Hydrochemical Characteristics of Multilayer Dupi Tila Aquifer System Beneath Dhaka Mega City, Bangladesh

GHENT UNIVERSITY

Jahangirnagar University
জাহাঙ্গীরনগর বিশ্ববিদ্যালয়

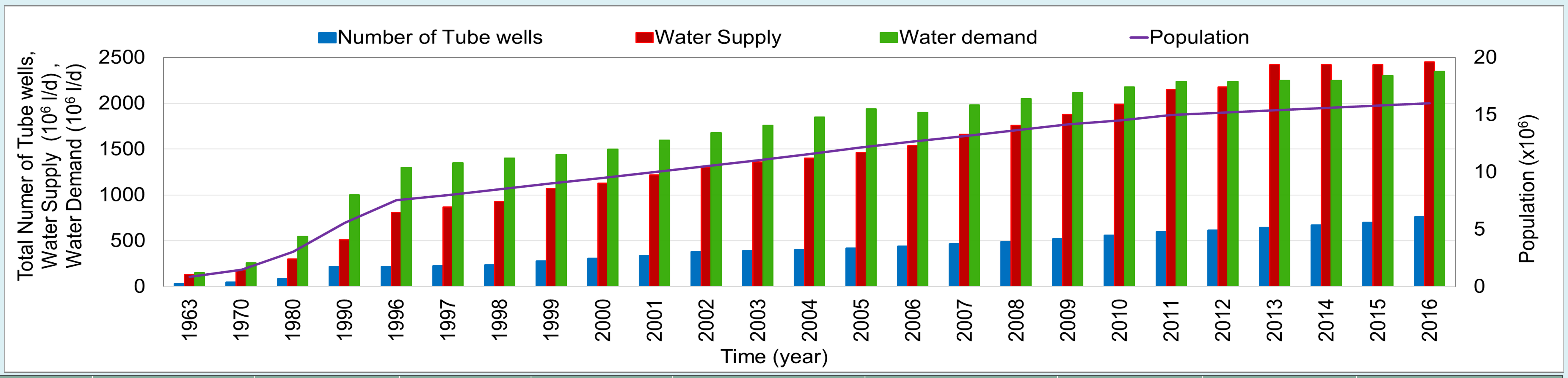
Mazeda Islam[1,2], Marc Van Camp[1], Thomas Hermans[1], Md. Mizanur Rahman Sarker[1,2], Md. Abdul Quaiyum Bhuiyan[3], Nasir Ahmed[3], Md. Masud Karim[3] and Kristine Walraevens[1]

[1]Laboratory for Applied Geology and Hydrogeology, Department of Geology, Ghent University, Belgium
[2]Department of Geological Sciences, Jahangirnagar University, Savar, Dhaka, Bangladesh
[3]Bangladesh Atomic Energy Commission, Dhaka, Bangladesh

1. Introduction

Around 20 million people are living in Dhaka with a growing rate of 4.2 percent per year. Major part of the water supply is depending on groundwater from the Plio-Pleistocene fluvio-deltaic sands of the Dupi Tila Formation. Massive abstraction from the aquifer by water-wells has been causing a significant aquifer dewatering and huge drop in groundwater level up to 89 m PWD (Public Works Department) datum beneath the part of the city. The resulting depression cone is thought to prompt recharge from rivers and surrounding area.

Fig. 1: **Historical Evolution:** Groundwater and Surface Water Supply and Demand with the Expansion of Dhaka City, Bangladesh. (Source: DWASA, 2016)



