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Impact of anthropogenic activities on groundwater within Budgam district of J&K, India, with special emphasis on nitrate concentrations

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Abstract

This research aimed to assess the influence of anthropogenic activities on groundwater, specifically focusing on nitrate concentrations in the Budgam district and potential health risks to the local population. Thirty sampling sites underwent a comprehensive physicochemical analysis, including key anthropogenic indicators such as sulfate, chloride, phosphate, fluoride, and nitrate. The hydrogeochemical data from these sites indicated that concentrations of nearly all parameters adhered to the permissible limits established by the World Health Organization (WHO) and the Bureau of Indian Standards (BIS). Notably, chloride ranged from 25-90 mg/l, sulfate from 25-90 mg/l, phosphates from 0.01-0.3 mg/l, and fluoride from 0.01 mg/l to 0.3 mg/l. Nitrate concentrations fluctuated between 8 and 25 mg/l, with an average value of 15.32 mg/l, peaking at sites S1 (Soibugh) and S29 (Kralpora) and reaching the lowest at site S9 (Larikpora). The examination of nitrate concentrations across the summer and winter seasons revealed a moderate spatial seasonal variation in the study area's groundwater. Most sample sites exhibited higher nitrate concentrations during the summer, potentially linked to agricultural activities and the use of nitrogenous fertilizers. This study suggests that while the current impact of anthropogenic activities in the study area is relatively low, there has been an increase compared to previous assessments. The insights gained from this research can contribute to the development of an effective groundwater management strategy in the future.

Keywords: Groundwater, hydrogeochemical data, anthropogenic indicators, nitrates, nitrogenous fertilizers, WHO, BIS, spatial seasonal variation, Budgam

Introduction

Groundwater stands as one of the Earth's most crucial natural resources, and the indispensability of water, especially clean water, is paramount. Groundwater systems are essential to human welfare, whether they are delivering usable and abstractable water or performing a variety of in situ purposes, including maintaining moist surroundings and buffering the climate (Jac van der Gun, 2021) ^[8]. Anthropogenic activities, such as domestic and municipal solid waste, industrial waste, landfill leachate, careless disposal of human and animal waste, inadequate on-site sanitation facilities, septic tank systems, and the use of fertilizers and pesticides during irrigation, pose a serious threat to groundwater contamination. A variety of pollutants are frequently released into the environment as a result of the development trajectory, which is characterized by industry, urbanization, and modern agriculture. The quality and services offered by natural resources are seriously threatened by the improper disposal of industrial chemicals. In the contemporary era of human development, groundwater emerges as a precious water source for industrial and agricultural activities. However, in developing regions, groundwater serves as a critical resource for potable water supplies in both rural and urban areas. However, its long-term sustainability is threatened by the ongoing impacts of anthropogenic activities and industrial expansion during the past few decades (Niu *et al.*, 2014; Chen *et al.*, 2016; Gallardo and Marui, 2016; Li, 2016) ^[13, 5, 7, 10]. Groundwater contamination occurs when specific pollutants exceed the prescribed limits set for drinking water. The reasons behind groundwater contamination include natural impurities resulting from geological formations and human-induced chemicals. The issue of groundwater contamination in agricultural regions is a global concern due to its repercussions on the environment, drinking water, and, notably, human health (WHO, 2011). Challenges related to groundwater quality are particularly pronounced in densely populated, heavily industrialized areas with shallow groundwater tube

