ISSN: 2586-6036
JWMAP website: http://accesson.kr/jwmap
doi: http://dx.doi.org/10.13106/jwmap.2025.Vol8.no4.61

An Assessment of The Impact of Car Washing Stations Effluents on Water Quality in Gilgit Baltistan, Pakistan

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Received: August 11, 2025. Revised: August 24, 2025. Accepted: August 25, 2025.

Abstract

Purpose: This study investigates the environmental impact of vehicle washing station effluents on surface water quality in Gilgit City, Gilgit-Baltistan, Pakistan. With an increasing number of car wash stations washing 15–30 vehicles per day and consuming 150–350 liters per vehicle, large volumes of untreated wastewater are discharged directly into nearby streams. **Research design, data and methodology:** Wastewater samples were collected from three major stations—Nagaral, Dumiyal, and Danyore—and analyzed for physicochemical parameters (pH, turbidity, EC, TDS, salinity, K, PO_4, $CaCO_3$, and Na) using standard laboratory methods. Macroinvertebrates were sampled using hand nets, and a questionnaire survey was conducted with station staff to document washing practices and water use. **Results:** ANOVA results revealed statistically significant differences ($p<0.05$) in TDS, EC, salinity, K, and PO_4 between sites. The highest EC (2.2 mS/cm) and salinity (524 mg/L) were observed at Dumiyal, while Nagaral showed elevated $CaCO_3$ (213 ppm). Macroinvertebrate data indicated the presence of pollution-tolerant Diptera larvae at two sites. **Conclusions:** Most parameters exceeded WHO recommended limits, indicating ecological degradation and potential health risks. The findings highlight the urgent need for regulation, treatment, and reuse of vehicle wash wastewater. Future studies should assess heavy metal contamination to better understand long-term environmental and public health implications.

Keywords : Vehicle Wash Wastewater, Water Quality, Physicochemical Parameters, Macroinvertebrates

JEL Classification Code : K32, Q25, Q53, R11

1. Introduction

Over 96 percent of the 332.5 million water that makes up the world's entire water supply is saltwater. Over 68 percent of all freshwaters is frozen in glaciers and ice. In the ground, there is an additional 30% of fresh water. Most of the fresh surface water that people consume comes from rivers, however rivers only make up approximately 509 mi3 (2,120 km3), or roughly 1/10,000th of one percent of all water (USGS. 2019). Water resources are essential for maintaining a plentiful food supply and a productive

This work was supported by the research grant of the KODISA Scholarship Foundation in 2025.
This work is financially supported by Korea Ministry of Environment (MOE) as 「Graduate School specialized in Climate Change」.

environment for all living creatures. As human populations and economies grow, the demand for freshwater globally has been rising quickly. (Kılıç 2020). Additional risks encompass pathogen or chemical toxicant publicity through the food chain (e.g., due to irrigating plants with contaminated water and poisonous chemical bioaccumulation with the aid of aquatic creatures, including shellfish and fish) or all through exercise (e.g., swimming in polluted surface water) (Organ, U. E. S. C., 2009).) Environmental pollution, particularly the tainting of water supplies, is a problem that today's society must deal with. Global pollution is a result of growing urbanization, industry, modernization of agriculture, and a rise in traffic, necessitating accurate monitoring and information about the condition of water resources (Durmishi et al., 2012). One of the best examples of water pollutants is the direct throwing of waste in water, sewer water, and waste from homes directly into water bodies, which harm water quality and damage both aquatic life and people. Aquatic systems in watersheds experience a dramatic decline in surface water quality because of anthropogenic activity (Massoud et al., 2006). All these issues have been dealing with for a few years, but now there is a rising problem that badly damages the water at a fast rate, this is the wastewater which is released from vehicle stations without treatment. Vehicle washing, alternatively, is a water-intensive operation that still involves the usage of chemical compounds, resulting in risky wastewater effluents. (Zaneti et al. 2012). According to the worldwide burden of contamination document, 102 humans died in advance in 2017 due to consuming infected water, which accounts for 1.2 million deaths every year. (Hannah and Max 2022).

The largest concern with carwashes that collect carwash effluents in large underground tanks is that when a leak occurs, crude oil and oil hydrocarbons (TPH) will leak into the groundwater (Todd et al. 1999). Vehicle washing is a very water-intensive process that also uses chemicals. Wastewater from this process is highly contaminated with surfactants, oils, greases, waxes, and other toxins, making it hazardous to aquatic ecosystems. (Brasino and Dengler, 2007). Vehicle washing utilizes a ton of water, has a great deal of synthetic substances in it, and delivers possibly unsafe wastewater effluents (Zaneti et al., 2012). Oil hydrocarbon squanders (petroleum, diesel, and engine oil), supplements (phosphorous and nitrogen), surfactants, black-top, salts, natural materials, and heavy metals are undeniably found in VWW (Boluarte et al., 2016). Suspended solids can influence oceanic life by raising BOD, turbidity, lessening accessible living space, and obstructing fish and large-scale spineless creatures' gills, leading to respiratory issues (Harding, 2005). "Engineered cleansers utilized for washing vehicles are accounted for to be intensely harmful to fish and large-scale spineless creatures ‘ (Abel, 1974). Cleanser use likewise adds to the statement of phosphate in sea-going conditions, which can cause Eutrophication (Kundu et al., 2015). Particularly in Pakistan, even though Pakistan has been honored normally with sufficient surface and groundwater resources since industrialization, urbanization, and quick population growth have put stress on water resources. According to UNDP, with 135 million people, Pakistan has the sixth-highest population density in the world and the highest population growth rate in Asia at 2.5%. Despite being at a crossroads in terms of economic development, the country is still having trouble determining how to move towards sustainable development. Historically, health policies have promoted curative and treatment services over preventive (Adnan et al., 2000). By the year 2015, 43.2 million Pakistanis will lack access to basic sanitary facilities, and if this situation continues, 52.8 million people won't have access to clean drinking water (Gov. of Pakistan, 2001). According to a survey by the Asian Development Bank, Pakistan is one of the countries with the greatest water stress in the world and is unable to conserve 80% of the water needed for modern, private, and agricultural uses (Khair et al., 2012). Another issue that at present Pakistan currently has is that 150 million inhabitants, of which 85% lives in urban areas and 55% in rural ones. Only 65% of the population has access to safe drinking water (World Bank 2002). Water for human utilization should be liberated from destructive pollutants and substance fixations that could affect the existence of people and oceanic animals (Abdul Salam and Ajiboso, 2003). Over time, humans have contaminated water in various ways: modern pollution, agricultural runoff, and, surprisingly, homegrown sewage have all contaminated surface water (Ogedengbe and Elutade, 2003). Pakistan is a developing country in South Asia where, since its freedom in 1947, the utilization of engine vehicles has increased (Adanan et al., 2000). There are many explanations for the expanding number of vehicles. There is no legitimate policing check in balance in Pakistan, due to which Pakistan is full of NCP vehicles. ‘Car wash stations are taking the shape of industry and the amount of water consumed for washing cars may vary from 6.5m^3 to 0.60m^3’’ (Lau et al., 2013). The rising number of vehicles and stations isn't an issue, really. The wastewater set free from washing vehicles opened in water, which causes environmental as well as health issues because it contains many harmful pollutants such as detergents, wax, oil, grease, and so on. Around 80% of wastewater is released directly to the environment without any treatment in the world (WWAP).

