Nature Environment and Pollution Technology
An International Quarterly Scientific Journal
p-ISSN: 0972-6268 (Print copies up to 2016)
e-ISSN: 2395-3454
Vol. 22 | No. 3 | pp. 1457-1468 | 2023
Original Research Paper
https://doi.org/10.46488/NEPT.2023.v22i03.031
Open Access Journal

Identification of Surface and Groundwater Interaction by Isotopic Hydrological Study - A Critical Review for Kelambakkam Region, Chennai, India

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Nat. Env. & Poll. Tech.
Website: www.neptjournal.com

Received: 06-01-2023
Revised: 02-03-2023
Accepted: 27-03-2023

Key Words:
Isotopes
Stable oxygen(δ^{18}O)
Deuterium (δ^2 H)
Surface & groundwater
Spatial techniques

ABSTRACT

Due to the increase in population and urbanization, the availability of freshwater with standard quality to the human population is of great challenge. Recently there has been a demand for fresh water in surface and groundwater, so it is necessary to go for advanced isotopic techniques for identifying surface and groundwater resources. Isotopes are atoms of elements having the same atomic and different mass numbers. The isotopes found their wider application in water resources-related problems. The isotopes in water resources proved to be an effective tool in solving many critical hydrologic problems where conventional methods cannot be used due to their limitations. This research article discusses isotope application in water resources and focuses on different types of stable and unstable isotopes and their applications at Global and National levels. The methodology and research steps are proposed based on research gaps identified through various literature studies. The study will be conducted in the Kelambakkam zone, south of Chennai sub-urban. This research paper will discuss the sequential steps in identifying recharge and discharge mechanisms in study zones through stable isotopic techniques. The hydro-chemical analysis will also be done by measuring water quality in the Kelambakkam zone. The electrical resistivity survey for aquifer mapping will also be developed to identify the groundwater recharge zones. The proposed study will give complete information about recharge and discharge in the study area and recommend suitable groundwater harvesting structures.

INTRODUCTION

The isotopes in catchment hydrology were introduced around 1960 as an alternative tool to conventional hydrologic methods for identifying the water sources, origin, distribution, and the travel time taken for water to reach from one place to another place (Dansgaard 1964, Klauss & McDonnell 2013). In recent decades, isotopes have been used extensively in research on hydrology and water resources.

The stable oxygen and hydrogen isotopes are conservative tracers in hydrological studies (Hu et al. 2009). The stable and unstable isotopes detect the origin, flow patterns, and mixing of surface and groundwaters in hydrological studies (Zhang et al. 2005). The stable isotopes can be used up to 0.01 to 100 sq. km watersheds (Duarte Carlos 2017). The isotopes also renovate continental paleoclimatology and paleohydrology (Aaron et al. 2017). The travel time from surface to groundwater for present and future scenarios can be identified using isotopic techniques. Stable isotopes are commonly used in field investigations and research projects to better understand hydrological processes (Elliott Arnold et al. 2018). Isotopes of oxygen and hydrogen also extend their application to vapor sources, atmospheric circulation, and paleoclimatic investigations (Westerhold et al. 2018). Recently in hydrological investigations, isotopes were used in phase transitions in the transport paths of water.

The stable δ^{18} O and δ D in precipitation are controlled by atmospheric parameters such as temperature, relative humidity, evaporation, and moisture sources. The effects of geographic factors such as altitude and latitude are seen in meteoric water. The Tritium isotopes in hydrology differentiate groundwater's age and residence time. Meteoric water in various places will have various stable hydrogen and oxygen compositions. When meteoric water infiltrates the ground to form groundwater, the differences in isotopic compositions can be seen and used as a base for identifying groundwater resources. The isotopic fractionation also occurs when there is evaporation from seawater to inland precipitation, as it causes changes in the composition of hydrogen and oxygen in meteoric water (Gibson et al. 2016).

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The linear relationship of meteoric water was developed by (Craig 1961), which is used as a reference line and a standard tool in isotopic hydrology research. The temperature, quantity of precipitation, height, sampling distance, and location from the sea are the influence parameters in isotopic characteristics at a particular location. The depletion and enrichment of isotopic characteristics are observed in higher and lower altitudes, known as the altitude effect.

Merits of Isotopic Techniques Over Other Tracer Techniques

Isotopes are the advanced tracer methods used for detecting water resources in the field of hydrology. Precipitation is input to surface and groundwater, so the isotopic composition of precipitation gives some knowledge on surface and groundwater interaction. The World Meteorological Organization (WMO), International Atomic Energy Agency (IAEA), and Global Network of Isotopes in Precipitation (GNIP) recognized isotopes as perfect tracers in hydrological studies. The limitations in isotopic studies are fractionation and evaporation, as it affects isotopic composition and characteristics, and their impact is seen in accurate water resources detection.

