ORIGINAL ARTICLE

Nitrate in Gravity Feed System (GFS) Water and Health Risk Assessment in Orang Asli Village in Rembau, Negeri Sembilan

Farhah Nadiah Mokhtar[1], Retno Adriyani[2] and *Shaharuddin Mohd Sham[1]

[1] Department of Environmental and Occupational Health, Faculty of Medicine and Health Sciences, Universiti Putra Malaysia, 43400 Serdang, Selangor, Malaysia
[2] Department of Environmental Health, Faculty of Public Health, Universitas Airlangga, Kampus-C, Jl. Ir. Soekarno, Surabaya 60115, Indonesia

ABSTRACT

Introduction: To determine the health risk assessment due to exposure to nitrate in Gravity Feed System (GFS) water in the Orang Asli Village of Rembau, Negeri Sembilan. **Methods:** This study involved 48 respondents who fulfilled the inclusion and exclusion criteria. Respondents with a filtration system installed in their houses were excluded from the study. A modified questionnaire was used to obtain the socio-demographic data. All collected water samples were analyzed using a HANNA Instruments multimeter with an attached nitrate electrode. **Results:** Nitrate in drinking water did not exceed the maximum limit of 45 mg/L set by health authorities. It ranged from 2.15 to 7.65 mg/L, with a mean ± standard deviation of 4.99 ± 1.37 mg/L. Further to this, the minimum and maximum pH values were 6.57-7.10. It was interpreted that there was no significant association between the concentration of nitrate and pH value in drinking water. The Hazard Quotient (HQ) calculation recorded that all respondents recorded an HQ of less than 1, indicating no cancer risk to consumers. Conclusion: The nitrate levels in GFS water are relatively low and do not threaten human health. However, it is recommended to conduct assessments on a regular basis to guarantee the levels within the permissible limit of the Malaysian National Drinking Water Quality Standard (NDWQS).
Malaysian Journal of Medicine and Health Sciences (2023) 19(SUPP14): 1-7. doi:10.47836/mjmhs.19.s14.1

Keywords: Nitrate; GFS water; Chronic Daily Intake; Rembau

Corresponding Author:
Shaharuddin Mohd Sham, PhD
Email: shaha@upm.edu.my
Tel: +603-9769 2407

INTRODUCTION

Safe and easily accessible water is vital for public health. As the human population and economies increase, global freshwater demand has risen considerably. The Malaysian government has prioritized clean water supply in urban and rural areas. In collaboration with the Ministry of Rural Development (KLBW) Malaysia and the Ministry of Health (MOH) Malaysia, actions have been taken to enhance the living standard and safe water quality in rural areas (1). Hence, MOH under Rural Water Supply and Sanitation (BAKAS) has taken the initiative by developing Gravity Feed System (GFS) in rural regions. GFS is one of the water supply schemes that provide the most rural water supply system coverage (2).

GFS is a downstream distribution system powered by gravitational force to households. Interpretation by the Ministry of Health (1984) describes GFS as the gravity-conveyance of water from a river or spring to residences in rural areas. To add, GFS is the most realistic solution for rural water supply problems as it only requires basic maintenance costs and is comparably affordable. It is an example of a sustainable water delivery technique needing no treatment for a rural area. GFS comprises secure catchment areas, storage tanks, and piped water delivery network (2). This approach is appropriate for streams and rivers with enough variations in elevation to enable gravity to carry water from the input to the user or storage tank. GFS also serves primarily as a low-cost technology plan for a temporary solution until the proper infrastructure reaches the area (2).

GFS commonly employed by hilly-area populations, including Orang Asli communities, as they cannot be provided with a centralized water supply system. As of 2017, it was estimated that the Orang Asli in Malaysia made up approximately 13.8% of the country's 31.66 million population (3). It comprises 18 tribes, and each of the tribes has a distinct group of people with unique cultures, languages, and social norms (4). The 9th Malaysian Plan recognized Orang Asli as one of Malaysia's most vulnerable communities, having a disproportionately high prevalence of poverty and extreme poverty (5). The Orang Asli in Malaysia still struggled to secure adequate clean water supplies to achieve household food security (6).

