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Hydrogeochemical analysis of part of the alluvial aquifer, Rupendehi District, Nepal

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ABSTRACT

This study is mainly focused on detail hydrogeochemical study and water quality test of inorganic constitutes for drinking and irrigation purposes. The study area occupies part of the Siwalik and the Terai with total area of 331 sq. km. Total 30 samples were analysed at applied geology and hydrogeology laboratory, Ghent University, Belgium. The major cations (Na^+, Ca^{2+}, Mg^{2+}, K^+, Fe^{2+}, Mn^{2+}, Al^{3+} and NH_4^+), anions (Cl^-, SO_4^{2-}, NO_3^-, NO_2^-, HCO_3^-, CO_3^{2-}, PO_4^{3-}, and OH-) and trace elements (F^- and Br^-) were measured. Results were treated using Piper diagram, Scatter diagram and Stuyfzand (1986) classification of groundwater. It showed that groundwater of the study area was slightly acidic to basic in nature. Ca^{2+} and Mg^{2+} and HCO_3^- were major cations and anion for all samples. The sources of these ions in the water were from dissolution of calcite ($CaCO_3$) and dolomite CaMg $(CO_3)_2$. The amount of Na+ and K+ was from hydrolysis reaction of silicate minerals such as K-feldspar and Na-feldspar. Small concentration of SO4-2 was from oxidation of pyrite. Most of the samples (27 out of 30) were fresh, moderately hard, $CaHCO_3$ water type with surplus of (Na^++K^++Mg^{2+}). Water of the study area was found suitable both for drinking and irrigation purposes in accordance with WHO (2004) and National Drinking Water Quality Standards (2005).

Keywords: Groundwater, Aquifer, Hydrochemical Analysis, Water Quality

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INTRODUCTION

Agriculture is a principle economic source of the country employing 65 % of the population but only about 21% land is cultivatable (Prasai, 2010). Terai, the southern lowland plain, is highly productive land for cultivation because of the flat topography and fertile soil where most part of the study area situates. The main source and easily available source of water for all purposes is groundwater. Three governmental authorities are performing groundwater exploration and exploitation in the area. Two government authorities, the Groundwater Irrigation Development Division and Bhairahawa Lumbini Groundwater Irrigation Project are distributing groundwater as an irrigation water whereas, Water Supply and Sanitation Division Office is supplying deep tube well water as drinking water through pipeline system.

Water quality is a fundamental requirement for the living organism to survive. Rapid population growth change in life style, industrialization, urbanizations can be the key factors in reducing water quality in the study area. The chemical alteration of infiltrated water depends on soil- water interaction, anthropogenic activities and dissolution of mineral (Plummer et al., 2003). Quality of the groundwater is normally influenced by geology and anthropogenic activities through which it passes. Nearly 95 % solute in water are calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^+), potassium (K^+), chloride (Cl^-), sulphate (SO_4^{2-}) and bicarbonate (HCO_3^-) (Plummer et al., 2003). It further depends on certain factors such as precipitation, temperature and pH. Aquifers have been developed within the unconsolidated fluvial sediment systems provide large quantities of water. However, these aquifers are commonly unconfined, occur at shallow depth and are vulnerable to contamination by surface activities. Direct disposal of wastewater and solid from industry and household to the surface water degrades not only surface water but also groundwater in urban area of the country. Use of pesticides and chemical fertilizer also degrades the quality of groundwater in shallow depth. In this scenario, detail hydrogeochemical study is the principal objective of this research.

Study area

The study lies in the Rupendehi District, south-western part of the Nepal. It is bounded by latitude 27⁰ 30' to 27⁰ 45' N and longitude 83⁰ 18' to 83⁰ 30'E. Most part of the area is relatively flat, and the elevation gradually increases towards the north. Location map is shown Fig. 1. It has sub-tropical climate characterized by hot summers and relatively cool and dry winters. Surface drainage is from north to south by means of rivers and streams. The Tinau River and the Dano Rivers are the main rivers. Texture of the soil of the area is mainly moderately fine to fine such as silty loam, silty clay, loam and silty clay (BLGWIP, 2000).

GEOLOGICAL AND HYDROGEOLOGICAL SETTING

Study area belongs to the Terai and the Siwalik zones of Nepal. The Terai is the southernmost part of Nepal with flat