The aim of this paper is to discuss various isotopes used in hydrological studies. It also discusses isotope applications in precipitation, surface and groundwater interaction, recharge, and discharge in water sources. Based on the previous studies, suitable stable isotopic techniques in the Kelambakkam zone are adopted for identifying surface and groundwater interactions. The study also deals with developing Local Meteoric Water Lines (LMWL) and spatial isotopic maps for various seasons, which has not been attempted in this study area so far. The electrical resistivity survey will be conducted to determine the aquifer thickness for proper groundwater modeling and management. The study also elaborates on the present situations of isotopic hydrology across the National and Global level, and the objectives are framed accordingly.

Objectives of the Study

- To study the isotopic signatures in precipitation of the Kelambakkam zone.
- To identify the surface, groundwater interaction, and groundwater resources of the study area
- To identify the origin and recharge of surface and groundwater in the Kelambakkam zone.

Need for the Study

The Kelambakkam zone comprises residential, IT, small-scale industries, education sectors, and agricultural fields (Fig. 1 & Fig. 2). The residential and industrial areas near Kelambakkam and Kalavakkam mainly depend upon lakes and nearby wells to supply fresh water for drinking and commercial purposes. So, it necessitates identifying the

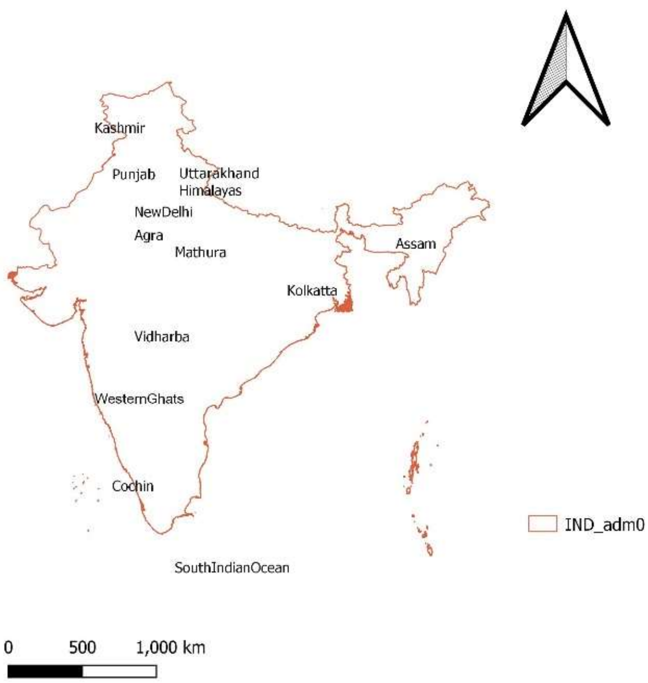

Fig. 1: Isotopic studies in India.

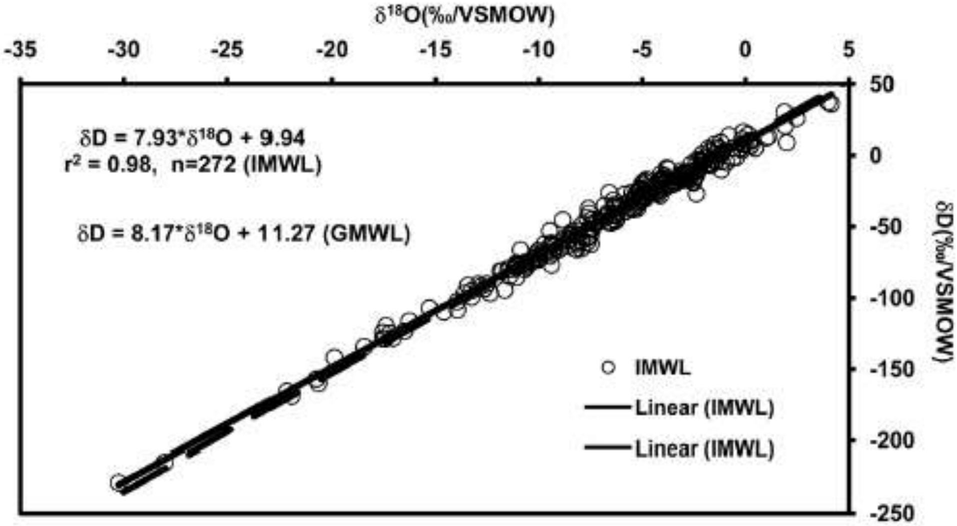

Fig. 2: Handbook for stable isotope data interpretation in India 2020.

water sources, occurrences, origin, recharge, and discharge in the Kelambakkam zone. The stable isotopes of oxygen and hydrogen will be used in the study area for identifying the surface and groundwater interaction.

The following research gaps have been noted from a detailed literature review, and it is to be sought for the present study:

- The study on isotopes in water sources is the first study conducted in the Kelamabakkam zone.
- To date, no studies in the Kelambakkam zone have been done using isotopic techniques to identify the surface and groundwater interaction.
- The spatial isotopic mapping and updated aquifer groundwater modeling will be done for the study area.

