to desertification. It is said to be very precise in defining these areas (de Jesus et al. 2019). Aridity is one of the aspects that can be used to classify climate sensitivity, and it refers to the degree of dryness of a region. This dryness is measured using the Aridity Index (AI), which is a critical parameter when mapping areas of dryness (Alawadi et al. 2024) and their sensitivity to desertification. As a result of climatic change, there is an increase in arid and semi-arid regions across the globe. PET is higher than AET in all climate regions, thus enhancing aridity (Shoshany et al. 2023). It conjures up pictures of barren, arid landscapes devoid of precipitation and natural surface water bodies (Mustafa et al. 2018). Regions that are characterized by arid and semi-arid environments in the world are very sensitive to changes in land use and or climate occasioned by human beings. The process of desertification is regarded to be one of the most vital impacts of global warming on the environment. The research that has been carried out shows that total PET augments the dryness in all the climatic zones since it exceeds the precipitation, whether it is annual or seasonal (Pour et al. 2020). Climate models predicted that the worldwide arid and semi-arid climate area will increase by 11% to 23% by 2100, which will exacerbate aridification in various regions of the world (Ahmed et al. 2019). Numerous scholars have examined the spatial variance, shifting of climate, and trends of the global and regional aridity index (Mustafa et al. 2018, Kumar et al. 2021, Ramarao et al. 2019, Önder et al. 2009, Ahmed et al. 2019, Ramachandran et al. 2015, Sarma & Singh 2019, Pour et al. 2020).

Two-thirds of the workforce in India is employed in agriculture and related industries. The country is an agrarian society. It is the most rain-fed country in the world, with almost 61 percent of farmers relying on it (Kumar et al. 2021). Estimating aridity patterns has a big influence on climate change worldwide. Arid and semiarid regions comprise around 40% of the Earth's total area (Mustafa et al. 2018). Rainfall, evapotranspiration, and temperature are the aspects of climate that are of importance to the productivity of agriculture. The climate is gradually altering in some aspects of India, especially in the semi-arid regions where the dry season is longer, water is scarce, and regions are prone to desertification. It is essential to understand these trends in the context of designing strategies for mitigating the impact of climate change on agriculture, water resources, and sustainable development in India (Sharma et al. 2023).

Trends of aridity in the geography of Karnataka depend a lot on the plateau area, western ghats, and other coastal areas of the state. Spread over the large area of the Deccan plateau, which essentially is a trapezium of the semi-arid region. The region boasts several river basins, such as the rivers Krishna, Kaveri/Tapi, and Tungabhadra, that support a high level of agriculture. (Shankara et al. 2023). These bodies of water are essential for producing hydroelectric power and for irrigation, but the plateau is especially susceptible to the effects of climate change, which can worsen aridity and have an impact on the water supply (Ghimire et al. 2019). The natural equilibrium and water resources of the state largely depend on the colossal rainfall of the Western Ghats. It means that coastal areas can affect the state's general climatic adaptability to heat, water avails, farming, and other trends pointing to the escalation of dryness even while they are blessed with humid tropical marine conditions (Mann et al. 2023).

The analysis comparing the changes of aridity in Karnataka, India (Table 1) points out how important it is to understand climate change to foresee and maintain the policies and planning. Coastal areas remain somewhat marshy, which is still possible for human existence, but increasing desertification in the interior zone of Karnataka poses threats to water and sustainable farming (Beeraladinni & Patil 2023). Research of temporal and spatial characteristics of aridity can contribute to the development of strategies for increasing climate resistance depending on the availability of water and water resources for sustainable agriculture under conditions of climate change (Xu et al. 2023). Planning for regional water conservation, irrigation infrastructure, agriculture sustainability, and climate resilience policies in Karnataka can be informed by the aridity information generated.

MATERIALS AND METHODS

Study Area

Karnataka, a state in southwest India, is renowned for its vibrant economy and rich cultural legacy. The geographic coordinates of Karnataka (Fig.1) are latitude 11.6° N and longitude 18.5° E and 74.1° E, respectively. It is crucial to understand that this state has an incredible variety of topography, climate, and ecosystems, which are distinguished by a variety of topographical features, including the Deccan Plateau, the Eastern Ghats, and the Western Ghats. The Western Ghats, with their abundant vegetation and rich wildlife, are crucial for maintaining Karnataka's balance of nature. On the other hand, due to its undulating landscape, the Deccan Plateau completely supports agricultural activity. The Eastern plains are less noticeable and do not play a significant role. The state's varied geography is the cause of its varying climate. Adjacent to the enormous Arabian Sea on the west, the coastline regions experience a humid, tropical maritime environment. Furthermore, it is noteworthy that the Western Ghats have relatively high rainfall, which supports lush forests and feeds the main rivers that traverse the state of Karnataka.

Table 1: Index values of AI Subtypes (Mustafa et al. 2018) (Pinjarla et al. 2021).

Climate Type	Aridity Index
Dryland Subtypes	
Hyper-arid	AI <= 0.05
Arid	AI <= 0.2
Semi-arid	AI <= 0.5
Dry Subhumid	AI <= 0.65
Non-Drylands	
Humid	AI > 0.65
Cold	PET < 400mm

The semi-arid environment of the Deccan Plateau supports agricultural activity with the help of rivers and reservoirs. There is an extensive network of watercourses throughout Karnataka, the most prominent being the Krishna, Kaveri, and Tungabhadra. The state's topography includes the coastal strip, the humid Western Ghats, and the arid Deccan Plateau, all of which contribute to the state's varying levels of aridity (Tripti et al. 2016). Due to their high evapotranspiration and low rainfall, the northern inland areas are primarily semi-arid and, therefore, susceptible to rising trends in aridity. The Malnad region in the Western Ghats, on the other hand, receives a lot of rainfall, which keeps the temperature humid and promotes lush forests and a high level of biodiversity (Venkatesh et al. 2021). High humidity is a result of tropical maritime conditions in coastal Karnataka. Because of this climatic variation, a thorough analysis of aridity is required to comprehend the temporal and geographical dynamics of dryness throughout the state. This understanding is essential for managing water supplies, agricultural methods, and initiatives for climate resilience (Naik & Kunte 2023).