In addition to this, nitrate contamination in both surface and groundwater has become the greatest concern, worsening day by day. Nitrate (NO_{3-}) is one of the most significant and widespread chemical contaminants found in drinking water. It is ubiquitous in the environment. Nitrate commonly originates from both natural and anthropogenic sources. Naturally-occurring nitrate is part of the nitrogen cycle, while anthropogenic sources, including nitrogenous fertilizer, septic tanks, and animal manure, consequently increasing the concentration of nitrate in the environment (7). Over the course of decades, nitrate may accumulate in groundwater (8).

Excessive exposure to nitrate has been linked to the development of a number of human diseases. High amounts of nitrate in drinking water have been linked to neonatal methemoglobinemia, popularly known as a blue baby syndrome, since the 1940s. Methemoglobinemia disorder impairs the capacity of blood cells to transport oxygen throughout the body (9). High amounts of methemoglobin can cause the skin to turn bluish or grey (cyanosis syndrome), making the body more vulnerable to severe health consequences. Methemoglobinemia may also occur in adults who have undergone medical procedures using topical anesthetics that are often administered on the skin (10). Most recently, high levels of nitrates in drinking water have given rise to birth abnormalities in pregnant women during the first trimester. Nitrate may also increase the risk of thyroid illness, diabetes, and some cancers.

In Malaysia, a growing trend in water usage can be seen due to the prevalence of tropical climatic conditions. This has resulted in more people, especially those living in rural areas becoming vulnerable to exposure to a higher concentration of nitrates. As stated in the Malaysian National Drinking Water Quality Standard (NDWQS), the maximum concentration limit for nitrate in drinking water shall not exceed 45 mg/L NO3- after considering the water consumption of the population and other sources (11). The objective of this study was to determine the health risk due to exposure to nitrate in gravity feed system water in the Orang Asli Village of Rembau, Negeri Sembilan. The justification of this research was that there was little or no data on nitrate contamination in GFS water in Malaysia at the present moment, and data obtained can be used as a baseline for other studies in the future.

MATERIALS AND METHODS

This cross-sectional study design was conducted to determine the health risk of indigenous people in Ulu Chuai Village of Rembau, Negeri Sembilan due to the exposure to nitrate in the Gravity Feed System (GFS). This study used purposive sampling as its sampling method. Based on criteria such as lifetime residence and usage of GFS water as the primary source of water supply, 48 people were selected to participate in this research. Residents who built a water filtration system or utilized other water sources were excluded from participating. Besides, a screening process was conducted by answering a questionnaire to determine the respondent's eligibility. Data collection of this study was carried out in August 2022.

Study Area

Negeri Sembilan is a state on Malaysia's southwest coast (Fig. 1). It is situated in Negeri Sembilan's southernmost region, near Malacca. Ulu Chuai Village in the Rembau district was selected as the study location where all the residents highly depend on the GFS water supply as their primary water source. Ulu Chuai Village is located in a hilly area outside Rembau town where the GFS water system is commonly employed due to difficulties providing them with a centralized water supply. The residents rely heavily on the GFS for domestic purposes, including bathing, drinking, and cooking.

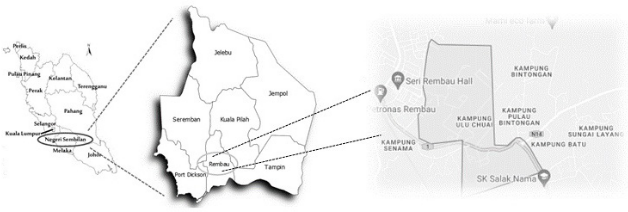

Figure 1 : Map of Ulu Chuai Village, Rembau.

