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REVIEW ARTICLE

A comparative review of hydroenvironmental and socio-economic characteristics of the Thamirabarani and Cauvery River Basins

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Abstract: Monsoon-dependent rivers, such as the Thamirabarani and Cauvery play critical roles in South India's water and livelihoods. This review compares the hydroenvironmental and socio-economic characteristics of two important peninsular India river basins—the Thamirabarani and the Cauvery—over 2014–2023. The Thamirabarani River, a short perennial river originating in the Western Ghats, flows through Tamil Nadu. The Cauvery River spans Karnataka, Tamil Nadu, and Puducherry, with complex hydrology. Both basins are influenced by the southwest and northeast monsoons (NEM). The Thamirabarani Basin receives over 55% of its annual rainfall during the NEM, averaging around 1,050 mm/year. The Cauvery Basin shows wide spatial variability, from 600 mm to 2,000 mm/year, depending on elevation and location. Groundwater dynamics show contrasting patterns. The Thamirabarani Basin maintains shallow water tables (2–3 m pre-monsoon), relatively stable due to consistent recharge and lower abstraction. In contrast, several heavily agricultural blocks in the Cauvery Basin exhibit seasonal fluctuations of 5–7 m, with pre-monsoon depths exceeding 12 m. Spatial and statistical analyses indicate strong correlations between rainfall variability and groundwater responses, especially in agriculturally intensive regions. Rainfall trend and groundwater fluctuation analyses highlight the influence of shifting monsoons on aquifer recharge and water security. The socio-economic assessment—highlighting the implications for agriculture, urban demand, and inter-state conflicts—emphasizes the need for integrated water resource management. These strategies include rainwater harvesting, regulated groundwater extraction, and crop planning based on climatic trends. These insights are relevant to other monsoon-dependent basins facing similar hydrological and socio-economic pressures under changing climate conditions.

Keywords: Hydroenvironmental variability; Groundwater dynamics; Monsoon rainfall; Integrated water resource management; Thamirabarani and Cauvery Basins

1. Introduction

Rivers have historically played a vital role in shaping civilizations, ecosystems, and livelihoods. In India, they are not only crucial for water supply, agriculture, and hydropower but are also deeply embedded in the cultural and spiritual fabric of society. However, in recent decades, rapid urbanization, industrial expansion, and agricultural intensification have increased pressure on river systems, resulting in degraded water quality, overuse of resources, and declined ecosystem health.

The Thamirabarani and Cauvery River Basins, located in southern India, present two hydro-climatically contrasting but critically important systems. The Thamirabarani River, originating in the Western Ghats and flowing eastward through Tirunelveli and Thoothukudi districts, is relatively short but perennial due to sustained base flow and topographic advantage. The Cauvery River, originating in the Brahmagiri hills of Karnataka, flows over 800 km through Karnataka, Tamil Nadu, and Puducherry, traversing multiple agro-climatic zones. It is one of the most water-stressed and politically sensitive basins in the country.[1]

The Indian monsoon system governs both basins. The Thamirabarani Basin receives over 55% of its rainfall from the northeast monsoon (NEM), while the Cauvery Basin receives a major portion during the southwest monsoon (SWM) but also depends on NEM, especially in Tamil Nadu.[2,3] Rainfall variability significantly affects river flows, groundwater recharge, and agricultural outputs across both basins.

Recent studies show that the human-river distance—the growing spatial and functional disconnection between people and rivers—has widened in southern India due to urban sprawl, riverfront encroachment, and intensive groundwater use.[4] This shift has serious implications for water governance, ecosystem services, and social conflict. The Cauvery Basin, in particular, has witnessed increasing land-use pressure and rising demand from agriculture and urban sectors, which further stresses surface and subsurface hydrological systems.[5]

Despite several studies focusing individually on rainfall, groundwater, or land use, few have conducted a basin-scale comparative study integrating hydroenvironmental and socio-economic dimensions across both rivers. This study aims to fill that gap by evaluating 10 years of data (2014–2023) on rainfall variability, groundwater levels, land use, and socio-economic stressors in the Thamirabarani and Cauvery Basins. It also demonstrates how hydrological variability and resource dependency differ in perennial versus monsoon-fed river systems.

Furthermore, the insights from this study are relevant to India's National Water Policy, which promotes integrated and decentralized water resource planning. The comparative findings are generalizable to other monsoon-dependent basins, such as Vaigai, Godavari, and Krishna, which face similar climatic and socio-economic challenges. By synthesizing hydro-climatic and anthropogenic trends, this study contributes to a better understanding of water security risks and sustainable river basin governance in a changing climate.

2. Importance of evaluating the Thamirabarani and Cauvery River systems

The accelerating anthropogenic stresses on river ecosystems and the impending dangers of climate variability require systematic and comparative investigations of river basins, particularly in countries, such as southern India, where water scarcity and unevenness pose significant challenges for sustainable development. The Thamirabarani and Cauvery River Basins, although geographically close, have unique hydrological, ecological, and socio-economic conditions that necessitate a systematic comparative examination. Over the past few decades, water availability in the Cauvery Basin has become a highly politicized and controversial subject. Conflicts over water sharing between Karnataka, Tamil Nadu, Kerala, and Puducherry have resulted in multiple judicial and interstate interventions. These conflicts are not solely driven by hydrological stress but also by archaic or splintered water-sharing arrangements that fail to account for recent trends in climate or land use.[6] At the same time, groundwater overexpansion in certain regions of the basin exacerbated the crisis. On the other hand, the Thamirabarani Basin, although comparatively smaller, remains one of the most reliable perennial systems of Tamil Nadu. Nevertheless, the basin is under increasing pressure from urbanization, industry, and agricultural intensification, particularly in the Tirunelveli and Thoothukudi districts.[7]

An increasing number of research papers emphasize the importance of understanding river differential behavior under changing land use and hydrometeorological conditions. The upper Cauvery Basin, for example, has experienced rainfall variability and a drying trend over the past few years, affecting surface and subsurface storage.[8] Conversely, the Thamirabarani Basin experiences comparatively uniform rainfall due to its position on the windward side of the Western Ghats, which facilitates perennial flow. The differing climatic inputs to the two basins make them excellent case studies for assessing the contribution of geography to water sustainability. A further principal motivation for this comparative overview is the imperative to update water quality assessment systems.[9] A significant number of water quality monitoring systems in both basins remain dependent on traditional approaches, often without spatial and seasonal resolution.[10,11] Sophisticated technologies, such as geospatial modeling, hydrogeochemical facies analysis, and remote sensing-based land use and land cover change detection, can contribute to enhancing basin-scale management if accompanied by extensive data sets.[12] Other studies conducted in Indian basins have demonstrated the utility of integrated water quality indices and geographic information system-based mapping in detecting significant zones of pollution, which could also be employed for the Thamirabarani and Cauvery systems.[13]

Moreover, both rivers play a crucial role in sustaining agricultural economies. The Cauvery delta area is among the most water-rich regions in the country, which favors the intensive cultivation of rice and sugarcane.[14] Nonetheless, the expansion in the application of chemical fertilizers and uncontrolled groundwater abstraction is causing soil salinization and deterioration of the aquifer.[15] The Thamirabarani Basin, on the other hand, sustains banana, paddy, and other high-yielding crops under canal irrigation systems that are fairly efficient. Nonetheless, site-specific groundwater pollution in the vicinity of industrial areas has started to become a genuine issue.[16]

In view of the rivers' socio-ecological significance, a comparative evaluation becomes necessary not merely for scholarly interest but for pragmatic policymaking. An integrated evaluation will enable stakeholders to discern the variations in basin responses to climatic events, land-use pressures, and pollution inputs, which in turn will guide basin-specific strategies toward sustainable water use. In addition, findings from such studies can be extrapolated to other comparable tropical monsoon river basins with converging issues of resource distribution, pollution management, and environmental protection. Against this backdrop, the present study brings together heterogeneous studies that pertain to the hydrology, pollution profile, land-use directions, and management issues in the Cauvery and Thamirabarani Basins. By creating a harmonious comparative setting, this research endeavor aims to contribute to evidence-based water governance and sustainable environmental planning.