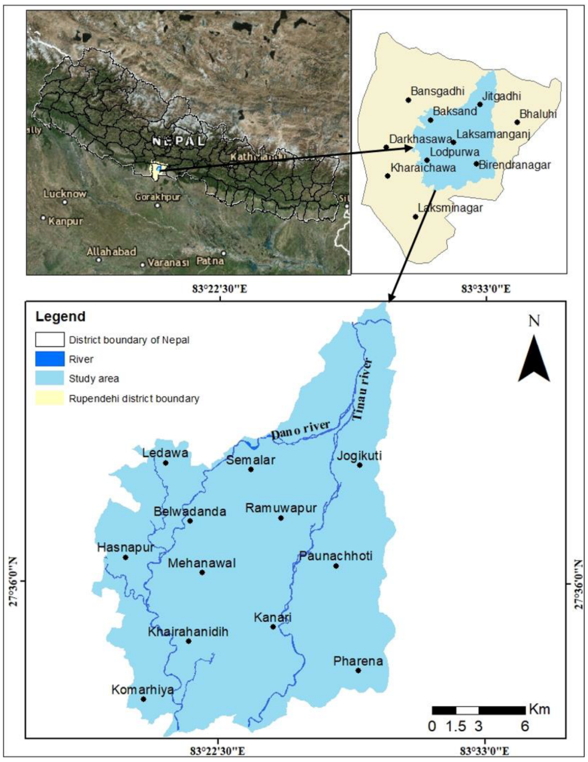

Fig.1: Location map of the study area

topography which extends from Nepal-India border (south) to the Siwalik (north). Both zones are separated by a thrust known as the Main Frontal Thrust (MFT)(Fig. 2a). The Terai Zone consists of alluvial deposits of Pleistocene age which is weathering product of rocks of the Siwalik and the Lesser Himalaya zones. The Siwalik Zone consists of sedimentary rock such as shale, mudstone, sandstone and conglomerate ranging in age from Middle Miocene to Pleistocene.

Intercalation of coarse sediments is found throughout the study area as shown in geological cross-sections (Figs. 2b and 2c). Thickness of sediments varies both in vertical and lateral directions. The proportion of the coarser sediments decreases from the north to the south (Fig. 2b) and moving away from the main rivers (Fig. 2c). Considering coarser sediments (sand, gravel and pebble) as an aquifer material, northern part of the study area has thick unconfined aquifer whereas, southern part has only semi-confined aquifer bounded by thick aquitard. Similarly, thickness of the aquifer decreases moving from the east to the west.

METHODOLOGY

Groundwater sampling and lab work

Total 30 samples were collected including springs, Deep Tube Wells (DTWs), Shallow Tube Wells (STWs) and river. Location of individual samples is shown in the Fig. 3. Twelve