Data Collection

This study employed purposive sampling to identify whether the respondents fulfilled the characteristics set by the researcher. The respondents must meet the inclusion and exclusion criteria of this research before a modified health risk assessment questionnaire is administered. The questions were adapted from the NHEXAS-Arizona research's baseline, descriptive, and time-activity questionnaires (12). From the questionnaire, respondents were screened based on the criteria that fit the inclusion and exclusion criteria of this research to continue with completing modified health risk assessment questionnaires. Before any sample was collected, a consent form was provided to the respondent to ensure participation and authorization voluntarily. It was permissible for any respondents to withdraw from the research if they did not want to participate.

GFS water samples were collected in duplicate directly from kitchen taps using HDPE bottles from each of the respondent's houses. Both readings of pH and nitrate levels was carried out on-site. Numerous research had employed HDPE bottles to collect water samples for heavy metals analysis (13). The tap water was collected directly from the kitchen pipe in each residence. Before collecting samples, the tap was turned on and allowed to flow for one to two minutes. Water samples were collected in duplicate and kept in 250 mL high-density polyethylene (HDPE) bottles that had been cleaned. All the bottles involved in water sampling were cleaned by soaking them in diluted nitric acid (HNO_3) for 24 hours and then thoroughly washed with deionized water. The collecting of water took between 5 and 10 minutes. The water samples were then stored in an ice box, and analysis of nitrate and pH was carried out immediately.

Like pH analysis, the nitrate analysis was measured on the site to inhibit the growth of bacteria in the sample until it was analyzed. Nitrate was immediately measured using a Hanna Instrument model HI98190 portable PH/ORPASE multimeter with a nitrate electrode attached. While pH was measured using portable Thermo Scientific™ Eutech™ pH 450 Meter Kit. Both instruments were calibrated before analysis took place, as the calibration step helps reduce measurement errors by ensuring the accuracy of test equipment. Aside from that, age, gender, and weight of respondents were recorded to ease the calculation of health risk assessment. The body weight was taken by using a Digital Body Weight Scale.

For this study, the respondents were required to measure their water intake using a 250 mL mineral water bottle for the quantity reference of daily water intake or they can use any cup with a scale of up to 250 mL. Then, they were asked to note of their daily water consumption, which the researcher used to measure the Estimated Daily Intake (EDI) and Hazard Quotient (HQ).

Health Risk Assessment

The estimated Daily Intake (EDI) formula was used to calculate the health risk of respondents following the exposure of nitrate in GFS water.

$$CDI = \frac{C \times DI}{BW}$$

Where,
CDI = Chronic daily intake dose of nitrate through ingestion (mg/kg/day)
C = Concentration of nitrate in GFS water (mg/L)
DI = Average daily intake rate of water (L/day)
BW = Body weight (kg)

The insufficient evidence on the carcinogenic effects of nitrate in drinking water on humans leads to the quantification of non-carcinogenic effects of chronic nitrate exposure in drinking water in terms of the Hazard Quotient (HQ).

$$HQ = \frac{CDI}{RfD}$$

Where,
HQ = Hazard Quotient
RfD = Dose of Reference (mg/kg/day)

In humans, the RfD for nitrate is 1.6 mg/kg/day (14). An HQ score of less than 1 implies no danger of non-carcinogenic consequences, whereas an HQ value of more than 1 suggests the possibility of non-carcinogenic health impacts.

Statistical analysis

SPSS Windows Version 23.0 and Microsoft Excel 2013 were used to produce the questionnaire-based findings.

Ethical clearance

This study was approved by Research Ethics Committee, Faculty of Medicine and Health Sciences, Universiti Putra Malaysia Reference No.: JKEUPM-2022-399.

