Original Research

ASSOCIATION BETWEEN HARDNESS OF DRINKING WATER AND BLOOD PRESSURE – A COMMUNITY BASED CROSS SECTIONAL STUDY IN THENI

Ram Prabhakar[1*], SV Saranya[2], Geethanjali S[3], Mukesh Kumar[4]

[1*]Dr. Ram Prabhakar, Associate Professor, Department of Community Medicine, Government Medical College, Dindigul, Tamil Nadu, India.

[2]Dr. Saranya SV, Senior Assistant Professor, Department of Community Medicine, Government Theni Medical College Hospital, Theni, Tamil Nadu, India.

[3]Dr. Geethanjali S, Senior Assistant Professor, Department of Community Medicine, Government Kilpauk Medical College, Chennai, Tamil Nadu, India.

[4]Mukesh Kumar KB, CRMI, Department of Community Medicine, Government Theni Medical College Hospital, Theni, Tamil Nadu, India.

Email: ramprabhakarmbbs@gmail.com

Corresponding Author: Dr. Ram Prabhakar V, Associate Professor, Department of Community Medicine, Government Medical College, Dindigul, Tamil Nadu, India.

ABSTRACT

Title: Association between Hardness of Drinking Water and Blood Pressure A Community Based Cross Sectional Study in Theni **Background:** Hypertension remains a major public health concern and is a leading risk factor for cardiovascular morbidity and mortality. Emerging evidence suggests that the mineral composition of drinking water, particularly calcium and magnesium contributing to water hardness, may influence blood pressure levels. However, findings across studies remain inconsistent. The present study aimed to assess the association between drinking water hardness and hypertension among adults residing in urban and rural areas of Theni district. **Materials and Methods:** A community-based cross-sectional study was conducted from October 2022 to September 2024 among 857 adults (urban: 444; rural: 413). Sociodemographic details, duration of stay, socioeconomic status (Modified B.G. Prasad scale 2025), education and occupation of the head of the family, and drinking water characteristics were collected using a structured questionnaire. Blood pressure was measured using standard procedures and classified according to JNC 8 guidelines. Drinking water samples were collected in pre-cleaned containers and analysed on the same day for hardness concentration using the SPADNS spectrophotometric method at the MDRU laboratory, GTMCH, Theni. Total dissolved solids (TDS) and calcium carbonate ($CaCO_3$) levels were estimated to assess water quality. Water hardness was classified as Soft (<60 mg/L), Moderately Hard (60–120 mg/L), Hard (120–180 mg/L), and Very Hard (>180 mg/L). Pearson's correlation analysis was used to determine the relationship between $CaCO_3$ levels and blood pressure parameters. Univariate and multivariable logistic regression analyses were performed to identify independent predictors of hypertension. A p-value <0.05 was considered statistically significant. Data were entered in Microsoft Excel and analysed using Open Epi software version 3.01. **Results:** The overall prevalence of hypertension was 32.3%, and 37.5% were pre-hypertensive. Regarding water hardness, 6.5% had soft water, 36.5% moderately hard, 37.5% hard, and 19.5% very hard water exposure. $CaCO_3$ levels demonstrated a significant negative correlation with systolic blood pressure ($r = -0.391$; $p < 0.001$) and diastolic blood pressure ($r = -0.523$; $p < 0.001$), and a weak positive correlation with TDS ($r = +0.174$; $p < 0.001$). In univariate analysis, very hard water appeared protective against hypertension (OR 0.244; 95% CI: 0.150–0.395; $p < 0.001$). However, in multivariable analysis, exposure to very hard water (>180 mg/L) was independently associated with hypertension (AOR 7.013; 95% CI: 3.431–14.338; $p < 0.001$). **Conclusion:** The study demonstrated higher $CaCO_3$ levels were inversely correlated with systolic and diastolic blood pressure, the adjusted association between very hard water and hypertension indicates a complex, multifactorial relationship requiring further longitudinal and mechanistic investigation to inform public health policy.

Keywords: Hypertension, Water Hardness, Calcium Carbonate, Total Dissolved Solids, Urban - Rural Population.

www.ajmrhs.com
eISSN: 2583-7761

Date of Received: 23-01-2026
Date Acceptance: 01-02-2026
Date of Publication: 02-03-2026

INTRODUCTION

Water is one of the most essential constituents having a high impact on health. In 1981 the 34th World Health Assembly emphasized that safe drinking water is a basic element of Primary Health Care.[1] Recently the Sustainable Development Goal

(SDG) 6 highlights the importance of clean water and sanitation thereby accentuating the fact that 785 million people still lack safe drinking water service.[2] Beyond microbiological safety, the chemical composition of drinking water—particularly its mineral content—has emerged as an important but under-explored public health concern. Hardness of water is defined as the soap destroying power of water. It is traditional measure of capacity of water to react with soap, hard water requiring considerably more soap to produce lather. Hardness is caused by a variety of dissolved polyvalent metallic ions, predominantly calcium and magnesium ions. The presence of any one of the four dissolved compounds like Calcium Bicarbonate, Magnesium Bicarbonate, Calcium Sulphate and Magnesium Sulphate produce hardness. Hardness is classified as temporary (carbonate) and permanent (non-carbonate).[3] Hardness is most expressed as milligrams of calcium carbonate equivalent per litre. Water containing calcium carbonate concentrations below 60 mg/L is generally considered soft; 60-120 mg/L Moderately hard; 120-180 mg/L Hard and more than 180 mg/L Very Hard.[4] Drinking water should be moderately hard.

Hypertension remains one of the leading contributors to global morbidity and mortality, especially in low- and middle-income countries such as India.[5] While established risk factors like dietary salt intake, obesity, physical inactivity, and psychosocial stress are well documented, environmental determinants including drinking water composition have received comparatively limited attention. Reports from several studies have shown an inverse association between hardness of drinking water and cardiovascular diseases like ischemic heart disease, degenerative heart disease, stroke and hypertension.[6] Areas supplied with soft drinking water showed a significantly higher prevalence of these diseases. Some randomized prospective studies showed that higher content of calcium and magnesium salts in hard water decreases vascular tone and thus protective against hypertension though the disease itself is multifactorial in origin.[7] However no clear association has been reported in some studies.[8] Methodological heterogeneity, regional variations in mineral content, and inadequate control of confounding factors have contributed to this uncertainty. Importantly, Indian data on this relationship remain sparse, particularly at the community level and across rural -urban gradients.

Theni district in Tamil Nadu offers a unique natural setting to examine this association, as communities consume both moderately hard river water (Vaigai river) and Soft water (Purified drinking water either by Reverse Osmosis or Ultra violet radiated or combination of both).[9] This coexistence of exposure patterns within the same geographic region provides a pragmatic model for evaluating potential differences in blood pressure linked to water hardness while minimizing large-scale ecological confounding. Accordingly, the present study is aimed to assess the association between drinking water hardness and blood pressure among adult residents of rural and urban areas in Theni, and to compare these parameters across settlement types.

Objectives:

1. To find out the association between Hardness of Drinking water and Blood pressure among the study population.
2. To compare the Hardness of Drinking water and Blood pressure between urban and rural populations.

MATERIALS & METHODS

A community-based cross-sectional analytical study was conducted from October 2022 to September 2024 in Aundipatti Community Development Block (rural) and Aundipatti Jakkampatti Town Panchayat (urban) of Theni district, Tamil Nadu. As per Primary Census Abstract 2011[10], the Aundipatti Community Development Block comprises of 18 villages with total households of 29,827 and total population 1, 11,000. Aundipatti Jakkampatti Town Panchayat comprises of 18 wards with total households of 7512 and total population of 27,287. These areas were selected because the population consumed drinking water from heterogeneous sources, including moderately hard river water and softened purified water systems, thereby providing a suitable natural setting to assess the association between water hardness and blood pressure.