Gilgit Baltistan (GB), Pakistan's border region with China, is located between 35 and 37 N and 72 and 75 E. With a minimum elevation of 1500 meters, it is a mountainous area. It has a population of about 1.5 million people and a land area of 72496 km. The main reason Gilgit is well known, especially during the summer months when many tourists travel there, is for its breathtaking natural beauty. Every person in GB owns a personal automobile and refuses to use public transportation. Roads are always congested with traffic, and during peak hours like those of schools, offices, and workplaces, individuals can experience delays of up to two hours on several main roads. Gilgit is the main hub of business, which has also increased the number of vehicles in Gilgit. Authorities affirmed that 10,000 NCP autos were recently enlisted in G-B, while many vehicles remain unregistered with the traditions and extract organization. The quantity of cars in the city has risen emphatically since non-exclusively paid (NCP) vehicles showed up in Gilgit (Tanveer Ahmad., 2017). “It has become a serious issue and is bound to get worse in the future,” said Qayyum Khan. “The imprisoned auto thief believes that Gilgit-Baltistan is the "World Bank" of stolen cars and that, with the GB government's assistance, he will be able to locate and seize at least 45,000 of the vehicles currently driving around the city's streets (Gilgit-Baltistan Times).

As the number of vehicles increases, the number of service stations is increasing to provide services for the public by cleaning their vehicles. In each main road and street minimum of 3 to 4 service stations are located that provide services. For cleaning purposes, they use different chemical agents to get more money. The emerging trend in vehicle washing stations is that people in stations use strong chemicals to make vehicles new and attract more customers. But this behavior destroyed vehicles as well as our environment. The wastewater of the station is discharged directly into the river. In many areas of GB, the stations are located on the side of the main river from where the water from vehicles is directly entered into the water, even in some stations, people have made a way for wastewater to enter directly into the water body. Amidst a lack of response from the local authority and the Gilgit Baltistan Environmental Protection Agency, the Gilgit River has been turned into an auto wash facility. (GBEPA) (Tanveer Ahmed 2017). This contaminated water affects aquatic life and destroys water quality, and affects human health because all GB use the river water for agricultural, cooking, and drinking purposes. This exercise increases during main events like Eid covers, and mainly in the summers when tourist activity increases. According to locals, the Gilgit River from the Basin to Sonikoat has been transformed into a free car wash, with dozens of automobiles serviced regularly (Tanveer Ahmed 2017). The scenario is similar in front of the Gilgit Press Club Owners and drivers of motors wash their automobiles by means of the riverbank, ignoring the attention board that warns of harsh penalties for violators. This board was established by using GBEPA remaining 12 months to warn the drivers to keep away from washing cars (Tanveer Ahmed., 2017). This all because of poor management and law enforcement.

Therefore, this study assesses the impact of untreated wastewater from selected vehicle washing stations in Gilgit city on surface water quality by analyzing key physicochemical parameters. Focused on three major sites Nagaral, Dumiyal, and Danyore—the research examines the types of detergents used and the direct discharge of wastewater into nearby streams without treatment. While the study provides valuable insights into the chemical and physical changes in water quality, it is limited to a few stations due to time constraints and does not include a detailed investigation of the effects on aquatic life.

2. Literature Review

The rapid growth in the number of automobiles worldwide has led to a parallel increase in automobile service stations, which in turn has resulted in significant wastewater generation. Vehicle washing is a water-intensive activity, often consuming between 150–350 Liters per vehicle (Hashim et al., 2016), and produces large volumes of contaminated wastewater containing detergents, oils, greases, waxes, suspended solids, and dissolved salts (Rasino & Dengler, 2007). Detergent pollution is particularly harmful to aquatic life; concentrations as low as 5 ppm can be lethal to fish eggs, while 15 ppm can cause fish mortality (Andanagouda & Suresh, 2017). These effluents, if untreated, enter natural water bodies, altering their physicochemical and biological characteristics and posing severe risks to aquatic ecosystems.

The high pollutant load in vehicle wash wastewater (VWW) has been linked to deterioration of water quality when discharged into surface water bodies. Studies have documented that parameters such as dissolved oxygen (DO), pH, biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), total suspended solids (TSS), turbidity, oil and grease, and sulphates are significantly elevated in VWW, which in turn impacts benthic macroinvertebrate communities (Rai et al., 2020). Macroinvertebrates are particularly useful bioindicators, with pollution-tolerant taxa dominating in habitats affected by vehicle wash effluents.

In many developing countries, including Pakistan, the increasing number of automobile service stations has become an emerging industrial-scale activity (Syed et al., 2018). This expansion is occurring in the context of widespread water scarcity, where both urban and rural populations often rely on contaminated surface and groundwater sources (Schwarzenbach et al., 2010). Anthropogenic activities, including industrial discharge, agricultural runoff, and domestic sewage, are primary contributors to water pollution, with waterborne diseases accounting for approximately 80% of illnesses and 33% of deaths in Pakistan (Daud et al., 2017). The untreated effluents from car washing stations exacerbate this situation, introducing phosphates, heavy metals, hydrocarbons, and surfactants into aquatic systems (Chukwu et al., 2008). Elevated phosphate levels, for instance, can stimulate eutrophication, leading to oxygen depletion and biodiversity loss.