wells (Shivran *et al.*, 2006; V. Satish Kumar *et al.*, 2016) [19, 15]. Nitrate contamination represents a widespread issue in global groundwater systems (Ako *et al.*, 2014) [1]. Nitrogen (N) is a crucial element for sustaining agriculture (Shrestha and Ladha, 2002; Schröder *et al.*, 2004) [20, 16]. Nevertheless, the worldwide prevalence of nitrate contamination in groundwater is a significant concern (Kyllmar *et al.*, 2004; Liu *et al.*, 2005) [9, 11]. Nitrate, being water-soluble and negatively charged, readily leaches from the soil, ultimately depositing in groundwater (Wongsanit *et al.*, 2015) [23]. Almasri (2007) [2] identifies various sources contributing to nitrate contamination, including point sources such as industrial activities, septic tanks, and dairy and livestock waste, as well as non-point sources like the extensive use of nitrogen fertilizers and atmospheric deposition in agriculture. Multiple factors, often additive, contribute to groundwater nitrate contamination, with agriculture being a major source. While nitrogen fertilizers enhance crop yields, their excessive use can lead to water, air, and soil contamination. Agricultural overuse of nitrogen fertilizers, a common consequence, significantly degrades groundwater quality and pollutes drinking water sources, posing potential threats to human health (Wick *et al.*, 2012) [22]. Several studies highlight the correlation between nitrate

contamination and intensive agricultural practices, particularly the heavy use of nitrate fertilizers (Sham-Suddin *et al.*, 2016) [18]. Nitrates, highly soluble compounds, migrate from agricultural lands to groundwater, sustaining contamination even after a decrease in nitrate load. Consumption of water containing high NO_3 levels can pose severe health risks, especially in children (< 5 years). In the human body, nitrates convert to nitrites through specific enzymes, further transforming into carcinogenic nitrosamines. The main biological effect of nitrites involves the oxidation of hemoglobin to methemoglobin, which is incapable of supplying tissues with oxygen. Effects range from cyanosis and cardiac arrhythmia to circulatory failure and impacts on the central nervous system. Methemoglobinemia (blue baby syndrome) occurs when methemoglobin levels exceed 10%, leading to cyanosis and asphyxia, posing high risks to newborns (Mensinga *et al.*, 2013; Renseigne *et al.*, 2007; Smical *et al.*, 2014; WHO, 2011) [12, 14, 21, 24]. Threshold values for nitrates have been established, with the BIS and WHO setting the maximum allowable limit for nitrates at 45 mg/L and 45 mg/L, respectively.

