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# Assessment of Seasonal and Spatial Variation of the Organic Carbon and Nutrients in the Ghaghara River Sediment

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**Abstract:** To assess the organic carbon and nutrients content and its seasonal and spatial variation, sediment samples were collected three times from 18 different locations starting from Keuna, Nepal to Doriganj, Bihar from Ghaghara River during the year 2018-19. The value of pH varied from 7.6 to 8.8 during the study period and indicated the alkaline nature of the sediment. The electrical conductivity (EC) value varied from 0.09 to 0.47 (m S $cm^{-1}$) in the study area, which shows the contribution of the anthropogenic input mainly from domestic and industrial sources to the sediment of the Ghaghara River. The sediment organic carbon (SOC) was in the range of 0.14 to 1.26 %, with relatively higher concentrations during the post-monsoon and monsoon season. The concentration (Mean ± SD) of nitrate, ammonium, phosphate, sulphate and silica in the sediment samples of Ghaghara River were 7.05 ± 1.19, 5.5 ±1.7, 1372 ± 509, 562 ± 157, and 159306 ± 36192 (mg $kg^{-1}$), respectively, during post-monsoon season, 2.05 ± 0.59, 18.0 ± 5.2, 1814 ± 318, 602 ± 139, and 180152 ± 52098 (mg $kg^{-1}$) in pre-monsoon season, and were 7.3 ± 3.3, 7.8 ± 1.4, 1835 ± 696, 438 ± 85, and 163625 ± 68143 (mg $kg^{-1}$) in monsoon season, respectively. The bulk density (BD), pH, EC, nitrate, ammonium, sulphate, and phosphate content showed significant seasonal variation and in the case of spatial variation, while only EC and sediment organic carbon showed significant variation in the Ghaghara river sediment.

**Key words:** Ghaghara River, sediment, organic carbon, nitrogen, phosphate.

## Introduction

The increasing demands on water resources by the growing population and the decline in quality of existing water resources lead to an extreme load on the freshwater resources due to the additional requirements of serving the growing industrial and agricultural growth (Dhawan, 2017; Gautam et al., 2020; Rawat et al., 2018). These anthropogenic activities may also affect the organic matter and nutrient concentration in the river water and sediment system (Khatri and Tyagi, 2015). The sediment in the river system can be contributed to the weathering and erosion of the rock present in the catchment area, dry precipitation along runoff from urban and agricultural areas (Sharma et al., 2017). The chemical composition of sediment depends upon the composition of source rocks, mechanical and chemical weathering, winnowing, and sorting taking place during the transportation along the river stretch, deposition from the water column, and anthropogenic

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sources present in the catchment area (Gautam et al., 2020; Gibbs, 1967; Piper et al., 2006). The nutrient concentration in sediment can be influenced by hydrological parameters like river morphology, flow velocity, in-stream biota, and particle size and density (Forsberg, 1989). Chambers et al. (1991) discussed the role of bottom sediments in stream metabolism and in providing nutrients to the aquatic biota.

The sediment characteristics include its particle size, organic matter concentration, pH, and Eh condition control the sorption and desorption of nutrients from the sediment and contribute nutrients to the upper water layer (Hou et al., 2013). Sediment can act as a source and sink of nutrients and once contaminated it can also act as a secondary source of river pollution, therefore, its characterisation in terms of nutrient concentration is very important (Haslam, 1990). In the recent past, the sediment load in the river system had increased due to land use land cover change occurring in the catchment area due to anthropogenic activities that may affect the benthic ecological population in rivers and lakes (Williams and Melack, 1997). The present study was carried out to assess the seasonal and spatial variation in the concentration of sediment organic carbon and inorganic nutrients in the Ghaghara River sediment.

## Material and Methods

### Study Area

The Ghaghara River is a major tributary of the River Ganga with a total length of around 1080 km. It is the largest tributary of Ganga after the Yamuna in terms of discharge. The total catchment area of the Ghaghara River is about 1, 27,950 km$^2$ and the average discharge is 94,400 m$^3$ yr$^{-1}$(Singh et al., 2016). The Ghaghara basin is mainly composed of older alluvium deposited during the Pleistocene and newer alluvium deposited during the Holocene period and particle size includes coarse sizes including gravel and sand along with fine size particles including silt and clay (Ravi et al., 2021). In the area of the Ghaghra basin, the major rock types include Bundelkhand granite gneisses of the Archaean age and the Vindhyan Super Group of rocks (SWARA 2020).

Sediment samples (*n* = 54) were collected in the zip lock polythene bags using a scoop sampler from 18 locations in the Ghaghara River and its tributaries during the year 2018-19 (Figure 1). Samples were collected from the riverbed at the depth of about 10 ~15 cm and taken in the icebox to the laboratory for further analysis. The sediment samples were air-dried at room