Globally, approximately 10% of rivers are heavily polluted (Chukwu et al., 2008). The unregulated disposal of VWW into drainage systems and stormwater networks facilitates the transport of suspended solids, oils, and detergents into rivers and streams, resulting in long-term environmental contamination (Hashim et al., 2016). The quality of VWW can vary seasonally and geographically (Kashi et al., 2021), but it is consistently characterized by high turbidity and elevated COD levels, making treatment essential before discharge.

Research has also emphasized the importance of wastewater reuse and sustainable water management in mitigating pollution and addressing water scarcity. Decentralized water reuse systems have been described as environmentally friendly solutions that align more closely with natural processes (Partzsch, 2009). However, in Pakistan, untreated wastewater is often released directly into the environment, with minimal enforcement of environmental regulations (Edokpayi et al., 2017). The lack of proper infrastructure and monitoring allows pollutants from car wash effluents—such as petroleum hydrocarbons, phosphates, and detergents—to persist in aquatic systems, where they affect water chemistry, harm aquatic organisms, and pose risks to human health.

Overall, the literature underscores the urgent need for regulatory oversight, affordable wastewater treatment technologies, and public awareness campaigns to mitigate the ecological and public health risks posed by untreated vehicle wash wastewater. The absence of such measures in regions like Gilgit-Baltistan threatens to accelerate ecological degradation and exacerbate water scarcity challenges in the coming decades.

3. Research Methods and Materials

3.1. Study Area

Gilgit is the most urbanized region in Gilgit-Baltistan, Pakistan, with a population of approximately 216,760 and a geographical area of 72,469 km² (35.55°N, 75.9°E). Rapid urbanization and increasing population have led to a significant rise in the number of vehicles and associated automobile washing facilities.

3.2. Sampling Sites

Wastewater samples were collected from three key areas in Gilgit city: Danyore, Dumiyal, and Nagaral Road. Three samples of untreated vehicle wash wastewater were obtained from each station before discharge into the nearby stream. Additionally, three stream water samples were collected from the discharge points at each site to assess the direct impact.

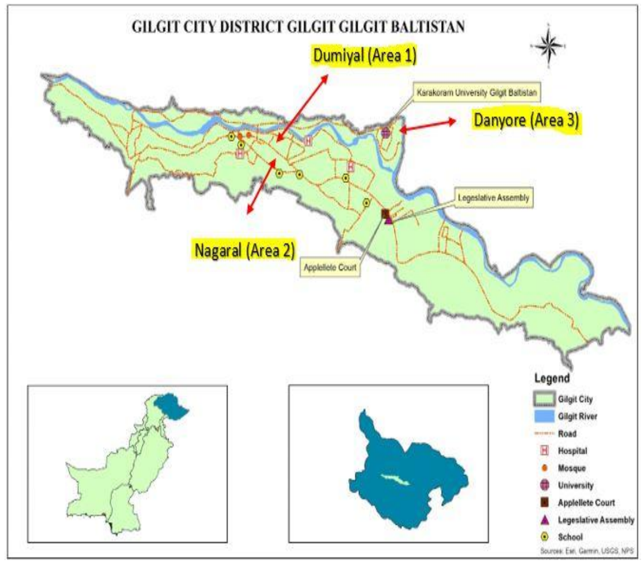

Figure 1: Map of the Study Area: Gilgit city, District Gilgit, Province Gilgit-Baltistan

3.4. Sample Collection

Sampling was conducted once during the pre-monsoon season (May). At each of the three locations, four samples were collected: three from wastewater effluents and one from the water used for washing (bore or tap water). Macroinvertebrates were also collected from the wastewater using hand nets to assess biological indicators of water quality. Stations 1 and 2 utilized bore water, while Station 3 used tap water. Vehicle washing frequency varied: Station 1 washed 25–30 vehicles/day, Station 2 handled 8–10, and Station 3 serviced 10–12 vehicles daily. Additional data on water usage and practices were collected through interviews and open-ended questionnaires with station owners.

3.5. Materials and Equipment

The materials and tools used for sampling and analysis included:

- Hand nets
- Sterilized bottles
- Gloves
- Notebooks and permanent markers

- Alcohol (for preservation)
- Sample dishes

3.6. Data Collection

Both primary and secondary data were utilized. Primary data were collected through sampling, interviews, and questionnaires, while secondary data were sourced from scientific literature, books, and online resources.

3.7. Physicochemical Analysis

All samples were analysed at the Water Quality Testing Laboratory, Karakoram International University.

- **pH:** Measured using a calibrated digital pH meter (Model 1020, ADWA).
- **Turbidity:** Assessed using a turbidimeter (TB1, VELF Scientifica), results expressed in NTU.
- **Electrical Conductivity (EC):** Measured with a digital conductivity meter (AD3000, ADWA), reported in µS/cm.
- **Total Dissolved Solids (TDS):** Measured using the same conductivity meter, expressed in mg/L.
- **Salinity:** Determined from EC data and calibration standards.
- **Phosphate (PO_4):** Analysed spectrophotometrically using the molybdenum blue method with readings at 890 nm.
- **Calcium Hardness ($CaCO_3$):** Assessed using a Mini kit with CAL-test tablets and measured with a Tinto meter.
- **Potassium (K) and Sodium (Na):** Measured using flame photometry after standard solution preparation using KCl and NaCl stock solutions

3.8. Statistical Analysis

Data were compiled using Microsoft Excel and analyzed using SPSS software. One-way ANOVA was used to determine significant differences in water quality parameters among stations. Pearson correlation analysis evaluated relationships between parameters, and Least Significant Difference (LSD) tests were used for post-hoc comparisons.