	1	2	3	4	5	6	7	8	9	10	11
1953	**1959**	**1963**	**1971**	**1971 -1985**	**1990**	**1996**	**2000**	**2010**	**2013**	**2015**	**2016**
Growth expansion and development of Dhaka city	-First master plan -Water demand for 0.58 x10^6 people	Establish ment of Dhaka WASA	Independence of Bangladesh: -2 x10^6 population -47 deep tube wells (DTWs) -50 x10^{6}m^3/yr	DTWs installed in Upper Dupi Tila aquifer (UDA) near the rivers	-216 DTWs in UDA -510 x10^6 l/d ->5 times than 1970	-2nd master plan -1st plan for 10 x10^6 inhabitants	-10 x10^6 population -308 DTws -deficit 380 x10^6 l/d - Drawdown to -65 m PWD	Water supplied 1990 x10^6 l/d -Water demand 2180 x10^6 l/d -560 DTWs - 4 surface water treatment plants(SWTP).	Supply capacity 2250 x10^6/l/d -644 DTWs and 4 SWTP	Supply capacity 2420 x10^6 l/d -DTWs 702 4 SWTP.	-16 x10^6 population - Supply capacity 2450 x10^6 l/d -760 DTWs and 4 SWTP.

2. Aim of the Study

The present work investigates groundwater chemistry in the multilayer Dupi Tila aquifer using hydrochemical data, stable isotopes along with physico-chemical parameters.

3. Hydrostratigraphy: Aquifer System

- Upper Dupi Tila Aquifer (UDA): Upper part mainly composed of fine sand to medium sand and lower part medium sand to coarse sand occasionally with gravel. Average bottom depth is 142.5.
- Middle Dupi Tila Aquifer (MDA): Mainly composed of medium sand to coarse sand with gravel. Average bottom depth 254.5 m.
- Lower Dupi Tila Aquifer (LDA): Predominantly composed of fine sand to medium sand . Avg. bottom depth is 385 m.

4. Hydrograph

Mirpur Area (UDA): Fig. 4a

- ✓ Seasonal fluctuation and no falling trend up to 1985
- ✓ Lowest Groundwater level (GWL): - 65.06 m PWD (2010),
- ✓ Sharp decline rate: 5.4 m/year (2000-2005).
- ✓ Relatively stable after 2010-2016
- ✓ Recovery GWL 2017 to - 60.84 m PWD (5 m rise).

Gulshan Area(UDA) : Fig. 4b

- ✓ Lowest GWL: - 72 m PWD (2018)
- ✓ Highest decline rate: 4.1 m/year (2000-2005).

Sutrapur Area (UDA) : Fig. 4c

- ✓ Due to proximity of Buriganga river ,GWL was very much different.
- ✓ Lowest GWL: -14.2 m PWD (2010)
- ✓ Relatively stable from 2000 to 2010 in UDA.

Sabujbagh Area (UDA) : Fig. 4d

- ✓ Lowest GWL: -62.8 m PWD (2009)
- ✓ Maximum decline rate: 2.8 m/year (2000-2005)

5. Piezometric Maps

UDA

- ❑ **1985** (Fig. 5a)
  - Depression in South central part down to -10 m PWD
  - Most of the area : -1 m PWD
- ❑ **2017** (Fig. 5b)
  - Lowest GWL (depression cone) down to - 80 m PWD
  - Peripheral part: -50 m PWD

MDA

- ❑ **2005** (Fig. 6a)
  - Shape and extent of depression showed sporadic pattern.
  - Lowest GWL in southeast side down to -36.82 m PWD
- ❑ **2017** (Fig. 6b)
  - Lowest GWL (depression cone) down to -65 m PWD
  - Peripheral part: -35 m PWD

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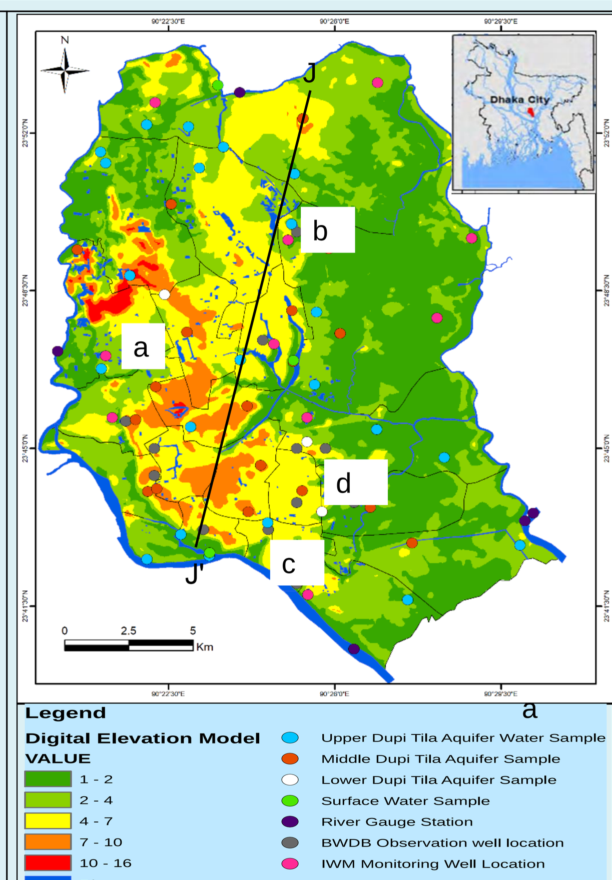
Fig. 2: Study area with water sample location, observation well and cross section line map.