Methodology

The methodology section of this research paper elucidates the process of acquiring and processing datasets essential for calculating the aridity index, a critical measure in ecological and hydrological studies. The datasets required for this computation include precipitation (PPT) and potential evapotranspiration (PET), which were sourced from the TerraClimate database, accessible via http://www.climatologylab.org, in the netCDF (Network Common Data Form) format. TerraClimate is renowned for providing comprehensive climatic data, offering pivotal inputs for global-scale ecological and hydrological research. The datasets feature time-variant attributes with high spatial resolution, enabling detailed analysis of climatic variations over time.

This research utilizes the datasets representing monthly distributions spanning 63 years, from 1958 to 2020. The calculation of the Aridity Index (AI) is based on the formula proposed by the United Nations Environment Programme (UNEP) in 1992, where AI is defined as the ratio of annual precipitation to potential evapotranspiration (AI = PPT/PET) (Tegos et al. 2023). This formula facilitates the derivation of the monthly Aridity Index, which serves as a foundational element for subsequent calculations (Tegos et al. 2023). The study extends the utility of these monthly indices to compute temporal, seasonal, and annual aridity indices, thereby enabling a multifaceted analysis of aridity trends over the study period (Fig.2).

RESULTS AND DISCUSSION

Spatial Analysis of Yearly Mean Aridity Index for 63 years (1958-2020)

Karnataka, which covers 191,881 sq. km, has two main

Fig. 1: Study area Map.

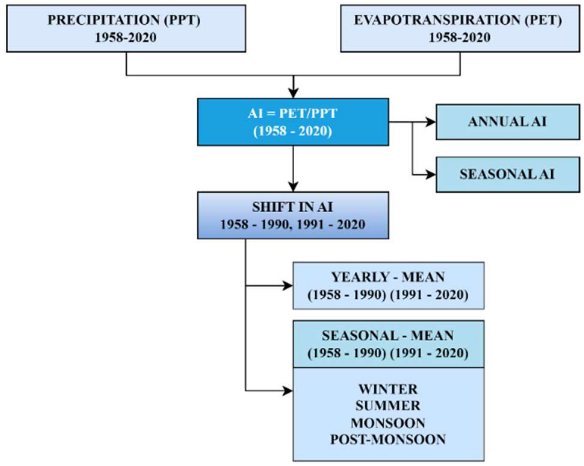

Fig. 2: Flow chart of Aridity Index, Karnataka.

climate types, according to the research: non-dryland areas and dryland variants. Dryland, with 142,464 square kilometers, makes up around 74% of the state and has semi-arid and dry-subhumid climates. The Western Ghats' rain shadow effect, which blocks the southwest monsoon winds and reduces rainfall and arid conditions, is the main factor influencing these dryland areas (Dupdal et al. 2022) in districts such as Bagalkot, Vijayapura, and Kalburgi. The remaining 26% of the state, or 49,416 square kilometers, is classified as non-dryland and has a humid climate. This comprises regions that receive substantial rainfall due to the orographic lift of moist monsoon winds over the Western Ghats, such as Uttara Kannada, Udupi, Dakshina Kannada, and Kodagu (Fig. 3).

Known for hot and occasionally extremely hot conditions, the semi-arid regions include districts like Bagalkot, Vijayapura, Kalburgi, Bidar, Raichur, Koppal, Gadag, Haveri, Ballari, Chitradurga, Tumakuru, Kolar, Bengaluru (Urban), Bengaluru (Rural), Mandya, Chikkaballapura, Ramanagara, Yadgir, and Vijayanagara (Chowdari et al. 2023). The orographic lift effect, on the other hand, causes the Western Ghats and coastal areas, which include districts like Uttara Kannada and Kodagu, to have a humid climate (Venkatesh et al. 2021). In addition, districts with a combination of humid, semi-arid, and dry-subhumid climates include Belagavi, Dharwad, Chikkamagaluru, Hassan, Davanagere, Shivamogga, Chamarajanagara, and Mysuru. Their position as a transition zone between the arid interior regions and the Western Ghats has resulted in a variety of microclimates, which in turn has caused this climatic diversity. So, the interaction of terrain, monsoonal patterns, and regional geography results in the total climatic heterogeneity in Karnataka.

Spatial Analysis of Winter Seasonal Mean Aridity Index for 63 years (1958-2020)

Karnataka is mostly characterized by severely dryland subtypes during this time, according to an analysis of the winter seasonal aridity index data. To be more precise, a dry-subhumid climate is found in just 5% (10,342 sq. km) of the state, while 95% (181,539 sq. km) of the state is classed as semi-arid. Belagavi, Kalburgi, Kolar, Kodagu, Mysuru, Chamarajanagara, and Ramanagara are among the districts

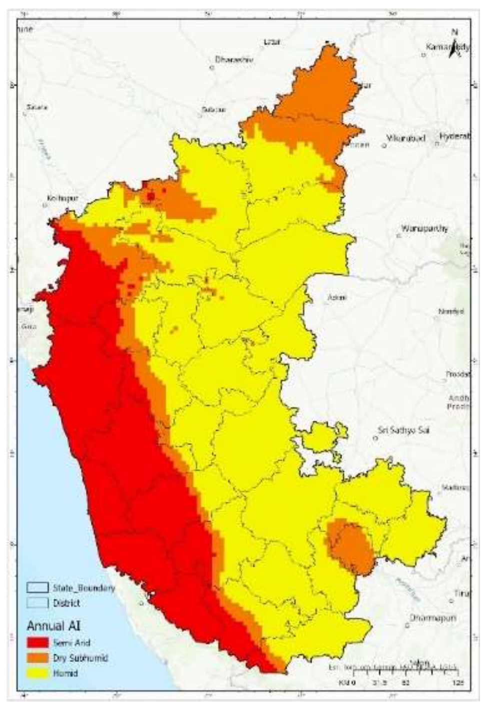

Fig. 3: Annual Mean Aridity Index for 63 years (1958-2020).

that have small areas of dry-subhumid climate, whereas the remaining districts are primarily semi-arid (Fig. 4).

