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# Ionic characteristics of river Ganga, Yamuna and their canals: Ultimate level of ions in the drinking water supply

**J.S.Jangwan, N.Semwal***

**Deptt. of Chemistry, SRT Campus Badshahithaul, Tehri Garhwal, Uttarakhand, (INDIA)**

**Tel : 09725324435**

**E-mail : nrip_semwal@yahoo.co.in**

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## ABSTRACT

The chemistry of fresh water is dictated mainly by ions. Composition of ions in Himalayan Rivers is predominantly governed by chemical weathering process. Calcium and magnesium were the major ions, accounting for more than 85% of the total cation concentration of 1.408844331meq./l in River Ganga and 1.063554785 meq./l in River Yamuna. Among rest 15% sodium was the most abundant ion followed by trace quantities of potassium and ammonium ions. Total cation levels were increased to 2.115125212 meq./l and 3.085396688 meq./l in Gang Canal and Western Yamuna Canal respectively, having same pattern of ions. The levels of calcium and magnesium ions in drinking water supply of these canals were also in the range of 78 - 84% of the total concentration of 3.0 meq./l approx. Bicarbonate and sulphate were the major ions accounting for 86% of total anion concentration of 1.499494169 meq./l in River Ganga and 1.084299371 meq./l in River Yamuna. The levels of bicarbonate and sulphate were raised to 92-94% of total anion concentration of 2.164310984 meq /l in Gang Canal and 2.99235742 meq./l in Western Yamuna Canal. Chloride is the next most abundant ion followed by trace quantities of nitrates. Sulphur springs located in the high altitude region are the prominent source of bicarbonate, sodium and chloride ions respectively to both these rivers. Levels of bicarbonate and sulphate present in drinking water supply were at 75-83% of total anion concentration (3.0 meq./l approx.). The ionic levels found in rivers supporting high diversity of aquatic life was slightly lower compared to drinking water supply for human consumption.


## KEYWORDS

Himalayan;
Cation;
Anion;
Sulphur spring;
Chemical weathering.

## INTRODUCTION

Water is an eternal source of minerals to the human beings. Most population of himalayan region use surface water from River Ganga, Yamuna and their tributaries for their daily requirements, including drinking need. Likewise the Gang Canal and Yamuna Canal caters the need of most part of Delhi, Haryana and Uttar Pradesh. These water bodies are vulnerable to contamination due to surface run-off, open defecation along the course and other anthropogenic activities. In view of this the study of physical, chemical and biological composition of these rivers is an important prerequisite. The study of chemical composition of rivers in himalayan region is important for determining erosion rate and also to learn about sources of elements to these rivers. In addition, information on river chemistry is essential to assess water quality for domestic, agricultural and industrial use. Fresh water chemistry is mainly dictated by its ionic composition and their respective concentration levels. Rivers integrate the major ion from the sources such as; rain/precipitation, chemical weathering in drainage basins, anthropogenic inputs, springs and ground waters in the vicinity. Studies have indicated that snowpack melt water contributes directly to stream water[1]. Among the natural sources, chemical weathering of the drainage basin is the dominant component, a process which consumes atmospheric $CO_2$ and hence global climate is influenced by chemical weathering process, silicate weathering in particular[2]. River basins, particularly of large size rivers, such as Ganga and Yamuna are multi-lithological, comprising of silicates/carbonates and lesser amounts of evaporites. Chemical weathering of river basins supplies major ions to solution from all these lithologies[3]. In the Himalaya, high Total Dissolved Solids (TDS) levels are observed in River Yamuna system as compared to River Bhagirathi, particularly in its lower reaches and in the rivers from the plains. As per drinking water quality standards, maximum desirable limit of TDS is 500mg/l, beyond this limit, palatability decreases and may cause gastro- intestinal irritation[4]. Every time the TDS value of all the samples were found well below the prescribed limit. However, sulphur springs located in vicinity of upstream reaches of River Ganga and Yamuna have high TDS values with major abundance of chlorides and sulphates, indicative of major ion supply from weathering of evaporites and alkaline/saline soils. Studies carried out during early 1980s on River Bhagirathi showed bi-carbonate, sulphate and chloride constitute the bulk anions and calcium, magnesium and sodium the bulk cations[5]. The desirable concentration of some important ions in drinking water is as; Ca- 75 mg/l, Mg-30 mg/l, $SO_4$-150 mg/l, Cl- 250 mg/l and $NO_3$-45 mg/l. The concentration level of these ions found in the drinking water supply as well as raw water sources of River Ganga and Yamuna are mostly well below the above stipulated limit. River Bhagirathi and its tributaries predominantly drain over greywacke, granites, gneisses, schist and calc-silicates rocks[6]. The head waters of River Yamuna drain a variety of lithologies, ranging from crystalline in the Higher Himalaya consisting of granites and granodiorites to sedimentaries in the Lesser Himalaya, comprising of quartz-arenite, slate, limestone, dolomite, shale and siltstone[7]. As a result various ions are weathered in the water quality of River Ganga and Yamuna. Ions are important in creating the electrical energy within our body. Calcium, potassium, sodium and chloride ions are some key ions that participate in the body's electrical events[8]. Ionic chlorine is the most abundant negative ion in the human body. Imbalance of any of these ions or certain trace ions in the body can lead to a general body disturbance and loss of ability to maintain somewhat stable internal conditions. Majority of these ions are consumed by human body through drinking water sources, hence the ionic characterization of drinking water sources is very important from our point of view. Another important observation is development of canal network, which results in alteration of ionic levels in water quality as the flow and substratum composition gets change. A study entitled 'impact on ionic characteristics due to trans basin transfer' i.e. the river is diverted into a canal, has reported for reduction in concentration of sodium, magnesium, chloride and sulphate but not calcium and bicarbonate[9]. Present study deals with ionic characterization of River Yamuna and Ganga with respect to their sources and change in the levels of these ions after diversion into Western Yamuna Canal and Gang Canal respectively, and ultimately their levels in drinking water supply. Present study also briefly discusses the role of various ions on human physiology and existence of water quality sensitive benthic macro- invertebrates in River Ganga, Yamuna and their respective canals.