3. Study area

The present study focused on two large river basins of southern India: The Cauvery and Thamirabarani. The Cauvery Basin stretches from Karnataka, Tamil Nadu, and Kerala to Puducherry, encompassing a diverse range of geomorphological aspects from the Western Ghats to the coastal plains. Conversely, the Tamirabarani Basin is confined more within Tamil Nadu but is ecologically relevant due to perennial flow and biodiversity-harboring Western Ghats origin. Both basins are vital water resources for agriculture, household uses, and industry. Their unique climatic, geological, and hydrological features are worth comparing.[17]

3.1. Thamirabarani River

The Tamirabarani River, also known as the lifeline of southern Tamil Nadu, originates from Agasthiyar Peak, a part of the Western Ghats, at an elevation of approximately 1,725 m in Tirunelveli district. In contrast to most of the peninsular rivers, the Thamirabarani is a perennial river system due to uniform rainfall in the upper catchments and continuous groundwater outflow from the Western Ghats.[18] The total drainage area of the river basin is approximately 4,400 km^2, encompassing large parts of Tirunelveli and Thoothukudi districts, with minor parts flowing into Kanyakumari district, as indicated in Figure 1.

The river runs for approximately 128 km before emptying into the Gulf of Mannar at Punnaikayal. The river is supplemented by major tributaries along its course, such as the Karaiyar, Servalar, Manimuthar, Pachaiyar, and Chithar. These tributaries supplement the river's base flow through surface runoff and subsurface recharge of the aquifer.[19]

Geologically, the basin consists of Archaean crystalline rocks, with prevailing soil types being red loamy soils, coastal alluvium, and clay loam. These soil types make the region suitable for intensive farming, as depicted in Figure 2.[20] Land use within the basin is largely agricultural, aided by an extensive canal irrigation system from main reservoirs, such as Papanasam and Manimuthar dams. This has made the area suitable for growing paddy, banana, and sugarcane year-round.[21] Climatically, the basin is blessed with an average annual rainfall of approximately 1,100–1,400 mm, made possible with the influences of both SWM and NEM. High rainfall and dense forest cover are seen in the upper catchments near the Ghats, whereas agricultural activity and increasing urban settlements characterize the lower plains.

Recent land use changes, urbanization, and industrialization, particularly in and around Tirunelveli and Srivaikuntam, have led to environmental issues, including water quality deterioration and groundwater pollution.[22] Seasonal variations in water supply, along

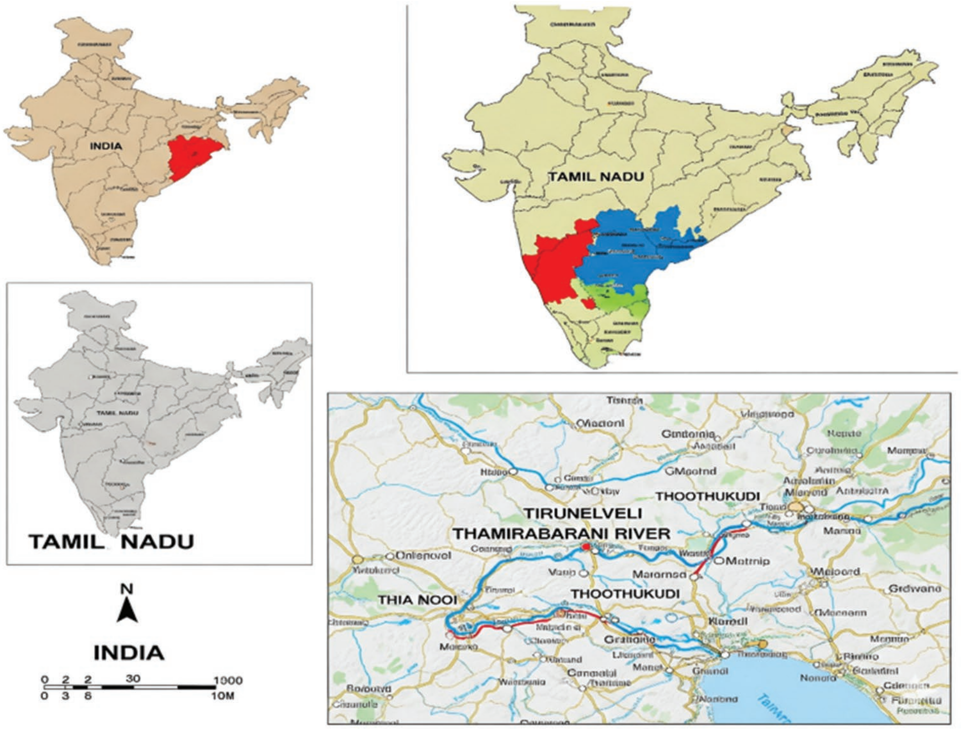

Figure 1. A map of the Thamirabarani River Basin network, delineated using the Horton–Strahler stream ordering method

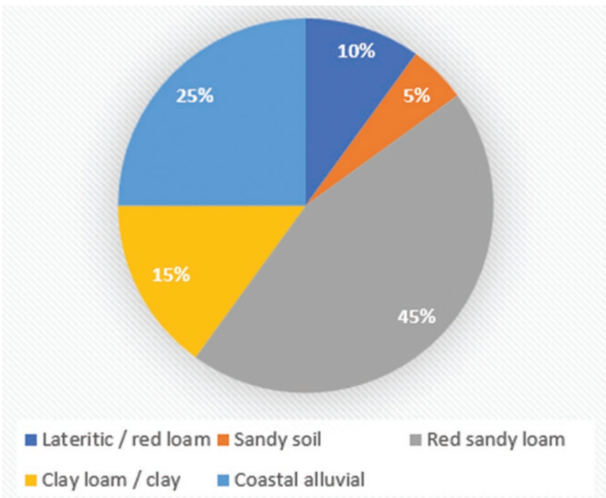

Figure 2. The distribution of basin soil types

with pollution from domestic and industrial sources, have highlighted the importance of integrated river basin management. In general, the Thamirabarani Basin presents a unique combination of hydrological wealth,[23] ecological vulnerability, and mounting anthropogenic pressure. Therefore, the Thamirabarani Basin represents an intriguing candidate for comparative river basin studies in the framework of sustainable water resources planning.

