MultiCraft

International Journal of Engineering, Science and Technology
Vol. 16, No. 4, 2024, pp. 11-19

INTERNATIONAL JOURNAL OF ENGINEERING, SCIENCE AND TECHNOLOGY

www.ijest1-ng.com
www.ajol.info/index.php/ijest


# Analysis and insights of groundwater quality and water quality index values with reference to different sources: a case study

**B. Vamsi[1*], Sk. Apsar[2], S. Eswar[3], G. Viraj[4], B. Chandrsekhar[5], M. Gopi Kiran[6]**

*[1, 2, 4, 6]Department of Civil Engineering, Lingayas Institute of Management and Technology, Vijayawada-521212, India*
*[3]Department of Computer Science and Engineering, Lingayas Institute of Management and Technology, Vijayawada-521212, India*
*[5]Department of Chemical Engineering, RGUKT RK Valley, Iddupulapaya, Vempalli, YSR Kadapa, India*
*[*]Corresponding Author: e-mail: rnc.lingayas@limat.edu.in*
*ORCID iDs: https://orcid.org/0009-0004-2726-4644 (Vamsi); https://orcid.org/0009-0006-4310-6907 (Apsar); https://orcid.org/0009-0004-1536-7304 (Eswar); https://orcid.org/0009-0008-5714-4335 (Viraj); https://orcid.org/0000-0002-6653-7498 (Chandrasekhar); https://orcid.org/0000-0002-5972-1094 (Gopi Kiran)*

**Abstract**

Groundwater quality variation due to consequent changes in the standard of living of a community is of great unease owing to the fact that the groundwater is regarded as one of the significant water supply sources available. For the sustainable use of water resources and water quality management, monitoring and assessment of water quality acts a catalyst for an appropriate judgment on the water quality. In this study, groundwater samples were collected from Lingayas Institute of Management and Technology (LIMAT), Vijayawada campus and Mudirajupalem, Krishna district, Andhra Pradesh, India for monitoring and assessing the water quality for alkalinity, total dissolved solids (TDS), pH, acidity and total hardness (TH) using standard methods. Very high values of pH and TDS were obtained in the groundwater collected from Mudirajupalem, which is within the vicinity of agricultural fields. Added to this, Student's t test analysis of TDS values signposted a noteworthy P value (<0.001) for which the mean difference was substantial statistically. The groundwater collected from Mudirajupalem further affirmed that the water is unfit for drinking, which is evident from water quality index (WQI) values. This study emphasizes on implementing various locale specific rainwater garnering schemes, which is one of the solution for augmenting the groundwater recharge and maintaining the groundwater balance.

*Keywords:* Groundwater recharge, rainwater harvesting, groundwater analysis, total dissolved solids, statistical analysis.

DOI: http://dx.doi.org/10.4314/ijest.v16i4.2

*Cite this article as*:
Vamsi B., Apsar S., Eswar S., Viraj G., Chandrsekhar B., Kiran M.G. 2024. Analysis and insights of groundwater quality and water quality index values with reference to different sources: a case study. *International Journal of Engineering, Science and Technology*, Vol. 16, No. 4, pp. 11-19. doi: 10.4314/ijest.v16i4.2

Received: June 2, 2024 Accepted: August 3, 2024; Final acceptance in revised form: August 6, 2024

## 1. Introduction

In the recent times, it has become an unprecedented fact that in the entire world, groundwater resources are being utilized as a major viable source of water for various applications (Li et al., 2020; Batarseh et al., 2021; Chen et al., 2022; Fuentes-Rivas et al., 2023). As per the statistics available in the literature, 65% of global demand of drinking water is met by groundwater, whereas it is 43% for irrigation (Adimalla and Qian, 2021). The water resources, both surface and groundwater are facing irreversible issues owing to uncontrollable population, uncontrollable pollution, increase in industrialization and urbanization and unsustainable agricultural practices, ultimately making it as a global issue resulting in water unfit for human consumption (Khatri and Tyagi, 2015; Khatri et al., 2017; Rawtani et al., 2017).

In the recent years, groundwater depletion has become an alarming and burning issue due to hasty progress, ever-increasing population, changes in the agricultural practices and the mounting waste disposal issues (Ibrahim et al., 2023). Further, the entire world is encountering groundwater quality challenges, more specifically developing countries, due to extensive use of agrochemicals, inappropriate industrial waste disposal practices, rapid urbanization; saltwater intrusion owing to abnormal climate changes and landfill leachate issues (UN World Water Development Report, 2022). Thus, it is inevitable that periodic monitoring of groundwater resources is very much need of the hour for retaining the quality of water for its safe and justifiable consumption. Sustainable development goals (SDGs) were formulated by the United Nations wherein, the SDG 6 is treated as a significant pillar to ensure the sanitation and sustainable water management for all by 2030 (Uddin et al., 2023a). Globally, the increasing level of groundwater depletion is further making it difficult to outreach the SDGs (Mohammed et al., 2024). Research addressing the areas of groundwater laid down a very strong path for the progress, which ultimately lead to employing various techniques for monitoring the groundwater quality. The water quality index (WQI), which was developed in the early 1970s, contributes an indication of the health of the water quality and can be employed as a platform to keep track and analyze the changes in the water quality over time (Brown et al., 1972). The WQI is viably deliberated as one of the most applicable method, which converts huge data into a numerical score and reveals the water quality for various applications (Uddin et al., 2022a; Uddin et al., 2022b; Uddin et al., 2022c; Eid et al., 2023; Uddin et al., 2023b; Uddin et al., 2023c). Therefore, it is crystal clear that groundwater acts as a focal part of global drinking water resources, ultimately making it very crucial to constantly monitor and manage the groundwater quality to meet SDGs (Sajib et al., 2023). Also, monitoring groundwater quality levels is very vital for public water requirements apart from reaching out to development activities (Subba Rao et al., 2024).