## MATERIALS AND METHODS

The data was collected twice in a year i.e. winter and summer (premonsoon) season from 2006 to 2008. The arithmetic mean was calculated after the normal distribution of data for final observation. Statistical analysis viz. coefficient of variation, outlier value and standard error was also calculated for validating the mean value. Ionic balance was calculated by converting the mg/l value to meq/l (TABLES 1 and 2). Samples were also analyzed for pH, Total Dissolved Solids (TDS),

**TABLE 1: Average cation distribution in raw and treated drinking water supply**

| S. no. | Drinking water source | Sodium (meq/l) | Potassium (meq/l) | Calcium (meq/l) | Magnesium (meq/l) | Ammonium (meq/l) |
|---|---|---|---|---|---|---|
| 1. | River Ganga | 0.198757764 | 0.057692308 | 0.79375 | 0.411522634 | 0.00325 |
| 2. | River Yamuna | 0.108695652 | 0.025641026 | 0.6 | 0.329218107 | bdl |
| 3. | Gang Canal | 0.310559006 | 0.06959707 | 1.135714286 | 0.564373898 | 0.043389 |
| 4. | Western Yamuna Canal | 0.625 | 0.113553114 | 1.859090909 | 0.732510288 | 0.04104321 |
| 5. | Drinking water supply of Western Yamuna Canal | 0.439855072 | 0.051282 | 1.786111 | 0.817901 | 0.001667 |
| 6. | Drinking water supply of Gang Canal | 0.52173913 | 0.116667 | 1.581579 | 0.778988 | 0.043389 |
| 7. | Drinking water characterstics (IS: 10500:1991)[3]Desirable limits (meq/l) | No guideline | No guideline | 3.75 | 2.469135802 | - |
| 8. | Permissible limits (meq/l)[3] | No guideline | No guideline | 10.0 | 8.230452675 | - |

