Assesement of Surface Water Quality in and Around Penna River Basin, Kadapa District, Andhrapradesh, Using Analytical and Statistical Techniques

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Abstract

Water is a vital natural resource essential for sustaining life, ecological balance, agricultural productivity, and socioeconomic development. Rapid industrialization, intensive agricultural activities, and population growth have significantly accelerated the degradation of freshwater systems worldwide. The Penna River basin in the Kadapa district, a critical freshwater source, is increasingly subjected to anthropogenic pressures from untreated domestic sewage, agricultural runoff, and industrial discharges. This study investigates the physicochemical and biological characteristics of surface water across ten selected stations within the Penna River basin to assess its suitability for irrigation. Key hydro chemical parameters, including pH, electrical conductivity, total dissolved solids, total hardness, bicarbonate, carbonate, chloride, calcium, magnesium, and sulphate, were analyzed following standard methods and compared with prescribed regulatory limits. The results revealed substantial spatial variability and notable exceedances of permissible standards, particularly elevated alkalinity and related indices. These deviations indicate

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deterioration in water quality, rendering the surface water largely unsuitable for irrigation purposes. Spatial distribution mapping and Piper trilinear diagrams further elucidated hydrogeochemical patterns, emphasizing the urgent need for effective water quality monitoring and management strategies.

***Keywords**: Hydrochemistry, Anthropogenic pollution, Irrigation suitability, Spatial analysis, Physicochemical parameters.*

1. Introduction

One of the most important environmental issues of the twenty-first century is the growing scarcity of freshwater, which is essential to the survival of all living things [1]. River systems are essential for maintaining ecological balance, promoting agriculture, and advancing socioeconomic growth. However, the quality of river water has been seriously harmed by fast industrial growth, urbanization, and related developmental activities. Due to its reliance on surface water from rivers, reservoirs, and related groundwater systems, agriculture is especially susceptible to this kind of deterioration. The effects of environmental pollution have been exacerbated in recent decades by decreased river flow brought on by the construction of upstream dams, deterioration of drainage networks, and loss of forest cover. The physicochemical makeup of river water has changed as a result of the discharge of untreated household sewage and industrial effluents, endangering public health, reducing agricultural yields, and deteriorating soil quality [1, 2]. Physicochemical parameters, which are sensitive to anthropogenic water abstraction, seasonal fluctuations, and pollution sources, are frequently used to assess water quality [3].

The natural ability of rivers to purify themselves has been overtaken by increased urbanization and industrialization because pollutant inputs greatly outpace assimilation rates. As a result, assessments of water quality need to take long-term trends and current conditions into account. The Penna River has received little attention, whereas the Ganga River has been the subject of numerous studies [4-6]. The Penna, also called Pennar or Penneru, is a significant river in southern India that flows eastward. It starts in Karnataka's Nandidurg Hill Range, passes through Andhra Pradesh, and empties into the Bay of Bengal [3]. The goal of this study is to assess how the Penna River's physicochemical features vary geographically in the Kadapa area.