4. Results and Discussion

4.1. Variation of water physical, chemicals and biological properties among three different stations.

The analysis of physico-chemical parameters in untreated vehicle wash wastewater (VWW) collected from three locations—Nagaral, Dumiyal, and Danyore—revealed substantial variations in water quality across the sites (Table 1). The pH values at all three stations remained within the World Health Organization's (WHO) permissible range (6.0–9.0), with Danyore showing the highest mean pH of 8.5, followed by Nagaral at 8.1 and Dumiyal at 7.8. However, Total Dissolved Solids (TDS) were notably elevated at Danyore (6.5 ppt) and Nagaral (6.0 ppt), well above the acceptable range of 250–850 mg/L. Electrical Conductivity (EC) was particularly high at Dumiyal, recording a mean of 2.2 mS/cm, which also exceeded the WHO threshold. Turbidity values were alarmingly high across all sites, especially at Danyore (117 NTU), significantly surpassing the recommended limit of <10 NTU.

Table 1: Mean value of water parameters

Sites	PH	TDS (ppt)	EC (µS/cm)	Turbidity (NTU)	Salinity (mg/l)	CACO3 (ppm)	NA (mg/l)	K (mg/l)	PO4 (mg/l)
Nagaral	8.1±0.8	6.0±1.2	1.2±1.2	80±1.2	311±1.2	2.1±1.2	21±1.2	31±1.2	24±1.2.
Dumyial	7.8±.18	1.1±1.4	2.2±3.0	66±1.1	524±1.1	2.2±1.1	29±1.7	14±8.6	1.0±.7
Danyore	8.5±.27	6.5±7.4	1.3±1.4	117±101	353±45	2.1±1.0	30±1.8	10±6.4	.35±.
Waste water standard	6 to 9	250 to 850 mg/l/ppm	456.4- 982.7 µS/cm	< 10 NTU	1050mg/l	200 to 400 mg/l	136.3 to 1213.3mg/l	0.15 to 7.20mg/l	1.5 mg/l

Note: $<0.05^{*}$ $p<0.01^{**}$ $p<0.0001^{***}$ (shows significant) ''ns'' non-significant

Table 2: ANOVA-F values of different parameters of water

Ph	TDS (ppt)	EC (mS)	Turbidity (NTU)	Salinity (mg/l)	CACO3 ppm	NA (mg/l)	K (mg/l)	PO4 mg/l)
1.7^{ns}	38.2***	37.4***	.734	10.6*	.010^{ns}	.425^{ns}	12.5**	5.5*

Note: <0.05* p<0.01** p<0.0001*** (shows significant) ''ns'' non-significant

Table 3: LSD among study sites

Sites	Sites	pH	TDS (ppt)	EC (mS)	Turbidity (NTU)	Salinity (mg/l)	CACO3 (mg/l)	NA (mg/l)	K (mg/l)	PO4 (mg/l)
Nagaral	Dumyial	0.2	-537***	-1075***	13.8	-212***	-8.5	-8.2	16***	1.3*
Nagaral	Danyore	-0.4	-56	-106	-37	-42	-1.7	-8.5	21***	2.O**
Dumyial	Danyore	0.7	480***	969***	-51	170***	6.7	-0.2	4.2	0.6

Table 4: Correlation between water parameters among various sites

	PH	TDS (ppt)	EC (μS)	Turbidity (NTU)	Salinity (mg/l)	CAC03 Ppm	NA Mg/l	K Mg/l	PO4 Mg/l
PH	1								
TDS	-0.2	1							
EC	-0.3	0.99***	1						
Turbidity	-0.3	0.4	0.5	1					
Salinity	-0.1	0.9***	0.9***	0.1	1				
CACO3	0.2	0.3	0.3	0.6	0.5	1			
NA	0.3	0.4	0.4	0.6	0.7	0.9	1		
K	-0.04	-0.1	-0.1	-0.1	-0.09	0.4	0.2	1	
P04	0.04	-1.0	-0.9	0.04	-0.5	0.2	0.1	0.7	1

Note: <0.05* p<0.01** p<0.0001*** (shows significant) ns'' non-significant

Table 5: Answers of Respondents

Location	Station 1	Station 2	Station 3
No vehicles washed per day	25 to 30	8 to 10	10 to 12
Type of vehicles	All kinds	All kinds	All kinds
Type of water used	Boring water	Boring water	Tap water

Water required	Above 350 liters	180 liters	220 liters
Type of resource use	Detergents	Shampoo and detergents	Vim/ shampoo/detergents
Times of source on single vehicles	One time	3 to 4 times	6 times
Wastewater destination	Direct into river	Direct into river	Direct into river
Any treatment before discharge	No	No	No
Reuse	No	No	No
EPA visit	Don't know about EPA	Never	What is EPA

Salinity levels varied considerably, with Dumiyal recording the highest value (524 mg/L), followed by Danyore and Nagaral. Calcium carbonate ($CaCO_3$) concentrations were relatively consistent across stations, with minor fluctuations. Sodium (Na) concentrations were highest at Danyore (30 mg/L), while Potassium (K) peaked at Nagaral (31 mg/L). Phosphate (PO_4) levels were extremely high at Nagaral (24 mg/L), far above the WHO's standard of 1.5 mg/L, whereas Dumiyal and Danyore showed significantly lower concentrations.

Statistical analysis using one-way ANOVA indicated that TDS, EC, salinity, potassium, and phosphate concentrations varied significantly among the three stations Table 2. The differences in TDS and EC were highly significant ($p<0.0001$), while salinity showed significance at $p<0.05$, potassium at $p<0.01$, and phosphate at $p<0.05$. No significant differences were observed in pH, turbidity, $CaCO_3$, or sodium levels. Post-hoc analysis using the Least Significant Difference (LSD) test in Table 3 confirmed that TDS and EC varied significantly between Nagaral and Dumiyal, and between Dumiyal and Danyore. Salinity was also significantly different between Dumiyal and the other two sites. Potassium levels differed significantly between Nagaral and both Dumiyal and Danyore, while phosphate showed significant variation between Nagaral and the other two stations.

Correlation analysis using Pearson's method in Table 4 revealed strong positive relationships between TDS and EC ($r = 0.99$) and between salinity and EC ($r = 0.9$), both statistically significant at $p<0.0001$. In contrast, pH exhibited a negative correlation with TDS, EC, and salinity. Turbidity was positively correlated with $CaCO_3$ and sodium, indicating that higher suspended solids were associated with increased hardness and ionic concentration. Phosphate showed a strong negative correlation with TDS ($r = -1.0$) and EC ($r = -0.9$), but a positive correlation with potassium ($r = 0.7$), suggesting site-specific variability in nutrient and ion accumulation.