Study Area

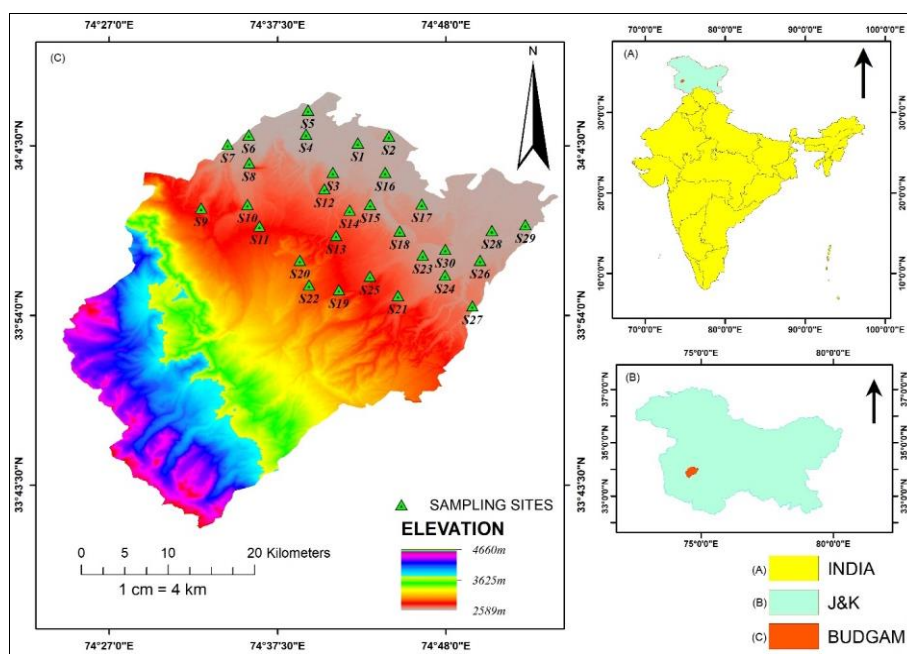


Fig 1: Depicting the Study Area and Sampling Sites of Budgam

Figure 1 delineates a detailed map of the Budgam district, including the locations of sampling sites. Budgam, positioned at the heart of the valley, is a centrally located district. It shares boundaries with District Baramulla in the northwest, District Srinagar in the northeast, and District Pulwama in the southeast. To the southwest, the Pir Panchal Range acts as a natural boundary, separating the district from Poonch District. Geographically, the district spans between latitudes $33^{\circ} 20'$ and $34^{\circ} 54'$ North and longitudes $73^{\circ} 55'$ and $75^{\circ} 35'$ East. Encompassing an area of 1361 sq. km, Budgam extends over both mountainous and plain terrains, characterized by varying heights and boasting an average altitude of 5281 feet (1610 meters) above sea level. A distinctive physiographic characteristic in this district is the presence of Karewas, a low elevated plateau-type

landform. The district encompasses both valley floors and rim lands. The climate is temperate, featuring heavy snowfall in the upper reaches during winter, and an average annual rainfall of 669.1 mm.

Methodology

Thirty representative sampling stations, corresponding to villages/blocks in the area, were selected for collecting groundwater samples during the summer season. High-density polyethylene (HDPE) bottles were employed to collect fresh groundwater samples. To eliminate contaminants and stabilize electrical conductivity, each sampling well was activated for a minimum of 2 minutes. To ensure sample integrity, each groundwater sample bottle was sealed tightly after collection to prevent leakage and

contamination during handling and transport. Meticulous labels were applied for identification and were placed in a 4°C freezer until chemical analysis. Throughout the entire process, from collection to analysis, meticulous procedures and necessary precautions were taken to prevent sample deterioration or contamination. The analysis of water samples followed the established analytical procedures as outlined in APHA (2005). High-quality analytical reagents and double-distilled water bottles were utilized in the preparation of solutions for this analysis. Water samples underwent spectrophotometric analysis to assess Nitrate, Chloride, Sulfate, and Phosphate concentrations.

Results and Discussion