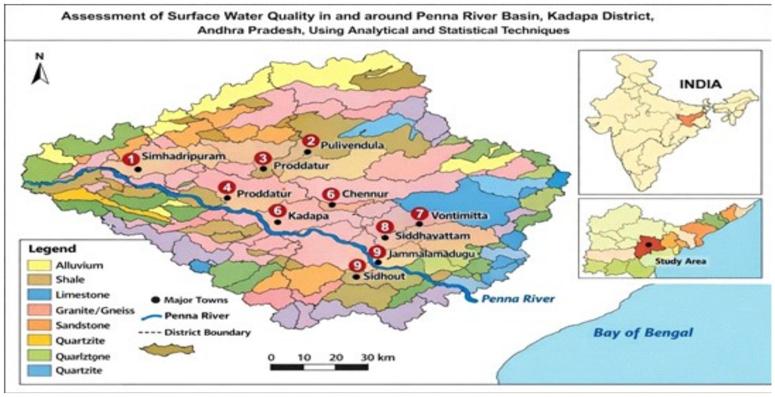


Figure 1: Graphical Representation

1. Materials and Methods

1.1 Study Area

The Penna Ahobilam Balancing Reservoir (PABR)-Mid Reservoir and its environs were the focus of the current study, which was conducted in the Penna River Basin, Kadapa District, Andhra Pradesh [Figure 1]. The Penna River is a significant river that flows eastward and serves the local population's domestic, drinking, and irrigation needs. The water quality in the basin is influenced by a variety of geological formations, including quartzite, sandstone, limestone, granite/gneiss, shale, and alluvium. Figure 1 depicts sampling locations dispersed along the river and surrounding towns; Table 1 provides coordinates while Table 2 summarizes methods used for analysis of physico-chemical parameters of water samples.

1.2 Sample Collection

Ten (10) groundwater samples were taken from tube wells near the river basin, and fourteen (14) Surface water samples were taken from specific locations along the Penna River and PABR. Clean 1-L polyethylene bottles that had been previously cleaned with detergent, thoroughly rinsed with distilled water, and then rinsed with the sample water prior to collection were used for the sampling process [7].

All samples were gathered in accordance with APHA guidelines and Indian Standards (IS 10500) standard procedures. To prevent any major changes in the water quality, the collected samples were brought to the lab in an icebox and examined for physico-chemical parameters within a day.

1.3 Physico-Chemical Analysis

Standard analytical techniques were used to examine the collected water samples for a variety of physico-chemical parameters. pH, Electrical Conductivity (EC), Total Dissolved Solids (TDS), Total Hardness, Alkalinity, Chloride, Sulphate, Dissolved Oxygen (DO), and Biochemical Oxygen Demand (BOD) are the parameters chosen for this investigation.

1.3.1 pH

The concentration of hydrogen ions is measured by pH, which shows whether water is acidic or alkaline. Within 24 hours following sample collection, a digital pH meter (Elico) calibrated with standard buffer solutions was used to measure the pH of surface and groundwater samples.

1.3.2 Electrical Conductivity (EC)

Electrical conductivity, which is measured in µS cm{ ¹, is a measure of the total ionic concentration in water. A digital conductivity meter (Elico) was used to test EC at room temperature.

1.3.3 Total Dissolved Solids (TDS)

The entire concentration of dissolved organic and inorganic materials in water is indicated by total dissolved solids. A TDS meter was used to test TDS, which was then quantified in mg L^{-1} (ppm).

1.4 Total Hardness

The primary cause of hard water is dissolved calcium and magnesium ions. The EDTA titrimetric technique was used to calculate total hardness. Using Eriochrome Black-T indicator at a pH range of 9–10, a standard solution of disodium ethylene diamine tetraacetic acid (EDTA) served as the titrant in this procedure. A colour shift from wine red to blue, signifying full complexation of Ca2+ and Mg2+ ions, was used to identify the endpoint.

1.5 Chloride

Using potassium chromate (K_2Cro_4) as the indicator and standard silver nitrate ($AgNo_3$) solution as the titrant, the argentometric titration method was used to measure the quantity of chloride in water. The formation of a reddish-brown precipitate indicated the endpoint.

1.6 Alkalinity

Water samples were titrated against standard N/50 sulfuric acid (H_2So_4) using phenolphthalein and methyl orange indicators to assess their total alkalinity. Bicarbonate alkalinity is represented by methyl orange alkalinity, whereas carbonate and hydroxide alkalinity is indicated by phenolphthalein. The endpoints were recorded using colour changes in a 100 mL water sample used for titration.

1.7 Dissolved Oxygen (DO)

A crucial indicator of the ecological health of water bodies is dissolved oxygen (DO). The Winkler's iodometric approach was used to estimate DO. Using this process, manganous hydroxide is oxidized by dissolved oxygen to manganese hydroxide, which then releases iodine equal to the DO when acidified. A typical sodium thiosulphate solution was used to titrate the released iodine.

1.8 Biochemical Oxygen Demand (BOD)

The quantity of oxygen needed by bacteria for the aerobic biological breakdown of organic matter is known as biochemical oxygen demand, or BOD. The samples were incubated at 20°C for five days, and the difference between the original and final DO levels was used to calculate BOD. BOD is a crucial sign of organic contamination in water.