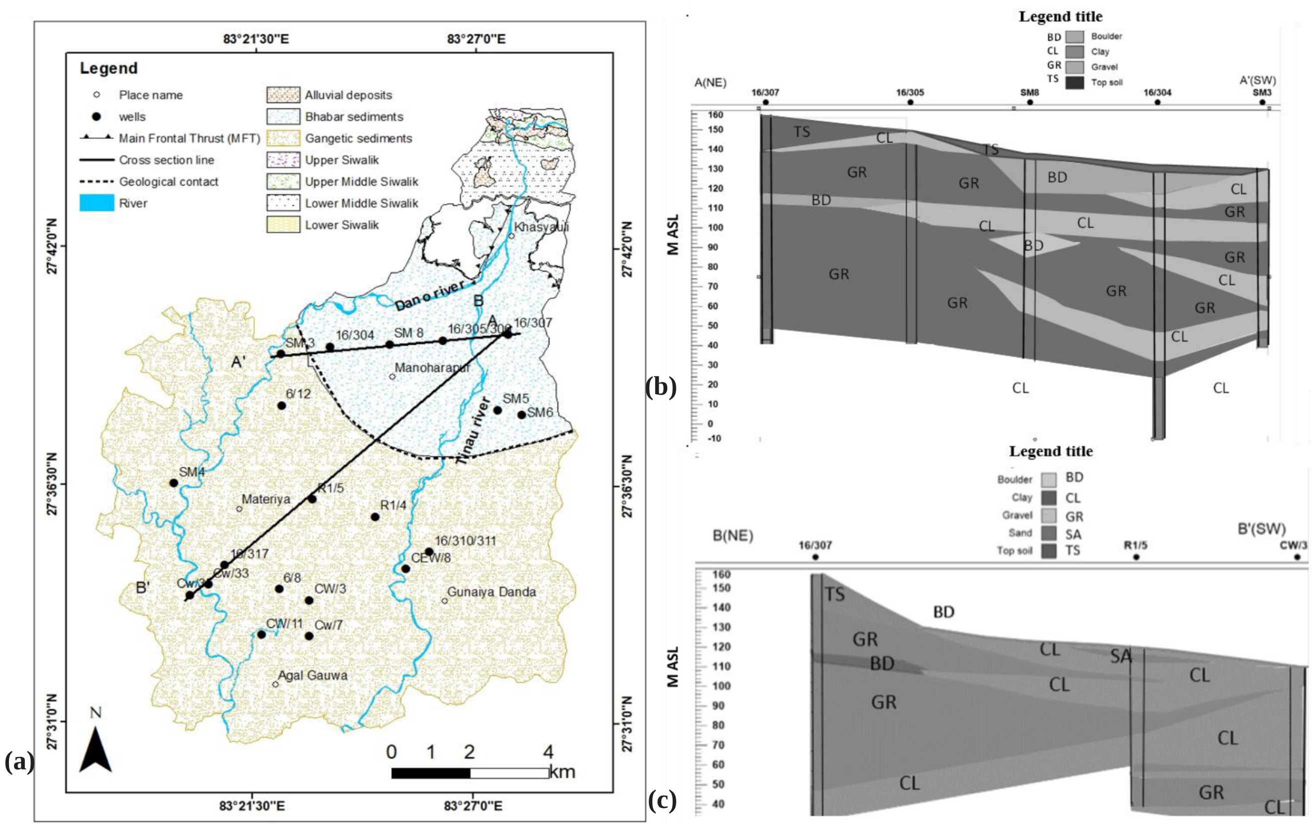

Fig. 2: Geological map of the study area with cross-section lines and geological cross-section passing along the line A-A' and B-B'

out of sixteen DTWs were being used for only irrigation and remaining four DTWs were being used both for irrigation and drinking purposes. Polyethylene half-liter drinking water bottles were used as sample bottles. These were ringed three times and were fully filled. All the samples were brought to Applied Geology and Hydrogeology laboratory, Ghent University, Belgium, where major cations (Na^+, Ca^{2+}, Mg^{2+}, K^+, Fe^{2+}, Mn^{2+}, Al^{3+} and NH^{4+}), anions (Cl^-, SO_4^{2-}, NO_3^-, NO_2^-, HCO_3^-, CO_3^{2-}, PO_4^{3-}, and OH^-) and trace elements (F- and Br-) were measured. Na^+, Ca^{2+}, Mg^{2+}, Fe^{2+} and Mn^{2+} were measured using Atomic Absorption Spectrometry (AAS). Cl^-, NO^{3-}, NO^{2-}, PO_4^{2-} and NH_4^+ were measured by spectrophotometry. HCO_3^- and SO_4^{2-} were measured after titration with HCL, F^- and Br^- was measured with specific ion electrodes. In addition of chemical properties of water, pH and EC were also measured using pH electrode and EC electrode, respectively.

Hydrogeochemical interpretation method

For the analysis of the obtained lab result Piper diagram, scatter diagram and a classification (Stuyfzand, 1986) were applied. Piper diagram was plotted using the software Aquachem 3.70. The percentage of major cations and anions from each sample in (meq/l) was plotted in a separate triangular diagram. Then each point was transferred to the diamond shape diagram. The position of the point in this diagram gave the type of water. Each corner of this diagram showed different water type namely, calcium bicarbonate (Ca-HCO_3), sodium bicarbonate (Na-HCO_3), sodium chloride (Na-Cl) and calcium chloride (Ca-Cl). The same software Aquachem 3.70 was used plotting scatter diagram where two parameters were plotted in the X-Y axis to see relation between different ions. Stuyfzand (1986) classification combines four symbols. First symbol was based on the Cl- content (mg/l) in sample, which was subdivided into Fresh, Fresh brackish, Brackish, Brackish salt, Salt and Hyperhaline. The second symbol was based on the total hardness. It expressed the concentration of Ca^{2+} and Mg^{2+} in water. Third symbol was based on the water type, the dominant cations and anions. Two different triangles, each for cation and anion were used to plot sum of major cation and anion with their hydrochemical families. These families were represented at the corner of their respective triangles and consisted of hydrochemical pair constituents. Each pair again consisted of one or more individual constituent and was separated by brackets. The fourth symbol of the classification was cation exchange code, which was based on nature of the cation exchange. The sum of the Na^+, K^+ and Mg^{2+} was corrected for the seawater contribution, determined from the Cl^- content. The hardness and cation exchange code in the classification was very useful studying salt water intrusion phenomenon.

Total dissolved solid (TDS) was obtained by summing up all analysed cations and anions present in the water sample. Ionic balance was checked by using the following formula where sum of the anions (meq/l) must be equal to sum of cations (meq/l) because of electro-neutrality.