LIST OF STABLE AND UNSTABLE ISOTOPES USED IN WATER RESOURCES

Tritium

Tritium (T) or ^{3}H is a radioactive isotope of hydrogen (two neutrons and one proton) with a half-life of 12.32 ± 0.02 years. The Tritium concentration is measured by tritium units (TU). 1 TU is due to the presence of one tritium in 1018 atoms of hydrogen. Secondary neutron cosmic rays generate the natural atmospheric tritium by bombarding nitrogen (Zhou et al. 2016). The Tritium atom combines with oxygen, forms water, and then falls as precipitation. The nuclear tests carried out by various countries during the early 1960s also contributed to Tritium in the atmosphere. During the 1960s, Tritium content in the atmosphere was 2- 8 TU; in recent years, a drop in Tritium content has been seen in the atmosphere (Duvert et al. 2016). Most of the tritium in the atmosphere is observed in surface water, and later its infiltration is seen on the groundwater table (Beyer et al. 2018). In isotopic hydrology, tritium is used to identify the groundwater recharge, movement, and mixing of water in the groundwater table. The Tritium concentration can also determine groundwater age (Jing et al. 2022).

Chlorine-36

Cl-36 is a cosmogenic isotope produced in the atmosphere by the spallation of 36 argon during interaction with cosmic ray protons. In a system of water resources, it enters groundwater through a wet deposition along with much more abundant stable Cl isotopes of (^{35} Cl and ^{37} Cl) from marine aerosols. Nucleogenic reactions in the sub-surface produce 36 Cl. The ^{36} Cl isotopes are used in measurements of dating very old groundwaters. The ^{36} Cl is also used to identify groundwater recharge and the distances of the recharge areas (Ram et al. 2021).

Ra Isotopes

The Radium has an element number of 88 in the periodic table, which belongs to Group IIA. The four naturally occurring radium isotopes are (^{224}Ra, ^{223}Ra, ^{228}Ra, and ^{226}Ra) continuously produced from the decay of their Th-isotopes parents of the U and TH decay series ^{228}Th, ^{227}Th, ^{232}Th, and ^{230}Th, respectively. The most abundant isotopes are ^{226}Ra from the ^{238}U with a half-life of 1600 y and ^{228} Ra from the ^{232}Th with a half-life of 5.8 y (Marc et al. 2017). The natural form of radium isotopes (^{223}Ra, ^{224}Ra, ^{226}Ra, and ^{228}Ra) are mostly used as geochemical tracers in marine environments. Initially, Ra isotopes were applied to study open ocean processes, and their common application is in the marine environment. Ra isotopes are used to identify and quantify the Surface Ground Discharge. In addition, it also finds its application in groundwater and submarine studies. In marine environment studies, Ra isotopes act as a geochemical tracer. Traditionally, they used to trace land-ocean interaction processes. It also finds its application in assessing transit times in coastal aquifers, sediment–water interface, and the age of coastal surface waters.

Oxygen and Hydrogen

Oxygen-18 and Hydrogen (^{2}H) are stable isotopes present in water in abundance nature. These stable isotopes are used to trace water sources' origin, occurrence, and movement from the surface and groundwater (Bowen et al. 2012). The stable isotopic composition in water can also measure and modeled on a large scale. The change in the isotopic ratio of $^{2}H/^{1}H$ and oxygen $^{18}O/^{16}O$ in water gives an idea of the water source and its quality. The physical process like evaporation can change the δ values of isotopes from the original precipitation sources, which occurs over a surface. The change in δ values will be used for identifying the origin of rainwater, recharging from groundwater, and evaporation from the ponds. The change in δ values will be expressed as fractional deviation from a standard procedure called SMOW (Standard Mean Ocean Water). The change in δ value expression is given as $[(R_s/R_r) – 1] \times 1000$ (‰), where R_s and R_r are the ratios of the abundances of the heavier isotope to the lighter isotope for the sample and reference standard, respectively. The common isotopes that can be used in water resources are listed in Table 1.

Table 1: Other common isotopes adopted in water resources.

Isotopes	Application
^{15}N, ^{11}B, ^{37}Cl, ^{87}Sr, ^{13}C, ^{34}S,	Pollution and contaminant sources identification
^{2}H, ^{18}O	Estimation of paleo-waters
^{2}H, ^{18}O	Estimating seepages and leakages from the dam
^{37}Cl	To identify the mechanism of salinization in water resources
^{87}Sr, ^{88}Sr, ^{34}S	Rock and water interactions
^{13}C, ^{223}Ra, ^{224}Ra, ^{226}Ra, ^{3}H, ^{87}Sr	In the identification of Sub-marine Groundwater Discharge
^{13}C, ^{3}H	Determining leachate from landfills
^{13}C, Ne, Ar, Kr, Xe	Groundwater monitoring and study in the permafrost regions
^{3}H	Hydrograph separation
^{85}Kr, CFC, ^{81}Kr, ^{35}S, ^{7}Be, Ne, He, ^{3}H, ^{13}C,^{39}Ar	For dating groundwater age