1.9 Statistical Analysis

To comprehend regional differences and interrelationships among water quality measures, the analytical results were statistically assessed. Standard software was used to apply fundamental statistical procedures like mean, minimum, maximum, standard deviation, and correlation analysis. To determine whether the water was suitable for home and agricultural use, the results were compared with WHO and Indian drinking water standards.

Table 1: Sampling Locations of Surface and Groundwater along the Penna River, Kadapa District [8]

Surface Water Samples			Groundwater Samples		
Sample No.	**Location**	**Coordinates (Lat, Long)**	**Sample No.**	**Location**	**Coordinates (Lat, Long)**
1	Pulivendula (Upstream)	14.58°N, 75.20°E	1	Pulivendula	14.77°N, 77.56°E
2	Near Pennahobilam	14.63°N, 76.30°E	2	Pennahobilam	14.83°N, 77.40°E
3	Proddatur	14.57°N, 75.38°E	3	Proddatur (Penakacherla)	14.98°N, 77.43°E
4	Kadapa (River Stretch)	14.68°N, 76.33°E	4	Kadapa (Kalluru)	14.92°N, 77.67°E
5	Chennuru	14.82°N, 75.34°E	5	Chennuru	14.94°N, 77.60°E
6	Jammalamadugu	14.82°N, 76.47°E	6	Jammalamadugu	14.92°N, 77.93°E
7	Siddavatam	14.83°N, 75.58°E	7	Siddavatam	14.92°N, 77.85°E
8	Chennuru (Downstream)	14.79°N, 77.82°E	8	Chennuru	14.83°N, 77.97°E
9	Proddatur (Downstream)	14.72°N, 76.73°E	9	Proddatur (Talla Prodduturu)	14.93°N, 78.26°E
10	Gandikota	14.88°N, 77.85°E	10	Gandikota	14.90°N, 78.42°E
11	Gandikota Reservoir	14.92°N, 77.95°E	—	—	—

Table 2. Summary of Methods Used for Analysis of Physico-Chemical Parameters of Water Samples [8]

S. No.	Parameter	Method of Determination	Instrument / Technique	Reference Code (IS)
1	Colour	Visual comparison	Cobalt scale	IS 3025 (Part 4)
2	Electrical Conductivity (EC)	Potentiometric measurement	EC meter	IS 1070 (1992)
3	Acidity	Acid–base titration	Titration against NaOH	IS 3025 (Part 22)
4	Alkalinity	Acid–base titration	Titration against HCl	IS 3025 (Part 23)
5	Total Hardness	Complexometric titration	EDTA titration	IS 3025 (Part 21)
6	Temporary Hardness	Complexometric titration	EDTA titration	IS 3025 (Part 21)
7	Biochemical Oxygen Demand (BOD)	Incubation method (5 days at 20 °C)	DO measurement	IS 3025 (Part 44)
8	Dissolved Oxygen (DO)	Iodometric titration	Winkler's method	IS 3025 (Part 38)
9	Total Dissolved Solids (TDS)	Gravimetric/instrumental method	TDS meter (back-scatter principle)	IS 3025 (Parts 16 & 17)
10	Total Suspended Solids (TSS)	Gravimetric method	Filtration	IS 3025 (Parts 16 & 17)
11	Total Volatile Solids (TVS)	Gravimetric method	Evaporation and ignition	IS 3025 (Parts 16 & 17)

2. Results and Discussion

In August 2025, surface water samples from the Penna River were taken at 14 different places, as shown in Tables 1 and 2. Home or field bore wells close to these surface water sampling locations provided groundwater samples. Ten groundwater samples in all were gathered and examined. Tables 3, 4, 5, 6, and 7 present the findings for both surface and groundwater samples and Figure 2 presents physico-chemical properties of Penna river water samples [9,10].