A multistage cluster sampling technique was employed. In the first stage, villages and wards were selected using Probability Proportional to Population Size (PPS) based on Primary Census Abstract 2011 data. In the second stage, households within selected clusters were chosen using systematic random sampling. Ten clusters each were identified from rural and urban areas. From every rural cluster, 42 households were sampled, while 45 households were selected from each urban cluster, yielding a total sample size of 857 participants (413 rural and 444 urban), calculated using Open Epi software version 3.01 with Hypothesized percentage prevalence of hypertension (23.4% in rural population and 26.4% in urban population as per NFHS 5- Tamilnadu report[10]), 5% absolute precision, 95% confidence level, and design effect of 1.5. All residents aged 18 years and above who had been living in the study area for at least five years were considered eligible for the study. Individuals consuming calcium or magnesium supplements, taking medications for chronic illnesses such as hypertension, diabetes, or cardiac conditions, and those using tobacco or alcohol were excluded to minimize confounding influences.

After obtaining written informed consent, data were collected using a predesigned, interviewer-administered questionnaire. Information regarding socio-demographic characteristics, duration of residence and source of drinking water, dietary patterns, and medical history was recorded. Drinking water samples were collected from each selected household in clean plastic bottles, which were double-rinsed with distilled water prior to sampling. All samples were labelled, coded, and transported on the same day to the Multi-Disciplinary Research Unit (MDRU) laboratory at Government Theni Medical College Hospital (GTMCH) for hardness estimation. Water hardness was determined using a spectrophotometric method[11] and expressed as milligrams of calcium carbonate equivalent per litre, allowing classification into soft, moderately hard, hard, and very hard categories.

Blood pressure measurements were obtained using a mercury sphygmomanometer following standard procedures.[12] Participants were seated comfortably, and two readings were recorded at an interval of five minutes. The lower of the two measurements was considered as the final blood pressure value for analysis. All measurements were performed by trained investigators to ensure consistency and minimize observer variability. Quality control measures included periodic calibration of equipment and supervision of field activities.

Statistical Analysis:

Collected data were initially entered into Microsoft Excel and subsequently analysed using Open Epi software version 3.01. Descriptive statistics such as frequency, percentage, mean, standard deviation, median, and interquartile range were computed. Normality of continuous variables was assessed using Shapiro–Wilk and Kolmogorov–Smirnov tests. Independent sample t-tests were applied to compare mean water hardness and blood pressure levels between rural and urban populations. Univariate analysis was performed to explore associations between water hardness and blood pressure. Variables demonstrating statistical significance were entered into a multiple logistic regression model to identify independent predictors while adjusting for potential confounders. Model diagnostics were conducted to assess goodness-of-fit, and a p-value of less than 0.05 was considered statistically significant.

Ethical considerations:

The study protocol received approval from the Institutional Ethics Committee, Government Theni Medical College Hospital (GTMCH) with (IEC Certificate no: 1515/ MEIII/21-05/09/2022). All eligible participants were provided with a comprehensive explanation of the study's purpose, objectives, and procedures in a language they could easily understand. Written informed consent was obtained prior to inclusion in the study. Participation was completely voluntary, and individuals were clearly informed of their right to discontinue involvement at any point without any repercussions. Strict confidentiality was ensured by anonymizing all collected data and limiting access exclusively to the research team. Personal identifiers were not used during data analysis or while reporting the findings. Clinical assessments, including blood pressure measurements, were performed with due consideration for participants' privacy and dignity. Individuals found to have elevated blood pressure or other health-related concerns were provided appropriate counselling and referred to the nearest health facility for further evaluation and management.

RESULTS

The age distribution differed significantly between urban and rural participants (p<0.001). Overall, most participants were in the 31–40 years age group (31.6%), followed by 21–30 years (22.4%) and 41–50 years (16.1%). In urban areas, the highest proportion was observed in the 31–40 years category (40.8%), whereas in rural areas, the 41–50 years age group constituted the largest proportion (24.2%). Participants aged 51–60 years accounted for 10.7% of the total sample, while those aged 61–70 years and ≥71 years represented 8.6% and 3.0%, respectively. The mean age of the study participants was 40.06 years ± 14.7 years. Regarding gender distribution, males constituted 42.0% and females 58.0% of the total study population. In urban areas, 43.7% were males and 56.3% were females, whereas in rural areas, 40.2% were males and 59.8% were females. The difference in gender distribution between urban and rural areas was not statistically significant (p=0.300). (Table 1)

Family type showed a statistically significant difference between urban and rural participants (p=0.028). Overall, most participants belonged to nuclear families (72.9%), followed by joint families (22.2%) and three-generation families (4.9%). In urban areas, 76.6% belonged to nuclear families compared to 69.0% in rural areas. Joint families were more common in rural areas (24.7%) than in urban areas (19.8%), and three-generation families were also slightly higher in rural areas (6.3%) compared to urban areas (3.6%). The duration of stay also differed significantly between urban and rural participants (p<0.001). Overall, 35.6% of participants had resided in the area for ≥21 years, followed by ≤5 years (25.2%) and 6–10 years (20.8%). Among urban residents, 30.0% had lived in the area for ≤5 years and 27.5% for ≥21 years. In contrast, among rural residents, 44.3% had a duration of stay of ≥21 years, indicating greater residential stability in rural areas. (Table 1)

Socioeconomic status, based on the Modified B.G. Prasad scale 2025[13], showed a significant difference between urban and rural populations (p<0.001). Overall, the largest proportion of participants belonged to Class IV (41.3%), followed by Class II (21.2%) and Class III (19.5%). In urban areas, Class IV constituted 42.1% of participants, while in rural areas, 40.4% belonged to Class IV. Higher socioeconomic classes were more prevalent in urban areas, with 15.3% in Class I compared to only 1.5% in rural areas. Conversely, Class III was more common in rural areas (32.0%) than in urban areas (7.9%). Education of the head of the family also showed a statistically significant difference between the two groups (p<0.001). Overall, 35.8% of heads of families had completed high school, 25.4% had primary school education, and 15.3% had middle school education. Graduates constituted 7.4% of the total sample, while 10.5% were illiterate. In urban areas, 42.1% of heads of families had completed high school and 22.7% had primary education. In rural areas, high school education accounted for 29.1%, while primary education was more common at 28.3%, and illiteracy was higher (12.6%) compared to urban areas (8.6%). (Table 1)

Occupation of the head of the family also differed significantly between urban and rural areas (p<0.001). Overall, 38.2% were skilled workers, 29.9% were unskilled workers, and 12.6% were semi-skilled workers. Technicians or associates accounted for 8.4%, clerks for 5.4%, and 5.6% were unemployed. In urban areas, 43.0% were skilled workers and 19.8% were unskilled workers. In contrast, rural areas had a higher proportion of unskilled workers (40.7%) and semi-skilled workers (13.6%), while technicians and clerks were less common at 4.8% and 1.9%, respectively. (Table 1)

The source of drinking water showed a statistically significant difference between urban and rural areas (p<0.001). Overall, the most common source was tap water, accounting for 54.4% of participants, followed by can water at 20.5% and borewell water at 12.7%. River water was used by 10.9% of participants, while pond water was the least common source at 1.5%. In urban areas, 49.5% relied on tap water and 29.3% used can water, whereas in rural areas, a higher proportion used tap water (59.6%) and river water (16.9%) compared to urban residents (5.2%). Borewell usage was also higher in urban areas (15.5%) compared to rural areas (9.7%). The source of water used for cooking purposes also differed significantly between urban and rural populations (p<0.001). Overall, 63.7% of participants used tap water for cooking, followed by river water at 13.9% and can water at 11.2%. Borewell water was used by 9.7%, while pond water accounted for 1.5%. In urban areas, 61.3% used tap water for cooking and 19.1% used can water, whereas in rural areas, 66.3% relied on tap water and 21.3% used river water, which was substantially higher than the 7.0% observed in urban areas. Pond water usage was minimal in both groups. (Table 2)