3.2. Cauvery River

The Cauvery River, the most prominent river system of peninsular India, originates at Talacauvery in Karnataka's Western Ghats at an elevation of about 1,341 meters. The river flows around 800 km through the states of Karnataka, Tamil Nadu, Kerala, and Puducherry before emptying into the Bay of Bengal. The Cauvery basin, as delineated in Figure 3, covers a large area of about 81,155 km².

The key tributaries of Cauvery are the Hemavathi, Kabini, Bhavani, Amaravathi, and Noyyal, which contribute to its spatial variation in discharge across physiographic regions. The upper basin, primarily in Karnataka, possesses undulating topography and red loamy soils, while the lower basin in Tamil Nadu consists of flat plains and fertile alluvial soils that are well-suited for cultivation, as shown in Figure 4.

The basin spans multiple agro-climatic regions and receives rainfall from both the southwest and NEMs. Rainfall ranges from over 2,000 mm in the hilly Western Ghats to <600 mm in the eastern plains, resulting in varied hydrological behavior within the same river system. This variation contributes to complex challenges in water management and distribution. The Cauvery delta, also called the "rice bowl of Tamil Nadu," is one of the most productive agricultural regions in India.

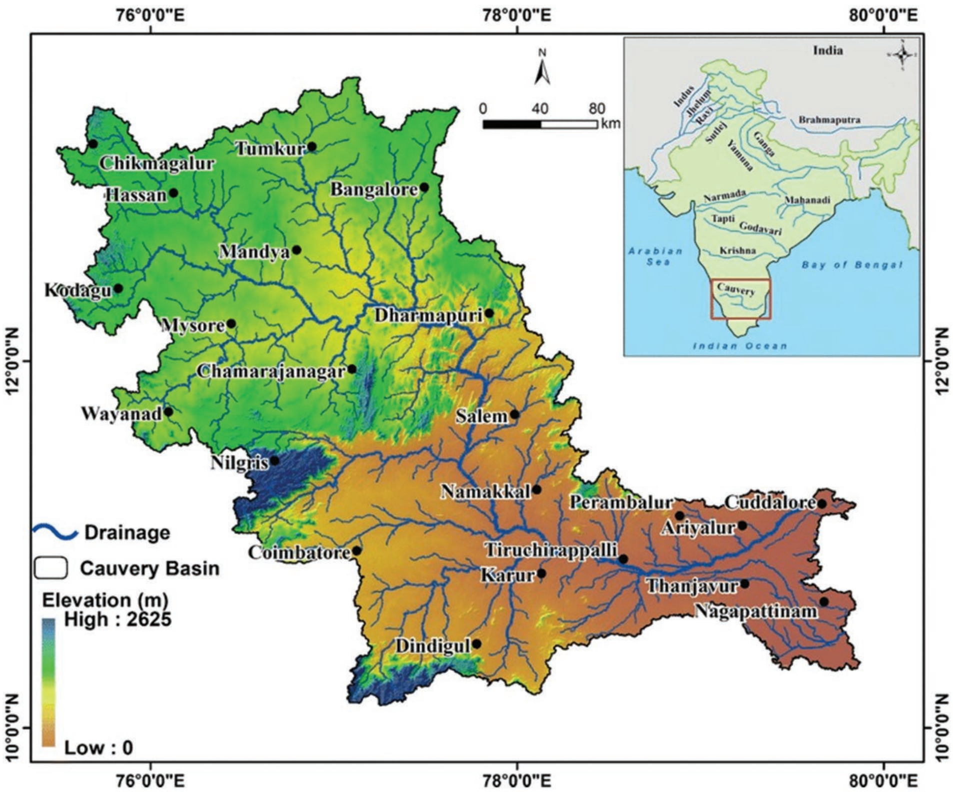

Figure 3. Map of the Cauvery River Basin network, delineated using the Horton–Strahler stream ordering method

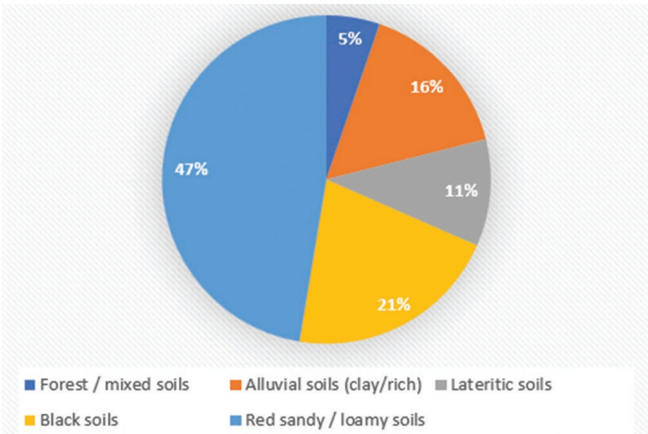

Figure 4. The distribution of soil types across the study area

Despite this richness, increasing population density and agricultural intensity have escalated the demand for irrigation, domestic supply, and industrial water. Key infrastructures, such as the Mettur Dam, Krishna Raja Sagara, and Lower Bhavani Project regulate river flow and storage capacity.

Nonetheless, several regions within the basin still experience seasonal water scarcity, groundwater depletion, and ongoing interstate disputes, particularly during drought years. These water-related stresses underscore the urgency of inter-basin planning and demonstrate the value of comparing a large and hydrologically stressed river system, such as the Cauvery with a smaller yet more stable system, such as the Thamirabarani.

4. Materials and methods

This research investigates rainfall variability and groundwater level behavior within the Thamirabarani and Cauvery River Basins over a 10-year duration (2014–2023). Information was obtained from 20 rainfall measurement stations and 18 groundwater observation wells[24] representing the spatial and climatic variability of the two basins. Stations were selected based on data availability, geographical spread, and uniformity.

4.1. Data sources and temporal resolution

Monthly rainfall records were collected from the Indian Meteorological Department (IMD) and local water resources systems.[25] Groundwater level records were collected from the Central Ground Water Board

(CGWB) and corresponding state agencies. The data were collected at the seasonal and yearly levels based on the IMD's four-season definition: Pre-monsoon (March–May), SWM (June–September), NEM (October–December), and post-monsoon (January–February).

4.2. Data cleaning and filtering

Early data processing had included assessing continuity and completeness. Outliers that were greater than ± 3 standard deviations were excluded. Missing values (≤ 5%) were linearly estimated. Stations with over 15% missing data were excluded from the final analysis. To minimize spatial bias caused by altitude and local anomalies, rainfall data were normalized to elevation where necessary.

4.3. Geospatial and stream network analysis

Quantum Geographic Information System (QGIS; version 3.32, QGIS Development Team, Switzerland) was employed for spatial visualization, interpolation, and river network demarcation.[26] Rainfall and groundwater variability maps were created by applying the inverse distance weighted method of interpolation. Basin boundaries and river systems were delineated from 30-m Shuttle Radar Topography Mission Digital Elevation Model data, and stream orders were assigned using the Horton–Strahler method to portray drainage hierarchy and basin structure.

4.4. Statistical analysis

Rainfall and groundwater time series were statistically analyzed using conventional indicators of mean, standard deviation, skewness, and kurtosis.[27] Autocorrelation analysis was applied to identify persistence and memory effects in each time series. Cross-correlation was performed to investigate the relationships between rainfall fluctuations and groundwater responses.[28] Long-term trends, where available, were tested using the Mann–Kendall approach for determining significance at the 5% level.