Hence, in line with the development of groundwater and its continuous analysis, in this study, groundwater samples were collected from Lingayas Institute of Management and Technology (LIMAT), Vijayawada campus and Mudirajupalem, Krishna district, Andhra Pradesh, India for a period of 35 days for monitoring and assessing the groundwater quality for alkalinity, total dissolved solids (TDS), pH, acidity and total hardness (TH) using standard methods, as there is a remarkable gap in the data on groundwater quality in the selected study area. This study resulted in producing basic database of the groundwater quality and the prevailing status. This study is probably first of its kind addressed by an academic institution in the selected study area mainly highlighting the gravity of the groundwater quality with respect to WQI, which could directly benefit the society, as water is a priceless naturally gifted resource. It aids in deciphering the groundwater chemistry in the selected study area for its suitability for various purposes. Additionally, the results reported in this study may further pave a strong base for constructive research and dwell into application of appropriate locale specific treatment techniques to improve the quality of water for human consumption and meet future water needs.

## 2. Materials and methods

### *2.1 Study area*

Groundwater samples were collected from LIMAT, Vijayawada campus and Mudirajupalem, Krishna district, Andhra Pradesh, India. The LIMAT campus is located in Maadalavarigudem, which is surrounded by Penamaluru Mandal and Kankipadu Mandal towards South, Agiripalli Mandal towards North and Unguturu Mandal towards East. Mudirajupalem village is located in Gannavaram mandal, Krishna district, Andhra Pradesh, India. The satellite images of the LIMAT campus and Mudirajupalem area are shown in Figure 1.


**(a)**


**(b)**

Figure 1. The study area satellite images of, a.) LIMAT, Vijayawada Campus and b.) Mudirajupalem, Krishna district.

*2.3 Methodology*

Keeping the time frame and limited resources available into view point, groundwater monitoring was carried out by collecting the samples for a period of 35 days (March to April, 2024) from the study area and the collected samples were analyzed for alkalinity, TDS, pH, acidity and TH using standard methods described in American Public Health Association (APHA) (APHA, 2005) as these parameters are common for water analysis. The pH values in the collected samples were verified using scientific pH papers (S. D. Fine-chem Ltd, Mumbai, India), whereas the TDS values in the samples were determined by a Generic Digital LCD TDS Meter (Generic, TDS-3, India). Acidity, TH and alkalinity values in the collected samples were quantified by titration methods available in APHA standard methods. Quality of the groundwater was gauged considering the water quality standards prescribed by Bureau of Indian Standards (BIS) (BIS, 2012) and World health organization (WHO). A method described by Brown et al. (1972) was applied to determine the WQI of the samples to inspect the aptness of the quality of groundwater for various applications. A statistical analysis tool, Students *t* test is employed to figure out the parameters for which the mean difference is statistically considerable.

**3. Results and discussion**

Among the water resources available, groundwater is regarded as a vital water resource, which dominates half of the India's urban water use and it may still further rise owing to rapid urbanization. Because of the dynamic nature of the groundwater, analysis and groundwater quality reports are prone to change from region to region. In view of this, it is essential to collect appropriate information on the quality of groundwater through monitoring, which improves understanding the groundwater quality issues, its sources, causes for it, and finding reasonable and resilient solutions for water quality issues.

The alkalinity of any aquatic system is computed as acid neutralizing capability (Murangan and Prabaharan, 2012). Variation of the alkalinity values in the study area samples during the monitoring period is shown in Figure 2. It was observed that a range of 460-850 mg/L alkalinity was obtained in the Mudirajupalem samples, whereas a range between 550-750 mg/L of alkalinity was obtained in the LIMAT campus samples. As per the literature, the anions, such as $SO_4^{2-}$, $Cl^-$, etc., and cations, such as $Ca^{2+}$, $Mg^{2+}$ and, alkaline metals contribute to alkalinity in the naturally existing water (Prasanth et al., 2012).