Table 1 outlines the recorded physicochemical parameters and anthropogenic indicators (chloride, sulfate, phosphate, fluoride, and nitrate) for the groundwater samples in the study area, which were measured at 30 sites during the summer season. Emphasis was placed on nitrates due to their significance in indicating the influence of above-ground anthropogenic activities. The concentrations of these parameters observed in the groundwater act as indicators of the influence of above-ground anthropogenic activities in the study area. Importantly, the assessment of all parameters measured in the groundwater samples involved a comparison with the standards set by the World Health Organization (WHO, 2017) and the Bureau of Indian Standards (BIS, 2012). It is noteworthy that all measured values are within the specified limits. In the groundwater samples, pH values ranged between 6.9 and 7.9, with a mean of 7.3, which is considered slightly alkaline (Figure 2). Electric conductivity varied from 200 to 1140 ($\mu\text{S}/\text{cm}$), with the highest at S17 and the lowest at S11 (Figure 3). Turbidity ranged between 0.9 to 4.4 NTU, with the highest at S17 and the lowest at S11. Total alkalinity ranged between 100 to 540 mg/l, with the lowest at S15 and the highest at S4, with a mean of 260 mg/l. Within the study area, groundwater samples exhibited a marked variability in total hardness, ranging from 120 mg/L to 512 mg/L. The maximum concentration was at S3 (Gariend Khurd) and the minimum was at S6 (Wata Magam). This study reveals that the calcium ion dominates the cation chemistry concentration in the study area, ranging from 39 to 142 mg/L, with the highest at S3 (Gariend Khurd) and the lowest at S6 (Wata Magam). The magnesium content of groundwater ranged from 6.0 to 43.5 mg/L, with an average value of 21.9 mg/L. The maximum value was recorded at S1 (Soibugh) and the minimum at S6 (Wata Magam). Analysis of total dissolved solids (TDS) in groundwater samples revealed a significant variation, with concentrations ranging from 112 mg/L to 805 mg/L, averaging 433.6 mg/L with the highest TDS value at S26 (Bogam) and the lowest at S19 (Arigam). Variation in total alkalinity, total hardness, and total dissolved solids is illustrated in Figure 4. Phosphates in groundwater ranged from 0.01-0.3 mg/L, with an average value of 0.1 mg/L. The maximum value was recorded at S18 (Ichgam), and the minimum value was recorded at S7 (Badran) and S13 (Gojra). Human sewage, agricultural runoff from farmlands, effluents from animal feedlots, and the regular use of non-biodegradable detergent are among the anthropogenic sources of phosphate. In our investigation, the fluoride concentration in the groundwater samples ranged from 0.01 mg/L to 0.3 mg/L, averaging 0.07 mg/L. The minimum values were recorded at S10