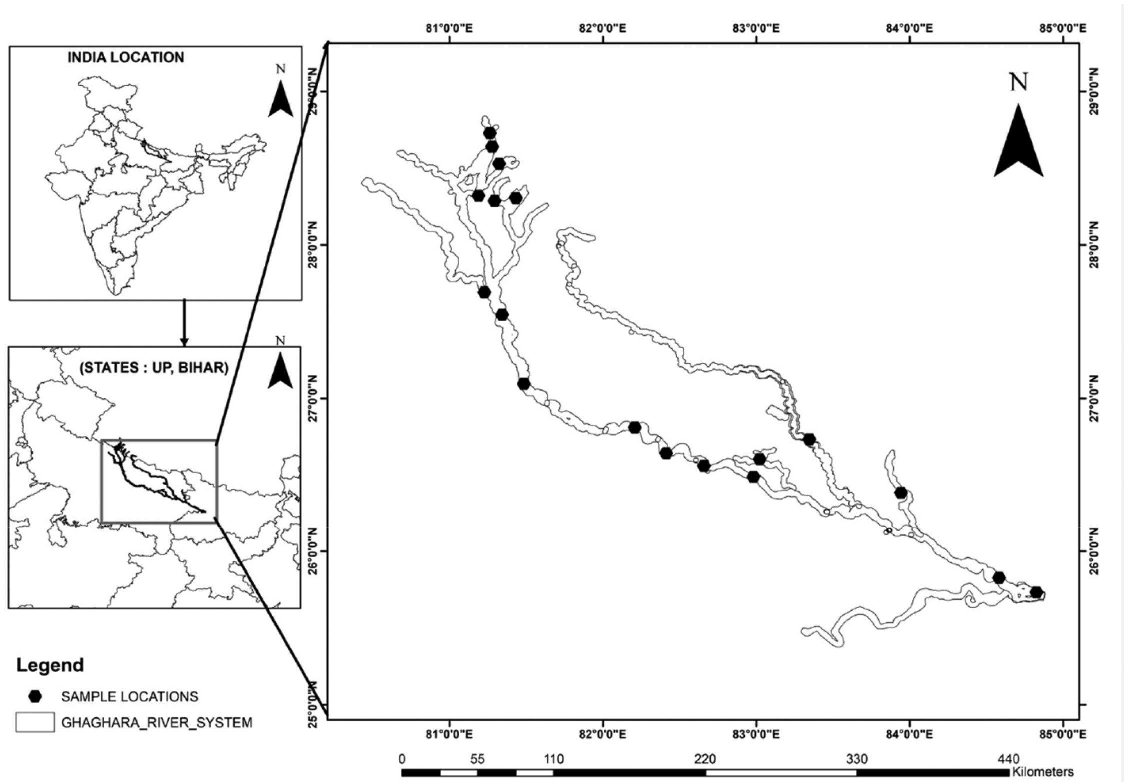


**Figure 1: Study area map showing sampling location.**

temperature and then homogenized using a porcelain mortar and pestle and used for further analysis (Sharma et al., 2017). The coordinates for the sample location were collected by using the Trimble Juno-3B GPS.

**Analytical Methodology**

The pH and EC were measured by using a sediment solution prepared by extracting the sediment with double distilled water at 1:10 (w/v) sediment: water ratio using a water and soil analysis kit (Labtronics, model-LT68). Sediment organic carbon (SOC) was analysed by the Walkley & Black titration method by oxidation of organic carbon in presence of potassium dichromate and concentrated sulphuric acid. In this method, a correction factor of 1.3 is used to include the unrecovered organic carbon in the sediment (Walkley & Black, 1934). The inorganic nitrogen (ammonium and nitrate) in the sediment was analysed by extracting the sediment with 2 KCl solution and concentration was measured by using standard methods given by APHA (2005). The sulphate concentration in the extract obtained by the extraction with monocalcium phosphate solution was analysed by using the barium chloride turbidity method (APHA, 2005). The silica and phosphate concentration in the sediment was measured by using the standard method given by Shapiro (1975). Grain size analysis was carried out by using a Laser Particle Size analyser (CILAS 1190).

**Statistical Analysis**

One-way analysis of variance (Analysis of Variance) was done for determining the spatial and seasonal variation of nutrient concentration in the Ghaghara River. The Pearson's correlation coefficient analysis was carried out to understand the factor controlling the sediment chemistry in the Ghaghara River system. MS Excel 2019 was used for ANOVA and Pearson's correlation coefficient analysis. GRADISTAT v8.0 software was used for the analysis of grain size distribution.

## Result and Discussion

The statistics of result including range, mean and standard deviation value for the measured parameter during the post-monsoon, pre-monsoon and monsoon season is given in Table 1. The seasonal and spatial variation in the concentration of measured parameters is given in the form of a boxplot in Figures 2 & 3, respectively. The significance of the seasonal and spatial variation is presented in the form of an ANOVA table and is given in Table 2.

The bulk density of the sediment depends upon the sediment texture and gets affected by the porosity and organic matter content (Jepsen et al., 1997). The bulk density was in the range of 0.14 to 1.26 with a relatively higher mean value observed during the post-monsoon and monsoon season (Table 1 & Figure 2). The bulk