This extensive semi-arid state in the winter months is caused by the monsoonal rainfall significantly decreasing and the northeast monsoon winds being predominant. By October, the southwest monsoon has passed, leaving the area with less moisture, which causes lower humidity and higher evaporation rates (Chowdari et al. 2023). The Western Ghats and other geological features of Karnataka, along with the lack of significant winter rainfall, exacerbate the dry conditions and prohibit the occurrence of humid climates (Venkatesh et al. 2021). This demonstrates the critical influence that monsoonal cycles and seasonal wind patterns have on determining the winter climate of Karnataka.

Spatial Analysis of Summer Seasonal Mean Aridity Index for 63 years (1958-2020)

The summer seasonal statistics reveal that only 1% (1,319 sq. km) of Karnataka is classified as non-dryland, while 99% (190,562 sq. km) comprises dryland subtypes. Non-dryland climates are present in 11% and 20% of Dakshina Kannada and Kodagu districts, respectively. The remaining districts predominantly exhibit semi-arid climates (95%) and dry-subhumid climates (4%) (Fig. 5).

Due to high temperatures and a delayed start of the southwest monsoon, dryland subtypes predominate in Karnataka throughout the summer months. After a protracted hot and dry stretch that leaves vast arid conditions in its wake, the monsoon usually arrives in June (Chowdari et al. 2023). Due to its early pre-monsoon showers and location along the Western Ghats, only portions of Dakshina Kannada and Kodagu maintain non-dryland climates (Mann et al. 2023). This highlights the impact of delayed monsoonal rainfall and high summer temperatures on Karnataka's climate.

Spatial Analysis of Monsoon Seasonal Mean Aridity Index for 63 Years (1958-2020)

During the monsoon season, approximately 80% of Karnataka (153,119 sq. km) experiences a humid climate, while 20% (38,761 sq. km) falls under dryland subtypes. Over 75% of the areas in districts such as Belagavi, Bagalkot, Vijayapura, Kalburgi, Bidar, Raichur, Koppal, Gadag, Dharwad, Uttara Kannada, Haveri, Davanagere, Shivamogga, Udupi, Chikkamagaluru, Bengaluru (Urban), Bengaluru (Rural), Dakshina Kannada, Kodagu, Yadgir, and Vijayanagara are classified as humid. Conversely, districts like Ballari (32%), Chitradurga (92%), Tumakuru (67%), Kolar (64%), Mandya (96%), Hassan (38%), Mysuru (43%), Chamarajanagara (81%), Chikkaballapura (41%), and Ramanagara (33%) have significant portions classified as semi-arid and dry subhumid (Fig. 6).

The extensive humid climate during the monsoon season results from the intense southwest monsoon winds, bringing heavy rainfall across most of the state. This increases humidity levels, particularly in areas along the Western Ghats and coastal regions, where orographic lift enhances rainfall (Venkatesh et al. 2021). Districts with sizable dryland subtypes experience reduced monsoonal rainfall as a result of their topographical barriers and geographic location, producing shadows cast by rain. This distribution highlights how important regional topography and monsoonal patterns are in determining the seasonal climatic dynamics of Karnataka (Chowdari et al. 2023).

Spatial Analysis of Post Monsoon Seasonal Mean Aridity Index for 63 years (1958-2020)

Approximately 70% of Karnataka's area falls under dryland subtypes, while 30% is classified as non-dryland climate. Over 75% of Udupi, Kolar, Bengaluru (Urban), Bengaluru (Rural), Mandya, Dakshina Kannada, Kodagu, Mysuru, Chamarajanagara, and Ramanagara districts experience a humid climate. In contrast, over 75% of Belagavi, Bagalkot, Vijayapura, Kalburgi, Bidar, Raichur, Koppal, Gadag, Dharwad, Haveri, Ballari, Chitradurga, Davanagere, Tumakuru, Yadgir, and Vijayanagara districts are classified as dryland subtypes. Districts like Uttara Kannada, Shivamogga, Chikkamagaluru, Hassan, and Chikkaballapura exhibit both dry-subhumid and humid climates during the post-monsoon season (Fig. 7).

The Western Ghats' rain shadow effect, which restricts the reach of monsoonal rainfall and creates vast semi-arid and dry-subhumid conditions, and the state's varied topography are the main causes of Karnataka's predominance of dryland

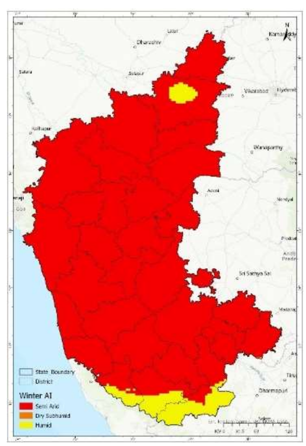

Fig. 4: Winter Mean Aridity Index for 63 years.

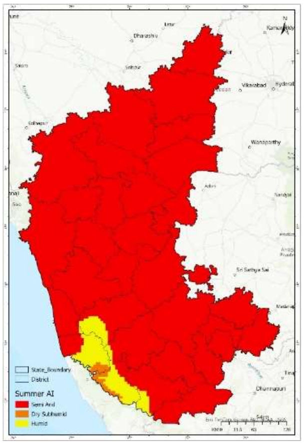

Fig. 5: Summer Mean Aridity Index for 63 years.

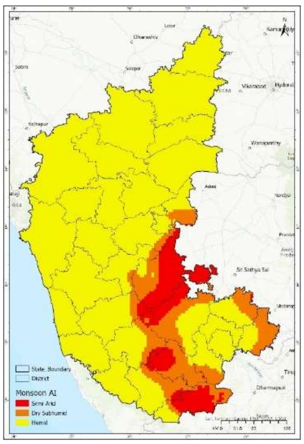

Fig. 6: Monsoon Mean Aridity Index for 63 years.