(Beerwah) and S21 (Hanjura), while the maximum value was observed at S9 (Larikpora), S17 (Baginder Humhama), and S28 (Chattergam). Fluoride-bearing minerals in rocks and their interaction with water and agricultural activities are considered the main causes of fluoride in groundwater. Elevated fluoride levels can lead to fluorosis, impacting the skeleton, teeth, and other body parts (Saxena and Saxena, 2013) ^[17]. The variation in phosphate and fluoride concentrations is shown in Figure 5. Chloride concentration ranged from 25 to 90 mg/L, with an average value of 57.5 mg/L, highest at S17 (BaginderHuhmhama) and lowest at S14 (Mahwara). Evaporation and precipitation significantly affect water chloride concentration, which is more harmful to plants than sulfate ions and serves as a primary indicator of pollution. The assessment of chloride concentration in water samples provides information regarding the contamination of water samples by wastewater, soluble chloride salts, and other contaminants. Chloride ions might be introduced to groundwater from the widespread domestic sewage, agricultural activities and leaching. Sulfate values ranged from 20 to 85 mg/l, with an average of 45.3 mg/l, peaking at S10 (Beerwah) and lowest at S14 (Mahwara). While not acutely toxic, sulfate in groundwater can cause health issues like diarrhea and, in rare cases, impact blood oxygen transport. It can also corrode pipes and damage concrete. Sources of sulfate in groundwater include natural minerals as well as human activities such as agriculture and improper wastewater disposal, which contribute to leaching processes and introduce sulfate into the groundwater system through anthropogenic activities. Nitrate is a common component found in raw water and predominantly exists in the form of the NO_3^- molecule, representing its oxidized state. Drinking water is harmful in the presence of excess nitrate concentrations. Infants younger than six months old suffer from methemoglobinemia, often known as blue baby disease, due to increased nitrate concentrations in water. The nitrate concentration in the water ranged from 8 to 25 milligrams per liter (mg/L), with an average value of 15.32 mg/L. The sources of nitrate in groundwater include domestic and animal waste, decaying organic matter, and agricultural practices, particularly the application of nitrogen-rich fertilizers. These fertilizers infiltrate the soil profile, potentially leaching excess nitrate and contaminating groundwater resources. Significantly, all measured nitrate concentrations adhered to established drinking water safety guidelines. Values remained well below the maximum permissible limits set by both the Bureau of Indian Standards (45 mg/L) and the World Health Organization (50 mg/L). This confirms the suitability of the water for consumption based on nitrate levels. There is a moderate spatial variation in nitrate concentration in the Budgam district, with the highest concentration at S1 (Soibugh), S29 (Kralpora), and the lowest at S9 (Larikpora). The former site can be attributed to anthropogenic impact, as NO_3^- that enters the water systems originates from wastes or fertilizers applied to the land surface, while the latter site can be considered unpolluted, as indicated by the low nitrate concentration. Figure 6 illustrates the variation in chlorides, sulfates, and nitrates. Notably, seasonal fluctuations in nitrate concentrations were observed in the Budgam district, as shown in Figure 7. Generally, the lowest values occurred during the winter season, while the highest values were noted in the summer season. The graphical representation of nitrate contamination comparison between the summer and