RESULTS

Socio-demographic background of respondents

A questionnaire that was provided to the respondent supplied some basic socio-demographic information. Table I shows a summary of the distribution of the study sample by gender, age, educational level, and residential duration. A total of 48 respondents participated as they fulfilled the inclusion and exclusion criteria of the study. Even though the number of houses chosen was 40, there were some respondents who shared the same address. The female participants were 38 (79.17%), while the male participants were 10 (20.83%). A total of 44 (91.67%) participants between the age of 18 and 59 dominated the respondents, followed by 4 (8.33%) participants from the age group of more than 60 years old.

Table I : The sociodemographic background of respondents (n=48)

Socio-demographic background	Frequency, n (%)
Gender	
Male	10 (20.83)
Female	38 (79.17)
Age Group	
18-59 years old	44 (91.67)
60 years old and above	4 (8.33)
Educational level	
No formal education	14 (29.17)
Primary education	11 (22.92)
Secondary education	23 (47.92)
Tertiary education	0 (0.0)
Residential Duration	
Less than 10 years	0 (0.0)
10-20 years	3 (6.25)
More than 20 years	45 (93.75)

A total of 23 individuals (47.92%) obtained secondary education, followed by 11 individuals (22.92%) with primary education and 14 (29.17%) individuals with no formal education. Next, no individuals received up to tertiary education because of the immediate availability of jobs and financial issues. Other than that, a total of 45 (93.75%) participants have lived in the study location for more than 20 years, followed by 3 (6.25%) with 10-20 years of residential duration.

Nitrate concentration in water samples
Nitrate concentration and pH were the parameters investigated in the water samples. Analysis showed that nitrate in GFS water ranged from 2.15-7.65 mg/L with a mean and standard deviation of 4.99 ± 1.37 mg/L (Table II and Figure 2). The maximum nitrate concentration of 7.65 mg/L was measured at Point 5, while the second highest concentration (7.40 mg/L) was also identified at the same site. The remaining samples exhibit lower nitrate concentrations, with all samples having concentrations below 8 mg/L. The concentration of nitrate in the drinking water was recorded below the NDWQS (45 mg/L NO_{3-}). This maximum acceptable value was established to protect the consumer against nitrate-related diseases, including methemoglobinemia.

For pH, the mean ± SD in drinking water was 6.87 ± 0.14 with a range of 6.57-7.10, as shown in Table II and Figure 3. The mean pH of all the drinking water falls within the NDWQS, which is 6.5 to 9.0. On average, water is considered neutral.

No significant correlation was found between pH and nitrate concentration with the $p>0.05$ using the Pearson correlation test since nitrate concentration data was found to be normally distributed. This implies alternative hypothesis (Ha) failed to be rejected. Therefore, it can be concluded that pH level was not correlated with nitrate concentration in drinking water.

Table II : The comparison of the nitrate content and pH levels of the water samples with the existing standards

Parameters	No of water samples	Mean ± SD (mg/l)	Median	Range	Drinking Water Standards (mg/l)
Nitrate	40	4.99 ± 1.37	4.97	2.15-7.65	45
pH	40	6.87 ± 0.14	6.86	6.57-7.10	6.5-9.0

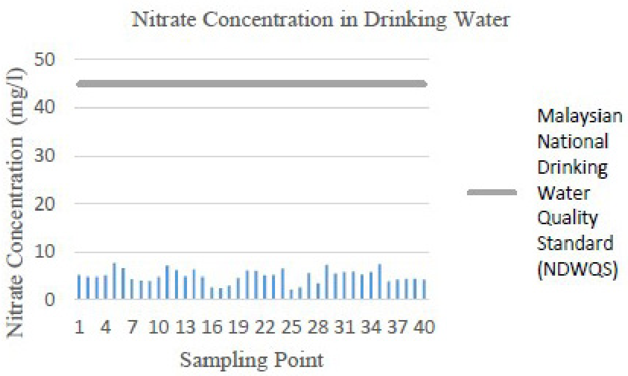

Figure 2 : Nitrate trends for water samples.