While river flow data were scarce for both basins, supplementary estimates from published works were used to support hydrological interpretation. Attention was still paid to how seasonal rainfall patterns affect groundwater dynamics and the nature of the relationships between a monsoon-dominated basin, such as the Cauvery, and a perennial system, such as the Thamirabarani. The overall methodology, starting from data collection, pre-processing, QGIS mapping, statistical analysis, and interpretation, is summarized in Figure 5.

5. Results and discussion

5.1. Rainfall data

Rainfall regime is central to characterizing hydrological processes within the Thamirabarani and Cauvery River Basins. The Thamirabarani River, which originates from the Western Ghats, receives uniform rainfall annually (1,100–1,400 mm) due to its location on the windward side. The rainfall is fairly distributed across the SWM and NEM. This ensures perennial flow, which is rare among South Indian Rivers. In comparison, the Cauvery River experiences seasonal fluctuations in rainfall, ranging from 600 mm in the interior plateau to over 2,500 mm in the Western Ghats districts of Karnataka. Surface runoff and groundwater recharge are dominated by both monsoons,[29] with the SWM to a greater extent. In upper basin regions, however, instability in rainfall over the past few years with declining trends has been observed, affecting river discharge and reservoir storage. These imbalances highlight the need for targeted water management measures in both basins.

5.1.1. Thamirabarani River Basin (Tirunelveli and Thoothukudi districts)

The Thamirabarani River Basin in southern Tamil Nadu, primarily Tirunelveli and Thoothukudi districts, has relatively high and spatially uniform rainfall compared to other river basins in the region. The basin's average annual rainfall is about 1,068 mm with notable contributions from both the SWM and NEM. As shown in Table 1, annual rainfall data across key stations in Thoothukudi and Tirunelveli highlight these variations, while Table 2 presents the average yearly precipitation across different monsoon seasons. The basin receives approximately 48% of its rainfall during the NEM season (October–December) and approximately 34% during the SWM season (June–September), while the rest comes during summer and intermittent winter

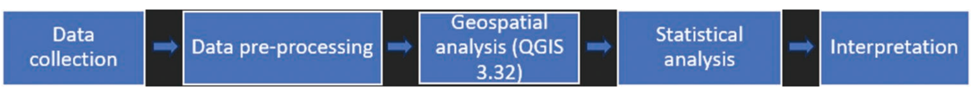

Figure 5. The overall methodology of the study

Abbreviation: QGIS: Quantum Geographic Information System.

Table 1. Annual rainfall data across key stations in Thoothukudi and Tirunelveli

Stations no.	Rain gauge station	Annual rainfall (mm)
1	Papanasam	1,099
2	Srivaikuntam	985
3	Ambasamudram	1,249
4	Kovilpatti	1,060
5	Nanguneri	1,057
6	Ettayapuram	979
7	Cheranmahadevi	1,028
8	Kayathar	947
9	Manur	1,162
10	Vilathikulam	1,024
11	Alangulam	1,071
12	Thiruchendur	964
13	Tenkasi	1,191
14	Ottapidaram	1,030
15	Radhapuram	1,104
16	Sattankulam	982
17	Kalakadu	1,129
18	Kadambur	1,000
19	Sankarankovil	1,081
20	Pudukottai	948

showers. The orographic impacts of the Western Ghats also have a significant effect on rainfall distribution, with upper catchment locations, such as Papanasam and Manimutharu, receiving more than 2,000 mm/year. In contrast, the downstream plains near Srivaikuntam receive less than 900 mm. From 2004 to 2024, rainfall records from main monitoring stations, including Papanasam, Ambasamudram, and Srivaikuntam, reveal a modest increase in annual rainfall with deep peaks during certain years, indicating an increasing impact of inter-annual climatic variability. The seasonal variability and rainfall partitioning are further illustrated in Figure 6, which shows the distribution across key stations in the Thamirabarani River Basin (2014–2023). This variability underscores the importance of enhanced forecasting and adaptive water resource planning to mitigate the risk of both droughts and flooding in the basin's ecologically sensitive and agriculturally intensive zones.

5.1.2. Cauvery Basin (Kodagu district of Karnataka)

The Cauvery Basin, covering areas of Karnataka, Tamil Nadu, Kerala, and Puducherry, has a varied rainfall regime influenced by both the SWM and NEM. The basin receives an average annual rainfall of between 600 mm in the eastern plains and well above 2,000 mm in the catchments located in the hilly tracts of the Western Ghats. Annual rainfall patterns across major Cauvery Basin stations are summarized in Table 3, and seasonal variations are presented in Table 4. SWM (June–September) provides approximately 52–60% of the basin's annual precipitation, particularly to the upper and central parts of the basin, whereas NEM (October–December) accounts for around 30–35%, primarily affecting the Tamil Nadu portion of the basin. Rainfall in the basin is topographically and regionally climate-dependent, with the western highlands functioning as efficient orographic barriers that enhance precipitation. The remaining 5–10% of the yearly rainfall occurs in the pre-monsoon season (March–May) and post-monsoon season (January–February) in the form of highly localized convection-driven showers. Long-term trends indicate rising variability and temporal changes in monsoon rainfall, with some of the sub-basins witnessing abnormal monsoon onset and declining intensity in the SWM, posing apprehension for agriculture, groundwater recharge, and inter-state water management. The seasonal distribution of rainfall between 2014 and 2023 across representative stations in the Cauvery Basin is illustrated in Figure 7.

5.2. Groundwater

The groundwater regimes of the Thamirabarani and Cauvery River Basins differ significantly in terms of depth, seasonal variation, quality, and level of exploitation over the study period from 2014 to 2023. These differences are closely related to basin size, geology, land use, and monsoon dependency.

5.2.1. Groundwater in the Thamirabarani River Basin

The Thamirabarani River Basin in southern Tamil Nadu enjoys perennial surface flow and orographic rain, particularly from the NEM. This guarantees consistent groundwater recharge and relatively low water tables over most of the basin.[30] Records gathered from 2014 to 2023 indicate pre-monsoon water levels of 2.3–2.7 m, but these decrease to 1.4–1.8 m post-monsoon, reflecting good seasonal response and baseflow support.[31] A comparative representation of average pre-monsoon groundwater levels in the two basins is shown in Figure 8. Groundwater fluctuation is moderate, generally 1.2–3.5 m, with minimum fluctuation occurring in alluvial plains and greater fluctuation in lateritic and upland red soil areas.[32]

Table 2. Average yearly precipitation reported at different rain gauge stations across the monsoon seasons in Thoothukudi and Tirunelveli