Regarding purification or pretreatment of drinking water, no statistically significant difference was observed between urban and rural areas (p=0.967). Overall, 49.0% of participants reported no purification or pretreatment, 44.2% practiced boiling, and 6.8% used reverse osmosis (RO) systems. The proportions were nearly identical between urban and rural residents, with approximately 44% in both groups practicing boiling and about 49% reporting no purification method. The total dissolved solids (TDS) level in drinking water showed a statistically significant difference between urban and rural areas (p=0.005). Overall, 52.4% of water samples were classified as excellent (<300 mg/L), 22.8% as good (300–600 mg/L), and 17.5% as fair (600–900 mg/L). Poor quality water (900–1200 mg/L) was observed in 6.2% of cases, and 1.2% fell into the unacceptable category (>1200 mg/L). Urban areas had a higher proportion of excellent TDS levels (56.3%) compared to rural areas (48.2%), whereas rural areas had relatively higher proportions in the good (26.4%) and fair (20.1%) categories. The mean TDS level of the study participants was 394.42 mg/L. The $CaCO_3$ level in drinking water did not differ significantly between urban and rural areas (p=0.056). Overall, 37.5% of water samples were classified as hard (120–180 mg/L), 36.5% as moderately hard (60–120 mg/L), 19.5% as very hard (>180 mg/L), and 6.5% as soft (<60 mg/L). In urban areas, 40.1% of water samples were moderately hard and 37.4% were hard, whereas in rural areas, 37.5% were hard and 32.7% were moderately hard. Very hard water was more common in rural areas (22.3%) compared to urban areas (16.9%). The mean CaC03 level of the study participants was 169.77 mg/L. (Table 2)

Table 3 shows the results of Univariate Logistic Regression and association between selected independent variables and hardness of drinking water (>180 mg/L), expressed as odds ratios with 95% confidence intervals. Place of residence was significantly associated with very hard water (p=0.047). Among urban residents, 75 (16.9%) were exposed to water hardness >180 mg/L, whereas 92 (22.3%) of rural residents had very hard water. Rural participants had 1.41 times higher odds of exposure to very hard water compared to urban residents (OR 1.410; 95% CI: 1.004–1.980).

The source of drinking water showed a statistically significant association with water hardness. Using borewell water as the reference category, 33 (30.3%) of borewell users had very hard water. In comparison, 30 (17.0%) of can water users had hardness >180 mg/L, with significantly lower odds (OR 0.473; 95% CI: 0.268–0.834; p=0.010). Only 1 (7.7%) of pond water users had very hard water, though this association was not statistically significant (OR 0.192; 95% CI: 0.024–1.537; p=0.120). River water users had the highest proportion, with 51 (54.8%) exposed to very hard water, and nearly three times higher odds compared to borewell users (OR 2.797; 95% CI: 1.569–4.983; p<0.001). Tap water users had significantly lower odds of very hard water exposure (52; 11.2%) compared to borewell users (OR 0.289; 95% CI: 0.175–0.477; p<0.001). (Table 3)

Similarly, the source of water used for cooking was significantly associated with water hardness. Among borewell users, 33 (39.8%) had very hard water and were considered the reference group. Can water users had 20 (20.8%) cases of very hard water, with significantly lower odds (OR 0.399; 95% CI: 0.206–0.772; p=0.006). Pond water users had 1 (7.7%) case, which approached statistical significance (OR 0.126; 95% CI: 0.016–1.018; p=0.052). River water users had 57 (47.9%) exposed to very hard water, but this was not statistically significant (OR 1.393; 95% CI: 0.789–2.458; p=0.253). Tap water users had significantly reduced odds of very hard water exposure (56; 10.3%) compared to borewell users (OR 0.173; 95% CI: 0.103–0.291; p<0.001). Pretreatment or purification of water was not significantly associated with hardness levels. Among those who boiled water, 59 (15.6%) had very hard water (OR 0.885; 95% CI: 0.424–1.847; p=0.745) compared to the reverse osmosis group (reference), where 10 (17.2%) had very hard water. Participants who did not practice any pretreatment had 98 (23.3%) with very hard water, but this association was not statistically significant (OR 1.461; 95% CI: 0.713–2.995; p=0.301). Total dissolved solids (TDS) was significantly associated with hardness of drinking water. For every one-unit increase in TDS level, the odds of very hard water increased marginally (OR 1.001; 95% CI: 1.000–1.001; p=0.002), indicating a statistically significant but small incremental effect. Overall, rural residence and certain water sources, particularly river water for drinking and borewell water for cooking, were significantly associated with higher odds of exposure to very hard water in Univariate Logistic Regression (Table 3).

Table 4 presents the Multivariate Logistic Regression and association between selected independent variables and hardness of drinking water (>180 mg/L). Place of residence was not significantly associated with very hard water in the adjusted analysis (p=0.084). Among urban residents, 75 (16.9%) were exposed to water hardness >180 mg/L and were taken as the reference category. Among rural residents, 92 (22.3%) had very hard water, with 1.44 times higher odds compared to urban residents (OR 1.443; 95% CI: 0.952–2.188), although this did not reach statistical significance. The source of drinking water showed significant associations with hardness levels. Using borewell water as the reference category, 33 (30.3%) of borewell users had very hard water. Among can water users, 30 (17.0%) had hardness >180 mg/L, with significantly lower odds compared to borewell users (OR 0.122; 95% CI: 0.032–0.468; p=0.002). Pond water users had 1 (7.7%) case of very hard water and showed significantly reduced odds (OR 0.064; 95% CI: 0.008–0.537; p=0.011). River water users had 51 (54.8%) with very hard water, but the association was not statistically significant (OR 0.413; 95% CI: 0.115–1.487; p=0.176). Similarly, tap water users had 52 (11.2%) cases of very hard water and did not show a significant association compared to borewell users (OR 0.783; 95% CI: 0.378–1.624; p=0.511).

Regarding the source of water used for cooking, borewell users (33; 39.8%) were considered the reference category. Can water users had 20 (20.8%) cases of very hard water, with higher odds compared to borewell users (OR 3.554; 95% CI: 0.928–13.616), although this was not statistically significant (p=0.064). Pond water users had 1 (7.7%) case of very hard water and showed significantly higher odds (OR 3.618; 95% CI: 1.083–12.088; p=0.037). River water users had 57 (47.9%) exposed to very hard water but did not show a statistically significant association (OR 1.454; 95% CI: 0.563–5.761; p=0.467). Tap water users had significantly lower odds of very hard water exposure compared to borewell users (56; 10.3%) (OR 0.173; 95% CI: 0.103–0.291; p<0.001). Total dissolved solids (TDS) was not significantly associated with water hardness in this model (OR 1.001; 95% CI: 1.000–1.001; p=0.122). Overall, the source of drinking and cooking water demonstrated important associations with hardness levels, while place of residence and TDS did not show statistically significant associations in the analysis. (Table 4).

The classification of blood pressure according to JNC 8 criteria[14] did not show a statistically significant difference between urban and rural populations (p=0.406). Overall, the largest proportion of participants were categorized as pre-hypertensive, accounting for 321 (37.5%), followed by normal blood pressure in 259 (30.2%) and Stage I hypertension in 254 (29.6%). Stage II hypertension was observed in 23 (2.7%) of the total study population. In urban areas, 155 (34.9%) participants were pre-hypertensive, 140 (31.5%) had normal blood pressure, 138 (31.1%) had Stage I hypertension, and 11 (2.5%) had Stage II hypertension. In rural areas, 166 (40.2%) were pre-hypertensive, 119 (28.8%) were normal, 116 (28.1%) had Stage I hypertension, and 12 (2.9%) had Stage II hypertension. About the overall presence of hypertension, there was no statistically significant difference between urban and rural populations (p=0.422). The mean SBP and DBP among the study participants were 120.82 mm of Hg and 80.71 mm of Hg respectively. Hypertension was present in 277 (32.3%) of the total study population, while 580 (67.7%) were non-hypertensive. Among urban residents, 149 (33.6%) had hypertension and 295 (66.4%) did not. Similarly, among rural residents, 128 (31.0%) were hypertensive and 285 (69.0%) were non-hypertensive. (Table 5).

Table 6 presents Univariate Logistic Regression and association between selected independent variables and the presence of hypertension. Age showed a statistically significant association with hypertension (OR 1.061; 95% CI: 1.049–1.073; p<0.001), indicating that with each one-year increase in age, the odds of hypertension increased by approximately 6.1%. Gender was significantly associated with hypertension (p=0.044). Among males, 130 (36.1%) had hypertension compared to 147 (29.6%) females. Males had 1.35 times higher odds of hypertension compared to females (OR 1.346; 95% CI: 1.008–1.796). Place of residence was not significantly associated with hypertension (p=0.422). Hypertension was present in 149 (33.6%) urban participants and 128 (31.0%) rural participants, with an odds ratio of 1.125 (95% CI: 0.844–1.498).