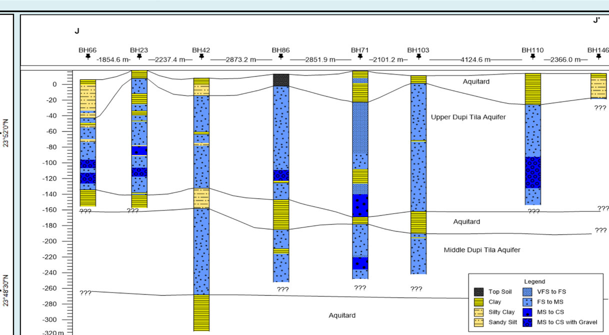
Fig. 3: Hydrostratigraphic cross section

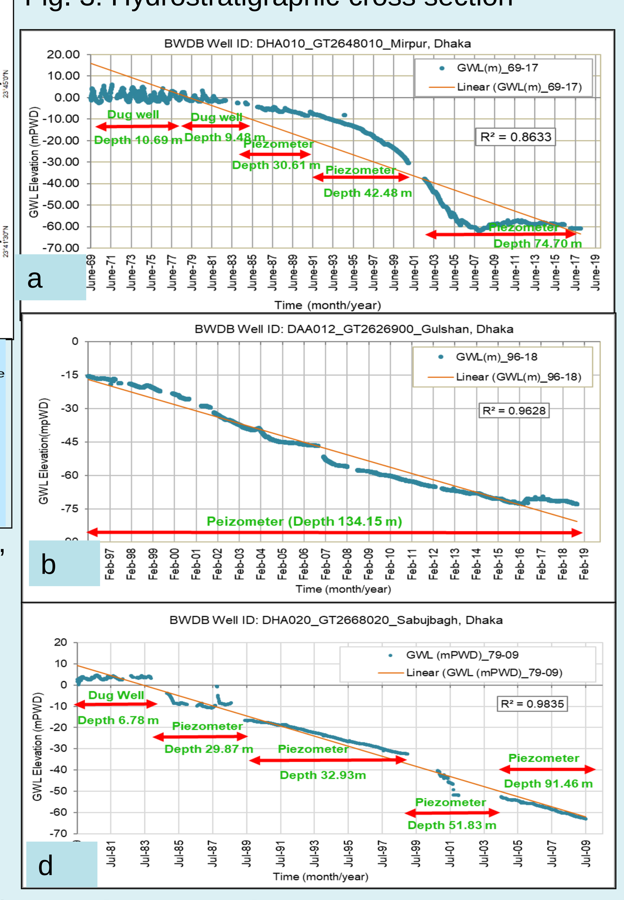
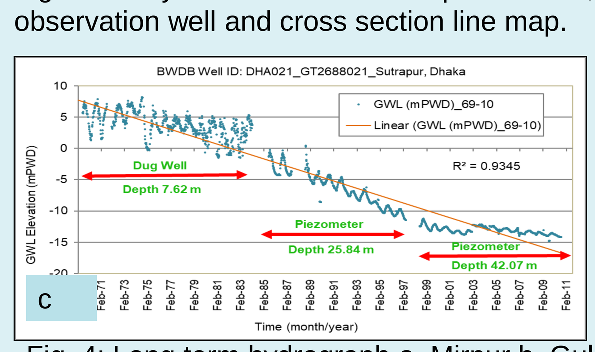
Fig. 4: Long term hydrograph a. Mirpur b. Gulshan c.Sutrapur d. Sabujbagh