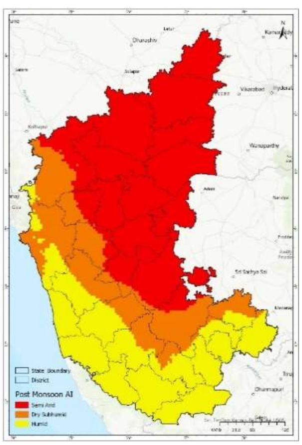

Fig. 7: Post-Monsoon Mean Aridity Index for 63 years.

subtypes (Gangadhara 2017). In contrast, the areas with primarily humid climates profit from the Western Ghats' orographic lift and the southwest monsoon winds, which provide significant rainfall and elevated humidity levels. Districts like Uttara Kannada and Shivamogga see a post-monsoon climate that retains the monsoon's lasting impacts, with residual moisture preserving a balance between humid and dry-subhumid temperatures. This demonstrates how, crucially, regional topography and monsoonal patterns affect Karnataka's seasonal climate changes (Johnson et al. 2017).

Shifting of Aridity Index

Spatial analysis of yearly mean aridity index shifts in different districts of Karnataka between 1958-1990 (33yrs) and 1991-2020 (30 yrs): The metrics that are displayed comprise the area that changes from being classified as dryland to non-dryland, the areas that remain unchanged, and the overall area of the district across two consecutive multi-decadal periods per year. The analysis shows that there are very few changes in aridity at the state level, with only 0.38% of Karnataka's total land area (191,881 sq km) going from dryland to non-dryland and 0.20% going the other way. In light of recent climate variability, nearly all districts (99.42%) showed no change in aridity patterns, demonstrating relative consistency in moisture availability across distinct agroclimatic zones (Fig.10) (Table 2).

District-level changes in dryland areas were somewhat larger in some semi-arid districts (Mysuru, Hassan, Shivamogga, Chikkamagaluru), with shifts ranging from 3 to 4%. These shifts were mainly due to the marginal development of non-dryland zones. But even in these districts, the aridity didn't change much, and the district remained over 95% steady. Concurrently, the dryland area changed by exactly 0% in 20 out of 31 districts. The meticulous geographical examination reveals that for the previous fifty years, Karnataka's winter and annual moisture availability have stayed comparatively consistent. Due to the state's varied terrain and the Western Ghats' protective role, which moderates sharp fluctuations in moisture availability and stabilizes local climates, the state is stable (Pinjarla et al. 2021).

Spatial analysis of yearly mean aridity index shifting in subtypes of arid lands between 1958-1990 (33yrs) and 1991-2020 (30yrs): Karnataka's yearly mean aridity index from 1958-1990 to 1991-2020 was analyzed spatially, and the results indicate that while 6.24% of the land area changed from semi-arid to dry subhumid, indicating increasing moisture availability, 93.12% of the districts did not change in aridity type. This change improves livelihoods in agriculture and water resources. Conversely, drier conditions resulted from a shift in the land area from dry subhumid to semi-arid due to decreased or irregular rainfall, accounting for 0.43% of the total land area. Furthermore, 0.20 percent

Table 2: Spatial Analysis of Annual Mean Aridity Index Shifting between 1958 – 1990 (33yrs) and 1991 - 2020 (30yrs).

District Names	Dryland to Non Drylands in sq. km.	Non Drylands to Dryland in sq. km.	No Shift area in sq. km.	Total area in sq. km.	%age of Area in shifting Dryland to Non Drylands	%age of Area in shifting Non Drylands to Dryland	%age of area with No Shift
Karnataka State	731.00	390.00	190760.00	**191881**	0.38	0.20	99.42
Belagavi	45.00	307.00	13056.00	**13408**	0.34	2.29	97.37
Bagalkot	6.00	0.00	6561.00	**6567**	0.09	0.00	99.91
Vijayapura	76.00	0.00	10433.00	**10509**	0.72	0.00	99.28
Kalburgi	0.00	0.00	10972.00	**10972**	0.00	0.00	100.00
Bidar	0.00	0.00	5449.00	**5449**	0.00	0.00	100.00
Raichur	0.00	0.00	8466.00	**8466**	0.00	0.00	100.00
Koppal	0.00	0.00	5578.00	**5578**	0.00	0.00	100.00
Gadag	0.00	0.00	4658.00	**4658**	0.00	0.00	100.00
Dharwad	0.00	41.00	4217.00	**4258**	0.00	0.96	99.04
Uttara Kannada	0.00	0.00	10302.00	**10302**	0.00	0.00	100.00
Haveri	0.00	41.00	4780.00	**4821.00**	0.00	0.85	99.15
Ballari	0.00	0.00	4262.00	**4262.00**	0.00	0.00	100.00
Chitradurga	0.00	0.00	8435.00	**8435.00**	0.00	0.00	100.00
Davanagere	0.00	0.00	4482.00	**4482.00**	0.00	0.00	100.00
Shivamogga	83.00	0.00	8396.00	**8479.00**	0.98	0.00	99.02
Udupi	0.00	0.00	3574.00	**3574.00**	0.00	0.00	100.00
Chikkamagaluru	83.00	0.00	7131.00	**7214.00**	1.15	0.00	98.85
Tumakuru	0.00	0.00	10599.00	**10599.00**	0.00	0.00	100.00
Kolara	0.00	0.00	3980.00	**3980.00**	0.00	0.00	100.00
Bengaluru (Urban)	0.00	0.00	2193.00	**2193.00**	0.00	0.00	100.00
Bengaluru (Rural)	0.00	0.00	2298.00	**2298.00**	0.00	0.00	100.00
Mandya	0.00	0.00	4955.00	**4955.00**	0.00	0.00	100.00
Hassan	167.00	0.00	6655.00	**6822.00**	2.45	0.00	97.55
Dakshina Kannada	0.00	0.00	4848.00	**4848.00**	0.00	0.00	100.00
Kodagu	0.00	0.00	4115.00	**4115.00**	0.00	0.00	100.00
Mysuru	251.00	0.00	6061.00	**6312.00**	3.98	0.00	96.02
Chamarajanagara	21.00	0.00	5615.00	**5636.00**	0.37	0.00	99.63
Chikkaballapura	0.00	0.00	4244.00	**4244.00**	0.00	0.00	100.00
Ramanagara	0.00	0.00	3525.00	**3525.00**	0.00	0.00	100.00
Yadgir	0.00	0.00	5274.00	**5274.00**	0.00	0.00	100.00
Vijayanagara	0.00	0.00	5633.00	**5633.00**	0.00	0.00	100.00

of the land area changed from humid to dry subhumid, indicating a shift in moisture content and a tendency toward drier weather (Fig. 8, 9) (Table 3).