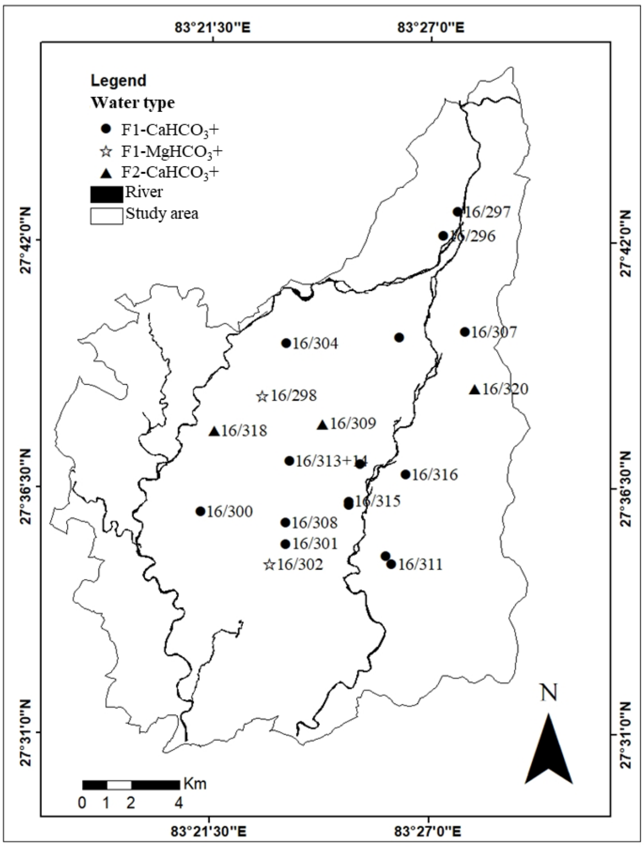

Fig. 3: Sampling location point

$$\text{Ionic balance} = [(\text{SUMc} - \text{SUMa})/(\text{SUMc} + \text{SUMa})].100 \quad (1)$$

where, SUMc is the sum of cations and SUMa is the sum of anions. The margin of the error is accepted ± 5%

Water quality test method

Deep tube wells in the study area were installed by government of Nepal. Groundwater is being distributed through pipeline system mainly in city area both for irrigation and for drinking purposes. In the case of unavailability of deep tube wells, shallow tube wells were being used for all purposes. The suitability of groundwater especially for drinking purposes was tested by comparing the lab analytical result with standards of WHO (WHO, 2004) and standards of government of Nepal (DWSS, 2005).

Similarly, the quality of water for irrigation was determined using several classification schemes. A classification of United States Department of Agriculture (USDA, 1954) was applied for Sodium Adsorption ratio (SAR) and Electrical Conductivity (EC) concentration in water. Quality of irrigation water was also tested based in Cl^- and SO_4^{2-} content, Na^+ percentage (Hopkins, et al., 2007; Mtoni et al., 2013) and Magnesium Hazard (MH). SAR, Na+ % and MH was calculated using the following formulas.

$$SAR = Na^+ / ((Ca^{2+} + Mg^{2+})/2)0.5 \quad (2)$$

$$Na^+\% = (Na^+ / (Na^+ + Ca^{2+} + Mg^{2+} + K^+)) * 100 \quad (3)$$

$$MH = (Mg^{2+} / (Ca^{2+} + Mg^{2+})) * 100 \quad (4)$$

RESULTS AND DISCUSSIONS

The laboratory results of the 30 samples are listed (Table 1). The pH of the water ranges from 6.71 to 7.79. Dominant cations and anion are Ca^{2+}, Mg^{2+} and HCO_3^- for all samples as shown in the Piper diagram (Fig. 4). Eighteen samples have the Ca-Mg-HCO_3 water type whereas remaining 12 samples are Mg-Ca- HCO_3.

All samples contain less than 150 mg/l Cl- ion, based on the first symbol of Stuyfzand (1986) classification, water samples are classified as fresh water, and code F is given for the representation. Total hardness for 26 samples is less than 20 ^{0}F and more than 20 (^{0}F) for four samples (16-307, 16-312, 16-318 and 16-320). Based on the third symbol of the classification, 28 samples have Ca^{2+} and HCO_3^- as a dominant cation and anion, respectively, whereas Mg^{2+} is higher than the calcium in two samples (16-298 and 16-302). Based on the fourth symbol of classification all samples have surplus of (Na^++K^++Mg^{2+}).

A mapping of the water type based on the Stuyfzand (1986) classification is shown in Fig. 5. The calculated value of saturation index for calcite and dolomite ranges from -2.08 to 0.33. As listed in Table 2, most of the samples are undersaturated with respect to calcite and dolomite. Three spring samples from Shanti toll (16/294), Siddharth highway (16/295) and Tamnagar (16/296) are saturated with respect to both calcite and dolomite. A deep tube well sample (Shankhanagar, 16/307) is saturated with respect to calcite but under saturate with dolomite.

Cross plots in the Fig. 6 shows the relationship of different ions such as Ca^{2+}, Mg^{2+}, SO_4^{2-}, with and TDS. There is linear relation between ions Ca^{2+} and HCO_3^- with TDS co-relation coefficient 0.53 and 0.94, respectively. High co-relation coefficient value indicates high concentration of calcium and bicarbonate ion with respect to total dissolve solid in water samples. There is also small concentration of magnesium. It indicates chemistry of the water of the area is from carbonate mineral dissolution such as dissolution of calcite ($CaCO_3$), dolomite CaMg $(CO_3)_2$.