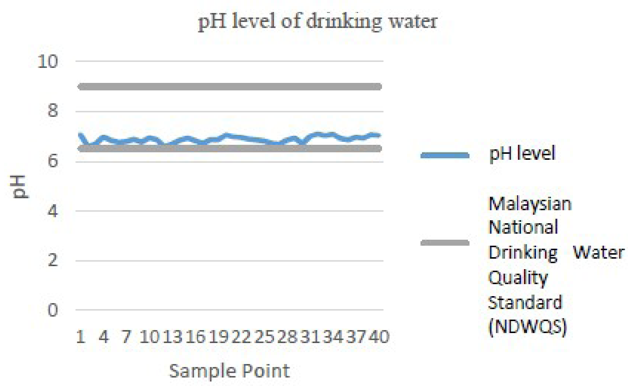

Figure 3 : pH trends for water samples.

Health Risk Assessment
Table III shows that the average amount of water consumed daily by the participants in this research was 1.31 L, with a mean body weight of 69.31 kg and a standard deviation of 16.6 kg. Chronic Daily Intake (CDI) and the Hazard Quotient (HQ) were used to calculate the health risk (HQ). The range of CDI was from 0.004 to 0.60 mg/kg/day, with a mean and standard deviation of 0.12 and 0.11, respectively. HQ value was obtained by dividing CDI with the Reference Dose (RfD). Nitrate has an RfD of 1.6 mg/kg (14). HQ value higher than one suggested the possibility of a detrimental health consequence. In this research, all respondents' HQ values were less than one, with a mean SD of 0.07±0.07. Therefore, no significant health effect was observed due to ingesting nitrate in drinking water.

DISCUSSION

As demonstrated in Table I, no sampling locations went beyond the Drinking Water Quality Standard maximum concentration limit. This finding was in line with a research done in Jelebu, Negeri Sembilan which showed that none of the water samples exceeded 5.3 mg/L(1). Another study done in Bachok, Kelantan revealed that the nitrate level in sampled groundwater in a village was low and not detrimental to health (15). According to the findings of another research that was conducted in Bijar and Oorveh in Iran, the average concentration of

Table III : Chronic Daily Intake estimation

Parameters	Weight (kg)	Drinking Water Intake (L/day)	CDI (mg/kg/day)	HQ value
Mean	69.31	1.31	0.12	0.07
SD	16.06	0.59	0.11	0.07
Range	40.9-112.4	0.48-3.0	0.004-0.60	0.003-0.37

N=48, *CDI=Chronic Daily Intake *HQ=Hazard Quotient

nitrate in the drinking water that was collected was 27.8 mg/L (16).

The presence of such nitrate concentration in drinking water may be due to agricultural activities upstream that did not give any significant impact, which can affect the water quality. To put it another way, a lower concentration of nitrate in drinking water indicates that the amount of nitrogen fertilizer applied was not significant and extremely low. Consequently, the amount of nitrate was still present in the water even though it was low. The most apparent source of nitrate in the study area is the use of ammonium nitrate as a fertilizer in the planting of rubber trees and durian trees in close proximity to the water supply. Excess fertilizer can runoff into surface water via rainwater and mechanical irrigation. In other words, the displacement of fertilizer components from their intended use on an agriculture site was leaked into local GFS water. Besides, nitrate compounds are highly soluble in water. Additionally, nitrogenous fertilizer may disrupt the natural ecology of a water supply by means of eutrophication and resulting in sedimentation. In short, the result of this study shows that low agricultural activities at the upstream of the GFS do not affect the water quality.

Agricultural activity influences the elevated nitrate concentrations in groundwater. A study in Kota Bharu, Kelantan also found that nitrogen fertilizers applied to rice crops were responsible for nitrate contamination (17).