winter seasons, using linear trend analysis (LTA), is presented in Figure 8. The linear trend analysis (LTA) showed a clear seasonal pattern in nitrate concentration, with significantly higher values observed during the summer months compared to winter, as indicated by the elevated position of the summer LTA line relative to the winter line. Several factors likely contribute to this seasonal disparity. Agricultural activity often intensifies during the summer in many regions, leading to increased application of nitrogen-based fertilizers (N-fertilizers). These fertilizers can become a significant source of nitrate contamination if not properly managed, as excess nitrogen can leach through the soil profile and into groundwater reserves. Furthermore, summer months often coincide with increased water use for irrigation, which can influence groundwater flow dynamics

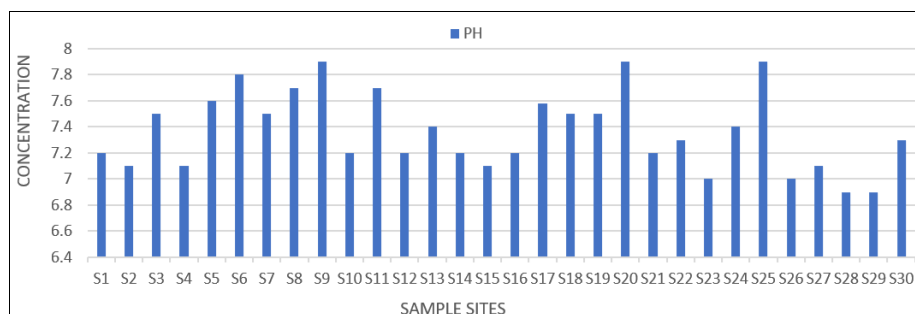
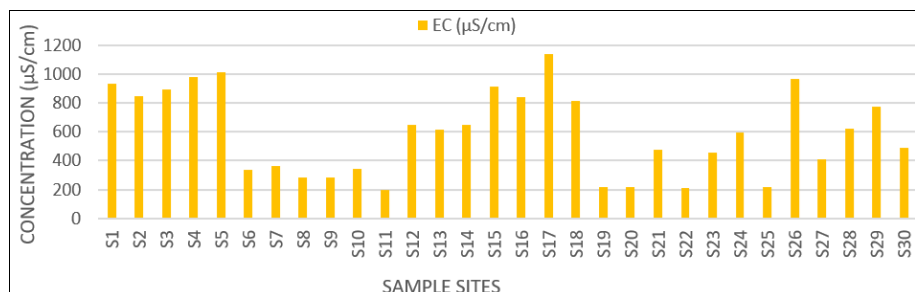
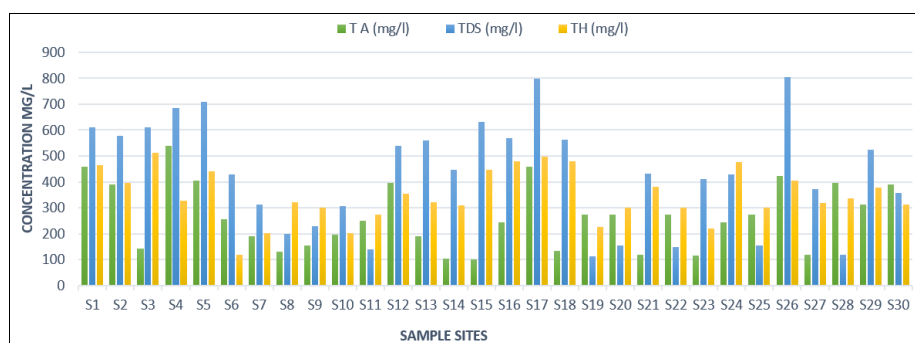
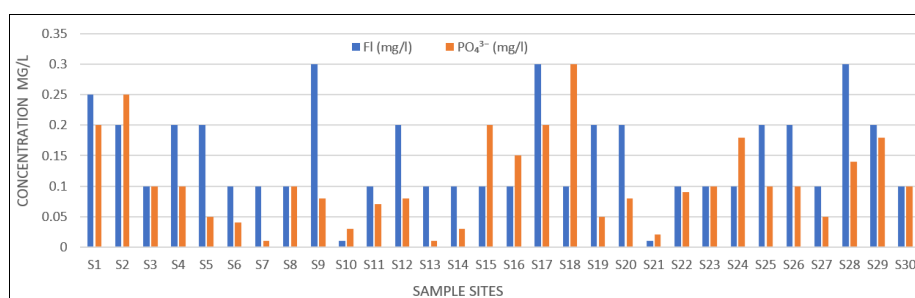
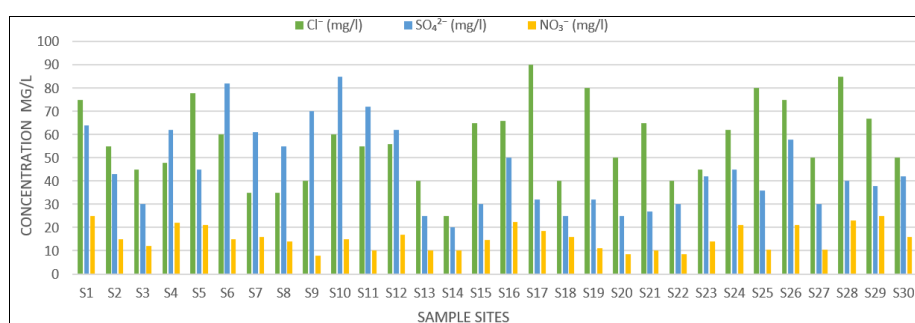
and potentially mobilize nitrate contamination already present within the subsurface. It's important to recognize that natural processes can also contribute to nitrate in groundwater. Within the soil zone, organic nitrogen (NH_4^+) can undergo a natural conversion process to nitrate (NO_3^-). This process, known as nitrification, can be influenced by various environmental factors, but it generally occurs under aerobic conditions. Additionally, human activities can influence nitrification rates, such as through land-use changes or soil disturbances (Freeze and Cherry, 1979) [6]. Table 2 shows the minimum, maximum, mean, and standard deviation of different parameters compared against the standard permissible limits established by reputable organizations such as the WHO 2017 (World Health Organization) and BIS 2012 (Bureau of Indian Standards).