Family type showed a statistically significant association with hypertension. Participants from nuclear families had 211 (33.8%) cases of hypertension (OR 1.508; 95% CI: 1.045–2.176; p=0.028), and those from three-generation families had 18 (42.9%) cases (OR 2.219; 95% CI: 1.109–4.438; p=0.024), compared to those from joint families (25.3%), which were considered the reference category. Duration of stay was also significantly associated with hypertension (OR 1.014; 95% CI: 1.007–1.022; p<0.001), indicating a 1.4% increase in odds per additional year of stay. Socioeconomic status demonstrated mixed associations. Participants belonging to Class I had 41 (55.4%) with hypertension and significantly higher odds compared to Class V (reference) (OR 2.733; 95% CI: 1.415–5.280; p=0.003). Class II (29.1%), Class III (40.1%), and Class IV (25.7%) did not show statistically significant associations (p>0.05). Education of the head of the family was significantly associated with hypertension in certain categories. Compared to illiterate heads of families (reference), those with intermediate/diploma education had markedly higher odds (OR 6.402; 95% CI: 2.873–14.266; p<0.001), and those with primary education also had significantly higher odds (OR 1.674; 95% CI: 1.005–2.786; p=0.048). High school education showed significantly lower odds (OR 0.397; 95% CI: 0.235–0.672; p=0.001), while graduate and middle school categories were not statistically significant. (Table 6).

Occupation of the head of the family revealed that technician/associate professionals had significantly higher odds of hypertension (OR 4.487; 95% CI: 2.025–9.942; p<0.001) compared to unemployed individuals (reference). Other occupational categories did not show statistically significant associations. Regarding drinking water source, can water users had significantly higher odds of hypertension (OR 1.848; 95% CI: 1.285–2.657; p=0.001), and river water users had even higher odds (OR 2.397; 95% CI: 1.520–3.779; p<0.001), compared to tap water users (reference). Borewell and pond water sources were not significantly associated. Similar findings were observed for cooking water source, where can water (OR 1.818; 95% CI: 1.163–2.842; p=0.009) and river water (OR 2.115; 95% CI: 1.409–3.174; p<0.001) were significantly associated with hypertension compared to tap water. Pretreatment or purification of water was not significantly associated with hypertension. TDS level showed a statistically significant but marginal inverse association (OR 0.999; 95% CI: 0.999–1.000; p=0.024). Hardness of water demonstrated a strong and statistically significant inverse association with hypertension. Among those exposed to water hardness >180 mg/L, 21 (12.6%) had hypertension compared to 256 (37.1%) among those with ≤180 mg/L hardness. Exposure to higher hardness was associated with significantly lower odds of hypertension (OR 0.244; 95% CI: 0.150–0.395; p<0.001). (Table 6).

Finally, $CaCO_3$ level in drinking water showed a significant inverse association with hypertension (OR 0.963; 95% CI: 0.958–0.968; p<0.001), indicating that increasing calcium carbonate levels were associated with reduced odds of hypertension. Overall, age, male gender, family type, duration of stay, higher socioeconomic class, certain educational and occupational categories, specific water sources, TDS level, hardness of water, and $CaCO_3$ levels showed significant associations with hypertension in Univariate Logistic Regression (Table 6).

Table 7 presents the multivariable logistic regression analysis examining factors independently associated with hypertension after adjusting for potential confounders. Age remained a strong independent predictor of hypertension. For every one-year increase in age, the odds of hypertension increased by 7.1% (AOR 1.071; 95% CI: 1.053–1.088; p<0.001). Gender was not independently associated with hypertension after adjustment. Although 130 (36.1%) males and 147 (29.6%) females had hypertension, males showed lower adjusted odds compared to females (AOR 0.717; 95% CI: 0.476–1.079), and this association was not statistically significant (p=0.111). Type of family did not retain statistical significance in the multivariable model. Participants from nuclear families had 211 (33.8%) with hypertension (AOR 1.424; 95% CI: 0.890–2.276; p=0.140), and those from three-generation families had 18 (42.9%) cases (AOR 0.893; 95% CI: 0.361–2.211; p=0.807), compared to joint families (reference). Duration of stay was also not independently associated with hypertension (AOR 0.999; 95% CI: 0.988–1.010; p=0.857).

Socioeconomic status showed significant independent associations in certain categories. Compared to Class V (reference), participants in Class I had significantly lower adjusted odds of hypertension (AOR 0.241; 95% CI: 0.076–0.767; p=0.016). Similarly, Class II (AOR 0.286; 95% CI: 0.131–0.624; p=0.002) and Class IV (AOR 0.422; 95% CI: 0.207–0.861; p=0.018) were significantly associated with reduced odds. Class III did not show a statistically significant association (AOR 0.600; 95% CI: 0.280–1.286; p=0.189). Education of the head of the family demonstrated significant associations in selected categories. Compared to illiterate heads of families (reference), intermediate/diploma education was associated with significantly higher odds of hypertension (AOR 4.755; 95% CI: 1.437–15.732; p=0.011), and primary school education was also associated with increased odds (AOR 2.432; 95% CI: 1.274–4.646; p=0.007). High school education showed borderline significance (AOR 0.535; 95% CI: 0.280–1.022; p=0.058), while graduate and middle school categories were not statistically significant. (Table 7)

Occupation of the head of the family showed strong independent associations. Compared to unemployed individuals (reference), technician/associate professionals had significantly higher odds of hypertension (AOR 8.925; 95% CI: 2.503–31.825; p=0.001). Clerks also had markedly increased odds (AOR 7.589; 95% CI: 1.947–29.584; p=0.004). Skilled workers (AOR 2.807; 95% CI: 1.015–7.760; p=0.047) and semi-skilled workers (AOR 6.066; 95% CI: 1.897–19.401; p=0.002) were significantly associated with hypertension, whereas unskilled workers did not show a significant association (AOR 2.209; 95% CI: 0.785–6.222; p=0.133). (Table 7)

Among drinking water sources, only river water remained independently associated with hypertension. Participants using river water for drinking had significantly higher odds of hypertension compared to tap water users (AOR 6.103; 95% CI: 1.729–21.533; p=0.005). Borewell, can water, and pond water were not statistically significant in the adjusted model. Cooking water source was not independently associated with hypertension in the multivariable analysis. TDS level also did not show a statistically significant association (AOR 1.000; 95% CI: 0.999–1.000; p=0.415). Hardness of water demonstrated a strong and statistically significant independent association with hypertension. Participants exposed to water hardness >180 mg/L had significantly higher odds of hypertension compared to those exposed to ≤180 mg/L (AOR 7.013; 95% CI: 3.431–14.338; p<0.001). Overall, age, selected socioeconomic classes, certain educational and occupational categories, use of river water for drinking, and exposure to high water hardness were independently associated with hypertension after adjusting for potential confounders. (Table 7)

A statistically significant moderate negative correlation was observed between $CaCO_3$ levels and systolic blood pressure (SBP) ($r = -0.391$; $p < 0.001$), indicating that higher calcium carbonate concentrations were associated with lower systolic blood pressure values. Similarly, $CaCO_3$ levels demonstrated a moderate to strong negative correlation with diastolic blood pressure (DBP) ($r = -0.523$; $p < 0.001$), suggesting that increasing calcium carbonate levels were significantly associated with decreasing diastolic blood pressure. In contrast, $CaCO_3$ levels showed a weak but statistically significant positive correlation with total dissolved solids (TDS) ($r = +0.174$; $p < 0.001$), indicating that higher calcium carbonate concentrations were modestly associated with higher TDS levels. (Figures 1, 2 and 3).