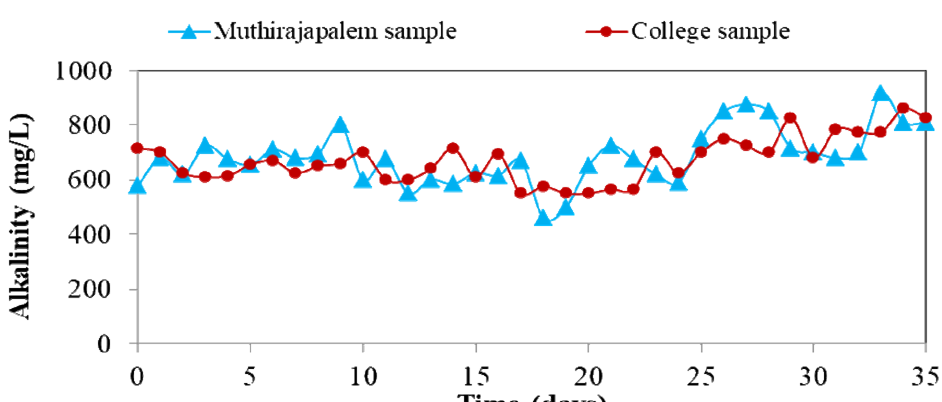


**Figure 2.** Variation of the alkalinity values in the study area samples during the monitoring period.

The alkalinity results obtained in the samples collected from two sources specify that the alkalinity is outside the range of permissible limit, which is in line with the BIS standards. Similar results were reported by Khatri et al. (2020). Further, it can be supposed that the water should undergo treatment process if it is intended for human consumption, as such; it is directly applicable for daily use. Excess amount of alkalinity can be eliminated from water by employing water softening processes.

Variation of the acidity values in the study area samples during the monitoring period is shown in Figure 3. A range of 45-525 mg/L acidity was obtained in the LIMAT campus samples, whereas for the Mudirajupalem samples, acidity was in the range of 45-480 mg/L (Fig. 3). The acidic quality persists in the groundwater; conditional to the aquifer carrying the groundwater is encompassed with carbonate rocks. Water with acidic quality is not in itself harmful to health; however, the concern of acidity in drinking water even with mild acidic nature may lead to dissolving of lead or copper metals that may be present in plumbing pipes. Owing to this fact, the standards formulated to standardize the water quality determined that a pH in the range of 6.5 and 8.5 should be maintained in the water to eliminate the buildup of scale deposits from water or dissolved contaminants concentration from acidic waters (American GroundWater Trust, 2003).

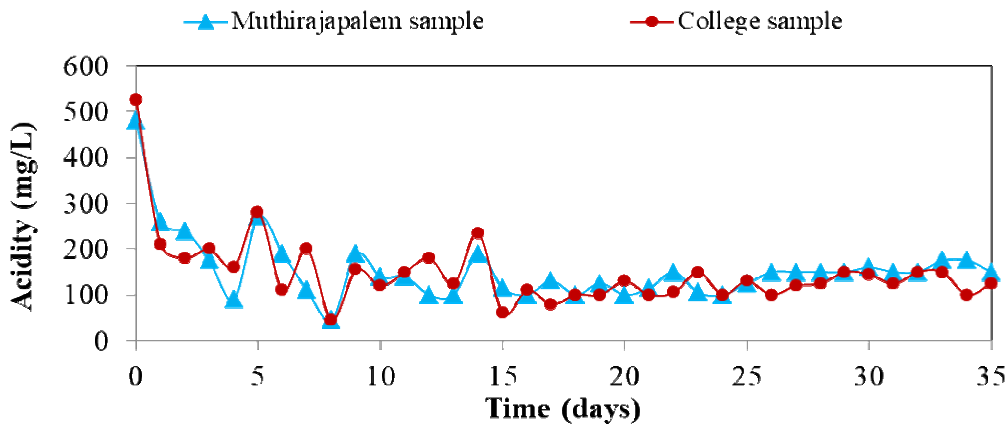


**Figure 3.** Variation of the acidity values in the study area samples during the monitoring period.

Variation of the pH values in the samples during the monitoring period in the study area is shown in Figure 4. Hydrogen ions concentration present in the water is represented by pH, wherein, even minor changes in pH values imposes impact on the water quality due to chemical reactions, therefore, pH value is detrimental to the aquatic ecosystems (Wang et al., 2002; Fakayode, 2005). From the results for the monitoring period of 35 days, it is apparent that the pH value was in the range of 8.5-10 for the Mudirajupalem samples, whereas pH value in the range between 6.5-8.0 was obtained in the LIMAT campus samples, which is outside the range of permissible limit in the former context in line with the BIS standards (Fig. 4). It is obvious that high pH values were obtained in the Mudirajupalem samples, possibly due to the presence of agricultural fields within the locality of the selected area, which is further backed by the results achieved in a study conducted by Khatri et al. (2020). The results obtained in this study further affirm groundwater to be alkaline in nature, which could be due to the presence of different types of buffers existing in the groundwater (Weber and Stun, 1963).