There have been notable increases in dry subhumid land, mostly semi-arid regions, in districts like Bengaluru (Rural), Bengaluru (Urban), Kalburgi, Ramanagara, Mysuru, Vijayapura, and Chamarajanagara. However, the least amount of aridity type change was seen in districts like Raichur, Chitradurga, Uttara Kannada, Mandya, Udupi, Dakshina Kannada, and Kodagu, which are primarily semi-arid and humid areas. Improved water management is to blame for some areas' enhanced moisture availability, while less rainfall in other areas has resulted in drier conditions. This highlights the impact of regional water practices and climate variability on Karnataka's aridity patterns (Tripti et al. 2016).

Spatial analysis of summer seasonal mean aridity index shifting between 1958-1990 and 1991-2020 periods in Karnataka: During the two periods, only 0.01% (21 sq km) of Karnataka's 191,880 sq km of land went from

Table 3: Spatial Analysis of Yearly Mean Aridity Index Shifting in subtypes of arid lands between 1958 – 1990 (33yrs) and 1991 - 2020 (30yrs)

District Names	No Shift area in sq. km.	Semi-Arid to Dry Subhumid in sq. km.	Dry Subhumid to Semi-Arid in sq. km.	Humid to Dry Subhumid in sq. km	Total area in sq. km.	%age of area with No Shift	%age of Semi-Arid to Dry Subhumid	%age of Dry Subhumid to Semi-Arid	%age Humid to Dry Subhumid
Karnataka State	178677	11981	833	390	**191881**	93.12	6.24	0.43	0.20
Belagavi	12798	154	147	307	**13406**	95.46	1.15	1.10	2.29
Bagalkot	6329	232	6	0	**6567**	96.38	3.53	0.09	0.00
Vijayapura	9833	599	76	0	**10508**	93.58	5.70	0.72	0.00
Kalburgi	6557	4414	0	0	**10971**	59.77	40.23	0.00	0.00
Bidar	5429	19	0	0	**5448**	99.65	0.35	0.00	0.00
Raichur	8466	0	0	0	**8466**	100.00	0.00	0.00	0.00
Koppal	5354	224	0	0	**5578**	95.98	4.02	0.00	0.00
Gadag	4614	44	0	0	**4658**	99.06	0.94	0.00	0.00
Dharwad	4197	19	42	0	**4258**	98.57	0.45	0.99	0.00
Uttara Kannada	10302	0	0	0	**10302**	100.00	0.00	0.00	0.00
Haveri	4572	208	41	0	**4821**	94.84	4.31	0.85	0.00
Ballari	4204	58	0	0	**4262**	98.64	1.36	0.00	0.00
Chitradurga	8435	0	0	0	**8435**	100.00	0.00	0.00	0.00
Davanagere	4441	41	0	0	**4482**	99.09	0.91	0.00	0.00
Shivamogga	8299	97	83	0	**8479**	97.88	1.14	0.98	0.00
Udupi	3574	0	0	0	**3574**	100.00	0.00	0.00	0.00
Chikkamagaluru	7021	110	83	0	**7214**	97.32	1.52	1.15	0.00
Tumakuru	10410	188	0	0	**10598**	98.23	1.77	0.00	0.00
Kolara	3939	41	0	0	**3980**	98.97	1.03	0.00	0.00
Bengaluru (Urban)	828	1365	0	0	**2193**	37.76	62.24	0.00	0.00
Bengaluru (Rural)	679	1619	0	0	**2298**	29.55	70.45	0.00	0.00
Mandya	4955	0	0	0	**4955**	100.00	0.00	0.00	0.00
Hassan	6327	328	166	0	**6821**	92.76	4.81	2.43	0.00
Dakshina Kannada	4848	0	0	0	**4848**	100.00	0.00	0.00	0.00
Kodagu	4115	0	0	0	**4115**	100.00	0.00	0.00	0.00
Mysuru	5611	450	250	0	**6311**	88.91	7.13	3.96	0.00
Chamarajanagara	5299	315	21	0	**5635**	94.04	5.59	0.37	0.00
Chikkaballapura	4184	59	0	0	**4243**	98.61	1.39	0.00	0.00
Ramanagara	2361	1164	0	0	**3525**	66.98	33.02	0.00	0.00
Yadgir	5047	226	0	0	**5273**	95.71	4.29	0.00	0.00
Vijayanagara	5629	4	0	0	**5633**	99.93	0.07	0.00	0.00

dryland to non-dryland, while 0.06% (123 sq km) went from non-dryland to dryland. Over the thirty years, a staggering 99.92% (191,736 sq km) of the state's summer aridity levels stayed unaltered. Except for Dakshina Kannada and Kodagu, nearly all districts had little change (Fig. 11) (Table 4). The summertime moisture availability is consistent, which emphasizes the enduring climatic conditions-such as increasing temperatures and little precipitation—that sustain high levels of aridity.