Overall, the results demonstrate that vehicle wash wastewater has significantly altered the water chemistry at all sampling locations, with several parameters exceeding WHO guidelines. These changes are likely to have ecological consequences, as further explored in the discussion.

4.1: pH

The pH values of water samples collected from the three stations ranged from 7.87 at Chinar Bagh to 8.57 at Danyore, with Nagaral recording an intermediate value of 8.13 Figure 2. All measurements were within the WHO recommended range of 6.5–8.8, indicating suitability for irrigation. The highest pH observed at Danyore suggests slightly more alkaline conditions, while Chinar Bagh showed the lowest but still alkaline value. Variations in pH are likely influenced by interactions between water, soil, and bedrock, as well as the presence of carbonates, bicarbonates, and hydroxides, which dissolve into the water and increase alkalinity. These findings align with previous studies, such as Rai et al. (2020), which reported pH ranges between 7.7 and 8.8 for water impacted by vehicle wash effluents, and Hashim and Hashim (2016), who found ranges from 7.8 to 8.3 in wastewater from vehicle stations. Similarly, Tekere et al. (2018) documented pH levels up to 8.6 in professional carwash effluents, supporting the conclusion that vehicle wash discharges generally result in slightly to moderately alkaline water conditions.

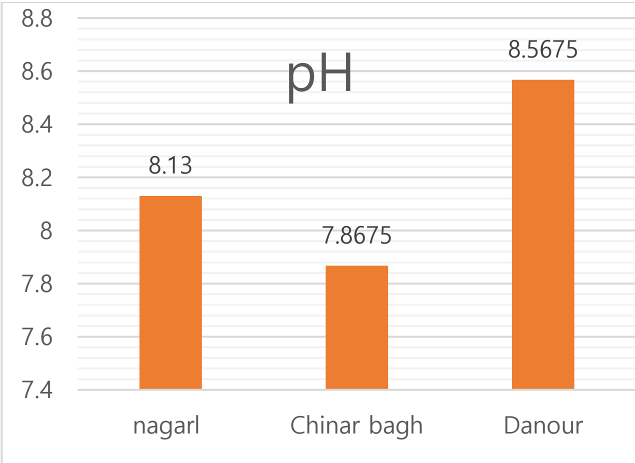

Figure 2: Mean value of pH

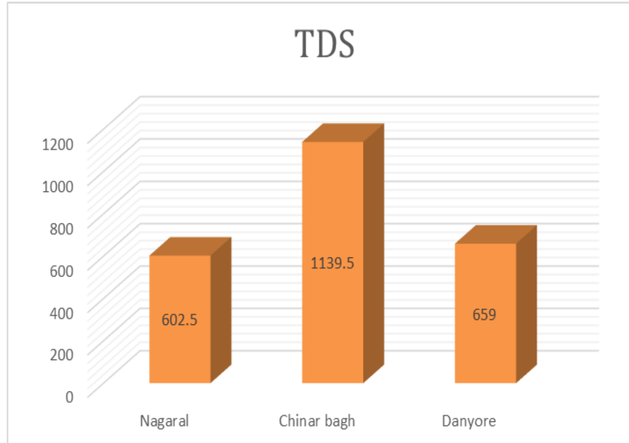

Figure 3: Mean value of TDS

4.2: Total Dissolved Solids

The Total Dissolved Solids (TDS) values recorded at the three stations were all above the WHO recommended limit of 500 mg/L. Chinar Bagh exhibited the highest TDS concentration at 1139.5 mg/L, followed by Danyore at 659 mg/L and Nagaral at 602.5 mg/L Figure 3. Elevated TDS levels indicate a high presence of dissolved inorganic salts such as chlorides, calcium, magnesium, potassium, sodium, bicarbonates, and sulphates, as well as dissolved organic matter. These elevated concentrations can reduce the solubility of gases in water, affecting aquatic ecosystems, and may be toxic to fish, amphibians, insects, and macroinvertebrates. The WHO standards indicate that water with such high TDS values is unsuitable for drinking and irrigation purposes. Previous studies (Peng et al., 2019; Sabata and Nayar, 1995) have shown that prolonged exposure to high TDS levels can result in negative impacts on both aquatic life and human health, not necessarily through waterborne diseases but due to excessive salt intake. The elevated TDS in these samples reflects the influence of untreated vehicle wash wastewater, which is often enriched with a mix of dissolved salts and organic pollutants.

4.3: Electric Conductivity

The Electrical Conductivity (EC) values recorded at all three stations exceeded the WHO recommended limit of 500 µS/cm for drinking water and 1000 µS/cm for irrigation purposes. Chinar Bagh exhibited the highest EC at approximately 2460 µS/cm, followed by Danyore at around 1460 µS/cm, and Nagaral at approximately 1380 µS/cm Figure 4. Elevated EC levels indicate a high concentration of dissolved salts and inorganic chemicals, which enhance the water's ability to conduct electrical current. Such high values are likely influenced by the presence of bicarbonate and calcium ions derived from local geological formations, as well as potential inputs from inorganic fertilizers and sewage contamination. Even tap water samples from these locations exceeded the permissible limits, rendering the water unsuitable for both irrigation and drinking. The results are consistent with findings by Kunz et al. (2021), who reported EC values between 1184 µS/cm and 1966 µS/cm in effluent samples with elevated potassium levels. The strong correlation between EC and salinity suggests that the high conductivity observed in these samples reflects substantial ionic loading from untreated vehicle wash wastewater.