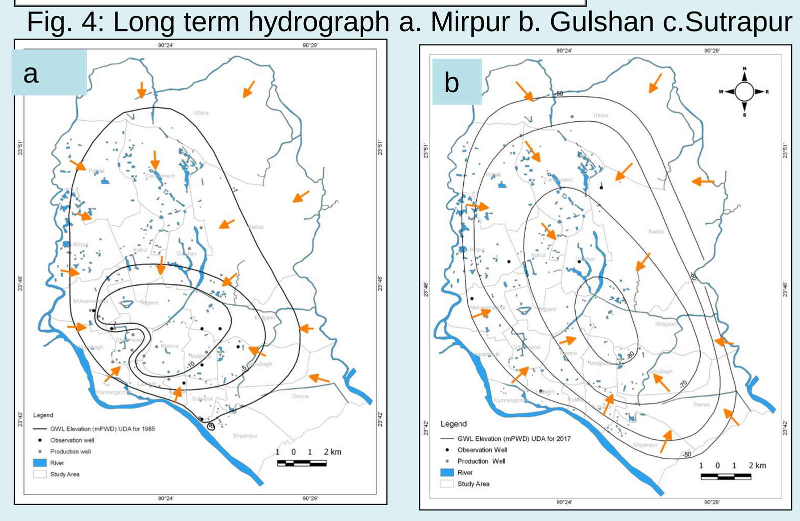
Fig. 5: Piezometric map of UDA for a. 1985 b. 2017

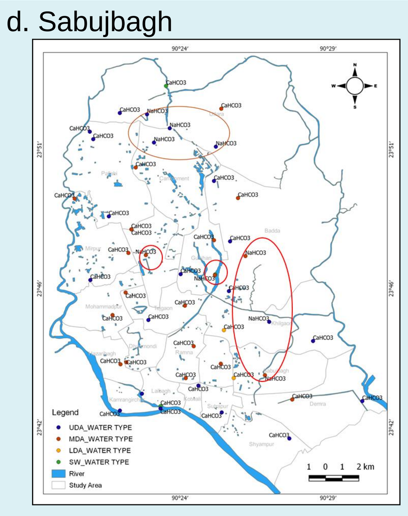
Fig. 7: Water type map

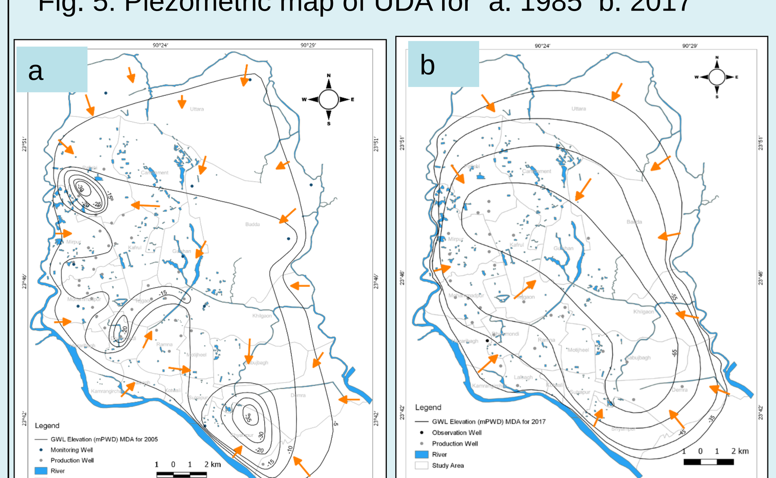
Fig. 6: Piezometric map of MDA for a. 2005 b. 2017