PROCEDURE INVOLVED IN CALIBRATION AND VALIDATION OF ISOTOPIC SIGNATURES

The International Atomic Energy Agency (IAEA) of Vienna, Austria, in collaboration with the World Meteorological Organization (WMO), established the Global Network of Isotopes in Precipitation (GNIP). The global precipitation samples were collected to monitor the isotopic composition of ($\delta^{2}H$, $\delta^{18}O$). The data produced by IAEA is an important asset to isotope hydrology (http://isohis.iaea.org). The $\delta^{2}H$ and $\delta^{18}O$ isotopic values are generally measured with standard references from Standard Mean Ocean Water (SMOW). The lower and high δ values represent the depletion and enrichment of isotopes. The other factors in the hydrological cycle, such as evaporation and condensation, also affect isotopic composition in water resources. The recharge and discharge processes also affect isotopic signatures due to different hydrogeological conditions.

The Global Meteoric Water Line (GMWL) shown in Equation (1) is developed from $\delta^{2}H$ and $\delta^{18}O$. The deviation of the Local Meteoric Water Line (LMWL) from the GMWL gives information about recharge, discharge, evaporation, and geographical conditions.

$$\delta^2 H = 8.17(\pm 0.07) X \delta^{18} o + 11.27(\pm 0.65) \quad \ldots(1)$$

For Indian conditions, the Indian MWL is developed for the Northern, Southern, Western, and Eastern Himalayas. These lines are different for each region in India. The differences between the South Indian meteoric water line and the Northern Indian meteoric water line are their slope and d excess values as shown from equations (2-4). The variations in slope and d excess are mainly due to temperature, evaporation, and geographical conditions.

$$\delta^2 H = 7.38(\pm 0.21)\delta^{18} o + 8.03(\pm 1.05)(n = 81, r^2 = 0.94) \quad \ldots(2)$$

$$\delta^2 H = 7.98(\pm 0.078)\delta^{18} o + 9.29(\pm 0.679)(n = 134, r^2 = 0.99) \quad \ldots(3)$$

$$\delta^2 H = 7.81(\pm 0.17)\delta^{18} o + 11.14(\pm 1.18)(n = 63, r^2 = 0.97) \quad \ldots(4)$$

In most cases in IMWL, there are not many differences in slope and intercepts since 70% of rainfall in India is during the monsoon season. The IMWL, when compared with GMWL, shows a difference in slope and intercept. These differences are mainly due to vapor sources during the Northeast and Southwest monsoons originating from the Bay of Bengal and the Arabian Sea. Altitude effects will also affect the isotopic signatures, mostly noted in western Himalayan regions. The lighter and heavier isotopes are observed in rainfall at high and low altitude areas. The $\delta^{18}O$ and $\delta^{2}H$ will show positive in lower air temperatures and negative values in colder regions. The continental effect also influences the isotopic compositions.

International Status

The methodology and inferences globally regarding the isotopic studies are discussed in detail in Table 2

Table 2: International Status of Isotopic Hydrological Study.

In Globally	Methodology & Isotopic tools	Inference from the Study
South Africa- Soutpansberg, Limpopo Province (Olatunde et al. 2019)	$\delta^{18}O$ and $\delta^{2}H$	Geochemical processes were studied from geothermal springs.
China- Heihe River Basin (HRB) (Zhao 2018)	($\delta^{18}O$, D, ^{3}H and ^{14}C)	The current and former relationships between precipitation, surface runoff, recharge in groundwater, and climate change was studied with the help of stable isotopic tools.
Lower Changjiang, Yangtze River (Li 2020)	Stable hydrogen and oxygen isotopes	The $\delta^{18}O$ shows much seasonal variation during the dry season and low during the flood season. The seasonal variation of $\delta^{18}O$ in the precipitation of the Changjiang basin is calculated based on long-term meteorological and hydrological data availability.
Rhone catchment area (France) (Jean-Baptiste et al. 2020)	Isotope geochemistry, water stable isotopes	The hydrological survey is conducted, and the isotopic signatures are identified in the flowing Rhone River.
Vosges Mountains North-eastern France (Viville et al. 2006)	^{18}O and lumped-parameter model	The water transit times are calculated by applying exponential piston and dispersion models to flow the PC program to isotopic input and output datasets.
Berlin, Germany (Kuhlemann et al. 2020)	Hydro-geochemistry	Sampling isotopes in precipitation, surface water, and groundwater are done for Berlin city on a spatial scale to detect the urban water cycle.
Vienna, Austria (Kern et al. 2020)	tracers, environmental isotopes, radioactive isotopes, deuterium, oxygen-18, tritium, radiocarbon	The groundwater origin, age, recharge, and flow direction between aquifers and characteristics were studied.
Wimbachtal, Germany (Paul et al. 2007)	Tritium and ^{18}O	Tritium and ^{18}O concentrations in precipitation and runoff were studied to identify groundwater recharge in Wimbachtal Valley.
Central, USA (Chao et al. 2018)	$\delta^{2}H$, $\delta^{18}O$ and $\delta^{17}O$	The stable isotopes of oxygen and hydrogen were used as a natural tracers to understand hydrological and meteorological processes in the USA. The stable isotopic study shows that meteorological factors do not affect the 17O excess in rainfall and snowfall. The study also concludes that ^{17}O-excess also be used as tracers during evaporative conditions.
Budapest, Hungary (Polona & Zoltán 2020)	Stable (^{16}O, ^{17}O, ^{18}O, ^{1}H, ^{2}H) and radioactive isotopes (^{3}H).	The use of stable isotopes in the hydrological process is discussed on regional or local scales related to precipitation. The study also discusses surface and groundwater interactions, soil and xylem water, and geochemical process.
Northern Italy, Lake Frassino (Carlo et al. 2016)	Stable isotopes	The stable isotopic composition was studied in Lake Frassino (Northern Italy). The study analyzes palaeo-hydrological, lithological, malacological, and delineation of freshwater shells using stable isotopic signatures.
Central Italy (Tazioli 2017)	Tritium, stable isotopes	In their study, they discussed monitoring groundwater resources and water flow properties by using isotopic techniques. The study also concludes by identifying recharge areas in the Central part of Italy.
Central Srilanka (Edirisinghe 2014)	Stable isotopic compositions	The stable isotopes were used as effective tracers in detecting surface and groundwater interaction in Central Sri Lanka.
Kilauea Volcano area, Hawaii (Scholl et al. 1995)	Stable isotopes and Tritium	This study discusses the tracer methods and their application in determining Hawaii's Kilauea volcano's flow paths, recharge areas, and groundwater age.
British Isles (Darling & Talbot 2003)	Stable isotopes	The study identifies that the stable isotopic compositions are poorly characterized in the British Isles. It is one of the first studies of a major British river with monthly isotopic records.