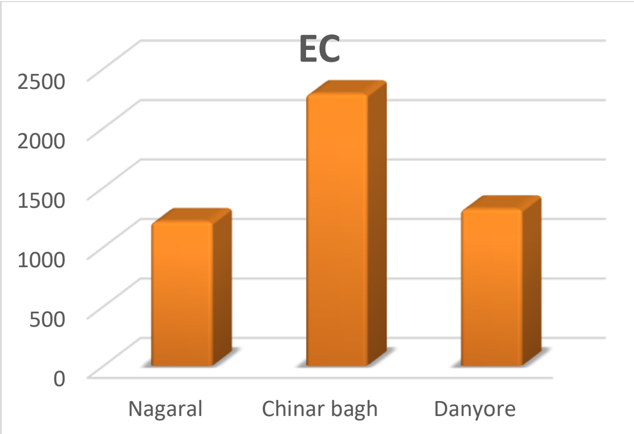

Figure 4: Mean value of EC

4.4: Turbidity

The turbidity values Figure 5 measured at the three sampling stations were all substantially higher than the WHO recommended limit of <5 NTU for drinking water, indicating poor water clarity and high levels of suspended matter. Station 1 recorded the lowest turbidity at 21.5 NTU, while Station 2 measured 29.75 NTU, and Station 3 exhibited the highest value at 30 NTU. These elevated levels suggest the presence of significant amounts of clay, silt, organic detritus, algae, and other microscopic particles, likely originating from untreated vehicle wash wastewater. Such high turbidity can reduce light penetration, disrupt aquatic ecosystems, and complicate water treatment by increasing filtration and flocculation costs. It also increases the risk of microbial contamination, as suspended particles can harbor pathogens. Similar findings were reported by Sarmadi et al. (2020), who observed turbidity values between 39.9 and 173 NTU in car wash effluents. Although WHO permits up to 500 NTU for irrigation purposes, the recorded turbidity levels in this study still reflect substantial particulate loading, making the wastewater unsuitable for direct discharge into natural water bodies without prior treatment.

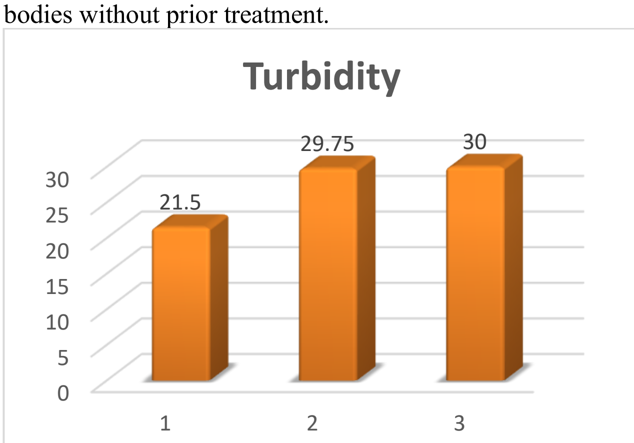

Figure 5: Mean value of turbidity

4.5: Salinity

The salinity levels recorded across the three sampling stations ranged from 311.5 ppm at Nagaral to 524 ppm at Chinar Bagh, with Danyore measuring 355.5 ppm Figure 6. All values were within the permissible limit of 1000 ppm set by USGS (2018) and below the SA Health recommended range of 600–900 mg/L for concern. Despite being within acceptable thresholds, the highest salinity at Chinar Bagh indicates a relatively greater concentration of dissolved salts, which may be influenced by wastewater discharge from vehicle washing activities. Elevated salinity, even at sub-threshold levels, can affect aquatic ecosystems by reducing organism performance, altering metabolic rates, and impacting survival and growth (Velasco et al., 2019). Human activities such as vehicle washing, agriculture, and other urban runoff likely contribute to the observed salt concentrations. While these values do not yet pose immediate risks for irrigation or aquatic life, continuous accumulation over time could lead to salinity intrusion, with implications for both ecological health and human well-being, as reported in similar studies from Bangladesh (Shammi et al., 2019; Razu et al., 2014). This highlights the importance of monitoring salinity trends in receiving water bodies to prevent long-term degradation.

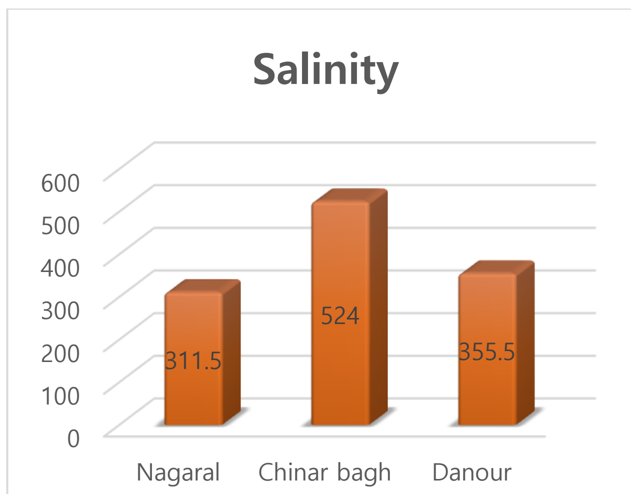

Figure 6: mean value of salinity

4.6: $CaCO_3$

The concentrations of calcium carbonate ($CaCO_3$) recorded at all three stations were substantially higher than the acceptable limit of 60 ppm, classifying the water as very hard according to Sengupta (2013). Dumiyal exhibited the highest value at 220 ppm, followed by Danyore at 213.25 ppm and Nagaral at 211.5 ppm Figure 7. Such elevated hardness levels are likely influenced by natural sources such as sedimentary rocks and geological deposits, as well as possible inputs from anthropogenic activities, including effluent discharge from vehicle washing stations. High water hardness can intensify the toxicity of surfactants, especially when combined with elevated temperatures (Zhimiao et al., 2017), thereby increasing ecological risk. The consistently high $CaCO_3$ values across stations suggest significant mineral content in the water, making it unsuitable for sensitive aquatic species and potentially problematic for domestic and industrial uses without prior treatment. These results are consistent with the findings of Kunz et al. (2021), who reported elevated hardness in effluents containing high potassium levels.