Stations no.	Rain gauge station	Post-monsoon (mm)	%	Pre-monsoon (mm)	%	SWM (mm)	%	NEM (mm)	%
1	Papanasam	41	3.7	98	8.9	312	28.4	648	59.0
2	Srivaikuntam	38	3.9	76	7.7	289	29.3	582	59.1
3	Ambasamudram	47	3.8	102	8.2	326	26.1	774	62.0
4	Kovilpatti	40	3.8	88	8.3	298	28.1	634	59.8
5	Nanguneri	42	4.0	95	9.0	318	30.1	602	56.9
6	Ettayapuram	36	3.7	82	8.4	284	29.0	577	58.9
7	Cheranmahadevi	39	3.8	90	8.8	301	29.3	598	58.2
8	Kayathar	34	3.6	74	7.8	276	29.1	563	59.4
9	Manur	46	4.0	101	8.7	333	28.6	682	58.7
10	Vilathikulam	37	3.6	86	8.4	296	28.9	605	59.1
11	Alangulam	40	3.7	92	8.6	310	28.9	629	58.7
12	Thiruchendur	35	3.6	78	8.1	281	29.2	570	59.1
13	Tenkasi	49	4.1	105	8.8	342	28.7	695	58.3
14	Ottapidaram	38	3.7	84	8.2	292	28.3	616	59.8
15	Radhapuram	43	3.9	94	8.5	319	28.9	648	58.7
16	Sattankulam	35	3.6	79	8.0	286	29.1	582	59.3
17	Kalakadu	44	3.9	97	8.6	327	29.0	661	58.6
18	Kadambur	36	3.6	81	8.1	289	28.9	594	59.4
19	Sankarankovil	41	3.8	93	8.6	312	28.9	635	58.9
20	Pudukottai	33	3.6	77	8.1	278	29.3	560	59.0

Abbreviations: NEM: Northeast monsoon; SWM: Southwest monsoon.

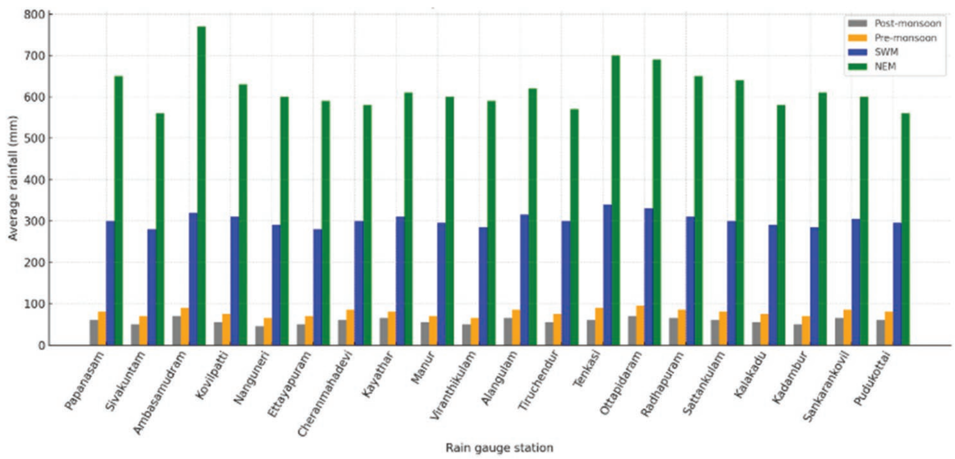

Figure 6. Seasonal rainfall distribution across key stations in the Thamirabarani River Basin (2014–2023)
Abbreviations: NEM: Northeast monsoon; SWM: Southwest monsoon.

According to the CGWB, the aquifer formations in the area are primarily composed of weathered granite, gneiss, and lateritic rocks that allow for moderate infiltration. Percolation is aided by soil texture, especially in the red loam and sandy loam zones, thereby increasing recharge efficiency. Urban fringe zones with clayey soils have delayed recharge due to low permeability.[33]

A total of 110 well samples were assessed during this period for the water quality. Most samples showed total dissolved solids (TDS) values of less than 1,000 mg/L,[34] which are suitable for irrigation and drinking purposes. Nitrate levels were within safe limits in most rural areas but increased above permissible levels near industrial corridors, such as Thoothukudi, attributable to fertilizer leaching and point-source contamination. Fluoride contamination was negligible. The basin had low microbiological occurrence, thereby further confirming its position as a comparatively low-stress groundwater area.

Table 3. Annual rainfall data across key stations in the Cauvery Basin

Stations No.	Rain gauge station	Annual rainfall (mm)
1	Madikeri	2,120
2	Kushalnagar	1,854
3	Krishnarajasagara	1,390
4	Mandya	970
5	Mysuru	850
6	Dharmapuri	820
7	Mettur	875
8	Erode	910
9	Bhavani	995
10	Namakkal	790
11	Karur	812
12	Tiruchirappalli	840
13	Thanjavur	1,200
14	Kumbakonam	1,130
15	Nagapattinam	1,280
16	Puducherry	1,365
17	Salem	945
18	Chidambaram	1,090
19	Mayiladuthurai	1,140
20	Srirangam	910

Notwithstanding its stable hydrological regime, signs of stress, including increased agricultural activity, urban development, and erratic rains, are observed. Preventive measures, such as aquifer recharge facilities, conjunctive use planning, and adjustments in cropping systems, are advisable to maintain groundwater reliability.[35]

5.2.2. Groundwater in the Cauvery River Basin

The Cauvery River Basin, spanning Karnataka, Tamil Nadu, and Puducherry, reflects high groundwater stress and variability, primarily dominated by intensive irrigation requirements and irregular monsoonal recharge. During the period 2014–2023, monitored pre-monsoon depths over the delta area (for instance, Karur, Trichy, Thanjavur) remained persistently less than 10 m, while yearly water stage variations were more than 7 m in the over-exploited blocks. Annual groundwater fluctuations across both basins are comparatively depicted in Figure 9.

Hydrogeologically, the basin has hard rock aquifers in the Karnataka uplands and alluvial aquifers in the deltaic plains of Tamil Nadu. Infiltration is poor in black cotton and clay soils, which cover extensive agricultural regions, thereby lessening recharge possibility and leading to extended periods of water table drawdown.

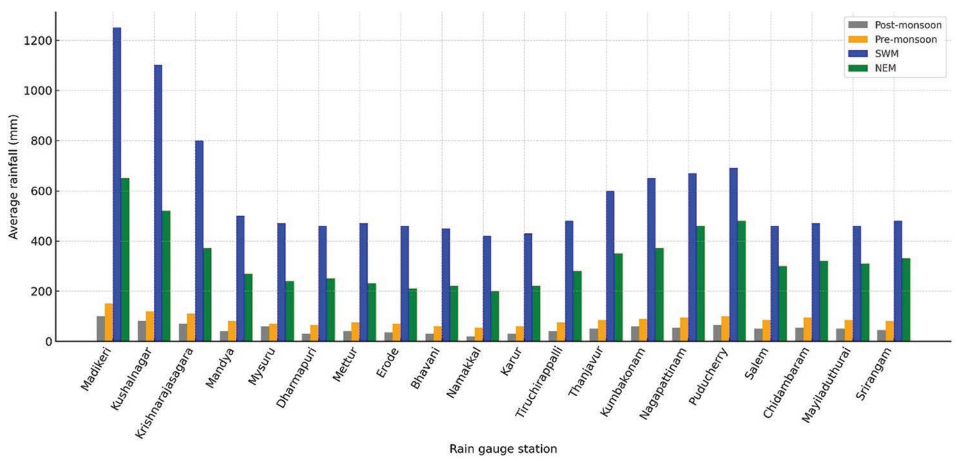

Figure 7. Seasonal rainfall distribution across key stations in the Cauvery River Basin (2014–2023)
Abbreviations: NEM: Northeast monsoon; SWM: Southwest monsoon.