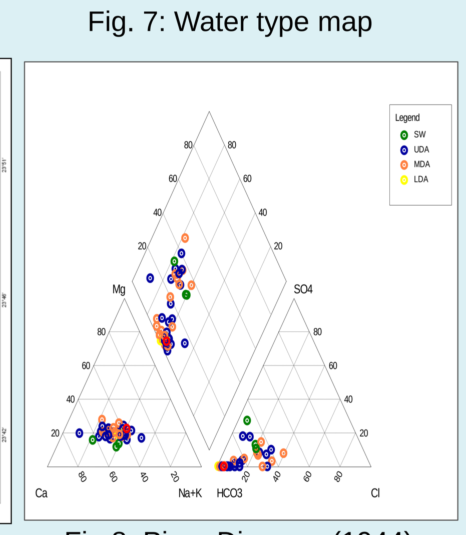
Fig.8: Piper Diagram (1944)

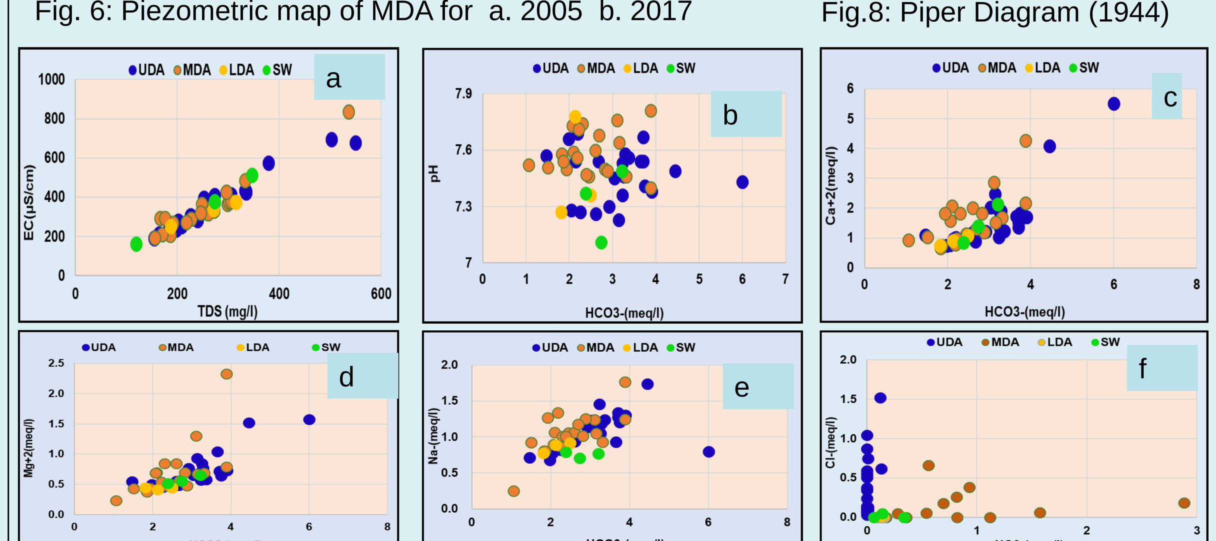
Fig. 9: Cross plots of a. EC vs TDS b-e. HCO_3^- vs major cations f. Cl^- vs NO_3^-

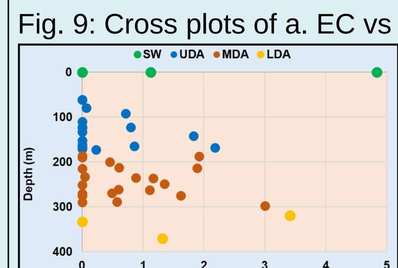
Fig. 10: As vs depth plot

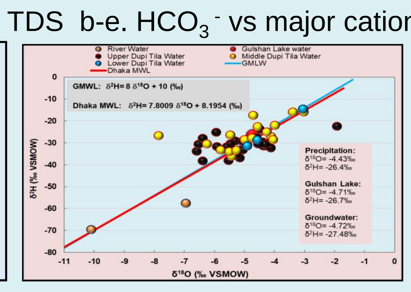
Fig. 11: Plot of $\delta^{18}O$ vs δ^2H.