Table Cont....

In Globally	Methodology & Isotopic tools	Inference from the Study
Siksik Creek in the Western Canadian Arctic (Doerthe 2017)	Arctic headwaters, isotopes	The data fusion modeling approach is adopted to determine the quantity and isotopic characteristics of the snowpack and its melted water. The soil moisture dynamics and active soil profile layer were also adopted in their study.
Wetlands, North Florida (Glynnis et al. 2020)	oxygen and hydrogen tracers	The stable water isotopes were used to identify the sensitivity and resolution in wetlands in North Florida. From the analysis, notable differences were observed in stable isotopic signatures of precipitation, surface, and groundwater in the forested wetlands of North Florida.
UAE (Ahmed 2009)	Deuterium excess	The stable isotopes and deuterium excess were used to identify groundwater recharge mechanisms in the Northwestern part of the Gulf of Oman and the Southeastern part of the Arabian Gulf. The origin of moisture from the Mediterranean Sea is also studied.
Canada, Mildred Lake Mine (Baer et al. 2016)	^{2}H and ^{18}O	Stable isotopes ^{2}H and ^{18}O are applied in mining water. The LMWL is developed to identify the precipitation characteristics at the mining site. The developed LMWL from this study can be used as a reference line for similar mines waters.

National Status

The isotopic studies regarding surface and groundwater in India are discussed in Table 3. The isotopic application in hydrological studies in India is shown in Fig. 1

MATERIALS AND METHODS

The methodology planned for the present study is shown in Fig. 3. The sequential steps in the study area selection, data collection, analysis, and calibration are discussed below.

Table 3: National level isotopic hydrological study.

National level	Isotopic tools	Inference from study
Western Ghats Mountain range, India (Kushank et al. 2019)	Deuterium excess, ^{2}H,^{18}O	The hydrogeological nature of the western Ghats shows many influences in isotopic signatures. The derived local evaporation line also indicates that water resources are cascaded and depleted isotopic compositions are seen in the precipitation of Western Ghats, as shown in Fig. 2 The water resources were traced in the Western Ghats from the derived evaporation line and depleted isotopes.
Himalaya, Uttarakhand, India (Rai et al. 2017)	Environmental isotopes, tracers, stable isotopes, radioisotope	The 57 water samples were collected from 19 sites, and isotopic analysis was done using $\delta^{18}O$, $\delta^{2}H$, and ^{3}H isotopes. The isotopic analysis identified the new water seepage downstream of Lake Nainital in the Himalayan region. A Dual Inlet Isotope Ratio Mass Spectrometer (DIIRMS) and an Ultra-Low-Level Liquid Scintillation Counter (ULLSC) were used in measurements of stable isotopes ($\delta\ ^{2}H$ and $\delta\ ^{18}O$) and a radioisotope (^{3}H) respectively.
Kolkata and New Delhi (Deshpande & Gupta 2012)	Stable isotopes	The isotopic signatures in the water resources of Kolkata and New Delhi were compared. The depletion in isotopic signatures observed in Delhi is due to the altitude effect of the Himalayas.
Agra and Mathura Cities Uttar Pradesh (Purushothaman et al. 2014)	Isotopes, Electrical conductivity	The surface water of river Yamuna and its influence on groundwater level were studied. The study concludes that Yamuna River water has a strong influence on Agra and Mathura's groundwater resources.
Western Himalayas (Kashmir) and Eastern Himalayas (Assam) (Ghulam & Deshpande 2017)	$\delta\ ^{18}O$ and $\delta^{2}H$	The precipitation samples were collected from the Western (Kashmir) and Eastern Himalayas (Assam) to study weather system disturbances and Indian summer monsoon characteristics in isotopic signatures. The isotopic analysis indicates a variation in isotopic signatures in the western and eastern Himalayas.