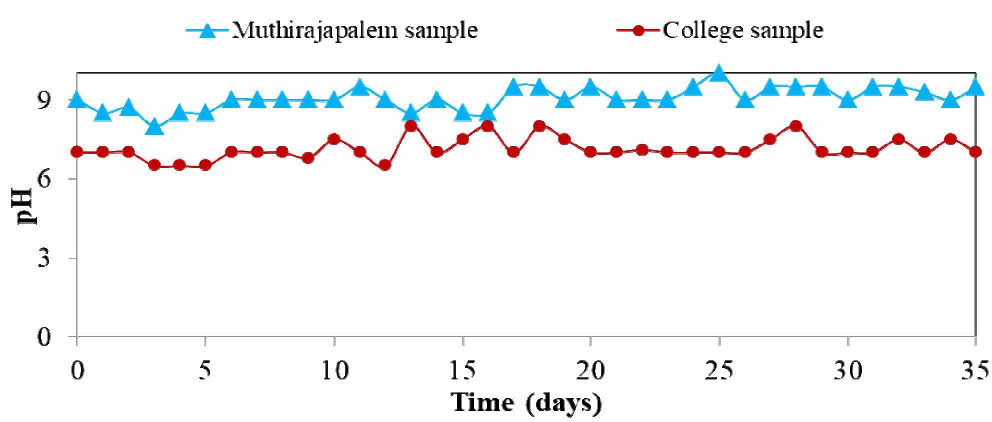


**Figure 4.** Variation of the pH values in the study area samples during the monitoring period.

Human induced developmental undertakings, climatic situations and geological formations are some of the deciding factors for groundwater quality variation in any area, which also may influence physical and chemical parameters (Matthess, 1982; Subramani et al., 2005). Moreover, the contact time of groundwater with a particular rock may show impact on the variation of groundwater chemistry. There is a scope for the effect of rock chemistry on the pH and groundwater formulation with more contact time of groundwater with a particular rock. Further, pH of the groundwater varies with the geo-chemical formulations happening in the bedrock. Also, the groundwater pH is bound to vary with respect to the rock composition and sediments adjacent to path of the water percolating into the groundwater (American GroundWater Trust, 2003).

The extent to which dissolved matter present in the water is indicated by TDS, which further indicates the pollution level. Variation of the TDS values in the study area samples during the monitoring period is shown in Figure 5. Very high values of TDS were obtained in the Mudirajupalem samples with a range between 931-994 mg/L, whereas TDS values ranged between 199-273 mg/L in the LIMAT campus samples. In a study conducted by Kumar et al. (2024) on groundwater quality evaluation using WQI and geospatial techniques, the TDS values ranged between 450-1820 mg/L, attributing the high values because of discarding municipal and industrial wastes, leaks, and the penetration of water comprising of solid materials to the ground. In general, groundwater consists of high TDS values because of the salts that leach from soil, apart from the domestic sewage that may percolate into the groundwater, which increases the TDS values (Prasanth et al., 2012). In the present study, as per the field survey conducted with the local public, it was informed that presence of solid materials (both dissolved and suspended) because of various human induced activities might have resulted in high TDS values in the Mudirajupalem groundwater samples. The results reported by Lamare and Singh (2016) further supported the present study results. The TDS value of the Mudirajupalem source is very much beyond the allowable limits compared with the BIS standards, which emphasized that there is a need for treatment of groundwater if it is meant for human consumption. Excess amount of TDS present in the water can be eliminated by employing Reverse osmosis (RO), deionization (DI) and distillation.

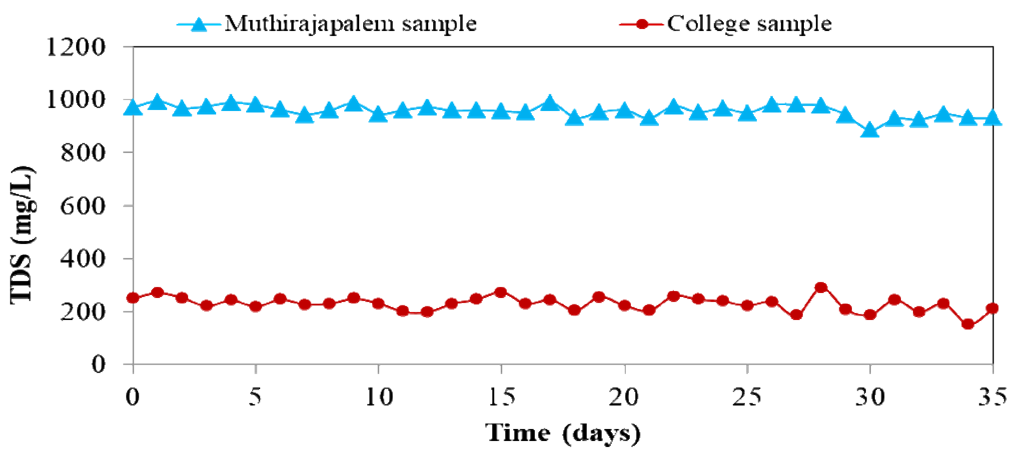


**Figure 5.** Variation of the TDS values in the study area samples during the monitoring.

Generally, the occurrence of several metallic salts, such as magnesium and calcium in water induce total hardness, which necessitates its determination for its suitability to industrial, drinking and domestic applications (Deepa et al., 2016). Variation of the TH values in the study area samples during the monitoring period is shown in Figure 6. It was observed that a range between 20-246 mg/L was obtained in the Mudirajupalem samples, whereas the LIMAT campus samples showed TH values in the range of 0-230 mg/L.