Dakshina Kannada saw a minor improvement in aridity, with 0.33% (16 sq km) going from dryland to non-dryland. This suggests that localized precipitation patterns have somewhat alleviated aridity. Kodagu also exhibits a little improvement. The analysis highlights the ongoing moisture

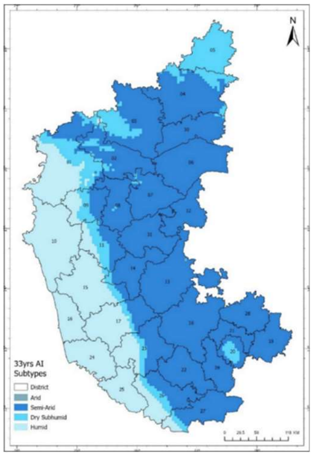

Fig. 8: Area Shifts of Aridity Index for 1958-1990.

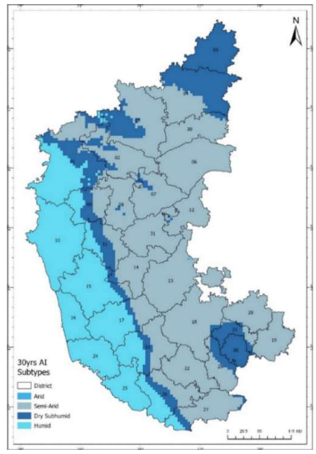

Fig. 9: Area Shifts of Aridity Index for 1991-2020.

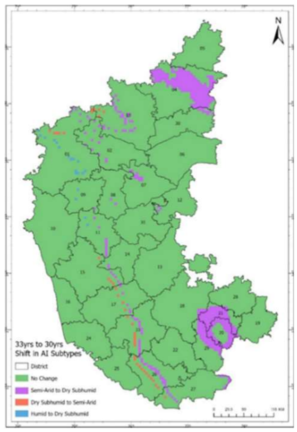

Fig. 10: Area Shifts of Aridity Index between 1958-1990 and 1991-2020.

deficit throughout the state throughout the summer months and shows that Karnataka's summer aridity has been mostly steady from 1991 to 2020 compared to earlier decades.

Spatial analysis of monsoon seasonal mean aridity index shifting between 1958-1990 and 1991-2020 periods in Karnataka: Out of Karnataka's total area of 191,881 sq km, only 2.42% (4,652 sq km) of dryland shifted to non-dryland, with no shift from non-dryland to dryland. A vast majority, 97.58% (187,229 sq km), remains unchanged, indicating stable moisture levels during monsoons. Districts like Belagavi, Kalburgi, Koppal, Uttara Kannada, Udupi, and Dakshina Kannada saw no shift in aridity patterns, suggesting consistent monsoon rainfall over the past 30 years (Fig. 12) (Table. 5).

Partial dryland to non-dryland conversion is observed in Ballari (12.41%), Chitradurga (5.61%), Davanagere (7.90%), Tumakuru (8.63%), Kolara (14.47%), and Chikkaballapura (15.74%) due to localized increases in precipitation. The limited percentage of relocated areas overall indicates that Karnataka's monsoon rainfall patterns have remained relatively steady, with some districts seeing slight improvements due to localized meteorological conditions and efficient water management.

Spatial analysis of post-monsoon seasonal mean aridity index shifting between 1958-1990 (33yrs) and 1991-2020 (30yrs): The analysis classifies Karnataka's land changes into drylands turning to non-drylands, non-drylands turning to drylands, and no-shift areas. Out of 191,881 sq km, 14.12% (27,087 sq km) of dryland transitioned to non-dryland, while 1.50% (2,877 sq km) of non-dryland shifted to dryland, indicating improved moisture availability over the past 30 years. A significant 84.38% (161,917 sq km) saw no change, suggesting stable aridity levels (Fig. 13) (Table 6). Districts like Bidar, Kalburgi, and Raichur showed no aridity shift.

Significant dryland to non-dryland shifts occurred in Uttara Kannada (59.21%), Mandya (82.97%), Hassan

Table 4: Spatial Analysis of Summer Mean Aridity Index Shifting between 1958-1990 (33 yrs) and 1991-2020 (30 yrs).

District Names	Dryland to Non Drylands in sq. km.	Non Drylands to Dryland in sq. km.	No Shift area in sq. km.	Total area in sq. km.	%age of Area in shifting Dryland to Non Drylands	%age of Area in shifting Non Drylands to Dryland	%age of area with No Shift
Karnataka State	21.00	123.00	191736.00	**191880**	0.01	0.06	99.92
Belagavi	0.00	0.00	13408.00	**13408**	0.00	0.00	100.00
Bagalkot	0.00	0.00	6566.00	**6566**	0.00	0.00	100.00
Vijayapura	0.00	0.00	10508.00	**10508**	0.00	0.00	100.00
Kalburgi	0.00	0.00	10972.00	**10972**	0.00	0.00	100.00
Bidar	0.00	0.00	5449.00	**5449**	0.00	0.00	100.00
Raichur	0.00	0.00	8466.00	**8466**	0.00	0.00	100.00
Koppal	0.00	0.00	5578.00	**5578**	0.00	0.00	100.00
Gadag	0.00	0.00	4658.00	**4658**	0.00	0.00	100.00
Dharwad	0.00	0.00	4258.00	**4258**	0.00	0.00	100.00
Uttara Kannada	0.00	0.00	10302.00	**10302**	0.00	0.00	100.00
Haveri	0.00	0.00	4821.00	**4821.00**	0.00	0.00	100.00
Ballari	0.00	0.00	4262.00	**4262.00**	0.00	0.00	100.00
Chitradurga	0.00	0.00	8435.00	**8435.00**	0.00	0.00	100.00
Davanagere	0.00	0.00	4482.00	**4482.00**	0.00	0.00	100.00
Shivamogga	0.00	0.00	8479.00	**8479.00**	0.00	0.00	100.00
Udupi	0.00	0.00	3574.00	**3574.00**	0.00	0.00	100.00
Chikkamagaluru	0.00	0.00	7214.00	**7214.00**	0.00	0.00	100.00
Tumakuru	0.00	0.00	10599.00	**10599.00**	0.00	0.00	100.00
Kolara	0.00	0.00	3980.00	**3980.00**	0.00	0.00	100.00
Bengaluru (Urban)	0.00	0.00	2193.00	**2193.00**	0.00	0.00	100.00
Bengaluru (Rural)	0.00	0.00	2298.00	**2298.00**	0.00	0.00	100.00
Mandya	0.00	0.00	4955.00	**4955.00**	0.00	0.00	100.00
Hassan	0.00	0.00	6821.00	**6821.00**	0.00	0.00	100.00
Dakshina Kannada	16.00	102.00	4730.00	**4848.00**	0.33	0.33	97.57
Kodagu	5.00	21.00	4090.00	**4116.00**	0.12	0.12	99.37
Mysuru	0.00	0.00	6312.00	**6312.00**	0.00	0.00	100.00
Chamarajanagara	0.00	0.00	5636.00	**5636.00**	0.00	0.00	100.00
Chikkaballapura	0.00	0.00	4244.00	**4244.00**	0.00	0.00	100.00
Ramanagara	0.00	0.00	3525.00	**3525.00**	0.00	0.00	100.00
Yadgir	0.00	0.00	5274.00	**5274.00**	0.00	0.00	100.00
Vijayanagara	0.00	0.00	5633.00	**5633.00**	0.00	0.00	100.00