Table 3. Physico-chemical properties of Penna River water samples in Kadapa District (pH, Temperature, Colour, EC, Acidity)

Sample No.	Sampling Site (Penna River – Kadapa District)	pH	Temperature (°C)	Colour	EC (µS/cm)	Acidity (ppm)
1	Pulivendula	7.4	36.0	Green	126	1074
2	Pulivendula (Downstream)	7.8	38.0	Light green	125	1674
3	Proddatur	7.77	35.0	Pale green	128	852
4	Proddatur (Downstream)	7.67	34.0	Green	124	851
5	Kadapa	7.75	37.0	Pale green	143	801
6	Kadapa (Urban Stretch)	7.69	35.0	Colorless	138	801
7	Chennuru	7.8	38.0	Colorless	127	776
8	Chennuru (Downstream)	7.76	36.0	Colorless	122	823
9	Jammalamadugu	7.88	34.0	Colorless	136	854
10	Jammalamadugu (Downstream)	8.12	35.0	Colorless	144	873
11	Siddavatam	8.08	38.2	Colorless	158	1035
12	Siddavatam (Downstream)	8.21	37.0	Light black	192	1610
13	Gandikota	8.14	36.0	Pale green	186	1615
14	Gandikota Reservoir	8.19	35.0	Green	183	1565

The pH readings of surface water samples taken from 14 locations along the Penna River in the Kadapa region ranged from 7.4 (Pulivendula) to 8.21 (Siddavatam Downstream), indicating neutral to slightly alkaline conditions. The water's temperature ranged from 38.2°C (Siddavatam) to 34.0°C (Jammalamadugu). The water samples' colours varied from colourless to green tones, with the majority of upstream areas exhibiting green or pale green water and the majority of downstream places being colourless. The colouring of Siddavatam Downstream was bright black. Electrical conductivity (EC) values varied along the river, ranging from 122 µS/cm (Chennuru Downstream) to 192 µS/cm (Siddavatam Downstream). The water's acidity levels fluctuated greatly, ranging from 801 ppm in the Kadapa Urban Stretch to 1610 ppm in Siddavatam Downstream. In general, downstream locales have higher EC and acidity than upstream ones.

****Table 4. Physico-chemical properties of Penna River water samples in Kadapa District** (Alkalinity, Total Hardness, Temporary Hardness, BOD, DO)**

Sample No.	Sampling Site (Penna River – Kadapa District)	Alkalinity (ppm)	Total Hardness (ppm)	Temporary Hardness (ppm)	BOD (ppm)	DO (ppm)
1	Pulivendula	299	1212	1148	11.5	5.2
2	Pulivendula (Downstream)	348	1223	1155	13	5.1
3	Proddatur	326	1248	1133	13	5.5
4	Proddatur (Downstream)	549	1248	1112	12	5.4
5	Kadapa	348	1323	1124	12	5.1
6	Kadapa (Urban Stretch)	312	1342	1213	11	5.5
7	Chennuru	603	1423	1215	13	5.4
8	Chennuru (Downstream)	352	1513	1314	14	5.3
9	Jammalamadugu	678	1513	1311	11	5.8
10	Jammalamadugu (Downstream)	704	1615	1414	13	5.3
11	Siddavatam	756	1665	1513	15	5.8
12	Siddavatam (Downstream)	1059	1838	1765	18	5.6
13	Gandikota	1142	1878	1655	16	5.5
14	Gandikota Reservoir	1212	1965	1812	17	5.7

Alkalinity levels in groundwater samples taken from 14 sites along the Penna River in the Kadapa area ranged from 299 ppm at Pulivendula to 1212 ppm at Gandikota Reservoir. All of the sampling locations had hard to extremely hard water, with total hardness ranging from 1212 ppm (Pulivendula) to 1965 ppm (Gandikota Reservoir). Temporary hardness readings showed a significant mineral concentration in the groundwater, ranging from 1112 ppm (Proddatur Downstream) to 1812 ppm (Gandikota Reservoir). Different levels of organic pollution were indicated by Biochemical Oxygen Demand (BOD) readings, which varied from 11 ppm at Pulivendula and Jammalamadugu to a maximum of 18 ppm at Siddavatam Downstream. All locations had dissolved oxygen (DO) concentrations between 5.1 and 5.8 ppm, with Jammalamadugu and Siddavatam having the highest DO. Significantly, downstream sites including Gandikota, Gandikota Reservoir, and Siddavatam Downstream showed greater BOD, hardness, and alkalinity readings, indicating more organic load and mineralization in the groundwater in these places.