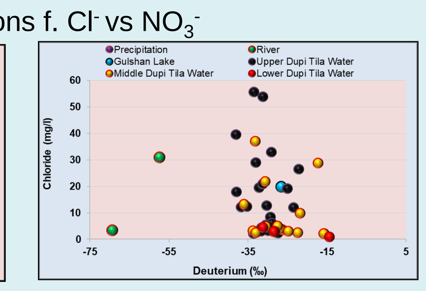
Fig. 12:Plot Cl^- vs δ^2H

6. Hydrochemical Characteristics

- Relative abundance of the ions $Ca^{2+} > Na^+ > Mg^{2+} > K^+ > Fe^{2+} > NH_4^+ > Mn^{2+}$ and $HCO_3^- > Cl^- > SO_4^{2-} > NO_3^- > PO_4^{3-} > NO_2^-$.
- Low mineralization water (EC: 161-835 (µS/cm – 25°C), TDS: 119-550 (mg/l) and neutral pH (pH: 7.11-7.81).
- Waters are mostly $CaHCO_3$ (86%) and 17% $NaHCO_3$ types (Fig. 7) localized in two zones due to infiltration of rain water or anthropogenic pollution.
- Dominant control of aluminosilicates weathering on the hydrogeochemical evolution of groundwater is confirmed by $CaHCO_3$ and $NaHCO_3$ types water and cross plots (Fig. 7, 8 & 9). Major alkaline and alkaline earth cations released from aluminosilicates weathering.
- HCO_3^- is formed from CO_2 involved in aluminosilicate weathering. The increase in major cations is accompanied by a parallel increase of bicarbonate (Fig. 9).
- Reactions (i-v) illustrate the weathering processes which can release Ca^{2+} and HCO_3^- to groundwater.
  - $2CaAl_2Si_2O_8 + 4CO_2 + 6H_2O = 2Al_2Si_2O_5(OH)_4 + 2Ca^{2+} + 4HCO_3^-$ ....(i)
    Anorthite Kaolinite
  - $CaMg(Si_2O_6) + 4CO_2 + 6H_2O = Ca^{2+} + Mg^{2+} + 4HCO_3^- + 2H_4SiO_4$ ....i)
    Pyroxene
  - $Ca_2Mg_5Si_8O_{22}(OH)_2 + 14CO_2 + 22H_2O = 2Ca^{2+} + 5Mg^{2+} + 14HCO_3^- + 8H_4SiO_4$ ....(iii)
    Amphibole
  - $CaCO_3 + CO_2 + H_2O = Ca^{2+} + 2HCO_3^-$ ....(iv)
    Calcite
  - $CaMg(CO_3)_2 + 2CO_2 + 2H_2O = Ca^{2+} + Mg^{2+} + 4HCO_3^-$ ....(v)
    Dolomite
- The average concentration (11 µg/l) of arsenic is low in all the water samples (Fig. 10) except two shallow water samples in UDA (161.88 and 383 µg/l at 14.63 and 42.67m depth respectively) in same location .
- Very few water samples exceed guideline of WHO, 2008.

7. Stable Isotopes

- ❑ LDA water falls on and to some extent below the LMWL and GMWL (Craig, 1961): recharge from rainwater. MDA and UDA : rainfall and/or flood water (Fig. 11).
- ❑ More depleted in river waters indicating that the river waters are composed of rainfall in the upstream catchment.
- ❑ Enriched isotopic composition and mean d-excess of LDA is 8.87‰ indicating evaporation has occurred before infiltration
- ❑ Cl^- vs δ^2H plot indicates no good relationship between the origin of GW other than river **(**Fig. 12).

8. Conclusion

- ✓ Huge GWL depletion in both UDA and MDA aquifers and highest depression is observed in central part of the city.
- ✓ Mainly $CaHCO_3$ type water with low mineralization.
- ✓ Aluminosilicates weathering as the primary process controlling groundwater chemistry.
- ✓ Groundwater supply may not be sustainable for long persisting period in Dhaka city because of massive decline of GWL.

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Piper AM (1944) A graphic procedure in the geochemical interpretation of water-analyses. Eos Trans Am Geophys Union 25(6):914–928
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