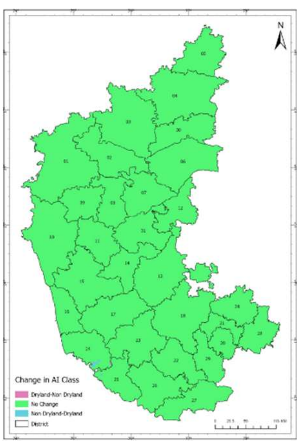

Fig. 11: Spatial Analysis of Summer Mean Aridity Index Shifting between 1958-1990 and 1991-2020.

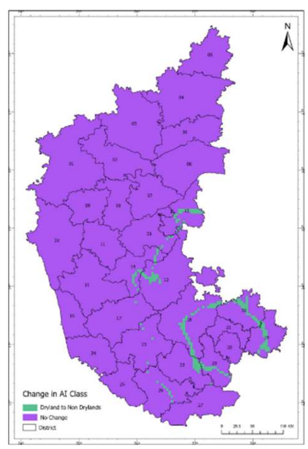

Fig. 12: Spatial Analysis of Monsoon Mean Aridity Index Shifting between 1958-1990 and 1991-2020.

Table 5: Spatial Analysis of Monsoon Mean Aridity Index Shifting between 1958-1990 (33yrs) and 1991-2020 (30 yrs).

S.No.	District Names	Dryland to Non Drylands in sq. km.	Non Drylands to Dryland in sq. km.	No Shift area in sq. km.	Total area in sq. km.	%age of Area in shifting Dryland to Non Drylands	%age of Area in shifting Non Drylands to Dryland	%age of area with No Shift
0	**Karnataka State**	4652.00	0.00	187229.00	**191881**	2.42	0.00	97.58
1	Belagavi	0.00	0.00	13408.00	**13408**	0.00	0.00	100.00
2	Bagalkot	0.00	0.00	6566.00	**6566**	0.00	0.00	100.00
3	Vijayapura	0.00	0.00	10508.00	**10508**	0.00	0.00	100.00
4	Kalburgi	0.00	0.00	10972.00	**10972**	0.00	0.00	100.00
5	Bidar	0.00	0.00	5449.00	**5449**	0.00	0.00	100.00
6	Raichur	0.00	0.00	8466.00	**8466**	0.00	0.00	100.00
7	Koppal	0.00	0.00	5578.00	**5578**	0.00	0.00	100.00
8	Gadag	0.00	0.00	4658.00	**4658**	0.00	0.00	100.00
9	Dharwad	0.00	0.00	4258.00	**4258**	0.00	0.00	100.00
10	Uttara Kannada	0.00	0.00	10302.00	**10302**	0.00	0.00	100.00
11	Haveri	0.00	0.00	4821.00	**4821.00**	0.00	0.00	100.00
12	Ballari	529.00	0.00	3733.00	**4262.00**	12.41	0.00	87.59
13	Chitradurga	473.00	0.00	7963.00	**8436.00**	5.61	0.00	94.39
14	Davanagere	354.00	0.00	4128.00	**4482.00**	7.90	0.00	92.10
15	Shivamogga	0.00	0.00	8479.00	**8479.00**	0.00	0.00	100.00
16	Udupi	0.00	0.00	3574.00	**3574.00**	0.00	0.00	100.00
17	Chikkamagaluru	21.00	0.00	7193.00	**7214.00**	0.29	0.00	99.71
18	Tumakuru	915.00	0.00	9685.00	**10600.00**	8.63	0.00	91.37
19	Kolara	576.00	0.00	3405.00	**3981.00**	14.47	0.00	85.53
20	Bengaluru (Urban)	0.00	0.00	2193.00	**2193.00**	0.00	0.00	100.00
21	Bengaluru (Rural)	0.00	0.00	2298.00	**2298.00**	0.00	0.00	100.00
22	Mandya	363.00	0.00	4592.00	**4955.00**	7.33	0.00	92.67
23	Hassan	83.00	0.00	6738.00	**6821.00**	1.22	1.22	98.78
24	Dakshina Kannada	0.00	0.00	4848.00	**4848.00**	0.00	0.00	100.00
25	Kodagu	0.00	0.00	4115.00	**4115.00**	0.00	0.00	100.00
26	Mysuru	188.00	0.00	6124.00	**6312.00**	2.98	2.98	97.02
27	Chamarajanagara	9.00	0.00	5627.00	**5636.00**	0.16	0.16	99.84
28	Chikkaballapura	668.00	0.00	3576.00	**4244.00**	15.74	15.74	84.26
29	Ramanagara	375.00	0.00	3149.00	**3524.00**	10.64	10.64	89.36
30	Yadgir	0.00	0.00	5274.00	**5274.00**	0.00	0.00	100.00
31	Vijayanagara	99.00	0.00	5534.00	**5633.00**	1.76	1.76	98.24

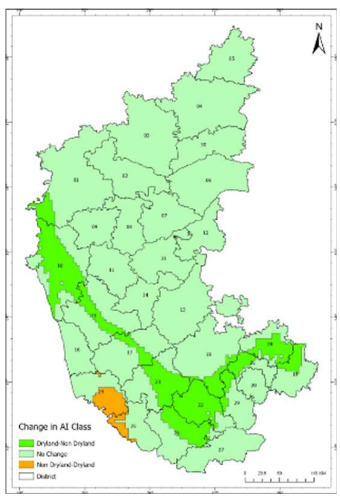

Fig. 13: Spatial Analysis of Post Monsoon Mean Aridity Index Shifting between 1958-1990 and 1991-2020.