Release of major ions in the water samples is from following reactions. When rainwater meets atmospheric CO_2, it becomes slightly acidic

$$H_2O + CO_2 = H_2CO_3$$

$$H_2CO_3 = HCO_3^- + H+$$

When this slightly acidic water infiltrates through the groundwater it dissolves carbonate minerals if they are present

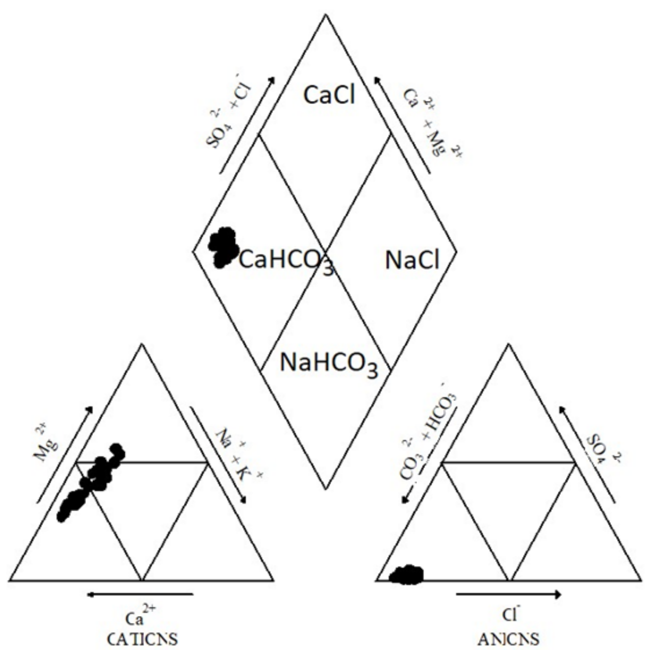

Fig. 4: Piper diagram plot of the area to know water type, unit of the ions plotted in this diagram is mg/l

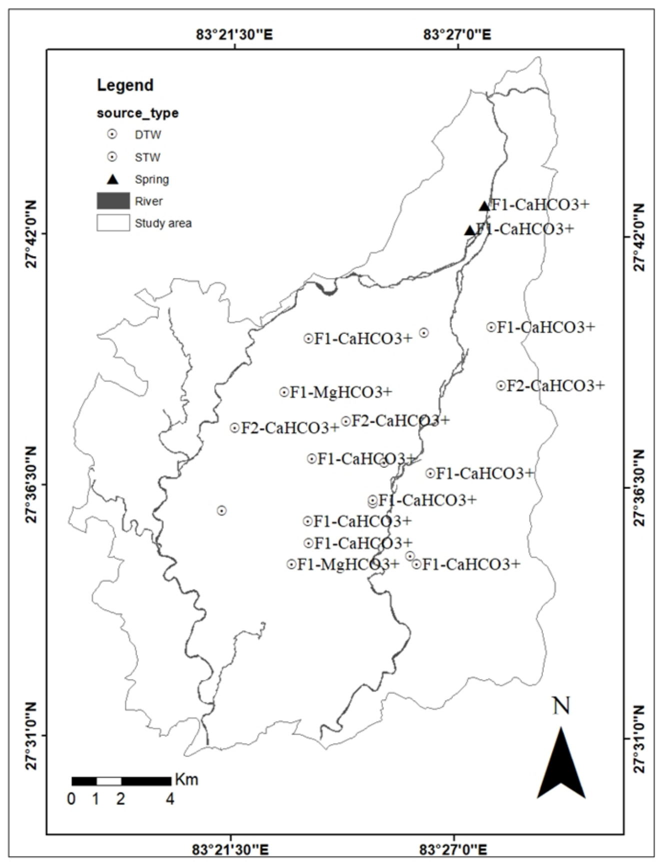

Fig. 5: Mapping of the water type based on Stuyfzand (1986) classification

Table 1: Analytical lab result for 30 samples, STW= Shallow Tube Well, DTW= Deep Tube Well