Table 1: Comparison of Socio Demographic Characteristics (N=857)

S. No.	Characteristics	Urban (444) N (%)	Rural (413) N (%)	Total N (%)	P Value
1.	**Age**				
	18 - 20 years	32 (7.2%)	32 (7.7%)	64 (7.5%)	<0.001•
	21 - 30 years	111 (25.0%)	81 (19.6%)	192 (22.4%)	
	31 - 40 years	181 (40.8%)	90 (21.8%)	271 (31.6%)	
	41 - 50 years	38 (8.6%)	100 (24.2%)	138 (16.1%)	
	51 - 60 years	38 (8.6%)	54 (13.1%)	92 (10.7%)	
	61 - 70 years	33 (7.4%)	41 (9.9%)	74 (8.6%)	
	≥ 71 years	11 (2.5%)	15 (3.6%)	26 (3.0%)	
2.	**Gender**				
	Male	194 (43.7%)	166 (40.2%)	360 (42.0%)	0.300
	Female	250 (56.3%)	247 (59.8%)	497 (58.0%)	

3.	**Family Type**				0.028•
	Nuclear family	340 (76.6%)	285 (69.0%)	625 (72.9%)	
	Joint family	88 (19.8%)	102 (24.7%)	190 (22.2%)	
	Three Generation family	16 (3.6%)	26 (6.3%)	42 (4.9%)	
4.	**Duration of stay**				<0.001•
	≤ 5 years	133 (30.0%)	83 (20.1%)	216 (25.2%)	
	6 - 10 years	100 (22.5%)	78 (18.9%)	178 (20.8%)	
	11 - 15 years	57 (12.8%)	29 (7.0%)	86 (10.0%)	
	16 - 20 years	32 (7.2%)	40 (9.7%)	72 (8.4%)	
	≥ 21 years	122 (27.5%)	183 (44.3%)	305 (35.6%)	
5.	**Socioeconomic class** [based on Modified B.G Prasad's scale 2025]				<0.001•
	Class I (PCI ≥8592)	68 (15.3%)	6 (1.5%)	74 (8.6%)	
	Class II (PCI 4296-8591)	108 (24.3%)	74 (17.9%)	182 (21.2%)	
	Class III (PCI 2578-4295)	35 (7.9%)	132 (32.0%)	167 (19.5%)	
	Class IV (PCI 1289- 2577)	187 (42.1%)	167 (40.4%)	354 (41.3%)	
	Class V (PCI <1289)	46 (10.4%)	34 (8.2%)	80 (9.3%)	
6.	**Education of Head of the Family (HOF)**				<0.001•
	Graduate	39 (8.8 %%)	24 (5.8%)	63 (7.4%)	
	Intermediate/ diploma	28 (6.3%)	20 (4.8%)	48 (5.6%)	
	High school	187 (42.1%)	120 (29.1%)	307 (35.8%)	
	Middle school	51 (11.5%)	80 (19.4%)	131 (15.3%)	
	Primary school	101 (22.7%)	117 (28.3%)	218 (25.4%)	
	Illiterate	38 (8.6%)	52 (12.6%)	90 (10.5%)	
7.	**Occupation of Head of the Family (HOF)**				<0.001•
	Technician/Associate	52 (11.7%)	20 (4.8%)	72 (8.4%)	
	Clerk	38 (8.6%)	8 (1.9%)	46 (5.4%)	
	Skilled worker	191 (43.0%)	136 (32.9%)	327 (38.2%)	
	Semi-skilled worker	52 (11.7%)	56 (13.6%)	108 (12.6%)	
	Unskilled worker	88 (19.8%)	168 (40.7%)	256 (29.9%)	
	Unemployed	23 (5.2%)	25 (6.1%)	48 (5.6%)	

•Statistically significant

Table 2: Comparison of Water Related Characteristics (N=857)

S. No.	Characteristics	Urban (444) N (%)	Rural (413) N (%)	Total N (%)	P Value
1.	**Source of Drinking water**				<0.001•
	Borewell	69 (15.5%)	40 (9.7%)	109 (12.7%)	
	Can water	130 (29.3%)	46 (11.1%)	176 (20.5%)	
	Pond	2 (0.5%)	11 (2.7%)	13 (1.5%)	
	River water	23 (5.2%)	70 (16.9%)	93 (10.9%)	
	Tap water	220 (49.5%)	246 (59.6%)	466 (54.4%)	
2.	**Source of water used for cooking purpose**				<0.001•
	Borewell	54 (12.2%)	29 (7.0%)	83 (9.7%)	
	Can water	85 (19.1%)	11 (2.7%)	96 (11.2%)	
	Pond	2 (0.5%)	11 (2.7%)	13 (1.5%)	
	River water	31 (7.0%)	88 (21.3%)	119 (13.9%)	
	Tap water	272 (61.3%)	274 (66.3%)	546 (63.7%)	
3.	**Purification/Pretreatment of Drinking water**				0.967
	Boiling	196 (44.1%)	183 (44.3%)	379 (44.2%)	
	Reverse Osmosis (RO)	31 (7.0%)	27 (6.5%)	58 (6.8%)	
	No purification/pretreatment	217 (48.9%)	203 (49.2%)	420 (49.0%)	

4.	**TDS level in Drinking water**				
	Excellent (<300 mg/L)	250 (56.3%)	199 (48.2%)	449 (52.4%)	0.005•
	Good (300-600 mg/L)	86 (19.4%)	109 (26.4%)	195 (22.8%)	
	Fair (600-900 mg/L)	67 (15.1%)	83 (20.1%)	150 (17.5%)	
	Poor (900-1200 mg/L)	35 (7.9%)	18 (4.4%)	53 (6.2%)	
	Unacceptable (>1200 mg/L)	6 (1.4%)	4 (1.0%)	10 (1.2%)	
5.	**CaC0$_3$ level in Drinking Water**				
	Soft (< 60 mg/L)	25 (5.6%)	31 (7.5%)	56 (6.5%)	0.056
	Moderately Hard (60 - 120 mg/L)	178 (40.1%)	135 (32.7%)	313 (36.5%)	
	Hard (120 - 180 mg/L)	166 (37.4%)	155 (37.5%)	321 (37.5%)	
	Very Hard (> 180 mg/L)	75 (16.9%)	92 (22.3%)	167 (19.5%)	

•Statistically significant

Table 3: Univariate Logistic Regression Analysis of Hardness with Various Factors (N = 857)

Independent Variable	**Hardness (>180 mg/L) N (%)**	**OR (95% CI)**	**P Value**
PLACE OF RESIDENCE			
Urban (444) (Ref)	75(16.9%)	1	
Rural (413)	92(22.3%)	1.410(1.004-1.980)	0.047•
DRINKING WATER SOURCE			
Can water (176)	30(17.0%)	0.473(0.268-0.834)	0.010•
Pond (13)	1(7.7%)	0.192(0.024-1.537)	0.120
River water (93)	51(54.8%)	2.797(1.569-4.983)	0.000•
Tap water (466)	52(11.2%)	0.289(0.175-0.477)	0.000•
Borewell (109) (Ref)	33(30.3%)	1	
COOKING WATER SOURCE			
Can water (96)	20(20.8%)	0.399(0.206-0.772)	0.006•
Pond (13)	1(7.7%)	0.126(0.016-1.018)	0.052
River water (119)	57(47.9%)	1.393(0.789-2.458)	0.253
Tap water (546)	56(10.3%)	0.173(0.103-0.291)	0.000•
Borewell (83) (Ref)	33(39.8%)	1	
PRETREATMENT/PURIFICATION OF WATER			
Boiling (379)	59(15.6%)	0.885(0.424-1.847)	0.745
Reverse Osmosis (Ref) (58)	10(17.2%)	1	
No Pre-treatment (420)	98(23.3%)	1.461(0.713-2.995)	0.301
TDS LEVEL (continuous variable)	----------	1.001(1.000-1.001)	0.002•

•Statistically significant

Table 4: Multivariate Logistic Regression Analysis of Hardness with Various Factors (N = 857)

Independent Variable	**Hardness (>180 Mg/L) N (%)**	**Or (95% Ci)**	**P Value**
PLACE OF RESIDENCE			
Urban (444) (Ref)	75(16.9%)	1	
Rural (413)	92(22.3%)	1.443(0.952-2.188)	0.084
DRINKING WATER SOURCE			
Can water (176)	30(17.0%)	0.122(0.32-0.468)	0.002•
Pond (13)	1(7.7%)	0.064(0.008-0.537)	0.011•
River water (93)	51(54.8%)	0.413(0.115-1.487)	0.176
Tap water (466)	52(11.2%)	0.783(0.378-1.624)	0.511