Table 4. Average yearly precipitation reported at different rain gauge stations across the monsoon seasons along the Cauvery River

Station no.	Rain gauge station	Post-monsoon (mm)	%	Pre-monsoon (mm)	%	SWM (mm)	%	NEM (mm)	%
1	Madikeri	90	4.2	120	5.7	1,260	59.4	650	30.7
2	Kushalnagar	85	4.6	110	5.9	1,130	61.0	529	28.5
3	Krishnarajasagara	60	4.3	95	6.8	810	58.3	425	30.6
4	Mandya	52	5.4	68	7.0	580	59.8	270	27.8
5	Mysuru	46	5.4	62	7.3	485	57.1	257	30.2
6	Dharmapuri	48	5.9	59	7.2	462	56.3	251	30.6
7	Mettur	53	6.1	63	7.2	490	56.0	269	30.7
8	Erode	50	5.5	67	7.4	510	56.0	283	31.1
9	Bhavani	55	5.5	68	6.8	580	58.3	292	29.4
10	Namakkal	44	5.6	62	7.9	452	57.2	232	29.3
11	Karur	46	5.7	59	7.3	470	57.9	237	29.2
12	Tiruchirappalli	48	5.7	64	7.6	475	56.5	253	30.1
13	Thanjavur	60	5.0	75	6.3	620	51.7	445	37.1
14	Kumbakonam	62	5.5	80	7.1	620	54.9	368	32.5
15	Nagapattinam	64	5.0	85	6.6	660	51.6	471	36.8
16	Puducherry	72	5.3	95	7.0	690	50.5	508	37.2
17	Salem	56	5.9	70	7.4	530	56.1	289	30.6
18	Chidambaram	68	6.2	88	8.1	610	56.0	324	29.7
19	Mayiladuthurai	72	6.3	90	7.9	635	55.7	343	30.1
20	Srirangam	61	6.7	78	8.6	520	57.1	251	27.6

Abbreviations: NEM: Northeast monsoon; SWM: Southwest monsoon.

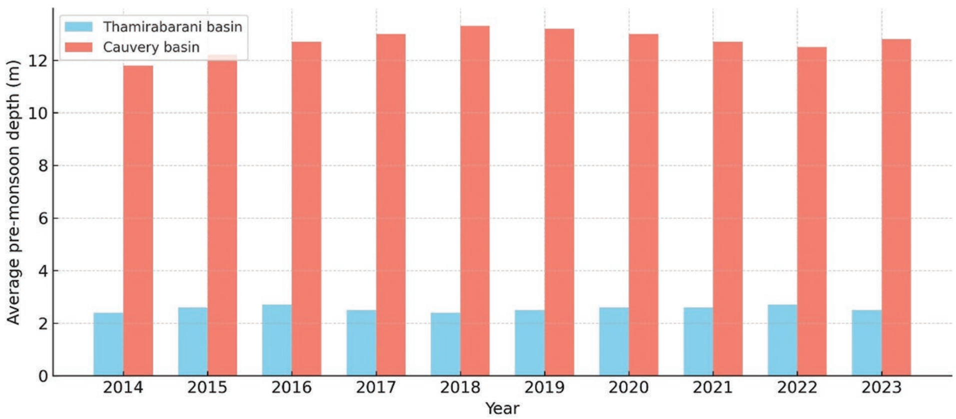

Figure 8. Comparative analysis of average pre-monsoon groundwater levels in Thamirabarani and Cauvery River Basins over the period from 2014 to 2023

Conversely, upland regions with fractured granite provide improved seasonal restoration, although such aquifers are sensitive to over-pumping.

A detailed water quality survey of 178 wells in three hydrozones (upper, middle, and deltaic) revealed that more than 35% of samples reported TDS contents exceeding 1,500 mg/L, with high nitrate levels in intensively cultivated regions, particularly due to excessive fertilizer application and leaching from surface irrigation systems. Fluoride pollution was also detected, primarily in groundwater-based rural settlements.[36] In addition, the coastal areas showed increasing salinity intrusion, presumably due to groundwater overdraft during the dry season.

Groundwater management is still a concern. According to CGWB's recent categorization, more than 40% of the administrative blocks are semi-critical or over-exploited, calling for urgent regulatory and restoration actions. Proposed interventions are managed aquifer recharge, diversification of crops, compulsory water budgeting, and borewell spacing norms, particularly in water-scarce sub-basins.

5.3. Statistical summary of rainfall and discharge

To gain a preliminary understanding of the hydrological regime in the Tamirabarani and Cauvery River Basins, we conducted a stringent statistical analysis of rainfall and streamflow for the long term. The descriptive statistics, including mean, standard deviation, and coefficient of variation, were calculated for the rainfall and river flow for representative stations in the two basins. As shown in Table 5, the annual rainfall means demonstrate clear spatial variability across the selected stations. In the Cauvery Basin, rainfall ranged from 875 mm at Mettur (Middle Basin) to 1,200 mm at Krishnarajasagara (Upper Basin), indicating greater precipitation in the upstream catchments. In the Tamirabarani Basin, rainfall varied between 980 mm at Srivaikuntam (Lower Basin) and 1,050 mm at Papanasam (Upper Basin), reflecting relatively uniform but slightly higher precipitation in the upper reaches. Overall, these variations highlight the spatial heterogeneity of rainfall across basins, which have important implications for water availability, reservoir storage, and downstream discharge patterns.

The discharge also followed a similar pattern. The Cauvery Basin experienced larger fluctuations in discharge, possibly due to the cumulative effect of surface runoff and variable groundwater contribution. These hydroclimatic parameters reflect the contrast in stability between the two basins. The Tamirabarani, with forested catchments and lesser anthropogenic effects, has comparatively stable flows throughout the year. Unlike the Cauvery, which is of greater size and intensive land use, it exhibits excessive fluctuations in hydrological parameters.

5.4. Uncertainty and long-term persistence analysis

Long-term persistence (LTP) in hydrological time series is a crucial characteristic indicating the memory effect of natural systems and the role of multi-decadal variability. For determining LTP in rainfall and discharge records of both the Cauvery and Tamirabarani basins, the Hurst exponent (H) was determined with the aid of the rescaled range analysis. H values between 0.5 and

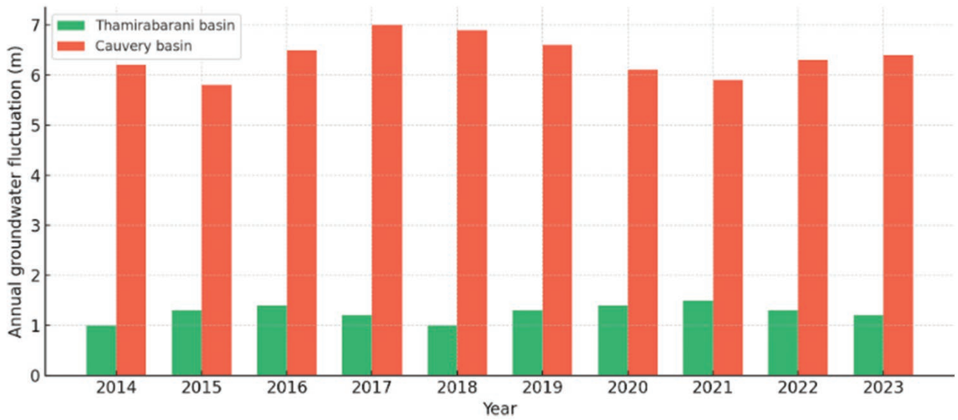

Figure 9. Comparative analysis of annual groundwater fluctuations in the Thamirabarani and Cauvery River Basins over the period from 2014 to 2023