Table 1: Physicochemical parameters of different well sampling sites in Budgam

S. No.	Sample Sites	PH	Turbidity (NTU)	EC ($\mu\text{S}/\text{cm}$)	TA (mg/l)	TDS (mg/l)	TH (mg/l)	Ca ²⁺ (mg/l)	Mg ²⁺ (mg/l)	Cl ⁻ (mg/l)	SO ₄ ²⁻ (mg/l)	PO ₄ ³⁻ (mg/l)	NO ₃ ⁻ (mg/l)	F ⁻ (mg/l)
S1	Soibugh	7.2	1.91	931	459	610	465	101	33	75	64	0.2	25	0.25
S2	Shareifabad	7.1	0.91	844	389	577	396	101	13	55	43	0.25	15	0.2
S3	Gariend Khurd	7.5	1.37	890	142	610	512	142	20	45	30	0.1	12	0.1
S4	Arath	7.1	2.24	979	540	685	328	112	9	48	62	0.1	22	0.2
S5	Check Kawoosa	7.6	1.1	1012	405	710	440	111	24	78	45	0.05	21	0.2
S6	Wata Magam	7.8	2.24	335	256	430	120	39	5	60	82	0.04	15	0.1
S7	Badran	7.5	1.25	364	191	312	203	61.5	16	35	61	0.01	16	0.1
S8	Rathsun	7.7	1.39	284	130	199	320	106	10	35	55	0.1	14	0.1
S9	Larikpora	7.9	2.9	282	155	230	300	69	14	40	70	0.08	8	0.3
S10	Beerwah	7.2	1.66	342	195	308	202	64	11	60	85	0.03	15	0.01
S11	Najan	7.7	1.6	200	250	140	275	75	14	55	72	0.07	10	0.1
S12	Chandpora	7.2	1.92	644	397	539	354	101	16	56	62	0.08	17	0.2
S13	Gojra	7.4	2.3	612	191	559	320	96	14	40	25	0.01	10	0.1
S14	Mahwara	7.2	1.9	645	105	447	310	92	18	25	20	0.03	10	0.1
S15	Zaberpora budgam	7.1	4.4	910	100	631	446	102	16	65	30	0.2	14.5	0.1
S16	Sebdan	7.2	2.8	840	243	570	480	128	29	66	50	0.15	22.5	0.1
S17	Baginder humhama	7.58	2.58	1140	460	798	496	96	19	90	32	0.2	18.5	0.3
S18	Ichgam	7.5	2.6	810	135	562	480	71.2	16	40	25	0.3	16	0.1
S19	Arigam	7.5	1.1	220	275	112	225	87.5	15	80	32	0.05	11	0.2
S20	Takia Farooq Shah	7.9	1.6	220	275	154	300	107	18	50	25	0.08	8.5	0.2
S21	Hanjura	7.2	1.13	475.6	118	430.9	380	60	14	65	27	0.02	10	0.01
S22	Khan Sahib	7.3	1.2	210	275	147	300	102	16	40	30	0.09	8.5	0.1
S23	Panzan	7	1.32	454	115	412	220	97	10	45	42	0.1	14	0.1
S24	Chadoora	7.4	2.9	592	243	428	477	102	18	62	45	0.18	21	0.1
S25	Dreygam	7.9	1.3	220	275	154	300	103	18	80	36	0.1	10.5	0.2
S26	Bogam	7	2.1	966	422	805	405	108	18	75	58	0.1	21	0.2
S27	Hayatpora	7.1	1.25	406	119	372	319	105	15	50	30	0.05	10.5	0.1
S28	Chattergam	6.9	1.6	620	396	120	337	72	25	85	40	0.14	23	0.3
S29	Kralpora	6.9	1.8	775	312	523	377	112	18	67	38	0.18	25	0.2
S30	Buchroo	7.3	2.87	487	389	356	312	92	22	50	42	0.1	16	0.1

Table 2: Statistical analysis of different parameters

Parameter	Minimum	Maximum	Mean	BIS (2012)	WHO (2017)	Standard Deviation
PH	6.9	7.9	7.3	6.5-8.5	6.5-8.5	0.3
Turbidity (NTU)	0.91	3.49	1.8	01-05	05	0.76
Electric Conductivity ($\mu\text{S}/\text{cm}$)	200	1140	593.8	750-3000	1400	295.03
T Alkalinity (mg/l)	100	540	260.96	200-600	----	126.11
TDS (mg/l)	112	805	433.6	500-2000	600-1000	212.13
T Hardness	120	512	347.8	200-600	200	100.7
Ca (mg/l)	39	142	93.9	75-200	100-300	22.06
Mg (mg/l)	05	33	16.8	30-150	50	5.7
Chloride (mg/l)	25	90	57.4	250-1000	250	16.89
Sulfate (mg/l)	20	85	45.37	200-400	250	18.28
Phosphate (mg/l)	0.01	0.29	0.1	0.5-5	----	0.07
Nitrate (mg/l)	08	25	15.3	45	50	5.3
Fluoride (mg/l)	0.01	0.3	0.15	01-1.5	1.5	0.07

**Fig 2:** Variation in pH**Fig 3:** Variation in EC**Fig 4:** Variation in TA, TDS and TH**Fig 5:** Variation in Fluorides and Phosphates**Fig 6:** Variation in Chlorides, Nitrates and Sulphates