**TABLE 2 : Average anion distribution in raw and treated drinking water supply**

| S. no. | Drinking water source | Sulphates (meq/l) | Chlorides (meq/l) | Bicarbonates (meq/l) | Nitrate (meq/l) |
|---|---|---|---|---|---|
| 1. | River Ganga | 0.395833333 | 0.204225352 | 0.8975 | 0.003870968 |
| 2. | River Yamuna | 0.302083333 | 0.14084507 | 0.6400101 | 0.001370968 |
| 3. | Gang Canal | 0.568452381 | 0.16498994 | 1.4200024 | 0.015216129 |
| 4. | Western Yamuna Canal | 0.7875 | 0.298591549 | 1.992727273 | 0.012274194 |
| 5. | Drinking water supply of Western Yamuna Canal | 0.783333333 | 0.458216 | 1.67875 | 0.011290323 |
| 6. | Drinking water supply of Gang Canal | 0.590428241 | 0.71518 | 1.646667 | 0.010142137 |
| 7. | Drinking water characterstics (IS:10500:1991)[3]Desirable limits(meq/l) | 4.166666667 | 7.042253521 | 4.0 | 0.725806452 |
| 8. | Permissible limits (meq/l)[3] | 8.33 | 28.16901408 | 12.0 | 1.612903226 |

**TABLE 3: Cations of glacial melt and sulphur spring water**

| S.no. | Cation sources | Sodium(meq/l) | Potassium(meq/l) | Calcium(meq/l) | Magnesium (meq/l) | Ammonium(meq/l) |
|---|---|---|---|---|---|---|
| 1. | Sulphur spring | 7.043478261 | 0.616666667 | 1.35 | 1.024691358 | Bdl |
| 2. | Glacial melt | 0.195652174 | 0.037179487 | 0.45 | 0.588477366 | Bdl |

**TABLE 4: Anions of glacial melt and sulphur spring water**

| S. no. | Anion sources | Sulphates(meq/l) | Chlorides(meq/l) | Bicarbonates(meq/l) | Nitrate(meq/l) |
|---|---|---|---|---|---|
| 1. | Sulphur spring | 1.229166667 | 2.591549296 | 12.01 | 0.008387097 |
| 2. | Glacial melt | 0.052083333 | 0.225352113 | 0.405 | 0.001225806 |

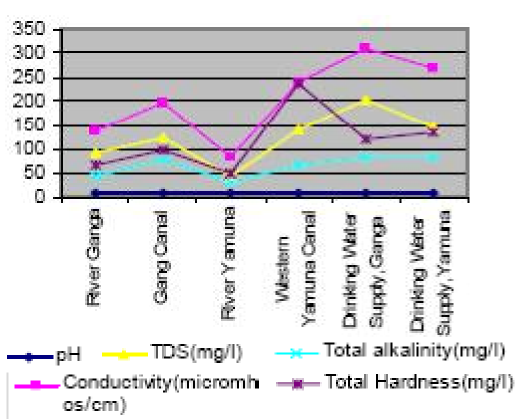


**Figure 1: Average physico-chemical water quality of raw and drinking water supply of River Ganga and Yamuna**

Conductivity, Total Alkalinity and Total Hardness to support the findings of ionic distribution (Figures 1 and 2). Since the pH of water quality was less than 8.2 at all the locations, concentration of bi-carbonate ions was calculated from Total Alkalinity values. Percent difference ratio of total anions and total cations in most of the samples were less than 10%. These values are almost confirming the reliability of the analytical results[10]. Average biological water quality was calculated from data of biomonitoring of upstream stretches of River Ganga and River Yamuna, however for Gang Canal and Western Yamuna Canal artificial substratum[11] was used for biomonitoring at drinking water intake points in Delhi.

## Brief description of the study areas

### River Bhagirathi (Ganga)

River Bhagirathi (Ganga) is an important river in Garhwal Himalayas, originating from Gaumukh in Gangotri glacier at an altitude of 3892 msl. Starting from

Gangotri, river passes through thickly populated towns like Uttarkashi, Tehri and Devprayag. At Devprayag, it meets River Alaknanda and from the confluence downstream, it is called the River Ganga. About 225 km stretch of River Bhagirathi from Gangotri to Devprayag was chosen for the present study.

### Gang Canal

Gang Canal originates from River Ganga at downstream of Haridwar, is basically used for raw water supply of drinking and irrigation purposes. The canal passes through agricultural and urbanized areas of Roorkee, Muzzafarnagar, Meerut, and Ghaziabad. Samples for the study were taken at Bhagirathi Water Treatment Plant in Gokulpuri, Delhi.