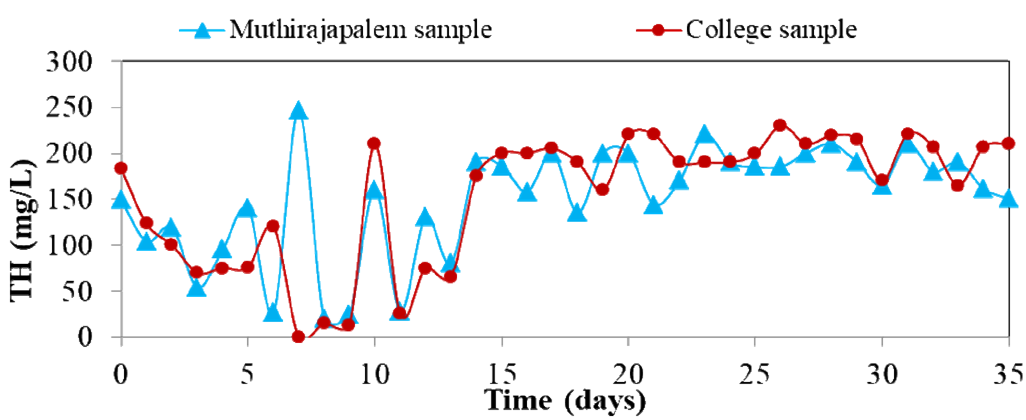


**Figure 6.** Variation of the TH values in the study area samples during the monitoring period.

The results reported by Uddin et al. (2023a) and Kumar et al. (2024) showed that TH values were in the range between 210 to 490 mg/L and 252-1049 mg/L, respectively, which is matching with the current study results, the difference is maybe due to geological formulations. Table 1 presents the groundwater quality classification with respect to the TH range (Sawyer and McCarty, 1967). In line with the information presented in Table 1, the results obtained in this study signpost the groundwater quality in the study area as hard to very hard. It is crystal clear that in the current study, TH values in the two sources are outside the range of the allowable standard values presented in the BIS standards. Water softening processes are widely popular for removing excess TH from water. One of the most popular tools which are extensively applied for quantifying the water quality is WQI. The water quality variation in any region can be monitored and assessed by employing WQI. Even though several water quality parameters constitute overall quality of the water, the advantage of computing the WQI is that, it converts voluminous data to a simple value. Table 2 highlights the relation between quality of water and WQI values.

**Table 1.** Groundwater quality classification with respect to the TH range (Sawyer and McCarty, 1967)

| TH range | Water Quality |
|---|---|
| <75 | Soft |
| 75 – 150 | Moderately hard |
| 150 – 300 | Hard |
| > 300 | Very hard |

**Table 2.** The relation between quality of water and WQI values (WHO, 2004)

| S. No. | WQI values | Water Quality |
|---|---|---|
| 1 | 0 – 25 | Excellent Water Quality |
| 2 | 26 – 50 | Good Water Quality |
| 3 | 51 – 75 | Poor Water Quality |
| 4 | 76 – 100 | Very Poor Water Quality |
| 5 | > 100 | Unfit for Drinking |

Groundwater from LIMAT campus and Mudirajupalem samples showed the WQI values as 20.32 and 358.34, respectively, which affirms that Mudirajupalem groundwater is not fit for public consumption as per the water quality status presented in the Table 2 (WHO, 2004). In a study conducted by Prajapati and Bilas (2018), similar WQI values were obtained and ranged between 28.48 and 535.32 demonstrating that the water samples don't fit for human ingestion, whereas the LIMAT campus groundwater quality suits for drinking, however, after an appropriate treatment. In a study conducted by Kumar et al. (2024), it was reported that the WQI values were in the range of 77.03-115.14, which is also similar with the current study results. Similarly, in a study conducted on bootstrap approach for quantifying the uncertainty in modeling of the WQI, Chawishborwornworng et al. (2024) reported the WQI values in the range of 41-90. The WQI values obtained in this study are also slightly similar to the results reported by Marfo et al. (2024) in which, the WQI values were in the range of 5.208-134.232.

Hypothesis testing is performed for the evaluation of means between different groups, which is basically executed by making use of statistical methods, such as analysis of variance (ANOVA), Student's *t* test (t test) and analysis of covariance (ANCOVA). Among the several statistical tools available, a distinctive *P* value decides the significance of means amid two variables in case of the Student's *t* test and multiple comparisons are not essential (Mishra et al., 2019a). Upon performing the hypothesis test, the means of groups would be statistically equal in the context of null hypothesis, while in the context of opposite to the null hypothesis, the means of groups would not be statistically equal, which is specified by a $P$ value of $<0.05$ (Jaykaran, 2010; Sundaram et al., 2014; Mishra et al., 2019b). Among the five parameters analyzed in the present study, pH and TDS showed a lot of variation in the Mudirajupalem groundwater samples; however, statistical Student's *t*-test is conducted for TDS alone as its variation is very high compared with the pH values. The result of Student's *t*-test for TDS values is presented in Table 3, which further specify a significant *P* value less than 0.001 of the Student's *t* test for which the difference in mean was statistically substantial.