**Table 1: Statistics including Range and Mean±SD for the concentration of nutrients in the Ghaghara river sediments**

| *Parameters* | *Post-monsoon* | | *Pre-monsoon* | | *Monsoon season* | |
|---|---|---|---|---|---|---|
| | *Range* | *(Mean±SD)* | *Range* | *(Mean±SD)* | *Range* | *(Mean±SD)* |
| BD ($gm/cm^3$) | 0.20-0.80 | 0.36±0.18 | 0.15-0.61 | 0.30±0.11 | 0.14-1.26 | 0.36±0.30 |
| pH | 7.6-8.1 | 7.88± 0.15 | 8.0-8.4 | 8.22± 0.13 | 7.87-8.8 | 8.18± 0.24 |
| EC ($mS\ cm^{-1}$) | 0.10 - 0.20 | 0.12± 0.03 | 0.29-0.47 | 0.36 ± 0.054 | 0.09-0.25 | 0.132 ± 0.036 |
| SOC (%) | 0.20-0.8 | 0.36± 0.18 | 0.15-0.61 | 0.30 ± 0.11 | 0.14-1.26 | 0.36 ± 0.30 |
| Nitrate ($mg\ kg^{-1}$) | 4.67 - 9.42 | 7.05 ± 1.19 | 1.61- 3.78 | 2.05 ± 0.59 | 2.18-14.37 | 7.35± 3.38 |
| Ammonium ($mg\ kg^{-1}$) | 3.36-9.80 | 5.52 ± 1.72 | 10.17- 28.71 | 18.0± 5.25 | 4.27-10.36 | 7.81 ± 1.41 |
| Phosphate ($mg\ kg^{-1}$) | 587-2657 | 1372 ± 509 | 1357-2459 | 1814 ± 318 | 1090-4239 | 1835 ± 696 |
| Sulphate ($mg\ kg^{-1}$) | 362-985 | 562 ± 157 | 449-1017 | 602 ± 139 | 319-568 | 438 ± 85 |
| Silica ($mg\ kg^{-1}$) | 106335-225243 | 159306 ± 36192 | 90310-263592 | 180152± 52098 | 73046-333153 | 163625 ± 68143 |

(BD = Bulk Density, EC = Electrical Conductivity, SOC = sediment organic carbon)