### Western Yamuna Canal

Western Yamuna Canal originates from River Yamuna at Tajewala headworks about 200 km upstream of Delhi, is used for raw water supply of drinking and irrigation purposes. As the Western Yamuna Canal passes through agriculture and urbanized areas of Haryana State, it receives domestic and industrial effluents alongwith agricultural run-off and ground water from these areas. Western Yamuna Canal through its tail tributary, supplies drinking water, to the National Capital, Delhi, at Haiderpur Water Works. Samples for the study were taken at Haiderpur Water Works.

### River Yamuna

River Yamuna originates from the Yamunotri glacier near Bandar Punch peak ($38^0 59^0$ N, $78^0 27^0$E) at an elevation of about 6320 MSL in the Mussoorie range of Lower Himalayas located in Uttarakhand. The length of Yamuna from origin to its confluence with the Ganga at Allahabad is 1376 km. After meandering for 200km, Yamuna enters the plains at Tajewala. It is tapped at Tajewala barrage through Western Yamuna Canal and Eastern Yamuna Canal which are mainly used for irrigation but also for drinking water for part of Delhi and some towns of Haryana and UttarPradesh, states of India.

## RESULTS AND DISCUSSION

The findings of the study indicated that the ionic composition in drinking water supply supports healthy aquatic environment in raw water sources as inferred from bio-monitoring observations. The average ($Ca+Mg/HCO_3$) equivalent ratio of 1.2 indicates a relatively high contribution of Ca and Mg to the total cations. The ratio of (Ca+Mg)/(Na+K) was also found towards higher side indicating chemical weathering of granite and carbonate rocks as the primary source of major ions to these rivers[10]. A brief taxonomic composition of benthic macro-invertebrates in the water quality indicates that the ionic concentration in upstream stretches are suitable for existence of most sensitive arthropods, indicating average clean water quality in River Yamuna, and presence of molluscs along with annelids indicates heavy pollution in biological water quality of River Ganga at certain specific locations i.e. reservoirs, which can be attributed to habitat destruction.

### Cation levels in rivers, canals and drinking water supply

The dominance sequence of cations in river, canals and drinking water supply of River Ganga and River Yamuna was identical, as; $Ca>Mg>Na>K>NH_4$. Calcium was the major ion accounting for 54 to 60% of total cation concentration in raw water sources of drinking water supply. In River Ganga calc-silicates rocks in Himalayas predominantly contribute the calcium ion to water quality[12]. In River Yamuna it is contributed through limestones and dolomite rocks. Calcium is an important structural component of all genetic material (nucleic acids) and contributes to 1.2% of human body. Magnesium was the next dominant ion ranged between 24-30% of total cations in raw waters. Although required in trace amount i.e. 0.1% found in bone, magnesium plays an important assisting role in many metabolic functions of body. About 52-56% of calcium and 26% of magnesium ions were maintained in drinking water sources, which were on higher side compared to raw water sources of rivers and their canals. Important sources of sodium cation in the rivers are halite, saline/alkaline soil, anthropogenic inputs and silicates. Sodium constitutes 0.2% of body and determines the conduction of electrical messages through cell membranes. The level of sodium ions in raw water sources of River Ganga and Yamuna varied between 10- 20%. Similarily, potassium ions contributes 0.4% (positive ions) in cells;

necessary for conduction of nerve impulses and muscle contraction. Potassium ions contributed only 2-4% to the total cations in raw and drinking water source of River Ganga and Yamuna. The levels of sodium and potassium ions in drinking water quality of River Ganga and Yamuna were found between 14-17% and 2.0-4.0% respectively of the total cations. Nitrogen contribute 4% to body requirement, is an important structural component of all genetic material (nucleic acids). Nitrogen enters in water through rain, fertilizers, sewage etc. In raw and treated water, ammonium ions were observed only in trace quantities i.e. less then 2% of total cations. There was significant increase in the concentration of ammonium ions in river waters of Ganga and Yamuna after diversion into their respective canals. Sodium and potassium levels were higher in River Ganga compared to River Yamuna, whereas the levels of calcium and magnesium were almost similar, indicating contribution from chemical weathering only[6]. On the contrary, the clean water quality of River Yamuna changed to moderate pollution in raw water source of Western Yamuna Canal and heavy pollution in River Ganga improved to clean water quality in Gang Canal.