Table 6: Spatial Analysis of Post Monsoon Mean Aridity Index Shifting between 1958-1990 (33 yrs) and 1991-2020 (30 yrs).

S.No.	District Names	Dryland to Non Drylands in sq. km.	Non Drylands to Dryland in sq. km.	No Shift area in sq. km.	Total area in sq. km.	%age of Area in shifting Dryland to Non Drylands	%age of Area in shifting Non Drylands to Dryland	%age of area with No Shift
0	**Karnataka State**	27087	2877	161917	**191881**	14.12	1.50	84.38
1	Belagavi	1195	0	12213	**13408**	8.91	0.00	91.09
2	Bagalkot	0	0	6566	**6566**	0.00	0.00	100.00
3	Vijayapura	0	0	10508	**10508**	0.00	0.00	100.00
4	Kalburgi	0	0	10972	**10972**	0.00	0.00	100.00
5	Bidar	0	0	5449	**5449**	0.00	0.00	100.00
6	Raichur	0	0	8466	**8466**	0.00	0.00	100.00
7	Koppal	0	0	5578	**5578**	0.00	0.00	100.00
8	Gadag	0	0	4658	**4658**	0.00	0.00	100.00
9	Dharwad	0	0	4258	**4258**	0.00	0.00	100.00
10	Uttara Kannada	6100	0	4202	**10302**	59.21	0.00	40.79
11	Haveri	0	0	4821	**4821**	0.00	0.00	100.00
12	Ballari	0	0	4262	**4262**	0.00	0.00	100.00
13	Chitradurga	0	0	8435	**8435**	0.00	0.00	100.00
14	Davanagere	0	0	4482	**4482**	0.00	0.00	100.00
15	Shivamogga	1779	0	6700	**8479**	20.98	0.00	79.02
16	Udupi	0	6	3568	**3574**	0.00	0.17	99.83
17	Chikkamagaluru	1095	0	9047	**10142**	10.80	0.00	89.20
18	Tumakuru	1553	0	9047	**10600**	14.65	0.00	85.35
19	Kolara	1080	0	2900	**3980**	27.14	0.00	72.86
20	Bengaluru (Urban)	0	0	2193	**2193**	0.00	0.00	100.00
21	Bengaluru (Rural)	1030	0	1268	**2298**	44.82	0.00	55.18
22	Mandya	4111	0	844	**4955**	82.97	0.00	17.03
23	Hassan	3284	0	3537	**6821**	48.15	48.15	51.85
24	Dakshina Kannada	0	2062	2786	**4848**	0.00	0.00	57.47
25	Kodagu	0	808	3308	**4116**	0.00	0.00	80.37
26	Mysuru	2818	0	3494	**6312**	44.65	44.65	55.35
27	Chamarajanagara	51	0	5585	**5636**	0.90	0.90	99.10
28	Chikkaballapura	2150	0	2093	**4243**	50.67	50.67	49.33
29	Ramanagara	839	0	2685	**3524**	23.81	23.81	76.19
30	Yadgir	0	0	5274	**5274**	0.00	0.00	100.00
31	Vijayanagara	0	0	5633	**5633**	0.00	0.00	100.00

(48.15%), Mysuru (44.65%), and Chikkaballapura (50.67%) due to expanded irrigation. Conversely, Dakshina Kannada saw a major shift from non-dryland to dryland (2,062 sq km), likely due to depleting water sources in the Western Ghats. This indicates localized improvements in moisture availability but overall stability in aridity across Karnataka.

Spatial analysis of winter seasonal mean aridity index shifting between 1958-1990 and 1991-2020 periods in Karnataka: Karnataka state in southern India has a heterogeneous climate ranging from semi-arid to wet-and-dry across districts. The Spatial mapping of the mean aridity index showed no major difference between the 1991-2020 period compared to the 1958-1990 baseline period across different districts. These findings indicate winter aridity patterns have remained largely similar in the state.

CONCLUSION

The temporal and spatial variations in aridity of Karnataka have been analyzed in the context of the 63-year data which in turn portrays the climatic variability of the region. When using extensive geospatial research, the distribution of arid zones in the state of Karnataka is presented, and it is affirmed that more than three-quarters of the state is categorized as semi-arid or dry subhumid dryland type while the rest of the area, slightly under one quarter, falls under the non-dryland or humid type category. The different forms of fluctuation in aridity revealed in the Deccan Plateau, the Western Ghats, and the coastal areas show how set-up factors such as topographical and climatic features affect different regions. Flora and Fauna account for specific regional climate differences, the increased dryness in winter compared to the humidity during the monsoon season. Thus, the trends indicate that the 6 level is decreasing in the long term. 24% of the region's aridity and an increase of 0 each, respectively. All these sums to the total of 43% over the study period and have become apparent thanks to the application of the Mann-Kendall test.

The significant analysis highlights the need to intensify policy measures and strategic development where especially water conservation, sustainable agriculture and climate change resilience need to be enhanced. The inherent climatic differences that define the difficulties faced by various regions in Karnataka form the basis of the recommendations for the planning and the development of strategies that would effectively address the climatic issues. This study suggests that in bid to reduce the impact of climatic fluctuations on water resources and food production to its minimum, concentrated resource management strategies that are flexible should be encouraged.

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