The groundwater sample analysis in the present study showed very high values of alkalinity in both the samples, whereas, groundwater collected from Mudirajupalem showed high values of pH and TDS as it is sited within the vicinity of agricultural fields, also supported by the results reported by Khatri et al. (2020). In a study conducted by Khatri et al. (2020), high values of hardness, alkalinity and TDS were reported in groundwater samples emphasizing the geological strata to be one of the reasons. The mineral compounds adjoining the groundwater show a tendency in leaching the ions into the groundwater thereby, increasing the alkalinity and hardness values, matching with the present study results. In southern part of India, it was reported that groundwater quality is subject to vary with hot climatic conditions and bedrock geology; however, sometimes pollution from agriculture and industries also cause a change in the groundwater quality (Ramakrishna et al., 2009).

**Table 3.** The results of Student's *t*-test conducted in case of TDS values: Two-Sample Assuming Equal Variances

| | Variable 1 | Variable 2 |
|---|---|---|
| Variance | 517.8920635 | 907.0571429 |
| Observations | 36 | 36 |
| Pooled Variance | 712.4746032 | |
| Hypothesized Mean Difference | 0 | |
| Df | 70 | |
| T Stat | 124.305162 | |
| P(T<=t) one-tail | <0.001 | |
| T Critical one-tail | 1.666914479 | |
| P(T<=t) two-tail | <0.001 | |
| t Critical two-tail | 1.994437112 | |

The present study results emphasize on the necessity of making use of local water treatment methods to transform the groundwater to potable. Also, to cater the water scarcity issues in future, rainwater garnering schemes, which are locale specific, can be examined and instigated, eventually resulting in improved groundwater recharge. Furthermore, to enrich the reliability of water quality assessment, several contemporary trending techniques, such as machine learning (ML), deep learning (DL), artificial neural networks (ANN), artificial intelligence (AI) techniques, etc. can be employed. Marfo et al. (2024) reported that remote sensing and geographical information system (GIS) can be applied to generate diverse digital themed layers and maps that can exhibit the spatial distribution of different water quality parameters, which opens a window for explorative research.

## 5. Conclusion

In this study, groundwater collected from two sources is monitored and evaluated for a period of 35 days to investigate the groundwater quality using parameters, such as alkalinity, pH, acidity TDS and TH. High alkalinity values were obtained in the groundwater from both the sources, whereas Mudirajupalem groundwater showed high values of pH and TDS as it is situated nearby agricultural fields. The groundwater from Mudirajupalem showed WQI value of 358.34 emphasizing that it doesn't fit for public consumption, whereas a WQI value of 20.32 is obtained in the LIMAT campus groundwater samples signifying that the groundwater can be used for drinking, provided after an appropriate treatment. Additionally, to expand the precision of groundwater quality assessment in the long run, a proposal is put forward to employing of ML, DL, ANN, AI techniques, etc. Furthermore, this study also proposes implementing locale specific rainwater garnering schemes that would target the groundwater recharge improvement, ultimately making it a feasible source of life.

## Acknowledgments

We feel happy to acknowledge all the individuals who contributed to this study and made it possible. The authors would like to sincerely thank the editor and the reviewers for their supportive comments that contributed to improving this work.

## References

American Public Health Association (APHA), American Water Works Association (AWWA) & Water Environment Federation (WEF): Standard Methods for the Examination of Water and Wastewater, 21st Edition, 2005, (Washington D.C.).

Acid Rain and Ground Water pH, (The American Well Owner, 2003, No. 3; © American Ground Water Trust)

Adimalla, N., Qian, H. 2021. Geospatial distribution and potential noncarcinogenic health risk assessment of nitrate contaminated groundwater in southern India: a case study, *Archives of Environmental Contamination and Toxicology*. Vol. 80, pp. 107–119, https://doi.org/10.1007/s00244-020-00762-7.

Batarseh, M., Imreizeeq, E., Tilev, S., Al Alaween, M., Suleiman, W., Al Remeithi, A.M., Al Tamimi, M.K., Al Alawneh, M. 2021. Assessment of groundwater quality for irrigation in the arid regions using irrigation water quality index (IWQI) and GIS-Zoning maps: case study from Abu Dhabi Emirate, UAE, *Groundwater for Sustainable Development.* Vol. 14, 100611, https://doi.org/10.1016/j.gsd.2021.100611.

Brown, R.M., McClellan, N.I., Deininger, R.A., Tozer R.G. 1972. A water quality index—do we dare? *Water Sew Works*, Vol. 117, pp. 339-343.

Chawishborwornworng, C., Luanwuthi, S., Umpuch, C., Puchongkawarin, C. 2024. Bootstrap approach for quantifying the uncertainty in modeling of the water quality index using principal component analysis and artificial intelligence, *Journal of the Saudi Society of Agricultural Sciences,* Vol. 23, pp. 17–33

Chen, X., Zhang, H., Cai, Y. 2022. Hydrochemical characteristics and processes of groundwater in the Cenozoic pore aquifer under coal mining, *Environmental Science and Pollution Research*. https://doi.org/10.1007/s11356-022-24561-w.