Additionally, environmental characteristics such as precipitation are one of the important co-factors. The quantity of precipitation similarly affected nitrate content in surface water close to the source. It was rainy season at Rembau during our sampling day. The nitrate in the drinking water can be higher during the dry season. Due to diluting effects, nitrate concentrations may drop when rainfall amounts are significant (18). This fact is also supported by a study conducted in Austria which found that higher average precipitation dilutes nitrates in the soil, hence decreasing the concentration of nitrates in groundwater (19). In contrast, findings from a study in Bachok, Kelantan revealed 33.2% of the groundwater samples had nitrate values exceeding the standards (10 mg/L $NO_{3-}N$) (20). Based on previous studies, high quantities of nitrate were mainly detected because of low evapotranspiration and heavy precipitation, along with a high soil nitrate excess resulting from organic matter mineralization and earlier fertilizer, which may produce nitrate runoff into groundwater (21). Fertilizers and organic matter may also be transferred into the groundwater by percolation of precipitation or irrigation water. In addition, high nitrate concentrations were also predicted in coconut, vegetable, and rubber plantation regions. This may be caused by applying fertilizer to these agricultural areas (20).

Other than that, all pH of the drinking water samples in this study falls within the NDWQS. No anthropogenic activity or natural process is present that may alter the pH level at the GFS water source. Thus, the drinking water is considered the pH of neutral. A study in Lumami, Nagaland in India found that the pH concentration ranges from 6.64 to 7.26, within the safe limit of drinking water standards (22).

In contrast, well water in the agricultural area of Bachok, Kelantan was slightly acidic compared to the non-agricultural area owing to the presence of dissolved carbon dioxide (CO_2) and bicarbonate in the aquiferous rocks (20). A study also demonstrates that pH values of groundwater samples in India's Noyyal basin range from 7.03 to 8.7, suggesting alkaline ground water (23). A pH level that was above the allowable limit was found in about 23.81% of the samples. High pH water may damage the skin, eyes, and mucous membranes when ingested over time.

This research also discovered that there is no significant relationship between pH and nitrate levels in drinking water. In contrast, a study on the drinking water distribution network of the City of Tabriz in Iran concluded that there was a reverse linear link between nitrate content and pH value (24).

In addition, not a single outcome scored higher than one on HQ. This is due to the fact that the nitrate concentration in all of the samples was lower than the maximum allowed concentration of 45 mg/L. As a consequence of this, it is projected that respondents would face a negligible amount of risk in terms of non-cancerous health impacts stemming from nitrate contamination in groundwater. This condition was quite similar to the research in Bachok, Kelantan, which found that respondents did not face a substantial danger to their health due to the low amount of nitrate in the drinking water (15).

The risks of nitrate exposure were shown in multiple studies that discovered a correlation between nitrate concentrations in drinking water and the blood condition methemoglobinemia (25). In comparison, the HQ associated with the possible non-carcinogenic risk varied from 0.007 to 1.143 in the agricultural region of Bachok, Kelantan, and from 0.002 to 0.468 in the non-agricultural area (20). The prior research's HQ range and mean value were more significant than what was found from this study. The overall HQ for this research reveals that the health risk of nitrate in drinking water was generally safe since all the water samples analyzed were under the Malaysia Ministry of Health guideline (45mg/L NO_{3-}).

The findings of this study indicate that long-term exposure to nitrates through drinking water does not increase the risk of non-carcinogenic risk or the negative consequences of nitrate exposure due to water consumption. This conclusion is supported by the fact that the population subjected to nitrate exposure remained unharmed throughout the study. In short, the risk was minimal, and the drinking water was safe to consume.

The study's main limitation was the small sample size, which may not be representative. This is because this study's sample size is confined to a rural area. The study focused on rural residents, just one region in the Rembau compared with the general population of Negeri Sembilan. This study might provide different results if it was conducted in urban areas or a few other regions, with various sub-populations, or in locales with varied issues of nitrate in drinking water. Besides, the information gathered from the respondents could not be confirmed to be 100% accurate, which is a drawback of this research. This is because recollection bias may have played a role in this research.