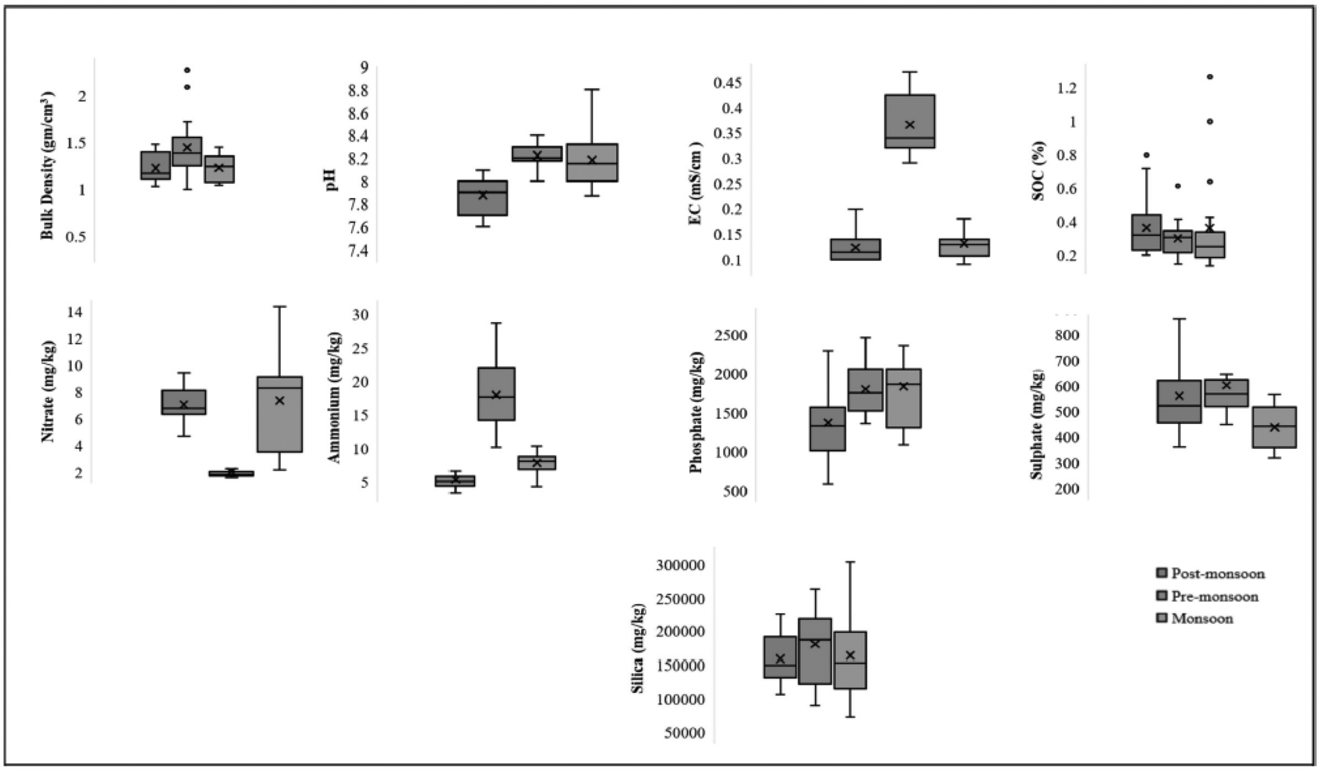


**Figure 2: Seasonal variation in the nutrient's concentration in the Ghaghara River sediments.**

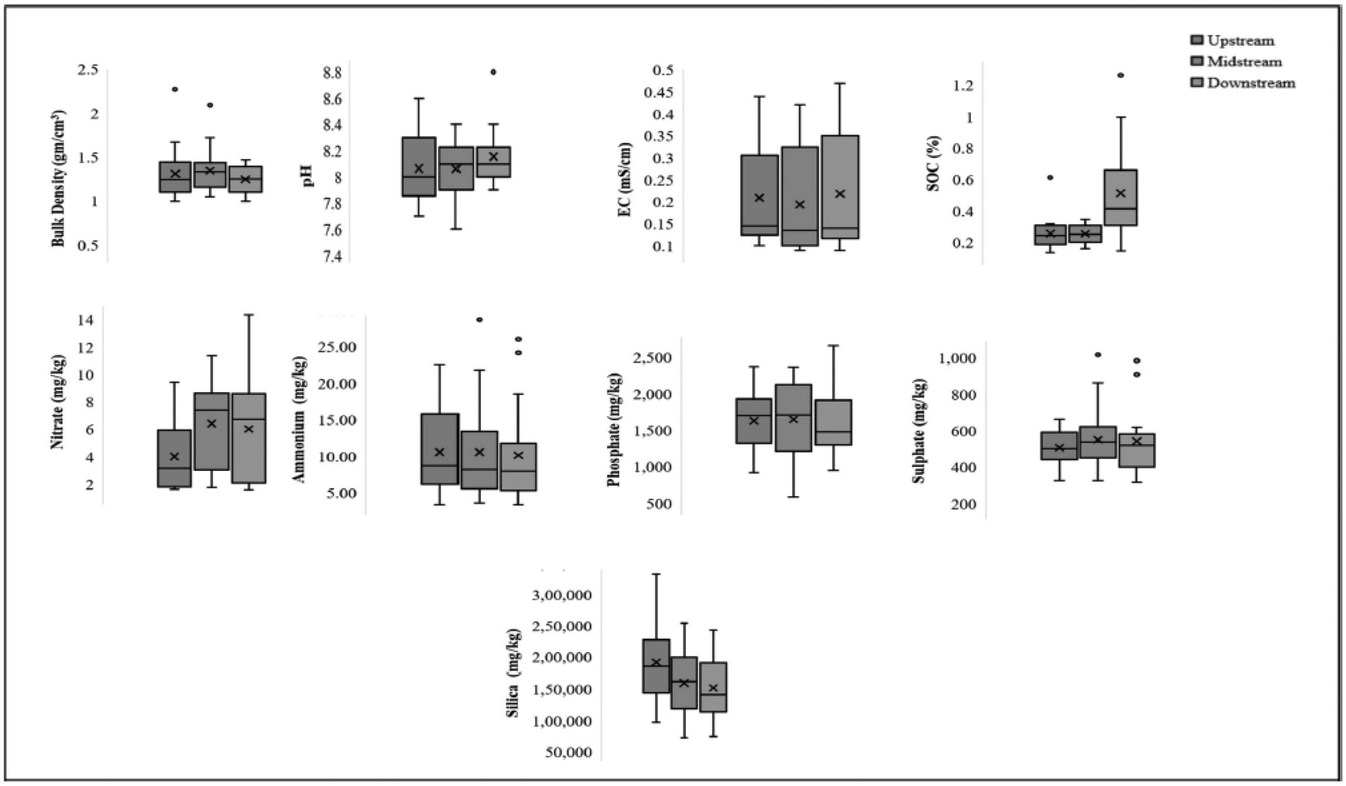


**Figure 3: Spatial variation in the nutrient's concentration in the Ghaghara River sediments.**

**Table 2: Results of analysis of variance (ANOVA) at 95% confidence level for seasonal and spatial variation of nutrients concentration in the Ghaghara river sediment**

| *Parameter* | *Fcalculated* | *Fcritical* | *P-value* |
|---|---|---|---|
| *Seasonal variation* | | | |
| Bulk density | 5.62 | 3.18 | 0.01 |
| pH | 18.86 | 3.18 | 0.00 |
| EC | 183.68 | 3.18 | 0.00 |
| SOC% | 0.52 | 3.18 | 0.60 |
| Nitrate | 36.25 | 3.18 | 0.00 |
| Ammonium | 70.60 | 3.18 | 0.00 |
| Phosphate | 4.05 | 3.18 | 0.02 |
| Sulphate | 7.32 | 3.18 | 0.00 |
| Silica | 0.74 | 3.18 | 0.48 |
| *Spatial Variation* | | | |
| Bulk density | 0.77 | 3.18 | 0.47 |
| pH | 0.90 | 3.18 | 0.41 |
| EC | 10.99 | 3.18 | 0.00 |
| SOC% | 12.51 | 3.18 | 0.00 |
| Nitrate | 0.03 | 3.18 | 0.97 |
| Ammonium | 3.14 | 3.18 | 0.05 |
| Phosphate | 0.14 | 3.18 | 0.87 |
| Sulphate | 0.44 | 3.18 | 0.65 |
| Silica | 2.66 | 3.18 | 0.08 |

density was relatively higher in the middle stretch of the Ghaghara River (Figure 3). The bulk density value showed significant seasonal variation ($p < 0.05$) in the study area but its spatial variation was not statistically significant ($p > 0.05$) (Table 2). The bulk density showed a negative correlation with the EC, SOC, and nutrient concentration indicating the role of particle size in the nutrient chemistry (Table 3). The Ghaghara River sediments were alkaline as indicated by their pH value (Table 1). The pH value showed significant seasonal variation ($p < 0.05$) in the study area with a relatively higher mean value during the pre-monsoon season (Table 2 & Figure 2). The spatial variation for the pH was not significant ($p > 0.05$) in the Ghaghara River system, however, a relatively higher mean value was observed in the lower stretch of the river indicating the influence of anthropogenic contribution (Table 2 & Figure 3). The pH value play important role in the mobility and bioavailability of trace element, organic matter mineralization, nitrification, and denitrification process occurring in the sediment (Neina, 2019). The EC value varies from 0.09 to 0.47 mS $cm^{-1}$ in the study area (Table 1). The EC value showed significant seasonal variation ($p < 0.05$) in the study area with a relatively higher mean value during the pre-monsoon season indicating the effect of low flow conditions on the sediment chemistry (Table 2 & Figure 2). The spatial variation for the EC was not significant ($p > 0.05$) in the Ghaghara River system (Table 2).