Location	Sample type	Lab number	pH	EC ($\mu S/cm$)	Na^+ (mg/l)	K^+ (mg/l)	Ca^{2+} (mg/l)	Mg^{2+} (mg/l)	Mn^{2+} (mg/l)	Cl^- (mg/l)	SO_4^{2-} (mg/l)	NO_3^- (mg/l)	NO_2^- (mg/l)	HCO_3^- (mg/l)	PO_4^{2-} (mg/l)	TDS (mg/l)	F (mg/l)	Br^- (mg/l)
Shanti tol	Spring	16/293	7.44	334	10.48	4.91	39.74	22.40	0.002	8.78	2.69	1.80	0.02	223	0.05	313.5	0.15	0.13
Chidiya Khola	Spring	16/294	7.76	334	8.56	2.83	32.08	22.06	0.001	9.62	4.14	4.41	0.03	228	0.04	311.3	0.92	0.08
Siddhartha highway	Spring	16/295	7.79	344	7.10	2.07	44.66	16.14	0.003	17.01	2.08	2.57	0.01	220	0.07	311.3	0.85	0.08
Tamnagar	Spring	16/296	7.79	298	9.62	1.53	25.86	19.08	0.004	17.34	1.67	3.66	0.01	189	0.04	267.9	0.11	0.08
Butwal	Spring	16/297	7.23	367	10.86	2.86	27.62	29.44	0.001	15.35	1.98	6.31	0.02	256	0.04	350.1	0.11	0.10
Khadgabangai	STW	16/298	7.32	314	10.44	0.93	34.10	21.48	0.003	13.99	3.42	4.15	0.08	204	0.04	293.0	0.61	0.11
Harnaiya	STW	16/299	7.25	308	10.10	3.72	25.94	21.88	0.001	15.75	5.02	3.95	0.01	179	0.04	265.8	0.14	0.15
Manmateria	STW	16/300	7.34	292	12.20	1.09	29.74	19.32	0.002	15.19	4.47	5.96	0.01	178	0.04	265.5	0.12	0.09
West Amuwa	STW	16/301	7.25	332	12.52	1.22	24.32	24.68	0.002	12.68	7.67	7.60	0.01	188	0.04	279.2	0.11	0.17
Pharsaktikar	STW	16/302	7.19	329	12.64	0.97	36.32	21.08	0.001	14.38	5.28	2.82	0.01	209	0.06	302.8	0.11	0.12
Aanandaban	DTW	16/303	7.22	277	10.23	1.47	30.00	16.28	0.003	7.01	5.69	9.64	0.01	158	0.05	238.4	0.17	0.13
Semlar	DTW	16/304	7.19	280	7.04	1.15	38.40	16.08	0.004	16.74	6.98	6.09	0.02	178	0.05	270.1	0.17	0.10
Motipur	DTW	16/305	7.28	298	6.80	1.33	52.40	16.75	0.003	17.54	7.22	2.93	0.01	223	0.06	328.3	0.11	0.09
Motipur	STW	16/306	7.30	295	6.78	1.80	29.26	19.12	0.002	16.51	5.27	5.89	0.01	171	0.06	255.3	0.11	0.11
Shankhanagar	DTW	16/307	7.37	342	7.46	1.10	64.28	17.80	0.001	11.14	3.81	14.02	0.02	244	0.06	363.7	0.09	0.15
S.Madanganj	DTW	16/308	7.33	301	7.46	0.99	29.30	22.20	0.006	11.94	4.06	4.75	0.01	195	0.06	275.4	0.10	0.09
Pharsatikar	DTW	16/309	7.29	281	6.76	1.02	43.06	17.02	0.005	17.13	4.21	2.86	0.02	195	0.06	287.3	0.10	0.08
Durganagar	DTW	16/310	7.26	285	6.44	0.95	35.50	17.62	0.001	11.95	5.23	6.16	0.02	184	0.06	268.2	0.11	0.08
Durganagar	STW	16/311	7.41	324	6.24	0.94	48.66	18.60	0.002	14.24	3.68	10.12	0.02	221	0.07	324.0	0.10	0.11
Betahi	DTW	16/312	6.74	296	6.06	1.41	56.02	16.48	0.004	14.64	3.85	3.68	0.14	226	0.08	328.7	0.11	0.08
East Sitalpat	DTW	16/313	6.81	341	9.38	4.46	32.68	22.32	0.005	13.15	7.03	13.66	0.01	180	0.07	282.7	0.13	0.22
East Sitalpat	STW	16/314	6.71	294	7.74	1.04	28.86	20.04	0.004	17.19	5.28	0.00	0.01	177	0.07	257.1	0.12	0.08
W.Sakhuwani	DTW	16/315	7.19	265	6.02	2.79	32.96	15.92	0.000	11.42	5.82	8.06	0.01	157	0.07	240.5	0.12	0.08
W.Pauni	DTW	16/316	7.28	282	6.76	1.24	31.48	20.00	0.003	15.10	4.44	7.17	0.02	172	0.08	258.3	0.12	0.11
Kotihawa	DTW	16/317	7.36	328	6.44	2.22	36.66	21.88	0.003	14.78	4.03	8.61	0.03	193	0.07	287.5	0.10	0.14
Puraini	DTW	16/318	7.05	381	6.02	1.05	61.36	15.54	0.002	13.25	5.04	5.22	0.01	235	0.08	342.4	0.11	0.08
Tinau River	River	16/319	7.24	276	5.98	1.25	40.80	14.36	0.002	16.30	3.87	9.04	0.01	174	0.08	266.2	0.10	0.08
Driver toll	DTW	16/320	7.17	327	6.47	1.01	60.08	19.30	0.004	15.38	4.01	12.95	0.03	235	0.08	354.2	0.09	0.17
Chidiya Khola	River	16/321	7.64	265	8.14	1.84	30.28	15.88	0.001	18.81	2.69	1.48	0.01	176	0.08	255.5	0.06	0.07
Butwal	River	16/322	7.32	311	6.88	1.95	45.12	15.14	0.003	11.60	5.38	3.35	0.01	188	0.08	277.4	0.07	0.11