Table Cont....

National level	Isotopic tools	Inference from study
Greater Cochin, Ernakulam district, Kerala (Aneesh et al. 2019)	δ D and $\delta^{18}O$	The precipitation samples of Cochin were collected, and isotopic analyses were done to identify the isotopic variation in precipitation sources.
Vidarbha, Maharashtra (Noble & Ansari 2019)	Environmental isotopes	The stable isotope and electrical resistivity tools were used to identify the water resources in drought-prone areas of the Vidarbha region. The monsoon characteristics, groundwater recharge, and evaporation were also studied using environmental isotopes.
Western Himalayas, (Rai et al. 2016)	Stable isotopes	The stable isotopic studies in snow melt water and glaciers were studied in the cryosphere waters of Ladakh and Kashmir regions in the Western Himalayas.
Southern Indian Ocean (Rahul et al. 2017)	$\delta^{18}O$ and δ D	The stable isotopic composition in the seawater surface, water vapor, and rainwater were studied from the Indian Ocean to the South Ocean regions.
India to Antarctica (Tiwari et al. 2013)	$\delta^{18}O$ and δD	The discrete water mass from the Indian and Southern oceans was studied using stable oxygen isotopes. The study addresses the relationships between oxygen and hydrogen isotope and sea surface salinity.
Southwest (SW) Region of Punjab, India (Krishan et al. 2022)	Stable isotopes, electrical conductivity	The groundwater samples were collected from 142 piezometers at 40 sites for stable isotopic analysis in three regions of Punjab to find the root cause of salinity in the groundwater resources.

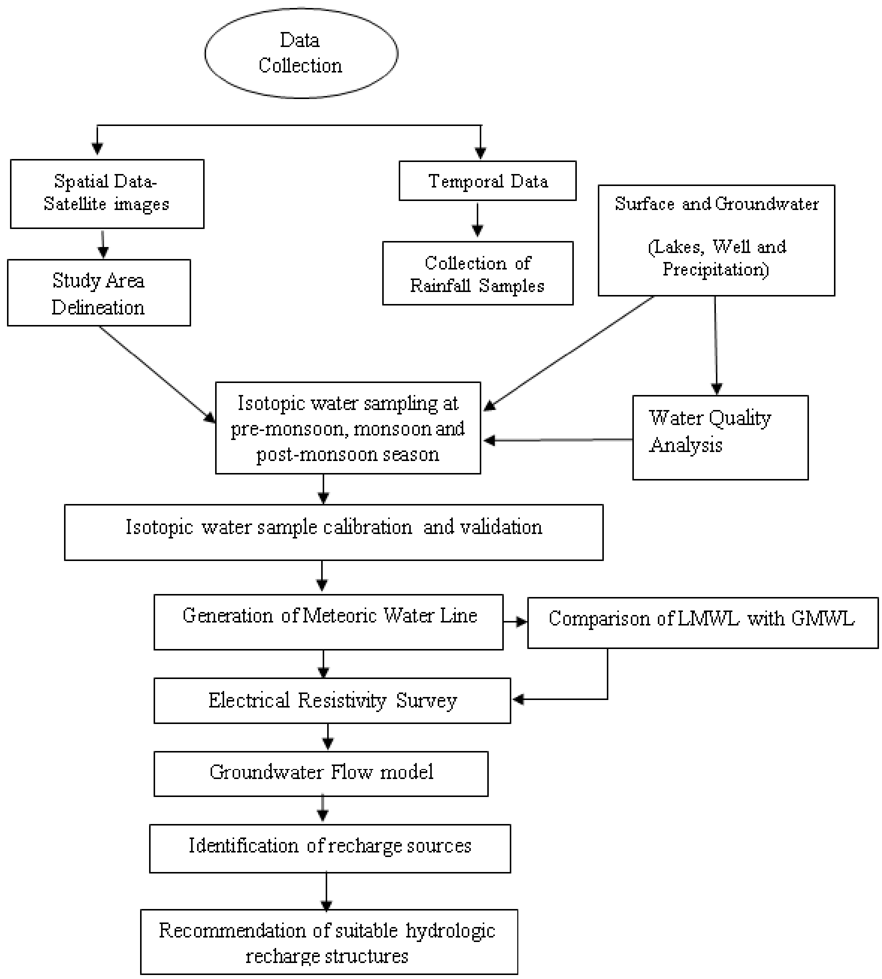

Fig. 3: Methodology adopted for the proposed study.