Deepa, P., Raveen, R., Venkatesan, P., Arivoli, S., Samuel, T. 2016. Seasonal variations of physico-chemical parameters of Korattur Lake, Chennai, Tamil Nadu, India. *International Journal of Chemical Studies*, Vol. 4, No. 3, pp. 116-123.

Eid, M.H., Elbagory, M., Tamma, A.A., Gad, M., Elsayed, S., Hussein, H., Moghanm, F.S., Omara, A.E.D., Kov´acs, A., P´eter, S. 2023. Evaluation of groundwater quality for irrigation in deep aquifers using multiple graphical and indexing approaches supported with machine learning models and GIS techniques, souf valley, Algeria, *Water (Switzerland),* Vol. 15, https://doi.org/10.3390/w15010182.

Fakayode, S.O. 2005. Impact assessment of industrial effluents on water quality of the receiving Alaro River in Ibadan, Nigeria. *Ajeam –Ragee*, Vol. 10, pp. 1-13.

Fuentes-Rivas, R.M., Santacruz-De Le´on, G., Ramos-Leal, J.A., Mor´an-Ramírez, J., Fonseca-Montes de Oca, R.M.G. 2023. Hydrogeochemical assessment and groundwater quality in a shallow aquifer: a case study of San Luis Potosí Valley, Mexico, *Groundwater for Sustainable Development,* Vol. 20, https://doi.org/10.1016/j. gsd.2022.100881.

Ibrahim, H., Yaseen, Z.M., Scholz, M., Ali, M., Gad, M., Elsayed, S., Khadr, M., Hussein, H., Ibrahim, H.H., Eid, M.H., Kov´acs, A., P´eter, S., and Khalifa, M.M. 2023. Evaluation and prediction of groundwater quality for irrigation using an integrated water quality indices, machine learning models and gis approaches: a representative case study. *Water* (Switzerland) Vol. 15, https://doi.org/10.3390/w15040694.

Indian Standards (IS) for Drinking Water as per Bureau of Indian Standards (BIS) specifications (IS 10500-2012; Second Revision).

Khatri, N., Tyagi, S. 2015. Influences of natural and anthropogenic factors on surface and groundwater quality in rural and urban areas. *Front Life Sciences,* Vol. 8, pp. 23–39.

Khatri, N., Tyagi, S., Rawtani, D. 2017. Recent strategies for removal of iron from water: a review. *Journal of Water Process Engineering,* Vol. 19, pp. 291–304.

Li, Y., Liu, J., Gao, Z., Wang, M., Yu, L. 2020. Major ion chemistry and water quality assessment of groundwater in the Shigaze urban area, Qinghai-Tibetan Plateau, China, *Water Science and Technology: Water Supply,* Vol. 20, pp. 335–347, https://doi.org/10.2166/ws.2019.167.

Rawtani, D., Khatri, N., Tyagi, S., Pandey, G. 2017. Nanotechnology-based recent approaches for sensing and remediation of pesticides. *Journal of Environmental Management,* Vol. 206, pp. 749–762.

Murangan, A.S., Prabaharan, C. 2012. Fish diversity in relation to physico-chemical characteristics of Kamala basin of Darbhanga District, India, *International Journal of Pharmaceutical & Biological Archive*, Vol. 3, No. 1, pp. 211-217.

Sarath Prasanth, S. V., Magesh, N. S., Jitheshlal, K. V., Chandrasekar, N., Gangadhar, K. 2012. Evaluation of groundwater quality and its suitability for drinking and agricultural use in the coastal stretch of Alappuzha District, Kerala, India. *Applied Water Science,* Vol. 2, 165–175. https://doi.org/10.1007/s13201-012-0042-5

Subramani, T., Elango, L., Damodarasamy, S. R. 2005. *Environmental Geology*, Vol. 47, No. 8, pp. 1099-1110.

United Nations, Groundwater: Making the Invisible Visible. UN World Water Development Report 2022, 2022. https://www.unwater.org/publications/un-world-water-development-report-2022/.

Uddin, M.G., Nash, S., Rahman, A., Olbert, A.I. 2023a. A sophisticated model for rating water quality, *Science of the Total Environment,* Vol. 868, 161614, https://doi.org/10.1016/ j.scitotenv.2023.161614.

Uddin, M.G., Nash, S., Rahman, A., Olbert, A.I. 2022a. A comprehensive method for improvement of water quality index (WQI) models for coastal water quality assessment, *Water Research,* Vol. 219, 118532, https://doi.org/10.1016/j.watres.2022.118532.

Uddin, M.G., Nash, S., Mahammad Diganta, M.T., Rahman, A., Olbert, A.I. 2022b. Robust machine learning algorithms for predicting coastal water quality index, *Journal of Environmental Management,* Vol. 321, 115923, https://doi.org/10.1016/j.jenvman.2022.115923.