Borewell (109) (Ref)	33(30.3%)	1	
COOKING WATER SOURCE Can water (96) Pond (13) River water (119) Tap water (546) Borewell (83) (Ref)	 20(20.8%) 1(7.7%) 57(47.9%) 56(10.3%) 33(39.8%)	 3.554(0.928-13.616) 3.618(1.083-12.088) 1.454(0.563-5.761) 0.173(0.103-0.291) 1	0.064 0.037• 0.467 0.000•
TDS LEVEL (continuous variable)	----------	1.001(1.000-1.001)	0.122

•Statistically significant

Table 5: Comparison of Blood Pressure & Presence of Hypertension (N=857)

S. No.	Characteristics	Urban (444) N (%)	Rural (413) N (%)	Total N (%)	P Value
1.	**Classification of Blood Pressure as per JNC 8** Normal Pre-Hypertension Stage I Hypertension Stage II Hypertension	 140 (31.5%) 155 (34.9%) 138 (31.1%) 11 (2.5%)	 119 (28.8%) 166 (40.2%) 116 (28.1%) 12 (2.9%)	 259 (30.2%) 321 (37.5%) 254 (29.6%) 23 (2.7%)	0.406
2.	**Presence of Hypertension** Yes No	 149 (33.6%) 295 (66.4%)	 128 (31.0%) 285 (69.0%)	 277 (32.3%) 580 (67.7%)	0.422

•Statistically significant

Table 6: Univariate Logistic Regression Analysis of Hypertension with Various Factors (N = 857)

•Statistically significant

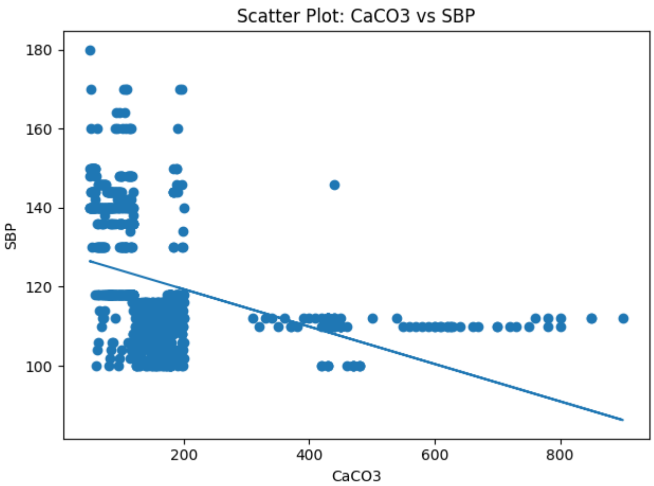
Independent Variable	Hypertension Present N (%)	OR (95% CI)	P value
AGE **(continuous variable)**	----------	1.061 (1.049-1.073)	0.000•
GENDER **Male (360)** **Female (Ref) (497)**	 130(36.1%) 147(29.6%)	 1.346(1.008-1.796) 1	0.044•
PLACE OF RESIDENCE **Urban (444)** **Rural (Ref) (413)**	 149(33.6%) 128(31.0%)	 1.125(0.844-1.498) 1	0.422
TYPE OF FAMILY **Nuclear (625)** **Three generation (42)** **Joint (190) (Ref)**	 211(33.8%) 18(42.9%) 48(25.3%)	 1.508(1.045-2.176) 2.219(1.109-4.438) 1	0.028• 0.024•
DURATION OF STAY **(continuous variable)**	----------	1.014 (1.007-1.022)	0.000•
SOCIOECONOMIC STATUS **Class I (PCI ≥8592) (74)** **Class II (PCI 4296-8591) (182)** **Class III (PCI 2578-4295) (167)** **Class IV (PCI 1289- 2577) (354)** **Class V (PCI <1289) (Ref) (80)**	 41(55.4%) 53(29.1%) 67(40.1%) 91(25.7%) 25(31.3%)	 2.733(1.415-5.280) 0.904(0.511-1.600) 1.474(0.838-2.593) 0.761(0.448-1.293) 1	 0.003• 0.729 0.178 0.312

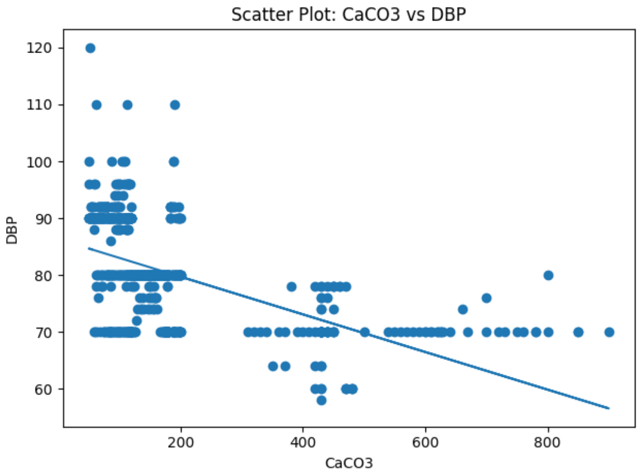
Table 7: Multivariate Logistic Regression Analysis of Hypertension with Various Factors (N = 857)

EDUCATION OF HOF **Graduate (63)** **Intermediate/ diploma (48)** **High school (307)** **Middle school (131)** **Primary school (218)** **Illiterate (90) (Ref)**	18(28.6%) 37(77.1%) 53(17.3%) 36(27.5%) 102(46.8%) 31(34.4%)	0.761(0.379-1.531) 6.402(2.873-14.266) 0.397(0.235-0.672) 0.721(0.404-1.288) 1.674(1.005-2.786) 1	0.444 0.000• 0.001• 0.269 0.048•
OCCUPATION OF HOF **Technician/Associate Professional (72)** **Clerk (46)** **Skilled worker (327)** **Semi-skilled worker (108)** **Unskilled worker (256)** **Unemployed (Ref) (48)**	45(62.5%) 15(32.6%) 90(27.5%) 32(29.6%) 82(32.0%) 13(27.1%)	4.487(2.025-9.942) 1.303(0.537-3.160) 1.022(0.517-2.021) 1.134(0.531-2.421) 1.269(0.637-2.526) 1	0.000• 0.559 0.949 0.746 0.498
DRINKING WATER SOURCE **Borewell (109)** **Can water (176)** **Pond (13)** **River water (93)** **Tap water (Ref) (466)**	29(26.6%) 72(40.9%) 5(38.5%) 44(47.3%) 127(27.3%)	0.968(0.604-1.550) 1.848(1.285-2.657) 1.668(0.536-5.195) 2.397(1.520-3.779) 1	0.891 0.001• 0.377 0.000•
COOKING WATER SOURCE **Borewell (83)** **Can water (96)** **Pond (13)** **River water (119)** **Tap water (Ref) (546)**	24(28.9%) 40(41.7%) 5(38.5%) 54(45.4%) 154(28.2%)	1.035(0.622-1.724) 1.818(1.163-2.842) 1.591(0.512-4.939) 2.115(1.409-3.174) 1	0.893 0.009• 0.422 0.000•
PRETREATMENT/PURIFICATION OF WATER **Boiling (379)** **Reverse Osmosis (Ref) (58)** **No Pre-treatment (420)**	114(30.1%) 21(36.2%) 142(33.8%)	0.758(0.425-1.352) 1 0.900(0.508-1.595)	0.348 0.718
TDS LEVEL **(continuous variable)**	----------	0.999(0.999-1.000)	0.024•
HARDNESS OF WATER **Hardness (>180 mg/L) (167)** **Hardness (≤180 mg/L) (Ref) (690)**	21(12.6%) 256(37.1%)	0.244(0.150-0.395) 1	0.000•
DRINKING WATER CaC03 LEVEL **(continuous variable)**	----------	0.963(0.958-0.968)	0.000•

Independent Variable	**Hypertension Present N (%)**	**Aor (95% Ci)**	**P Value**
AGE **(continuous variable)**	----------	1.071 (1.053-1.088)	0.000•
GENDER **Male (360)** **Female (Ref) (497)**	130(36.1%) 147(29.6%)	0.717(0.476-1.079) 1	0.111
TYPE OF FAMILY **Nuclear (625)** **Three generation (42)** **Joint (190) (Ref)**	211(33.8%) 18(42.9%) 48(25.3%)	1.424(0.890-2.276) 0.893(0.361-2.211) 1	0.140 0.807
DURATION OF STAY **(continuous variable)**	----------	0.999(0.988-1.010)	0.857
SOCIOECONOMIC STATUS			