The organic carbon in the river sediment can originate from a variety of autochthonous sources (produce within the system such as phytoplankton) and allochthonous (material transported from the land area including natural and anthropogenic contributions) (Westerhoff and Anning, 2000). The sediment organic carbon (SOC) content of Ghaghara River sediment varied from 0.14 to 1.26% (Table 1). Galy and France-Lanord (2005) reported organic carbon content in the range of 0.02 to 0.25% for the bed sediment of the Ganga-Brahmaputra system. The seasonal variation in the SOC content was not significant ($p > 0.05$) however relatively higher SOC content was observed during post-monsoon and monsoon seasons (Table 2 & Figure 2). The SOC content showed significant spatial variation ($p < 0.05$) with relatively higher content was observed in the downstream section of the Ghaghara River indicating the contribution from the anthropogenic activities taking place in the catchment area (Table 2 & Figure 3). The higher content of organic matter during the pre-monsoon and monsoon season can be due to increased contribution from the instream biotic production along with the contribution from the urban and agricultural areas (Adeyemo et al., 2008). SOC was positively correlated with the EC as organic carbon play important role in the cation exchange capacity of soil and sediment (Hunt, 1981) (Table 3). In the sediment, inorganic nitrogen can be present in the form of nitrate, nitrite, and ammonium ion form and mainly originated from the microbial decomposition of organic matter and subsequent nitrification of the ammonium ion to nitrate and nitrite. The ammonium and nitrate present in the sediment support the algal production through the process of sediment digenesis and can create an issue of eutrophication in the river system (Jiang et al., 2018). The nitrate content of Ghaghara River sediment was in the range of 1.61 to 14.37 mg $kg^{-1}$ in the study area (Table 1). Sharma et al. (2017) reported nitrate concentration in the range of 0.11 to 6.09 mg $kg^{-1}$ for the bed sediment of the Yamuna River system. The nitrate concentration showed significant seasonal variation ($p < 0.05$) in the Ghaghara River system with

**Table 3: Correlation coefficient analysis of nutrients for post-monsoon, pre-monsoon, and monsoon season in the Ghaghara river sediments**

| | *BD* | *pH* | *EC* | *SOC* | *$NO_3$* | *$NH_4$* | *$PO_4$* | *$SO_4$* | *Silica* |
|---|---|---|---|---|---|---|---|---|---|
| *Post-monsoon* | | | | | | | | | |
| BD | 1.00 | | | | | | | | |
| pH | 0.06 | 1.00 | | | | | | | |
| EC | -0.41 | -0.08 | 1.00 | | | | | | |
| SOC | -0.02 | 0.29 | 0.07 | 1.00 | | | | | |
| $NO_3$ | 0.70 | 0.05 | -0.44 | 0.09 | 1.00 | | | | |
| $NH_4$ | -0.06 | -0.15 | 0.19 | -0.09 | 0.00 | 1.00 | | | |
| $PO_4$ | 0.11 | -0.19 | -0.32 | 0.04 | 0.13 | -0.18 | 1.00 | | |
| $SO_4$ | 0.20 | 0.15 | -0.33 | 0.01 | 0.39 | 0.16 | 0.70 | 1.00 | |
| Silica | -0.40 | 0.10 | -0.09 | -0.34 | -0.22 | -0.01 | 0.21 | 0.26 | 1.00 |
| *Pre-monsoon* | | | | | | | | | |
| BD | 1.00 | | | | | | | | |
| pH | -0.10 | 1.00 | | | | | | | |
| EC | -0.50 | -0.26 | 1.00 | | | | | | |
| SOC | -0.46 | -0.10 | 0.60 | 1.00 | | | | | |
| $NO_3$ | 0.03 | 0.28 | -0.01 | 0.23 | 1.00 | | | | |
| $NH_4$ | -0.08 | 0.02 | 0.34 | 0.39 | -0.03 | 1.00 | | | |
| $PO_4$ | 0.15 | -0.21 | -0.24 | 0.06 | 0.19 | 0.07 | 1.00 | | |
| $SO_4$ | -0.15 | 0.14 | 0.18 | 0.25 | 0.67 | -0.04 | -0.03 | 1.00 | |
| Silica | 0.14 | -0.35 | -0.15 | 0.05 | -0.31 | -0.50 | -0.01 | -0.19 | 1.00 |
| *Monsoon* | | | | | | | | | |
| BD | 1.00 | | | | | | | | |
| pH | -0.18 | 1.00 | | | | | | | |
| EC | -0.05 | 0.32 | 1.00 | | | | | | |
| SOC | 0.00 | 0.12 | 0.04 | 1.00 | | | | | |
| $NO_3$ | -0.14 | 0.18 | -0.09 | 0.47 | 1.00 | | | | |
| $NH_4$ | -0.35 | 0.37 | 0.46 | 0.24 | 0.42 | 1.00 | | | |
| $PO_4$ | -0.25 | 0.52 | 0.35 | -0.17 | 0.17 | 0.20 | 1.00 | | |
| $SO_4$ | -0.48 | 0.50 | 0.26 | -0.18 | 0.05 | 0.10 | 0.31 | 1.00 | |
| Silica | 0.27 | -0.27 | 0.39 | -0.24 | -0.36 | -0.17 | -0.03 | -0.25 | 1.00 |