Table 5. Physico-chemical properties of Penna River water samples in Kadapa District

Sample No.	Sampling Site (Penna River – Kadapa District)	TDS (ppm)	TSS (ppm)	TVS (ppm)	TFS (ppm)	TS (ppm)
1	Pulivendula	223	1012	1001	221	1215
2	Pulivendula (Downstream)	222	1021	1040	222	1255
3	Proddatur	219	1012	993	222	1213
4	Proddatur (Downstream)	224	1011	975	253	1237
5	Kadapa	248	1009	982	271	1246
6	Kadapa (Urban Stretch)	235	1013	931	321	1242
7	Chennuru	222	1018	892	347	1252
8	Chennuru (Downstream)	222	1001	921	355	1286
9	Jammalamadugu	246	1021	903	377	1279
10	Jammalamadugu (Downstream)	252	1013	901	389	1289
11	Siddavatam	268	1022	933	392	1314
12	Siddavatam (Downstream)	312	1036	970	414	1362
13	Gandikota	293	1045	962	423	1375
14	Gandikota Reservoir	295	1212	1066	441	1511

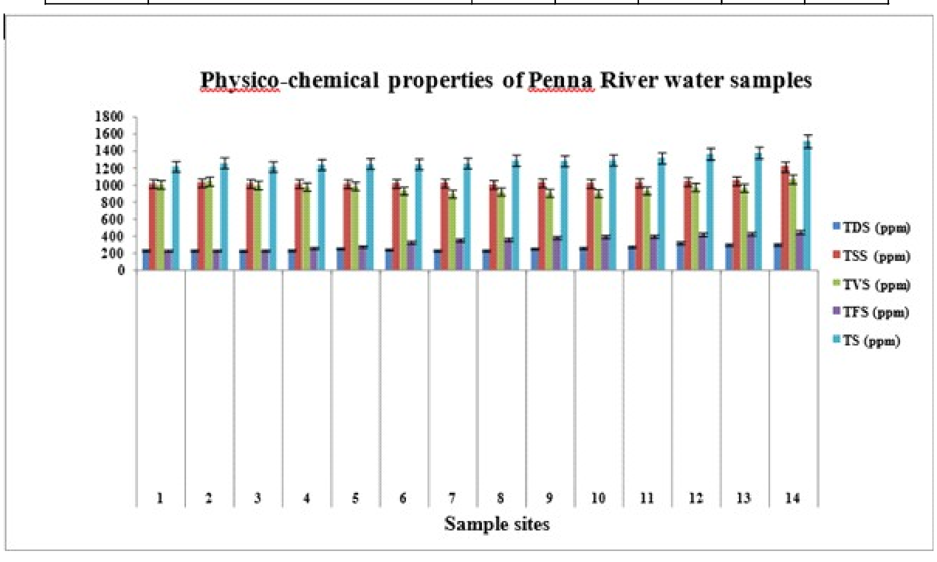
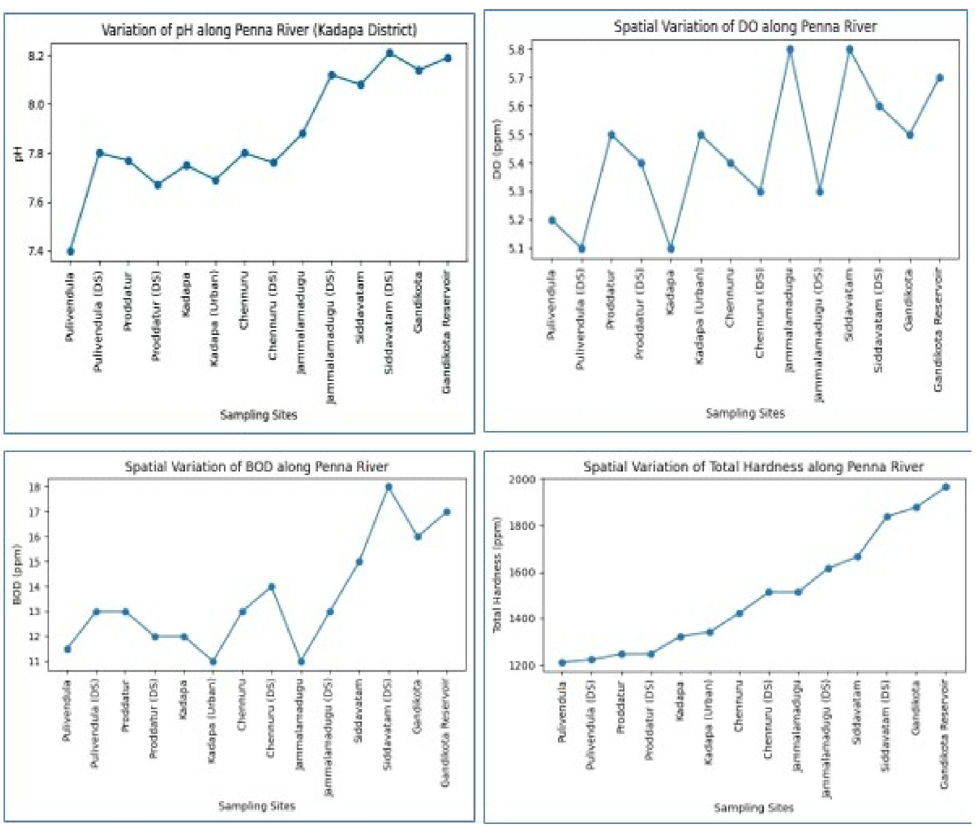