Uddin, M.G., Nash, S., Olbert, A.I. 2022c. Optimization of parameters in a water quality index model using principal component analysis, in: Proceedings of the 39th IAHR World Congress, *International Association for Hydro-Environment Engineering and Research (IAHR)*, Spain, pp. 5739–5744, https://doi.org/ 10.3850/IAHR-39WC2521711920221326.

Uddin, M.G., Nash, S., Rahman, A., Olbert, A.I. 2023b. Assessing optimization techniques for improving water quality model, *Journal of Cleaner Production,* Vol. 385, 135671, https://doi.org/10.1016/j.jclepro.2022.135671

Uddin, M.G., Nash, S., Rahman, A., Olbert, A.I. 2023c. A novel approach for estimating and predicting uncertainty in water quality index model using machine learning approaches, *Water Research*, 119422, https://doi.org/10.1016/j.watres.2022.119422.

Khatri, Nitasha., Tyagi, Sanjiv., Rawtani, Deepak., Tharmavaram, Maithri., Kamboj, R.D. 2020. Analysis and assessment of ground water quality in Satlasana Taluka, Mehsana district, Gujarat, India through application of water quality indices. *Groundwater for Sustainable Development,* Vol. 10, 100321

Weber, W. J. Jr., Stun, W. 1963. Mechanism of hydrogen ion buffering in natural waters. *Journal of American Water Works Association*. Vol. 55, 1553 1555.

Matthess, G. 1982. John Wiley & Sons, New York, 406.

Jaykaran 2010. How to select appropriate statistical test?. *Journal of Pharmaceutical Negative Results*, Vol. 1, pp. 61-3.

Kumar, P. R., Srinivasa Gowd, S., Krupavathi, C. 2024. Groundwater quality evaluation usingwater quality index and geospatial techniques in parts of Anantapur District, Andhra Pradesh, South India, *HydroResearch* Vol. 7, pp. 86–98

Lamare, R. E., Singh, O. P. 2016. Application of CCME water quality index in evaluating the water quality status in limestone mining area of Meghalaya, India. *The Ecoscan*, Vol. 10, No. 1&2, pp. 149-154.

Mishra, Prabhaker., Uttam Singh,, Chandra M Pandey., Priyadarshni Mishra., Gaurav Pandey. 2019a. Application of student's t-test, analysis of variance, and covariance. *Annals of Cardiac Anaesthesia*, Vol. 22, No. 4.

Marfo, J.N., Quaye-Ballard, J.A., Kwakye, S.O., Obeng, K., Arko-Adjei, A., Quaye-Ballard, N.L., Quao, R.N.A. 2024. Groundwater quality and potential analysis using geospatial techniques: The case of Ashanti Region in Ghana, *Heliyon,* Vol. 10, e27545.

Mohammed S. H., Flores, Y. G., Al-Manmi d, D. A. M., Mikita, V., P´eter Sz˝ucs. 2024. Assessment of groundwater level fluctuation using integrated trend analysis approaches in the Kapran sub-basin, North East of Iraq, *Groundwater for Sustainable Development,* Vol. 26, 101292

Mishra, P., Pandey, C.M., Singh, U., Gupta, A., Sahu, C., Keshri A. 2019b. Descriptive statistics and normality tests for statistical data. *Annals of Cardiac Anaesthesia*, Vol. 22, 67072.

Rajesh Prajapati., Ram Bilas. 2018. Determination of water quality index of drinking water in Varanasi district, UP, India. *Journal of Scientific Research,* Vol. 62, pp. 1-13.

Ramakrishna, C., Mallikarjuna Rao, D., Subba Rao, K., Srinivas, N. 2009. Studies on ground water quality in slums of Visakhapatnam, *Asian Journal of Chemistry*, Vol. 21, No. 6, pp. 4246-4250

Sawyer, C.N., McCarty, P.L. 1967. Chemistry for Sanitary Engineers, McGraw-Hill, New York.

Sajib, Abdul Majed., Diganta, Mir Talas Mahammad., Rahman, Azizur., Dabrowski, Tomasz., Olbert, Agnieszka I., Uddin, Md Galal. 2023. Developing a novel tool for assessing the groundwater incorporating water quality index and machine learning approach. *Groundwater for Sustainable Development,* Vol. 23, 101049

Sundaram, K.R., Dwivedi, S.N., Sreenivas, V. 2014. Medical Statistics: Principles and Methods. 2nd ed. New Delhi: Wolters Kluwer India.

Subba Rao, N., Das, R., Sahoo, H.K., Gugulothu, S. 2024. Hydrochemical characterization and water quality perspectives for groundwater management for urban development, *Groundwater for Sustainable Development,* Vol. 24, 101071. https://doi.org/10.1016/j.gsd.2023.101071

WHO, Guidelines for Drinking Water Quality, Third edition, 2004, Vol.1, Recommendation, world Health Organization, Geneva.

Wang, W., Chen, A., Wang, L., Liu, Y., Sun, R. 2002. Effects of pH on survival, Phosphrous Concentration, Adenylate Energy Charge and $Na^+$, $K^+$ ATPase Activities of Penaeus chinensis Osbeck Juveniles, *Aquatic Toxicology,* Vol. 60, pp. 75-83.