relatively higher concentration during the monsoon season may be due to increased contribution from the catchment areas with an increase in flow condition (Table 2 & Figure 2). The nitrate concentration did not show significant spatial variation ($p > 0.05$) however, a relatively higher concentration was observed in the middle stretch of the Ghaghra River system (Table 2 & Figure 3). The relatively higher concentration of nitrate in the middle stretch may be due to excess uses of chemical fertilisers, animal manure, pesticides (Fang and Ding, 2010; Rahmati, et al., 2015; Zarabi and Jalali, 2012) for higher agriculture yield (Goldberg, 1989) and direct disposal of sewage waste and poor maintenance of sewerage system in the catchment area of Ghaghara

River. Nitrate showed a positive correlation with the sulphate concentration indicating the contribution from the agricultural area present in the catchment (Table 3). The ammonium ion concentration was in the range of 3.36 to 28.71 mg $kg^{-1}$ in the study area (Table 1). The concentration was relatively lower than the value reported for the sediment of the Yamuna River due to less sewage discharge received by the Ghaghara River (Sharma et al., 2017). The ammonium concentration showed significant seasonal variation ($p < 0.05$) in the Ghaghara River system with relatively higher concentrations were observed during the pre-monsoon season (Table 2 & Figure 2). The spatial variation was not significant ($p > 0.05$) for the ammonium concentration in the Ghaghara River system.

Phosphate is considered as limiting nutrient in the aquatic system and is partitioned more towards the solid sediment phase of the river system (Correll, 1990). The phosphate in sediment can originate from the weathering of rocks and minerals, mineralisation of organic detritus, and agricultural and urban waste (Watson et al., 2018). The total phosphate concentration was in the range of 587 to 4239 mg $kg^{-1}$in the Ghaghara River sediment and was relatively higher than the value reported for the sediment of Indian rivers (700-1400 mg $kg^{-1}$) (Vaidyanathan et al., 1989). The higher value of phosphate concentration in the sediment can be due to the presence of phosphate containing minerals along with the contribution from the agricultural area and urban centres in the catchment area (Indian Minerals Yearbook, 2014). The total phosphate concentration showed significant seasonal variation ($p < 0.05$) in the Ghaghara River system with relatively higher concentrations were observed during the pre-monsoon season (Table 2 & Figure 2). The spatial variation was not significant ($p > 0.05$), however, a relatively higher concentration was observed in the lower stretch of the river indicating contribution from the agricultural fields and sewage discharge from the populated areas present in the catchment area (Table 2 & Figure 3). The sulphate ion in the bed sediment can originate from atmospheric deposition, runoff from agriculture and urban areas along with the dissolution of naturally occurring minerals such as gypsum and anhydrite in the catchment area (Lucassen et al., 2004). The sulphate concentration was in the range of 319 to 1017 mg $kg^{-1}$ in the Ghaghara River sediment (Table 1). The sulphate concentration showed significant seasonal variation ($p < 0.05$) in the Ghaghara River system with relatively higher concentrations observed during the pre-monsoon season (Table 2 & Figure 2). The spatial variation was not significant ($p > 0.05$). However relatively higher concentration was observed in the Upstream section of the river (Table 2 & Figure 3). Sulphate showed a positive correlation with the phosphate and nitrate concentration indicating the contribution from the agricultural area present in the catchment (Table 3). Silica in river sediment can originate from weathering of silicate minerals, deposition from wind along with sedimentation, and burial of biogenic silica (Frings et al., 2016). The total silica concentration was in the range of 73046 to 333153 mg $kg^{-1}$ in the Ghaghara River sediment. The observed mean concentration was relatively lower than the reported concentration in the world river sediment (285000 mg $kg^{-1}$) (Subramanian et al., 1985). The silica concentration did not show significant seasonal and spatial variation ($p > 0.05$) in the Ghaghara River system, however, relatively higher concentrations were observed during the pre-monsoon season and in the upstream section of the Ghaghara River (Table 2, Figures 2 & 3).

Grain size analysis is an important tool for determining the sedimentary depositional environments as it can provide important clues to nature, transport history, provenance, and depositional condition (Bui et al., 1990; Sheridan et al., 1987). Based on the Folk and Ward (1957) method, 72.22 % of sediments are poorly sorted, 11.11% moderately sorted, 11.11% very poorly sorted, 2.78% well sorted, and the remaining 2.78% moderately well sorted, respectively, in the Ghaghara River. Based on texture group classification, 50.00% of channel sediments are sandy gravel, 36.11% gravelly muddy sand, and the remaining (13.89%) gravelly sand in the Ghaghara River (Figure 4).