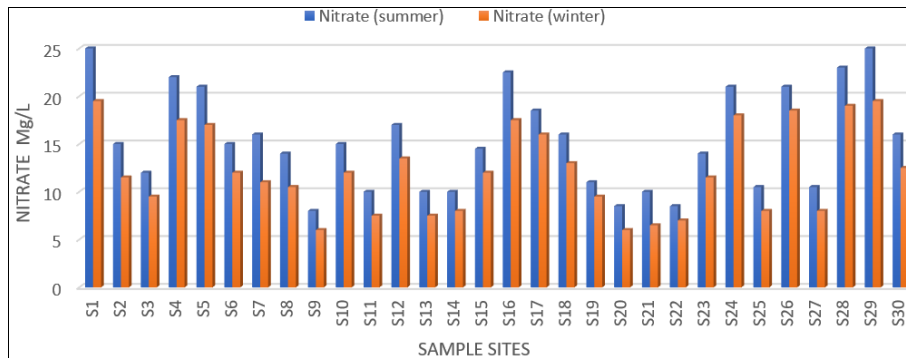


Fig 7: Seasonal variation in Nitrates

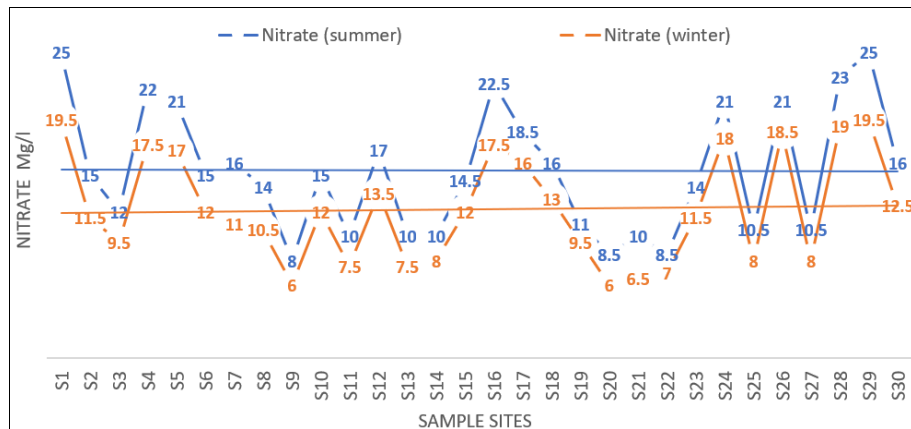


Fig 8: Trend Analysis in Nitrates

Conclusion

This study investigated the impact of anthropogenic activities on groundwater quality within the Budgam district of Jammu and Kashmir, India, with a specific focus on nitrate concentrations. Groundwater samples were collected from 30 representative sites during the summer season for analysis. The study examined various physicochemical parameters and anthropogenic indicators, including chloride, sulfate, phosphate, fluoride, and nitrate concentrations, to assess the influence of anthropogenic activities on groundwater quality in the area. All parameters, particularly the anthropogenic indicators derived from the collected groundwater samples, adhere to the recommended limits set by the World Health Organization (WHO 2017) and the Bureau of Indian Standards (BIS 2012). The findings indicate that key anthropogenic indicators such as chloride ranged from 25-90 mg/l, sulfate ranged from 25-90 mg/l, phosphates ranged from 0.01-0.3 mg/l, and fluoride ranged from 0.01 mg/l to 0.3 mg/l, all of which are within the permissible limits. Nitrate concentrations ranged from 8 to 25 mg/L, with an average of 15.32 mg/L, which is well below the safety guidelines. However, there was moderate spatial variation in nitrate concentration, with higher elevated levels observed in some locations as compared to others. This suggests the potential influence of anthropogenic activities like fertilizer use or sewage disposal in those locations. Seasonal variations were also observed, with higher nitrate levels recorded in the summer season compared to the winter season. This could be due to increased agricultural activities and lower dilution rates during the summer months. While the analysis of various parameters suggests overall satisfactory groundwater quality within the investigated area, observed variations in nitrate concentrations warrant a proactive management approach.

The implementation of ongoing monitoring programs, with a particular focus on areas exhibiting elevated nitrate levels, is crucial. This targeted approach will ensure the continued safety and sustainability of this vital water resource for both human consumption and environmental health.

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