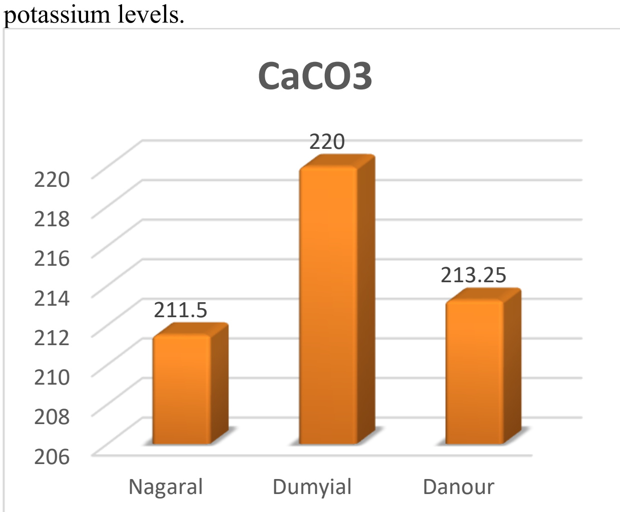

Figure 7: Mean value of CaCO3

4.7: Sodium (Na) (mg/l)

The sodium (Na) concentrations measured in the wastewater samples ranged from 21.5 mg/L at Nagaral to 30 mg/L at both Dumiyal and Danyore Figure 8. All values were below the WHO permissible limit of 50 mg/L for drinking water, indicating that sodium levels were within acceptable thresholds for human consumption. However, the higher values observed at Dumiyal and Danyore suggest a greater ionic load, likely influenced by detergents, cleaning agents, and other chemical additives used in vehicle washing. While these concentrations are not immediately hazardous, prolonged exposure to elevated sodium levels in drinking water can contribute to health risks such as hypertension, cardiovascular disease, and pregnancy-related complications, as noted by Shammi et al. (2019) and Alderman et al. (1995). The results are consistent with Kunz et al. (2021), who reported sodium concentrations in effluents ranging between 16 mg/L and 43 mg/L. The presence of sodium at these levels, combined with other contaminants in untreated vehicle wash wastewater, underscores the need for proper treatment before discharge to prevent cumulative environmental and health impacts.

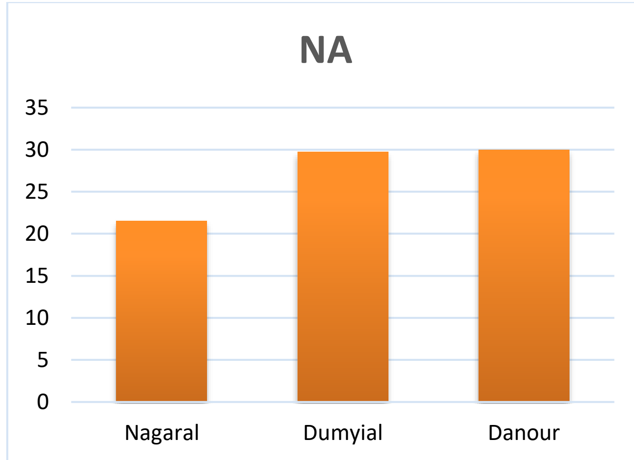

Figure 8: Mean value of NA

4.8: Potassium (K)

The potassium (K) concentrations recorded at the three sampling stations varied notably, with the highest value observed at Nagaral (31.5 mg/L), followed by Dumiyal (14.75 mg/L) and Danyore (10.5 mg/L) Figure 9. Although potassium is an essential nutrient for human health, elevated concentrations may pose risks to individuals with kidney disease, hypertension, heart conditions, or other related disorders (WHO, 1999). The relatively high potassium level at Nagaral suggests a greater contribution from detergents, cleaning agents, and other chemical inputs associated with vehicle washing activities. These findings are comparable to those of Rabinovich et al. (2017), who reported potassium concentrations ranging from 5 to 20 mg/L in wastewater from dairy and swine operations. Excess potassium in wastewater can also impact soil structure, particularly in soils with low potassium-adsorbing capacity (Arienzo et al., 2009). Kareem et al. (2021) reported average potassium values between 6 and 11 mg/L in their water quality studies, indicating that the levels found at Nagaral are substantially higher. While potassium intake from drinking water is unlikely to harm healthy individuals due to rapid excretion, the presence of elevated levels in untreated effluents underscores the need for proper wastewater management to mitigate environmental impacts.

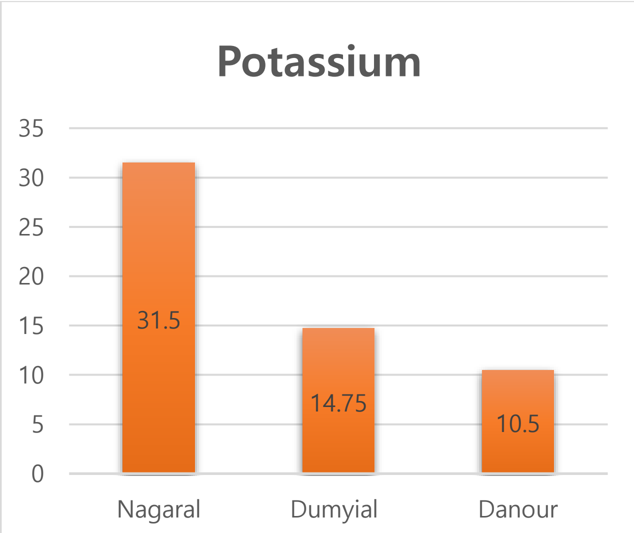

Figure 9: Mean value of K

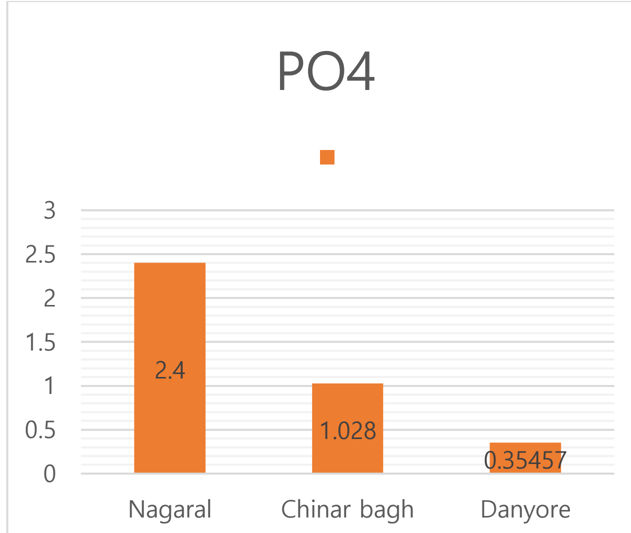

Figure 10: mean value of PO_4

4.9: Phosphates (PO_4)

The phosphate (PO_4) concentrations recorded at the three stations varied considerably, with Nagaral showing the highest level at 2.4 mg/L, followed by Chinar Bagh at 1.028 mg/L, and Danyore at 0.3546 mg/L Figure 10. Except for Danyore, all values exceeded the WHO recommended limit of 0.37 mg/L for surface water quality. Elevated phosphate levels are often associated with the use of detergents, cleaning agents, and other chemical inputs in vehicle washing operations. High PO_4 concentrations can stimulate excessive growth of aquatic plants and algae, leading to eutrophication and subsequent depletion of dissolved oxygen, which can negatively impact aquatic biodiversity (US EPA). The observed values align with findings by Sarmadi et al. (1989), who reported phosphate levels between 0.5 mg/L and 10 mg/L in wastewater sources, and with Mahmood et al. (2015), who linked high phosphate content to wastewater from household and industrial cleaning activities. Even modest anthropogenic increases in phosphorus availability can disrupt species competition and degrade water quality (Kroiss et al., 2011; Litke, 1999). These results indicate that untreated vehicle wash effluent is a significant contributor to nutrient enrichment in the receiving water bodies at the studied locations.