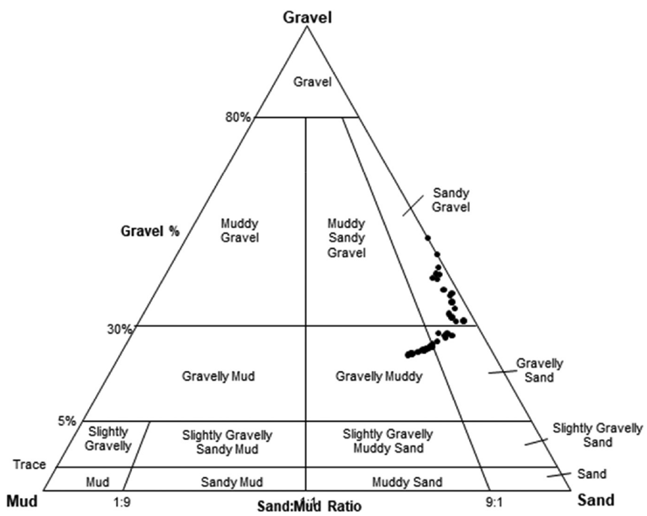


**Figure 4: Grain size distribution (Gravel-mud-sand diagram) of Ghaghara River sediments.**

## Conclusion

Ghaghara river sediment samples were collected and analysed for their organic carbon and nutrient content estimation. The sediment organic content was relatively higher than the value reported for the Ganga-Brahmaputra system indicating contribution from the anthropogenic activities taking place in the catchment area. The ammonium concentration was relatively lower than the concentration observed in the Yamuna River sediment as River Yamuna is more polluted through sewage waste. The total phosphate concentration in the Ghaghara River sediment was relatively higher than the value reported for the sediment of Indian rivers. The total silica concentration in the Ghaghara River sediment was relatively lower than the reported concentration in the world river sediment. The nutrient concentration in the sediment showed significant seasonal variation although spatial variation was not significant in the Ghaghara River. The Ghaghara River sediment samples were poorly sorted and mainly consist of sandy gravel texture.

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## References

Adeyemo, O.K., Adedokun, O.A., Yusuf, R.K. and E.A. Adeleye (2008). Seasonal changes in physicochemical parameters and nutrient load of river sediments in Ibadan city, Nigeria. *Global NEST Journal*, **10(3):** 326-336.

American Public Health Association (2005). Standard Methods for the Examination of Water and Wastewater, 21st ed. American Public Health Association/American Water Works Association/Water Environment Federation, Washington DC, USA.

Bui, E.N., Mazullo, J. and L.P. Wilding (1990). Using quartz grain size and shape analysis to distinguish between aeolian and fluvial deposits in the Dallol Bosso of Niger (West Africa). *Earth Surface Processes and Landforms*, **14:** 157-166.

Chambers, P.A., Prepas, E.E., Bothwel, M.M. and H.R. Hamilton (1991). Current velocity and its effects on growth of aquatic macrophytes in slow flowing rivers. *Ecol. Appli.,* **1(3):** 249-257.

Correll, D.L. (1990). Phosphorus: A rate limiting nutrient in surface waters. *Poultry Science*, **78:** 674-682.

Dhawan, V. (2017). Water and Agriculture in India Background paper for the South Asia expert panel during the Global Forum for Food and Agriculture. Hamburg, Germany: OAV – German Asia-Pacific Business Association.

Fang, J. and Y. Ding (2010) Assessment of groundwater contamination by $NO^{-3}$ using geographical information system in the Zhangye Basin, Northwest China. *Environmental Earth Sciences*, **60:** 809-816.

Frings, P.J., Clymans, W., Fontorbe, G., De La Rocha, C.L. and D.J. Conley (2016). The continental Si cycle and its impact on the ocean Si isotope budget. *Chem. Geol.*, **425:** 12-36.

Forsberg, C. (1989) Importance of sediments in understanding nutrient cyclings in lakes. *Hydrobiologia*, **176:** 263-277.

Folk, R.L. and W.C. Ward (1957). Brazos River bar: A study in the significance of grain size parameters. *Journal of Sedimentary Petrology*, **27:** 3-26.

Galy, V. and C. France-Lanord (2005). Particulate organic carbon transport from the Himalaya to the Ganga-Brahmaputra Delta. Presented at the American Geophysical Union, Fall Meeting 2005, Abstract id. H24B-08.

Gautam, S.K., Maharana, C., Sharma, D., Singh, A.K., Tripathi, J.K. and S.K. Singh (2015). Evaluation of groundwater quality in the Chotanagpur Plateau region of the Subarnarekha River Basin, Jharkhand State. *India Sustainability of Water Quality and Ecology*, **6:** 57-74. DOI:10.1016/j.swaqe.2015.06.001

Gautam, S.K., Tripathi, J.K. and S.K. Singh (2020). Assessing the suitability of Ghaghra River water for irrigation purpose in India. *In:* Agricultural Water Management - Theories and Practices. Elsevier Science Publishing Co Inc, Academic Press, USA.

Gibbs, R.J. (1967). The geochemistry of the Amazon river system: Part I- the factors that control the salinity and the composition and concentration of suspended solids. *Geol. Soc. Amber. Bull.*, **78:** 1203-1232.

Goldberg, V.M. (1989). Ground water pollution by nitrates from livestock wastes. *Environmental Health Perspectives*, **83:** 25-29.