Figure 2: Physico-Chemical Properties of Penna River Water Samples

Groundwater samples from the Penna River watershed showed moderate mineral richness, with total dissolved solids (TDS) ranging from 219 ppm in Proddatur to 312 ppm at Siddavatam Downstream. The readings of total suspended solids (TSS), which ranged from 1001 ppm (Chennuru Downstream) to 1212 ppm (Gandikota Reservoir), were constantly high. Total volatile solids (TVS), which indicate the presence of organic and volatile stuff in the water samples, range from 892 ppm in Chennuru to 1066 ppm in Gandikota Reservoir. The inorganic solids represented by total fixed solids (TFS) ranged from 221 ppm (Pulivendula) to 441 ppm (Gandikota Reservoir), indicating a downstream increase in mineral content. The sum of volatile and fixed solids, or overall total solids (TS), varied from 1213 ppm in Proddatur to 1511 ppm in Gandikota Reservoir. The highest values were found in Gandikota Reservoir, indicating a higher solid load downstream. The findings show a steady rise in suspended and dissolved solids along the river segment, most likely as a result of anthropogenic inputs affecting groundwater quality downstream and natural mineral dissolution [Figure 3].



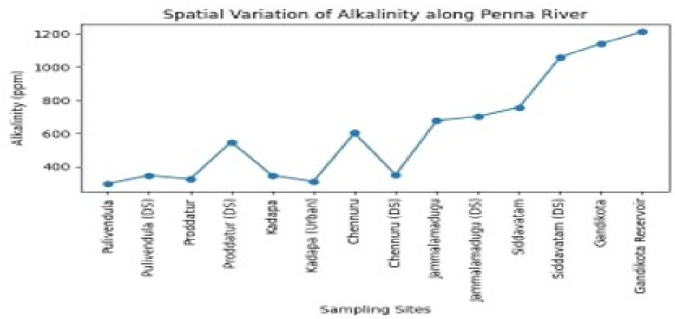


Figure 3: Various parameters such as various of pH, **Spatial variation of Alkalinity (ppm)**, **Spatial variation of Total Hardness (ppm)**, **Spatial variation of BOD (ppm)**, **Spatial variation of DO (ppm)**

Table 6. Analysis of water quality parameters of Ground water (pH, Temperature, Ec, TDS, Acidity)