Table 6: Macro invertebrates from different stations

ST NO	Station 1	Station 2	Station 3
Macroinvertebrates	Dipteral larva, Baby earth warm	dipteral larva, adult fly	Coptera larva

The analysis of macroinvertebrates collected from the three sampling stations Table 6 revealed distinct differences in species composition, reflecting variations in water quality. At Stations 1 and 2, Diptera larvae (maggots or grubs), baby earthworms, and adult flies were identified. The presence of Diptera larvae is indicative of extremely polluted water, as these organisms are highly tolerant to degraded environmental conditions. In contrast, Station 3 was characterized by the presence of Coptera larvae, which are typically associated with water bodies exhibiting low dissolved oxygen levels (<3 mg/L), elevated electrical conductivity (>900 µS/cm), high turbidity (>180 FAU), and contamination with oil (>11 mg/L) and heavy metals such as iron, copper, and lead (>0.4 mg/L). All collected macroinvertebrate specimens were preserved in alcohol immediately after sampling and later examined under a microscope for identification. The observed species distribution supports the physico-chemical findings, indicating that the effluent from vehicle washing stations has led to significant ecological degradation, with macroinvertebrate assemblages dominated by pollution-tolerant taxa.

The survey of vehicle washing station owners Table 5 revealed that Station 1 washed 25–30 vehicles daily using over 350 liters of boring water per vehicle, Station 2 washed

8–10 vehicles with 180 liters of boring water, and Station 3 washed 10–12 vehicles with 220 liters of tap water. Cleaning agents varied, with Station 1 using detergents, Station 2 using shampoo and detergents, and Station 3 using Vim, shampoo, and detergents, applied once, three to four times, and six times per vehicle, respectively. In all cases, wastewater was discharged directly into the river without treatment or reuse, and none of the respondents were aware of the Environmental Protection Agency (EPA) or National Environmental Quality Standards (NEQS), indicating poor environmental awareness and absence of regulatory compliance.

The results of this study demonstrate that effluents from vehicle washing stations in Gilgit City significantly degrade surface water quality. Across all three sites—Nagaral, Dumiyal, and Danyore—several physicochemical parameters exceeded WHO permissible limits, with particularly high values for TDS, EC, turbidity, salinity, $CaCO_3$, potassium, and phosphate. These findings are consistent with previous studies (Rai et al., 2020; Hashim & Hashim, 2016) showing that vehicle wash wastewater (VWW) contains high levels of dissolved salts, detergents, oils, and other contaminants that adversely impact aquatic ecosystems.

High TDS and EC values observed, especially at Dumiyal and Danyore, indicate substantial ionic loading, likely from detergents, bore water minerals, and chemical additives. Elevated salinity at Dumiyal (524 mg/L) remains within the permissible limit but may, over time, impair aquatic organism performance and reproduction (Velasco et al., 2019). The presence of high $CaCO_3$ levels at all stations classifies the water as "very hard" (Sengupta, 2013), which can intensify the toxicity of surfactants and reduce water suitability for sensitive species.

Nutrient enrichment was evident from elevated phosphate concentrations at Nagaral (2.4 mg/L), well above the WHO threshold of 0.37 mg/L, potentially driving eutrophication and oxygen depletion (US EPA). Similarly, high potassium at Nagaral (31.5 mg/L) and elevated sodium at Dumiyal and Danyore (30 mg/L) contribute to ionic imbalance, affecting both plant and human health. Excess turbidity across all stations (>20 NTU) suggests heavy particulate loading from soil, oil residues, and organic matter, which can reduce light penetration, raise surface water temperatures, and lower dissolved oxygen levels.

Biological analysis further corroborated the chemical findings. The dominance of pollution-tolerant Diptera larvae at Nagaral and Dumiyal and the presence of Coptera larvae at Danyore indicate severely degraded aquatic habitats with low dissolved oxygen, high turbidity, and contamination from heavy metals and hydrocarbons.

The questionnaire survey revealed low environmental awareness among station owners, absence of wastewater treatment, and direct discharge into rivers. This lack of compliance with environmental regulations (EPA, NEQS) indicates that poor governance and public unawareness are key drivers of ongoing water degradation.

Overall, the findings suggest that untreated VWW is a significant point source of pollution in Gilgit, altering water chemistry, accelerating ecological degradation, and posing risks to both aquatic life and human health.

5. Conclusions

This study provides the first comprehensive assessment of the impact of vehicle washing station effluents on water quality in Gilgit-Baltistan. The results clearly indicate that untreated wastewater discharged directly into rivers significantly exceeds WHO standards for multiple water quality parameters, including TDS, EC, turbidity, potassium, and phosphate. The observed alterations in water chemistry, coupled with the dominance of pollution-tolerant macroinvertebrates, confirm severe ecological degradation in affected stretches of the Gilgit River.

The findings highlight an urgent need for intervention. Without effective wastewater management, the increasing number of vehicles and washing stations will intensify water quality deterioration, threatening aquatic biodiversity, agricultural productivity, and public health. Preventive measures such as enforcing EPA regulations, implementing affordable treatment technologies, reusing treated wastewater, and raising public awareness are essential to mitigating these impacts.

In conclusion, the discharge of untreated VWW is a growing environmental challenge in Gilgit-Baltistan. Immediate policy enforcement, infrastructure improvements, and community participation are critical to safeguarding water resources for both current and future generations.

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