Table 2: Saturation index calculation for calcite and dolomite

Samples	Type	Calcite	Result with respect to calcite	Dolomite	Result with respect to dolomite
16/293	Spring	-0.08	undersaturation	-0.06	undersaturation
16/294	Spring	0.17	supersaturation	0.53	supersaturation
16/295	Spring	0.33	supersaturation	0.57	supersaturation
16/296	Spring	0.04	supersaturation	0.31	supersaturating
16/297	Spring	-0.41	undersaturation	-0.44	undersaturation
16/298	STW	-0.3	undersaturation	-0.46	undersaturation
16/299	STW	-0.55	undersaturation	-0.82	undersaturation
16/300	STW	-0.4	undersaturation	-0.63	undersaturation
16/301	STW	-0.56	undersaturation	-0.77	undersaturation
16/302	STW	-0.41	undersaturation	-0.71	undersaturation
16/303	DTW	-0.57	undersaturation	-1.05	undersaturation
16/304	DTW	-0.45	undersaturation	-0.93	undersaturation
16/305	DTW	-0.13	undersaturation	-0.41	undersaturation
16/306	STW	-0.46	undersaturation	-0.76	undersaturation
16/307	DTW	0.08	supersaturation	-0.05	undersaturation
16/308	DTW	-0.38	undersaturation	-0.52	undersaturation
16/309	DTW	-0.26	undersaturation	-0.56	undersaturation
16/310	DTW	-0.39	undersaturation	-0.74	undersaturation
16/311	STW	-0.03	undersaturation	-0.13	undersaturation
16/312	DTW	-0.72	undersaturation	-1.63	undersaturation
16/313	DTW	-0.96	undersaturation	-1.74	undersaturation
16/314	STW	-1.14	undersaturation	-2.08	undersaturation
16/315	DTW	-0.56	undersaturation	-1.09	undersaturation
16/316	DTW	-0.45	undersaturation	-0.75	undersaturation
16/317	DTW	-0.26	undersaturation	-0.39	undersaturation
16/318	DTW	-0.42	undersaturation	-1.09	undersaturation
16/319	River	-0.38	undersaturation	-0.86	undersaturation
16/320	DTW	-0.18	undersaturation	-0.51	undersaturation
16/321	River	-0.07	undersaturation	-0.07	undersaturation
16/322	River	-0.22	undersaturation	-0.56	undersaturation

on the way of water. The reactions taking place during the dissolution of calcite and dolomite are

$$CaCO_3 + H^+ = Ca^{2+} + HCO_3^-$$

$$CaMg(CO_3)_3 + 2H^+ = Ca^{2+} + Mg^{2+} + 2HCO_3^-$$

Small concentration of Na^+, K^+ and SO_4^{2-} in water can be released in water from hydrolysis reaction of silicate minerals and pyrite oxidation as following reaction.

$$(K^+, Na^+)\ AlSi_3O_8 + H^+ + H_2O = \text{clay mineral} + (K^+, Na^+) + SiO_2\ (aq)$$

$$2\ FeS_2 + 2H_2O + 7O_2 = 2Fe^{2+} + 4\ SO_4^{2-}$$

Analytical lab results are compared with the guidelines of WHO (2004) and with the National Drinking Water Quality Standards (DWSS, 2005) (Table 3). The concentration of inorganic constituents in every samples are below guidelines values which indicates water of the study area is good for drinking purposes. Calculated SAR value of the area ranges from 0.97-2.53. Based on USDA classification of SAR, water of the area is excellent for irrigation (Table 4 and 5). As shown in Table 6, value of SO_4^{2-}, Cl^- and Na% is below 192 (mg/l), 142 (mg/l) and 20%, respectively which indicates quality of water for irrigation is excellent. Based on Szabolcs and Darab (1964) classification value of magnesium hazard below 50 % is considered suitable water for irrigation and magnesium hazard for all samples of the area ranges between 41.59-20.21% (Table 7).

CONCLUSIONS

Most part of the study area consists of heterogenous mixture of alluvial sediments ranging in size from boulder to clay. Thickness of the aquifer varies throughout the area. In the north-eastern part, both confined and unconfined aquifers occur whereas in the southern part only confined aquifer occurs. Groundwater of the area is slightly acidic to basic. Major