Haslam, S.M. (1990). River pollution: An ecological perspective. London: Belhaven Press.

Hunt, D.C. (1981). Regulation of sedimentary cation exchange capacity by organic matter. *Chemical Geology*, **34(102):** 131-149.

Hou, D., He, J., Lü, C., Sun, Y., Zhang, F. and K. Otgonbayar (2013). Effects of environmental factors on nutrients release at sediment-water interface and assessment of trophic status for a typical shallow lake, Northwest China. *The Scientific World Journal*, **2013:** 716342. https://doi.org/10.1155/2013/716342

Indian Minerals Yearbook 2014 (Part- III: Mineral Reviews), 53rd Edition, Apatite and Rock Phosphate, Indian Bureau of Mines, Ministry of Mines, Government of India.

Jepsen, R., Roberts, J. and W. Lick (1997). Effects of bulk density on sediment erosion rates. *Water Air Soil Pollut.,* **99:** 21-31.

Jiang, Q., He, J., Wu, J., Hu, X., Ye, G. and G. Christakos (2018). Assessing the severe eutrophication status and spatial trend in the coastal waters of Zhejiang Province (China). *Limnol. Oceanogr.*, **9999:** 1-15.

Khatri, N. and S. Tyagi (2015). Influences of natural and anthropogenic factors on surface and groundwater quality in rural and urban areas. *Frontiers in Life Science*, **8(1):** 23-39. DOI: 10.1080/21553769.2014.933716

Lucassen, E.C.H.E.T., Smolders, A.J.P., Van der Salm, A.L. and J.G.M. Roelofs (2004). High groundwater nitrate concentrations inhibit eutrophication of sulfate-rich freshwater wetlands. *Biogeochemistry*, **67(2):** 249-267.

Neina, D. (2019). The role of soil pH in plant nutrition and soil remediation. *Applied and Environmental Soil Science*. Article ID 5794869: https://doi.org/10.1155/2019/5794869

Piper, D.Z., Ludington, S., Duval, J.S. and H.E. Taylor (2006). Geochemistry of bed and suspended sediment in the Mississippi river system: Provenance versus weathering and winnowing. *Science of the Total Environment*, **363:** 179-204.

Rahmati, O., Samani, A.N., Mahmoodi, N. and M. Mahdavi (2015). Assessment of the Contribution of *n*-fertilizers to nitrate pollution of groundwater in Western Iran (case study: Ghorveh–Dehgelan Aquifer). *Water Quality, Exposure and Health*, **7:** 143-151.

Rawat, K.S., Singh, S.K. and S.K. Gautam (2018). Assessment of groundwater quality for irrigation use: A peninsular case study. *Applied Water Science*, **8:** 233. https://doi.org/10.1007/s13201-018-0866-8

Ravi, N.K., Srivastava, A., Ram, K. and P.K. Jha (2021). Nutrient chemistry and eutrophication risk assessment of the Ghaghara River, India. *Water Supply*, **21(7):** 3486-3502. doi: 10.2166/ws.2021.110.

Sharma, S., Jha, P.K., Jindal, T., Ranjan, M.R. and U.K. Singh (2017). Assessment of Nutrient conc. In the sediment of Yamuna river, India. *Pollution Research*, **36(1):** 114-120.

Shapiro, L. (1975). Rapid analysis of silicate, carbonate and phosphate rocks, revised edition. *USGS Bull.*, **1401:** 1-54.

Singh, H., Pandey, R., Singh, S.K. and D. Shukla (2016). Assessment of heavy metal contamination in the sediment of the River Ghaghara: A major tributary of the River Ganga in northern India. *Applied Water Science*, **7:** 4133-4149.

Sheridan, M.F., Wohletz, K.H. and J. Dehn (1987). Discrimination of grain-size sub-populations in pyroclastic deposits. *Geology*, **15:** 367-370.

State water resources agencies (2020). Development of river basin assessment and plans for all major river basins in Uttar Pradesh. State water resources agencies, Government of Uttar Pradesh.

Subramanian, V., Van t" Dack, L. and R. Van Grieken ( 1985). Preliminary studies on the geochemistry of the Cauvery river basin. *Proc. Indian Acad. Sci. (Earth Planet. Sci.).*, **94(2):** 99-110.

Vaithiyanathan, P., Subramanian, V. and A. Ramanathan (1989). Transport and distribution of phosphorus by the rivers of India. *Geol. Soc. India Memoir*, **13:** 127-137.

Walkley, A. and I.A. Black (1934). An examination of the Degtjareff Method for determining soil organic matter, and a proposed modification of the chromic acid titration method. *Soil Science*, **37(1):** 29-38.

Watson, S.J., Cade-Menun, B.J., Needoba, J.A. and T.D. Peterson (2018). Phosphorus forms in sediments of a river-dominated estuary. *Frontiers in Marine Science,* **(5):** 302.

Westerhoff, P. and D. Anning (2000). Concentrations and characteristics of organic carbon in surface water in Arizona: Influence of urbanization. *Journal of Hydrology*, **(236):** 202-222.

Williams, M.R. and J.M. Melack (1997). Solute export from forested and partially deforested catchments in the central Amazon. *Biogeochemistry*, **38:** 67-102.

Zarabi, M. and M. Jalali (2012). Leaching of nitrogen from calcareous soils in western Iran: A soil leaching column study. *Environmental Monitoring and Assessment*, **184:** 7607-7622.

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