Table 5. Descriptive statistics of rainfall and discharge across selected stations

Basin	Station name	Basin location	Rainfall mean (mm)	Rainfall SD (mm)	Rainfall CV (%)	Discharge mean (m≥/s)	Discharge SD (m≥/s)	Discharge CV (%)
Cauvery	Krishnarajasagara	Upper	1,200	150	12.5	95	12	12.6
Cauvery	Mettur	Middle	875	160	18.3	100	15	15.0
Tamirabarani	Papanasam	Upper	1,050	120	11.4	85	10	11.8
Tamirabarani	Srivaikuntam	Lower	980	110	11.2	70	9	12.9

1.0 reflect positive persistence (long-term memory). In contrast, an H value of 0.5 reflects a totally random series (no persistence), and H values less than 0.5 reflect anti-persistent behavior.

Table 6 shows that the majority of stations in both basins have H values ranging from 0.65 to 0.76 for rainfall and 0.70 to 0.82 for discharge, indicating high dominance of LTP. This suggests that existing hydrological conditions determine future patterns, increasing the predictability of extreme events.[37] However, the persistence also introduces epistemic uncertainty into trend-based predictions, particularly in the condition of shifting climate and land use. Such uncertainties need to be taken into consideration within long-term water resources planning.

In addition, the evaluation of interannual variability reported CVs of 12–19% for rainfall and 15–25% for discharge (Table 5). This supports the idea that while rainfall and discharge are predictable to a certain extent, large natural fluctuations remain. The interplay between persistence and variability requires strong modeling strategies that incorporate stochastic inputs and uncertainty quantification frameworks.

5.5. Water use, agriculture, and socio-economic dynamics

Both basins accommodate intensive agriculture, but with very different socio-economic stresses. The Cauvery Basin, crossing several states, is a cauldron of inter-state water struggle, most notably between Tamil Nadu and Karnataka.[38] There is extensive irrigation infrastructure (e.g., Mettur Dam, Upper Anicut) to accommodate a large variety of crops, but over-drafting of both surface and groundwater has resulted in extreme season stress.

On the other hand, the Thamirabarani Basin is self-sustaining and supports agriculture under a stable flow regime. Nevertheless, industrial growth and urbanization have occurred in several districts in recent years, including Tirunelveli and Thoothukudi, affecting water quality and flow availability.[39] Socio-economic studies indicate that Cauvery Basin farmers are heavily reliant on canal irrigation and are more exposed to the politics of the upstream. In contrast, Thamirabarani farmers have localized tank systems and perennial flow assistance, despite growing competition from non-agricultural uses.

5.6. Environmental stressors and mitigation strategies

The Cauvery Basin is experiencing severe environmental degradation, particularly groundwater overexploitation, land cover change, and deforestation. Satellite-based

Table 6. Hurst exponent estimates for rainfall and discharge time series (2000–2020)

Basin	Station	Rainfall	Discharge
Cauvery	Krishnarajasagara	0.72	0.78
Cauvery	Mettur	0.68	0.75
Tamirabarani	Papanasam	0.65	0.70
Tamirabarani	Srivaikuntam	0.76	0.82

evaluation indicates accelerated urbanization in Bengaluru and Erode cities that affects recharge areas and catchment integrity. However, the Thamirabarani Basin is experiencing evolving risks from sand mining, industrial pollution, and wetland encroachment.[21]

Mitigation measures have to be basin-specific. For the Cauvery, inter-state cooperative administration, tightened regulation of groundwater, and integrated water budgeting are a priority. For Thamirabarani, pollution abatement, riparian buffer restoration, and conservation of wetlands are crucial to sustaining its relatively robust hydrological regime.

6. Conclusion

This comparative study of the Thamirabarani and Cauvery River Basins investigated data from 2014 to 2023, highlighting the hydrological, environmental, and socio-economic differences between two important river basins in southern India. The Thamirabarani Basin, while smaller in size, has perennial flow, regular NEM recharge, and lower degrees of groundwater stress. In contrast, the Cauvery Basin spans several climatic zones, demonstrating significant rainfall variation, excessive reliance on monsoonal supply, and extensive groundwater overexploitation, especially in deltaic and semi-arid areas. Seasonal patterns of rainfall indicate that the Cauvery Basin is more susceptible to SWM failure compared to the Thamirabarani Basin, resulting in severe water shortages, cropping risks, and aquifer depletion. The groundwater level variation in the Tamirabarani is 1.2–3.5 m, and in the Cauvery is 5–7 m/year. Quality measurements reveal rising TDS and nitrate concentrations in the Cauvery agricultural belts, caused by fertilizer leaching and the intrusion of groundwater salinity, whereas the Thamirabarani groundwater generally remains within acceptable limits. Although relatively stable, the Thamirabarani Basin exhibits localized stress due to urban growth and growing demand. These results affirm the importance of basin-scale water governance frameworks, designed to suit the unique hydroclimatic and socio-economic settings of a particular river system. Policy suggestions arising from this study include the adoption of managed groundwater abstraction in over-exploited regions, increased artificial recharge facilities, and enhanced climate-resilient farming practices, such as crop diversification and water-saving irrigation. Notably, the study advances the national interest of Integrated Water Resource Management by illustrating that sustainable water planning should merge rainfall variability, groundwater trends, and land-use pressures at the basin scale. The findings provide a template for other monsoon-dominated river basins in India that suffer from comparable climatic uncertainty, increasing demand, and human-induced stress.

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Conflict of interest

The authors assert that there are no conflicts of interest.

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Availability of data

All data used in this study were obtained from publicly available sources, including the IMD, CGWB, and Tamil Nadu Water Resource Information and Management System. No new datasets were generated.