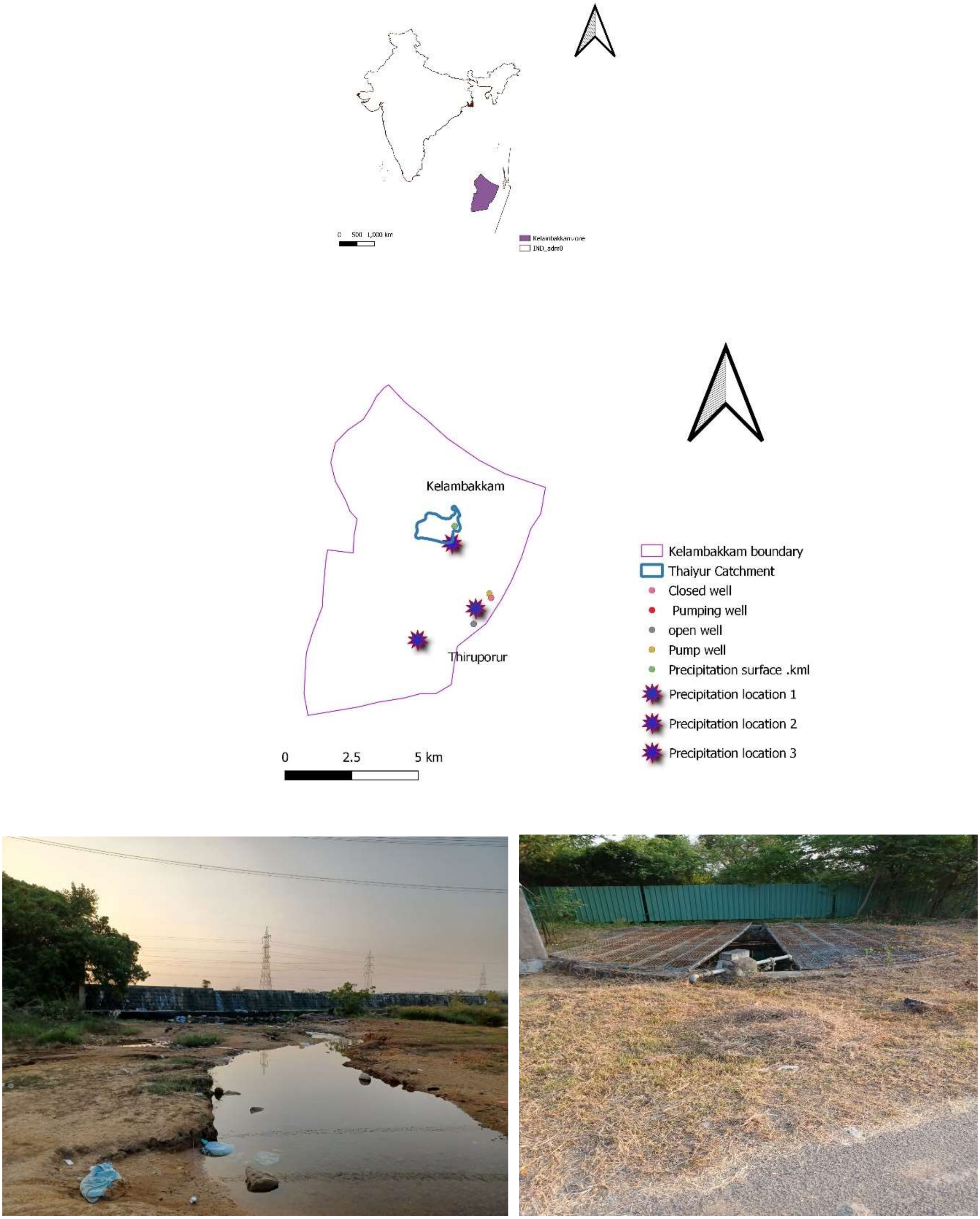

Fig. 4: Location of the study area.

Fig. 5: Isotope ratio mass spectrometer (Isoprime, Micro mass, UK) (George & Gerogios 2020).

Fig. 6: Ultra-Low-Level Liquid Scintillation Counter (ULLSC) (Wolfango & Lauri 2004).

Study Area Geographic Details

Kelambakkam region is a sub-urban of Chennai city, as shown in Fig. 4. It is in the South-Eastern portion of Chennai along Old Mahabalipuram Road (OMR). It extends from a latitude and longitude of 12.48º N to 80.13º E. The Kelambakkam region covers an area of 11.44 sq.km with a surrounding coastline of 57 km. The population in the Kelambakkam region is 4 lakhs as of the 2011 census, and it is expected to be doubled by 2030. The average annual rainfall of Kelambakkam is 1007 mm. The maximum and minimum temperatures during summer and winter range from 36.6ºC to 28.7ºC. Since Kelambakkam is located near the coastal parts, it receives copious rains based on seasonal patterns. The Southwest and Northeast monsoons are the major contributors of rainfall in the range of 36 % to 54%. The study area is underlain by formation dykes predominantly observed in Thiruporur and the East of Chengalpattu district. The notable hard rock aquifer with alluvial formation is observed in the Kelambakkam region with a good yield of 45-220 pm. The average Transmissivity (T) is 2 m.day^{-1} with permeability (k) of 0.5- 2.5 m.day^{-1}. The depth of the groundwater level in this region is from 5 m to 12.5 m.