Class I (PCI ≥8592) (74) **Class II (PCI 4296-8591) (182)** **Class III (PCI 2578-4295) (167)** **Class IV (PCI 1289- 2577) (354)** **Class V (PCI <1289) (Ref) (80)**	41(55.4%) 53(29.1%) 67(40.1%) 91(25.7%) 25(31.3%)	0.241(0.076-0.767) 0.286(0.131-0.624) 0.600(0.280-1.286) 0.422(0.207-0.861) 1	0.016• 0.002• 0.189 0.018•
EDUCATION OF HOF **Graduate (63)** **Intermediate/ diploma (48)** **High school (307)** **Middle school (131)** **Primary school (218)** **Illiterate (90) (Ref)**	18(28.6%) 37(77.1%) 53(17.3%) 36(27.5%) 102(46.8%) 31(34.4%)	0.809(0.312-2.103) 4.755(1.437-15.732) 0.535(0.280-1.022) 1.473(0.683-3.175) 2.432(1.274-4.646) 1	0.664 0.011• 0.058 0.323 0.007•
OCCUPATION OF HOF **Technician/Associate Professional (72)** **Clerk (46)** **Skilled worker (327)** **Semi-skilled worker (108)** **Unskilled worker (256)** **Unemployed (Ref) (48)**	45(62.5%) 15(32.6%) 90(27.5%) 32(29.6%) 82(32.0%) 13(27.1%)	8.925(2.503-31.825) 7.589(1.947-29.584) 2.807(1.015-7.760) 6.066(1.897-19.401) 2.209(0.785-6.222) 1	0.001• 0.004• 0.047• 0.002• 0.133
DRINKING WATER SOURCE **Borewell (109)** **Can water (176)** **Pond (13)** **River water (93)** **Tap water (Ref) (466)**	29(26.6%) 72(40.9%) 5(38.5%) 44(47.3%) 127(27.3%)	1.597(0.810-3.150) 1.799(0.749-4.321) 1.331(0.293-6.046) 6.103(1.729-21.533) 1	0.177 0.189 0.711 0.005•
COOKING WATER SOURCE **Borewell (83)** **Can water (96)** **Pond (13)** **River water (119)** **Tap water (Ref) (546)**	24(28.9%) 40(41.7%) 5(38.5%) 54(45.4%) 154(28.2%)	0.539(0.218-1.333) 1.108(0.421-2.917) 1.106(0.352-3.475) 1.124(0.323-4.538) 1	0.181 0.836 0.862 0.415
TDS LEVEL **(continuous variable)**	----------	1.000(0.999-1.000)	0.415
HARDNESS OF WATER **Hardness (>180 mg/L) (167)** **Hardness (≤180 mg/L) (Ref) (690)**	21(12.6%) 256(37.1%)	7.013(3.431-14.338) 1	0.000•





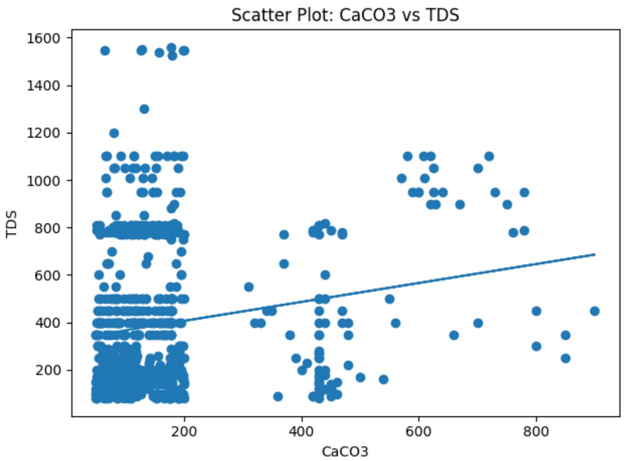


Figure 1,2,3: Scatter Diagram Showing Correlation Between Cac03 Level in Drinking Water With Systolic Blood Pressure (SBP), Diastolic Blood Pressure (DBP) and Total Dissolved Solids (TDS) Level. (N = 857)

S.No.	Variables	Pearson Correlation Coefficient (R)	P Value	Inference
1.	$CaCO_3$ vs SBP	r = −0.391	p < 0.001	moderate negative correlation
2.	$CaCO_3$ vs DBP	r = −0.523	p < 0.001	moderate to strong negative correlation
3.	$CaCO_3$ vs TDS	r = +0.174	p < 0.001	weak positive correlation

DISCUSSION

The present community-based cross-sectional study conducted in Theni district examined the relationship between drinking water hardness and blood pressure among 857 participants. The inverse relationship between calcium carbonate content and blood pressure observed in this study aligns with several epidemiological reports suggesting cardiovascular benefits of harder water due to higher calcium and magnesium content. Yang et al[15], in a Taiwanese case–control analysis of hypertension deaths, reported a significant protective effect of magnesium in drinking water; individuals in the highest exposure category had lower odds of hypertension-related mortality (adjusted OR for highest vs lowest quintile: 0.63; 95% CI: 0.47–0.84), while the apparent calcium effect diminished after adjustment for magnesium, indicating that magnesium may be the key protective component in "hard" water. Nerbrand et al[16] also observed a negative association between magnesium levels in drinking water and cardiovascular risk markers in Swedish populations supporting the biological plausibility that magnesium deficiency may contribute to vascular dysfunction and elevated blood pressure. The present findings particularly the significant negative correlations between $CaCO_3$ and both SBP and DBP are directionally consistent with this protective hypothesis, although our study did not directly quantify magnesium and calcium intake from diet separately, which may influence the magnitude and direction of association.

Similarly, Yousefi et al[17] demonstrated that hypertension prevalence was lower in regions supplied with higher hardness water and reported substantially reduced odds of hypertension in high-hardness areas (OR 0.26; 0.17–0.42), reinforcing the plausibility of a protective effect mediated through mineral-rich water. Rapant et al[18] also provided supportive evidence using vascular aging indicators, reporting higher arterial stiffness and higher arterial age among residents consuming soft water (calcium/magnesium deficiency) compared to those consuming harder water, with an "absolute" difference between arterial and chronological age of approximately 4–5 years across measurement phases. Naser et al[19], in their regional ecological investigation, reported that drinking water hardness demonstrated an inverse relationship with hypertension prevalence. These findings resonate with the mineral-vascular health hypothesis and support the view that chronic exposure to low-mineral water may adversely influence vascular tone, endothelial function, and long-term arterial health.

Evidence from paediatric and subclinical atherosclerosis studies also supports the protective role of hard water minerals. Poursafa et al[20] suggested that water hardness and its calcium and magnesium content may protect against early stages of atherosclerosis in children and adolescents, indicating that mineral exposure might have cardiovascular relevance even before overt hypertension develops. Morton et al[21] highlighted that long-term consumption of mineral-deficient (soft) water may increase cardiovascular risk, particularly in populations with low dietary mineral intake. In contrast, Vogiatzi et al[22] reported a positive association between extra hard water and carotid atherosclerotic burden, while also noting uncertainty regarding arterial stiffness. This contrasting observation suggests that the relationship between water hardness and cardiovascular outcomes may not be uniform across populations and may vary depending on mineral composition (relative calcium vs magnesium), accompanying contaminants, dietary sodium intake, and baseline metabolic risk profiles.

The present study's multivariable finding of increased odds of hypertension with hardness >180 mg/L (AOR 7.013) contrasts with the crude protective association (OR 0.244) and with several studies suggesting benefit. This possibility is due to that "hardness" in this setting may co-occur with other groundwater characteristics (e.g., salinity, sodium, or specific contaminants) that were not fully captured, which could shift the adjusted relationship. This likelihood is supported by Biswas et al[23], who reported using large-scale Indian NFHS-5 linked with groundwater maps that multiple physicochemical properties and contaminants (including electrical conductivity, sulphate, arsenic, nitrate, and magnesium) were important determinants of hypertension risk, underscoring that "water quality" is multifactorial and that hardness alone may not represent the net cardiovascular exposure.