Sample No.	Place	pH	Temperature (°C)	EC (µS/cm)	TDS (ppm)	Acidity (ppm)
1	Pulivendula	8.25	21.2	341.9	231	320
2	Proddatur	8.22	23.4	321.0	218	331
3	Kadapa	8.18	22.6	317.1	226	338
4	Jammalamadugu	8.21	22.7	336.0	331	342
5	Siddavatam	8.18	23.1	337.1	322	368
6	Chennuru	8.32	23.5	351.9	339	376
7	Tadipatri	8.31	23.7	345.2	346	377
8	Chitrachedu	8.41	24.1	341.7	357	387
9	Prodduturu	8.39	24.3	372.3	375	385
10	Near Gandikota	8.42	24.5	379.7	383	401

Table 7. Analysis of water quality parameters of Ground water (Alkalinity, Total Hardness, BOD, DO)

Sample No.	Place	Alkalinity (ppm)	Total Hardness (ppm)	Temporary Hardness (ppm)	BOD (ppm)	Dissolved Oxygen (ppm)
1	Pulivendula	525	1388	501	4.2	3.41
2	Proddatur	563	1412	521	5.1	3.62
3	Kadapa	591	1452	533	5.5	3.51
4	Jammalamadugu	642	1455	591	5.8	3.55
5	Siddavatam	721	1430	601	5.4	4.11
6	Chennuru	950	1472	650	5.8	4.16
7	Tadipatri	1177	1501	691	6.1	4.28
8	Chitrachedu	1312	1872	790	6.3	4.17
9	Prodduturu	1411	1921	801	5.5	4.29
10	Near Gandikota	1425	1963	815	6.1	4.38

3. Discussions

The Penna River Basin's Groundwater quality analysis shows moderate to high amounts of suspended and dissolved solids, which are a result of both anthropogenic and natural geochemical factors. The measured total dissolved solids (TDS), which range from 219 to 312 ppm, are in line with values found in comparable semi-arid river basins, where groundwater mineralization is largely caused by agricultural runoff and mineral dissolution [11, 12]. The slow rise in TDS downstream, particularly at Siddavatam and Gandikota Reservoir, indicates salt buildup that is probably caused by surface water-groundwater interactions and irrigated water infiltration**.** Also, this pattern was observed in their study on groundwater quality in similar Indian river basins [13].

Total suspended solids (TSS) levels above 1000 parts per million (ppm) at all locations are a sign of a high particulate matter presence, which can deteriorate water quality by carrying pollutants and decreasing clarity. This is consistent with research [14], who found that similar TSS levels were associated with land use changes and sediment erosion close to water bodies in southern India. Gandikota Reservoir's highest TSS could be the result of silt buildup brought on by reservoir-induced flow variations, supporting findings from reservoir impact studies.

The organic matter represented by the total volatile solids (TVS) component ranges from 892 to 1066 ppm, indicating significant organic pollution most likely from household effluents and agricultural runoff. These values are similar to those reported by [15], who found increases in organic load downstream in groundwater in river basins impacted by human settlements. In line with hydrogeochemical tests carried out by [16] in comparable alluvial aquifers, the increase in total fixed solids (TFS) downstream further validates improved mineral dissolving processes.

The overall increased trend of total solids (TS) downstream suggests that groundwater quality is being impacted by both natural and man-made sources. A pattern seen in several river basins in India and around the world, the combination of elevated volatile and fixed solids reveals intricate interactions between geogenic sources and human activity [12, 13]. These results highlight the necessity of integrated water management techniques in the Penna River basin, with an emphasis on monitoring mineralization to maintain groundwater usability, limiting organic contamination, and regulating sediment flow. Recent research on groundwater protection in semi-arid areas has recommended similar actions [14, 15]**.**

4. Conclusion

The Kadapa district's groundwater quality assessment along the Penna River basin shows moderate to high levels of dissolved and suspended solids, as well as rising trends in TDS, TSS, TVS, TFS, and total solids from upstream to downstream locations. This pattern shows how natural geochemical processes and human activities like sedimentation, household effluents, and agricultural runoff interact. Increased organic and mineral burdens downstream draw attention to possible threats to the drinking and irrigation utility of groundwater in the absence of proper treatment. To reduce sources of pollution, safeguard groundwater supplies, and guarantee sustainable water quality in the Penna River region, ongoing monitoring and integrated management techniques are crucial.

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