RESULTS AND DISCUSSION

Sequential Steps Involved in the Present Research Study

The steps involved in carrying out an isotopic hydrological study for the Kelambakkam zone are discussed in detail from step 1 to step 10.

Step 1	Source
Data Collection Spatial & Temporal	Satellite 1. Cartosat image of 2 m resolution to be procured from NRSC Hyderabad for generating spatial isotopic maps. 2. Meteorological data like temperature, humidity, and rainfall will be collected from the India Meteorological Department (IMD) portal.
Step 2 Water Sampling	Rainwater samples will be collected from selected Kelambakkam, Thaiyur, and SSN Campus locations for pre-monsoon, monsoon, and post-monsoon seasons. The surface water samples will be collected for pre-monsoon, post-monsoon, and monsoon seasons from Thaiyur Lake and its region. Groundwater samples were also collected from selected wells in the study area for pre-monsoon, monsoon, and post-monsoon seasons. The samples will be collected using 60 ml of high-density polyethylene bottles.
Step 3 Sampling Analysis	The collected samples will be analyzed for isotopic δ18O and δ^2H signatures at the Isotopic Hydrologic lab in the Centre for Water Resources Development and Management at Calicut. The Dual Inlet Isotope Ratio Mass Spectrometer (DIIRMS), as shown in Fig. 5, will be used for δ^2H measurements. The Continuous Flow Isotope Ratio Mass Spectrometer (CFIRMS), as shown in Fig. 6, is used to measure $\delta\ ^{18}O$ in water samples. The accuracy and precision measurement for $\delta^{18}O$ and δ^2H should be maintained around ±0.2% to ±0.06% respectively.
Step 4 Calibration	The samples' stable isotopic compositions of hydrogen and oxygen will be expressed using conventional delta notation relative to the Vienna Standard Mean Oceanic Water (VSMOW) in part per thousand. The VSMOW equation (5) is expressed as $\delta(\%) = \frac{(R_{sample} - R_{standard})}{R_{standard}} * 1000$ …(5) R represents either $^{18}O/^{16}O$ or the D/H ratio
Step 5 Validation	The LMWL will be developed for the study area. The developed LMWL will be compared with the VSMOW line. The deviation of LMWL from the VSMOW line will identify the study area's evaporation, recharge, and discharge process.
Step 6 Spatial Maps	The isotopic spatial pattern maps for stable hydrogen and oxygen in the study area will be generated. The generated maps will identify the spatial patterns of isotopes in the Kelambakkam region.
Step 7 Identification of recharge sources	The study area's surface and groundwater interaction, recharge, and discharge locations will be spotted.
Step 8 Quality Analysis	The groundwater quality with respect to pre-monsoon, monsoon, and post-monsoon was also to be analyzed.
Step 9 Electrical Resistivity Surveying	The aquifer mapping and groundwater monitoring will be done through an electrical resistivity survey.
Step 10 Water Harvesting Structures	Suitable groundwater harvesting structures will be recommended in the places of surface and groundwater interactions in the study area.

CONCLUSION

Isotopes in hydrology emerged as a multidisciplinary field as they found their wider application in the hydrological cycle and water resources engineering. The advanced technologies in isotopic measurements have made it easy to measure isotopic signatures with improved accuracy. In present days' geospatial techniques with modeling methods were also used in the spatial prediction of isotopic signatures in water resources. The isotopes in hydrology are useful for identifying water sources, their origin, movement, distribution, and recharge mechanisms. Isotopes are not only used for quantitative measures but are also helpful in tracing groundwater contaminants in terms of quality measurements. The age and residence time of surface and groundwater can also be identified using isotopes.

This study proposes using environmental isotopes to identify precipitation characteristics, surface and groundwater resources, and their interactions. The study will discuss isotopic signatures in groundwater and identify the source of groundwater recharge in the study area. The hydro-chemical analysis will be done to check the seasonal patterns' influence on the water quality parameters. The electrical resistivity survey will be conducted to delineate the potential groundwater zones in the Kelambakkam region.

The study's outcomes will be the spatial pattern of isotopic signatures of surface and groundwater sources in the Kelambakkam region. The study of stable isotopic signatures in the study area will help identify water movement, distribution, and recharge sources. The aquifer mapping of the study area will give a clear insight into recharge and discharge mechanisms in the study region. From a clear understanding of groundwater dynamics in the study area, a suitable water-harnessing hydraulic structure will be recommended. The study will be useful to farmers and town planners for managing the groundwater resources in developing regions of the Kelambakkam zone. The proposed study can also be adopted in places of similar hydrological conditions.

ACKNOWLEDGMENT

The author thanks the reviewers and editorial board for their valuable suggestions, which helped me improve the manuscript. The author also thanks the USGS earth explorer agency for providing Landsat image data for free.

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