CONCLUSION

Overall, nitrate levels in water samples were below the maximum acceptable value. This study also found that there was no significant association between nitrate concentration and pH. Furthermore, the Hazard Quotient (HQ) calculation results reveal that there is no possible danger to GFS users. Even if the risk is very low, it is essential to keep in mind that the World Health Organization (WHO) and national legislations base the maximum allowable amounts of components, for the most part, on animal toxicological research. There is still a lack of information on the long-term impact hazardous substances in the water may have on people.

A deterministic technique was used to evaluate exposure in this study. Instead of using the USEPA's default daily water intake rate of 2 L/day and an adult weight of 70 kg, this technique assesses exposure for each subject individually based on his unique body weight and daily water consumption rate. Ihe purpose was to minimize over-estimation or underestimation of population risk.

However, this study only managed to test one chemical which is nitrate, other chemicals like heavy metals, and microbiological testing, which was not done in this research, should also be done to confirm that the water is safe to ingest by the consumers.

Besides, concerned authorities must make the necessary efforts for effective management and implement some doable steps to raise drinking water quality by protecting water resources and creating water quality management strategies. In order to make sure that the water being delivered to the public complies with drinking water requirements, the GFS water supply must also undergo routine testing. Another issue to consider is that the data for this research was only taken at one moment, and more studies where the data may be collected at multiple points are encouraged.

Future research should consider expanding the sample region since including participants from other states might improve the accuracy of nitrate exposure. The accuracy of the estimate of a person's nitrate consumption from food and water, as well as the management of confounding variables like chemical exposure at work, might both be enhanced in the study.

ACKNOWLEDGEMENT

The people of Ulu Chuai Village in Rembau, Negeri Sembilan, deserve great credit for their unfailing help during the study. The Environmental Health Lab at the Department of Environmental and Occupational Health in the Faculty of Medicine and Health Sciences at Universiti Putra Malaysia generously provided equipment for this research.

REFERENCES

1. Moore Keith L, Dalley Arthur F. Clinically Oriented Anatomy. 4th ed. Philadelphia, Lippincott Williams and Wilkins; 1999.
2. Snell Richard, S. Clinical Anatomy by Regions. 9th ed. Baltimore, Lippincott Williams and Wilkins; 2012.
3. Prakash Kumari J, Bhardwaj AK, Jose BA, Yadav SK, Singh G. Variations in the origins of the profunda femoris, medial and lateral femoral circumflex arteries: a cadaveric study in the Indian population. Rom. J. Morphol. Embryol. 2010;51:167-170.
4. Savithri P. A rare variation of trifurcation of right femoral artery. IJAV. 2013;6:4-6.

5. Marcucci G, Antonelli R, Accrocca F, Siani A. A rare anomaly of the femoral vessels: complete transposition of the femoral artery and vein. Interact Cardiovasc. Thorac. Surg. 2010;11(6):838-839.
6. Dixit DP, Mehta LA, Kothari ML. Variations in the origin and course of profunda femoris. J. Anat. Soc. India, 2001;50:6-7.
7. Hughes P, Scott C, Bodenham A. Ultrasonography of the femoral vessels in the groin: implications for vascular access. Anaesthesia, 2000;55:1198-1202.
8. Suman S. Rao, Pradyumna Agasthi. Femoral vascular closure devices after catheterization procedure. National Library of Medicine updated 1st October 2022. Retrieved from https://www.ncbi.nlm.nih.gov/books/NBK557472/
9. Sanjay P, Reid TD, Bowrey DJ, Woodward A. Defining the position of deep inguinal ring in patients with indirect inguinal hernias. Surg. Radiol. Ant. 2006;28(2):121-124,
10. Hunt JA, Harris JP. Is the mid-inguinal point an accurate landmark for the common femoral artery in vascular patients? Aust. N. Z. J. Surg. 1996;66(1):43-45.
11. Bandyopadhyay M, Biswas S, Roy R. Vessels in femoral triangle in a rare relationship. Singapore Med. J. 2010;51:e3-e5.