Further, Moghimani et al[24] reported no discernible correlation between hard water consumption and cardiovascular disease development, including no significant association with calcium carbonate (p=0.651) or total hardness (p=0.660), concluding that heterogeneity across studies. Derda et al[25], in a systematic review with meta-analysis, suggested that higher drinking water hardness may have a lowering effect on cardiovascular mortality but emphasized high heterogeneity and confounding. These mixed findings mirror the complexity seen in the present study, where correlations suggested an inverse mineral–Blood Pressure relationship, yet the fully adjusted model indicated higher odds of hypertension with very hard water. In summary, the most important findings of the present study are the substantial burden of elevated blood pressure (pre-hypertension 37.5% and hypertension 32.3%), the significant inverse correlations between $CaCO_3$ and both SBP ($r = -0.391$) and DBP ($r = -0.523$), and the complex, model-dependent association between very hard water and hypertension.

CONCLUSION

These study findings highlight that drinking water quality, particularly mineral composition, may play a role in cardiovascular health, but its effect is multifactorial. In conclusion, while higher calcium carbonate levels in drinking water were negatively correlated with blood pressure parameters, the overall association between water hardness and hypertension requires cautious interpretation. Future research should prioritize prospective cohort designs to clarify temporality; direct measurement of calcium, magnesium, sodium, and salinity in household water; integration of dietary mineral intake and salt consumption; and geospatial linkage of groundwater contaminants to clinical outcomes. Mechanistic studies examining endothelial function, vascular stiffness, and renin–angiotensin–aldosterone pathways in relation to mineral composition may further explain why some populations benefit from harder water while others show neutral or adverse associations.

Acknowledgements:

We would like to acknowledge the participants of the study, Faculty, CRMIs, non-teaching staff of Department of Community Medicine and Nodal Officer, Research Scientists, Laboratory Technician, Data Entry Operator of MDRU, GTMCH, Theni for their valuable participations, suggestions and motivations. We also thank Department of Health Research (DHR) for their financial assistance to this study.

Funding: Department of Health Research (DHR)

Conflict of interest: None declared

REFERENCES

1. https://www.who.int. Geneva: World Health Organization; c2022 WHO Available from: https://www.who.int/neglected_diseases/mediacentre/WHA_34.25_Eng.pdf[Last accessed on 2025 Jun 15]
2. https://www.sustainabledevelopment.un.org. New York: United Nations; c2022 UN Available from: https://sustainabledevelopment.un.org/ [Last accessed on 2025 Jun 15]
3. www.who.int. Geneva: World Health Organization; c2022 WHO Available from: https://www.who.int/water_sanitation_health/dwq/chemicals/hardness.pdf [Last accessed on 2025 Jun 15]
4. McGowan W, Harrison JF. Water processing: residential, commercial, light-industrial. Lisle, IL. Water Quality Association. 2000.
5. Kario K, Okura A, Hoshide S, Mogi M. The WHO Global report 2023 on hypertension warning the emerging hypertension burden in globe and its treatment strategy. Hypertension Research. 2024 May; 47(5):1099-102.
6. Sengupta P. Potential health impacts of hard water. International journal of preventive medicine. 2013 Aug; 4(8):866.
7. Catling LA, Abubakar I, Lake IR, Swift L, Hunter PR. A systematic review of analytical observational studies investigating the association between cardiovascular disease and drinking water hardness. Journal of water and health. 2008 Dec 1; 6(4):433-42.
8. Razzaque S, Aidrus F, Kumar A, Kumar A, Ghauri I, Ullah S. Hypertension in people consuming hard water in Haji Samoa Goth Keti-Bundar Sindh. Annals of Abbasi Shaheed Hospital & Karachi Medical & Dental College. 2015 Jun 1; 20(1):17.
9. http://rchiips.org/nfhs/NFHS-5_FCTS/COMPENDIUM/Tamil_Nadu.pdf[Last accessed on 2022 Jun 15]
10. https://www.censusindia.gov.in/India: Census;c2022 Available from:https://www.censusindia.gov.in/2011census/dchb/3323_PART_B_DCHB_THENI.pdf. [Last accessed on 2025 Jun 15]
11. Gordon JS, Harman S, Weiss K, Pettegrew B. A Microscale Spectrophotometric Determination of Water Hardness. Journal of Chemical Education. 2001 Aug; 78(8):1089.
12. Vischer AS, Socrates T, Winterhalder C, Eckstein J, Mayr M, Burkard T. How should we measure blood pressure? Implications of the fourth blood pressure measurement in office blood pressure. The Journal of Clinical Hypertension. 2021 Jan; 23(1):35-43.
13. Jabeen R, Karthika P. Updated socioeconomic classification: revised modified BG Prasad and modified Kuppuswamy scales for January 2025. Int J Community Med Public Health. 2025 Apr 18; 12(5):2103-7.
14. Shrout T, Rudy DW, Piascik MT. Hypertension update, JNC8 and beyond. Current opinion in pharmacology. 2017 Apr 1; 33:41-6.
15. Yang CY, Chiu HF. Calcium and magnesium in drinking water and the risk of death from hypertension. American journal of hypertension. 1999 Sep 1; 12(9):894-9.
16. Nerbrand C, Agréus L, Lenner RA, Nyberg P, Svärdsudd K. The influence of calcium and magnesium in drinking water and diet on cardiovascular risk factors in individuals living in hard and soft water areas with differences in cardiovascular mortality. BMC public Health. 2003 Jun 18; 3(1):21.
17. Yousefi M, Saleh HN, Yaseri M, Jalilzadeh M, Mohammadi AA. Association of consumption of excess hard water, body mass index and waist circumference with risk of hypertension in individuals living in hard and soft water areas. Environmental geochemistry and health. 2019 Jun 15; 41(3):1213-21.
18. Rapant S, Cvečková V, Fajčíková K, Hajdúk I, Hiller E, Stehlíková B. Hard water, more elastic arteries: A Case Study from Krupina District, Slovakia. International journal of environmental research and public health. 2019 Jan; 16(9):1521.
19. Naser AM, Rahman M, Unicomb L, Doza S, Gazi MS, Alam GR, Karim MR, Uddin MN, Khan GK, Ahmed KM, Shamsudduha M. Drinking water salinity, urinary macro-mineral excretions, and blood pressure in the southwest coastal population of Bangladesh. Journal of the American Heart Association. 2019 May 7; 8(9):e012007.
20. Poursafa P, Kelishadi R, Amin MM, Hashemi M, Amin M. First report on the association of drinking water hardness and endothelial function in children and adolescents. Archives of Medical Science. 2014 Aug 29; 10(4):746-51.
21. Morton WE. Hypertension and drinking water constituents in Colorado. American journal of public health. 1971 Jul;61(7):1371-8.
22. Vogiatzi G, Lazaros G, Oikonomou E, Kostakis M, Kypritidou Z, Christoforatou E, Theofilis P, Argyraki A, Thomaidis N, Tousoulis D. Impact of drinking water hardness on carotid atherosclerosis and arterial stiffness: Insights from the "Corinthia" study. Hellenic Journal of Cardiology. 2023 Nov 1; 74:32-8.
23. Biswas S, Chattopadhyay A, Schilling K,Das A. Investigating the association between groundwater contaminants and hypertension

risk in India: a machine learning-based analysis. Journal of Exposure Science & Environmental Epidemiology. 2026 Jan; 36(1):125-42.

24. Moghimani M, Rahati S, Sobhani SR, Hashemi M, Afshari A. Evaluation of the Relationship Between Water Hardness and Incidence of Cardiovascular Diseases in Mashhad, Iran During 2018–2020: A Cross-Sectional Study. Health Science Reports. 2025 Mar; 8(3):e70376.
25. Bykowska-Derda A, Spychala M, Czlapka-Matyasik M, Sojka M, Bykowski J, Ptak M. The relationship between mortality from cardiovascular diseases and total drinking water hardness: systematic review with meta-analysis. Foods. 2023 Aug 29; 12(17):3255.

How to cite this article: Ram Prabhakar, SV Saranya, Geethanjali S, Mukesh Kumar, ASSOCIATION BETWEEN HARDNESS OF DRINKING WATER AND BLOOD PRESSURE – A COMMUNITY BASED CROSS SECTIONAL STUDY IN THENI, Asian J. Med. Res. Health Sci., 2026; 4 (1):-378-393.

Source of Support: Nil, Conflicts of Interest: None declared.