## Anion levels in rivers, canals and drinking water quality

Dominance sequence of anions in both the rivers, canals and drinking water supply was found to be similar, as; $HCO_3$>$SO_4$>Cl>$NO_3$. Among major anions, bicarbonate contribution was maximum ranging from 56 to 67% in raw and treated water. The major source of bicarbonates in raw waters of rivers is silicates, carbonate weathering and $CO_2$ dissolution. The dominance of carbonate rock weathering in the upland himalayan rivers has been reported earlier[13,10]. Increase in bicarbonate levels, resulting from rock weathering and disturbance in substratum composition of rivers, render the establishment of arthropod communities in raw waters. Bicarbonates, chlorides and nitrate ions, tend to increase in canals. The biological water quality of River Ganga used to be clean on most stretches, but during 2007 and 2008 it gradually deteriorated to heavy pollution with the construction of series of large hydroelectric projects all along its upstream stretches. However, the biological water quality remained clean even after its diversion to Gang Canal. Sulphate the next abundant anion was present in the range of 19-27% of the total anions. The sources of dissolved sulphate in rivers are rain, evaporites, pyrites etc. Sulphur is important component of muscle proteins, constitutes 0.3% of body. Higher levels of chloride ion in raw waters are deleterious to arthropod community but these levels in drinking water are suitable for human consumption. There was substantial reduction in chloride levels in canal water compared to rivers. In ionic form chloride is the most abundant anion outside the cell. On most occasions 0.3% nitrates was present in drinking water supply which is not harmful to the human health. Minor contribution of chloride and nitrate (14%) in total anions were observed in rivers and 8-10% in canal waters, which are found to be favorable for aquatic life. The levels of chloride and nitrate were increased to 16-24% in the drinking water supply. Figure 1 shows increase in the concentration of physico-chemical parameters in canal water as compared to rivers. These levels are further increased in drinking water sources after conventional treatment.

## Contribution of glacial melt and sulphur springs

Sulphur springs are the major source of ions to the rivers, which in turn is reflected from their high TDS value (778 mg/l). Sodium and potassium ions in sulphur spring water contributes 60% of total cation concentration (12.71033968 meq/l) compared to calcium and magnesium (18%). These levels appear to be unfavorable for the existence of macro biological life. In soft water acute toxicity to benthic macro-invertebrates may be caused by excessive levels of cations such as fluoride[14]. Among total anions (24.28668989meq/l), bicarbonate and chlorides were the major ions contributing about 60% with minor contribution from sulphates and nitrates. Among total cations (1.528675145meq/l) of glacial melt water, contribution of calcium and magnesium was maximum (68%) with minor contribution from sodium and potassium (15%). Chloride and bicarbonates were major anion contributing 93% to total anion concentration (0.676525822meq/l). Melt water influence on stream water chemistry, clearly showed preferential elution of sulphate and nitrate over chloride, hydrogen and other cations during the early melt of 1988 in Caimgorm mountains of Scotland[1]. Influence of major ions of sulphur spring was observed during winter season and that of glacial melt water during summers.

## CONCLUSION

River Ganga and Yamuna integrates ions mainly from chemical weathering process, however sulphur springs and glacial melt streams (precipitation) remains important direct sources with very little input from human activities. During lean period the ionic constitution is predominantly dictated by sulphur springs in both these rivers. The levels of individual cations and anions in the upland himalayan regions are higher in River Ganga compared to River Yamuna. The levels of total ions elevate significantly whenever the rivers are diverted into canals. Yamuna Canal is having quite high levels of ions compared to Gang Canal. High TDS and conductivity in the lower stretches of River Yamuna is attributed to the fragile river basin and more visible direct discharges in the river. The concentration of various ions in rivers and canals are found well below the BIS prescribed limit, but the levels increases after conventional treatment of the raw water. Calcium, magnesium among cations and bicarbonate, sulphate among anions were found most predominant throughout the water quality of rivers and canals. However, sodium concentration increases in canals significantly with marginal increase in potassium concentration, which comes mainly from anthropogenic activities. The chemistry of sulphur spring waters is altogether different from rivers and canals, as in sulphur springs sodium among cations and bicarbonate, chloride among anions dominated the total ionic distribution pattern. An optimum level of ions is required in raw waters for healthy aquatic life and the same is applicable for drinking water supply. Hence it is important to maintain the optimum levels of ions in drinking water supply, besides keeping a check at the higher prescribed levels for normal functioning of our body.

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