References

1. Venkatcharyulu S, Viswanadh GK. Runoff volume model for Godavari Sub-basin using HEC-RAS software. *Modell Earth Syst Environ.* 2022;8:3577-3589. doi: 10.1007/s40808-021-01311-4
2. Kulkarni PP, Pardeshi SD. Evaluation and interpolation of rainfall trends over the semi-arid upper godavari basin. *Meteorol Atmos Phys.* 2019;131:1565-1576. doi: 10.1007/s00703-018-0652-z
3. Brown E, Skougstad MW, Fishman MJ. *Methods for the Collection and Analysis of Water Samples for Dissolved Minerals and Gases*. Ch. A1. United States: USGS Techniques of Water-Resources Investigations; 1970.
4. Central Ground Water Board (CGWB). *Ground Water Yearbook Tamil Nadu and UT of Puducherry (2018-19)*. Chennai: SECR; 2019.
5. Central Water Commission. *Water and Related Statistics*. New Delhi: Ministry of Jal Shakti, Government of India; 2020.
6. Clesceri LS, Greenberg AE, Eaton AD. *Standard Methods for the Examination of Water and Wastewater.* 20th ed. Washington, D.C: APHA, AWWA, WEF; 1998.
7. Davina V, Gonsalves, Souza JD. *Ecology Environment and Conservation*. Vol. 5. New York: Syrawood Publishing House; 1999. p. 19-24.
8. Dhamodharan A, Shanthakumar S, Ganapathy GP. Assessment of seasonal disparity on hydrogeochemical facies distribution in Cooum River, India. *Asian J Earth Sci.* 2016;9:27-35. doi: 10.3923/ajes.2016.27.35
9. Elangovan NS, Dharmendirakumar M. Assessment of groundwater quality along the Cooum River, Chennai, Tamil Nadu, India. *J Chem.* 2013;2013:672372. doi: 10.1155/2013/672372
10. Etier I, Murugan CA, Kannan N, Venkatesan G. Measurement of secure power meter with smart IoT applications. *J Green Eng.* 2022;10(12):12961-12972.
11. Garcia MG, Hidalgo VM, Blesa MA. Geochemistry of groundwater in the alluvial plain of Tucuman province, Argentina. *Hydrogeol J.* 2001;9:597-610. doi: 10.1007/s10040-001-0166-4
12. Govindaraj V, Manokaran K, Sathaiya J, Baskar P. Environmentally-friendly bio-coagulants: A cost-effective solution for groundwater pollution treatment. *Asian J Water Environ Pollut.* 2023;20(3):19-28. doi: 10.3233/AJW230034
13. Govindaraj V, Sankar JI, Gnanamanickkam JNG, Amala S. Demarcation of non-carcinogenic risk zones based on the intake of contaminated groundwater in an industrial area of Southern India using geospatial technique. *Desalin Water Treat*. 2022;274:140-149. doi: 10.5004/dwt.2022.28901

14. Hem JD. *Study and Interpretation of the Chemical Characteristics of Natural Water.* Vol. 2254. United States: US Geological Survey; 1985.
15. Indian Meteorological Department (IMD). *Climatological Normals of Chennai (1991-2020).* New Delhi: IMD Publications; 2022.
16. Jayaraman A, Chandrasekar P. Groundwater quality assessment using GIS techniques: A case study of Chennai. *Environ Earth Sci.* 2017;76(15):519.
17. Joshi P, Chauhan A, Dua P, Malik S, Liou YA. Physicochemical and biological analysis of river yamuna at palla station from 2009 to 2019. *Sci Rep.* 2022;12:2870. doi: 10.1038/s41598-022-06900-6
18. Biswas B, Jadhav RS, Nilima T. Rainfall distribution and trend analysis for Upper Godavari basin, India from 100 years record (1911-2010). *J Indian Soc Remote Sens.* 2019;47:1781-1792. doi: 10.1007/s12524-019-01011-8
19. Mohamed Sheriff KM, Zahir Hussain A. Monitoring the quality of groundwater on the banks of the Cooum River at Chennai city Tamil Nadu, India. *Adv Appl Sci Res*. 2012;3(6):3587-3592.
20. Mishra A, Singh VP. *Soil Conservation and Hydrology.* United States: Water Resources Publications; 2003.
21. Mohana P, Nagamani K, Muthusamy S, VelmuruganPM. Environmental impact assessment of thamirabarani river basin, Tamil Nadu using remote sensing and GIS techniques. *Indian J Sci Technol.* 2018;11(22):1-7. doi: 10.17485/ijst/2018/v11i22/106246
22. Nageswara Rao K, Swarna Latha P, Ramesh Kumar PV. Groundwater quality assessment for irrigation use in the Godavari Delta region of east coast India using IRWQI and GIS. *Water Supply.* 2022;22(3):2612-2629. doi: 10.2166/ws.2021.454
23. Patel DP, Prasad RK, Singh R. Soil hydraulic properties and their impact on groundwater recharge in semi-arid regions. *J Hydrol.* 2013;476:38-45. doi: 10.1016/j.jhydrol.2012.10.048
24. Rajkumar S, Selvakumar S, Magesh NS, Kaliraj S, Venkatramanan S. Seasonal variations in water quality parameters of Thamiraparani River. *Environ Monit Assess.* 2022;194(3):178.
25. Ramasamy SM. Urbanisation and its impact on groundwater levels in Chennai Metropolitan Area. *J Hydrol Environ.* 2015;29(3):34-42.
26. Ramesh R, Purvaja R, Ramesh S, James RA. Historical pollution trends in coastal environments of India. *Environ Monit Assess.* 2002;79:151-176. doi: 10.1023/A:1020250717093
27. Rathod SD, Ghosh S. Rainfall trend and variability in the semi-arid Godavari basin. *J Water Clim Change.* 2021;12(8):3992-4006. doi: 10.2166/wcc.2021.003
28. Ravisankar N, Poogothal SA. Groundwater quality in tsunami-affected areas of Sirkazhi Taluk, Tamil Nadu. *Sci Tsunami Hazards.* 2008;27(1):47-55.
29. Rao GS, Rao NS. Groundwater quality in a coastal region of Andhra Pradesh. *Environ Monit Assess.* 2010;160:341-352. doi: 10.1007/s10661-008-0694-5
30. Rao NS, Subrahmanyam A, Sudarshan G, Srinivasulu P, Reddy GV, Nagamani M. Hydrogeochemistry and groundwater quality in a coastal region of Andhra Pradesh. *Environ Earth Sci.* 2012;66:2143-2169. doi: 10.1007/s12665-011-1448-0
31. Saha D, Sinha UK. Influence of soil texture on groundwater recharge in India. *Hydrogeol J.* 2010;18:123-134. doi: 10.1007/s10040-009-0506-2
32. Sharma BR, Rao KV, Vittal KPR. Soil water retention of major soil types in India. *Agric Water Manag.* 2006;82(1–2):29–41. doi: 10.1016/j.agwat.2005.07.001
33. Shirani M, Afzali KN, Jahan S, Strezov V, Sardo MS. Pollution and contamination assessment of heavy metals in the sediments of Jazmurian playa in southeast Iran. *Sci Rep.* 2020;10:4775. doi: 10.1038/s41598-020-61838-x
34. Siosemarde M, Kave F, Pazira E, Sedgh H, Ghaderi SJ. Relationship of TDS and EC. *World Acad Sci Eng Technol.* 2010;46:258-260.
35. Srinivas Y, Hudson Oliver D, Stanley Raj A, Chandrasekar N, Magesh NS. Groundwater quality in Nandyal, Andhra Pradesh. *Environ Earth Sci.* 2013;70:365-373. doi: 10.1007/s12665-012-2132-4
36. Prasanna MV, Chidambaram S, Hameed AS, Srinivasamoorthy K. Hydrogeochemical analysis and evaluation of groundwater quality in the Gadilam river basin, Tamil Nadu, India. *J Earth Syst Sci.* 2011;120(1):85-98. doi: 10.1007/s12040-011-0008-9
37. Nageswara Rao PV, Appa Rao S, Subba Rao N. Geochemical evolution of groundwater in the Western Delta region of River Godavari, Andhra Pradesh, India. *Appl Water Sci.* 2015;7:813-822. doi: 10.1007/s13201-015-0294-y
38. Government of Tamil Nadu. *Tamil Nadu Water Resource Information and Management System (TNWRIMS)*. Chennai: Government of Tamil Nadu; 2023.
39. Trivedy RK, Goel PK. *Chemical and Biological Methods for Water Pollution Studies.* Karad, India: Environmental Publication; 1986.