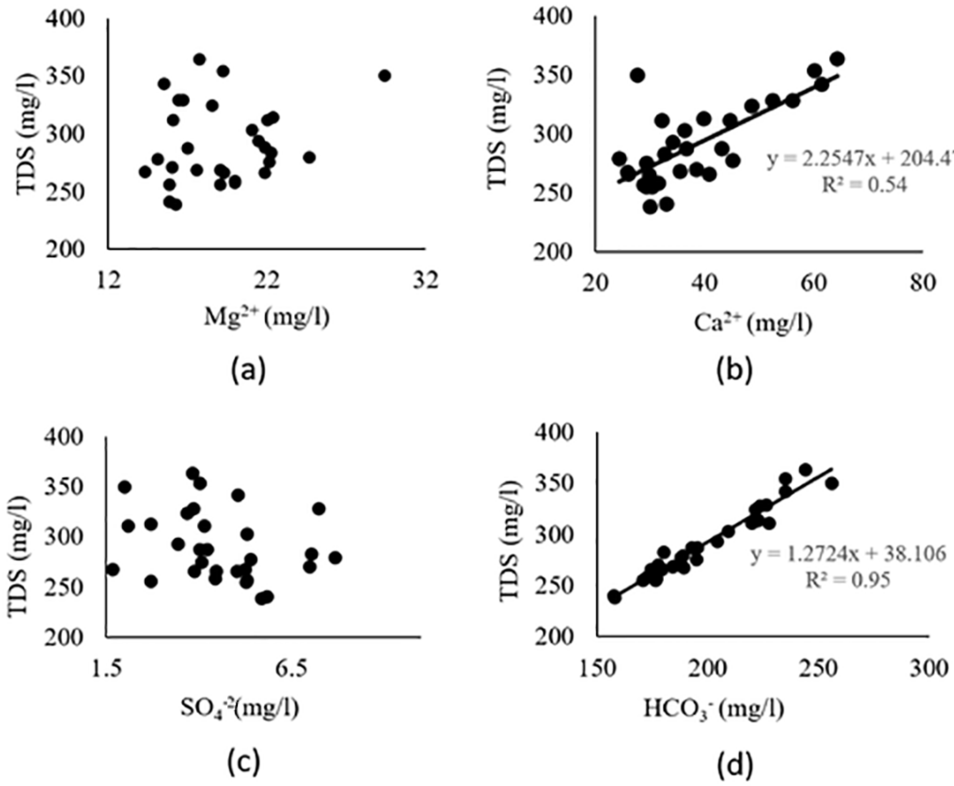

Fig. 6: Cross plots showing the relation of dominant cations with TDS

Table 3: Comparison of WHO and National drinking water quality standards with the samples

Parameters	WHO standards (2004)	National Drinking Water Quality Standards (DWSS, 2005), Government of Nepal	Ranges of parameters in water samples
pH	6.5-9.2	6.5-8.5	6.74-7.79
EC (µS/cm)	500-1500	1500	293-653
TDS (mg/l)	1000	1000	238-364
Na + (mg/l)	200	-	5.98-12.6
K (mg/l)	200	-	0.93-4.91
Ca 2+ (mg/l)	200	200	24-64
SO42- (mg/l)	250	250	1.67-7.67
Cl- (mg/l)	250	250	7-19
Fe (mg/l)	0.3	0.3	0
Br- (mg/l)	2.4	-	0.07-0.22
F^- (mg/l)	1.5	0.5-1.5	0.06-0.92
NO_3^- (mg/l)	50	50	14.02

dissolves ions are Ca^{2+} and Mg^{2+}, HCO_3^-, Na^+, K^+ and $SO4^{2-}$. Calcium bicarbonate is dominant water type of the area. Most of samples are fresh, moderately hard calcium bicarbonate water type and are surplus in (Na^++K^++Mg^{2+}) which is denoted by F1-$CaHCO_3^+$. The sources of these ions in the water are from dissolution of calcite, dolomite, feldspar, and pyrite. Quality of water in terms of inorganic constituents is good both for irrigation and drinking purposes.

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Table 4: Calculated value of different parameters for irrigation water quality test, SAR= Sodium Adsorption Ratio, MH= Magnesium Hazard

Lab number	SO_4^{2-}	Cl^-	SAR	Na%	MH
16/293	2.7	8.8	1.88	13.52	36.05
16/294	4.1	9.6	1.65	13.06	40.75
16/295	2.1	17.0	1.29	10.15	26.55
16/296	1.7	17.3	2.03	17.15	42.46
16/297	2.0	15.4	2.03	15.34	51.59
16/298	3.4	14.0	1.98	15.59	38.65
16/299	5.0	15.7	2.07	16.39	45.75
16/300	4.5	15.2	2.46	19.57	39.38
16/301	7.7	12.7	2.53	19.96	50.37
16/302	5.3	14.4	2.36	17.80	36.72
16/303	5.7	7.0	2.13	17.64	35.18
16/304	7.0	16.7	1.35	11.23	29.52
16/305	7.2	17.5	1.16	8.80	24.22
16/306	5.3	16.5	1.38	11.90	39.52
16/307	3.8	11.1	1.16	8.23	21.69
16/308	4.1	11.9	1.47	12.44	43.11
16/309	4.2	17.1	1.23	9.96	28.33
16/310	5.2	11.9	1.25	10.64	33.17
16/311	3.7	14.2	1.08	8.38	27.65
16/312	3.9	14.6	1.01	7.58	22.73
16/313	7.0	13.2	1.79	13.63	40.58
16/314	5.3	17.2	1.57	13.42	40.98
16/315	5.8	11.4	1.22	10.43	32.57
16/316	4.4	15.1	1.33	11.36	38.85
16/317	4.0	14.8	1.19	9.58	37.38
16/318	5.0	13.3	0.97	7.17	20.21
16/319	3.9	16.3	1.14	9.58	26.03
16/320	4.0	15.4	1.03	7.45	24.31
16/321	2.7	18.8	1.69	14.50	34.40
16/322	5.4	11.6	1.25	9.96	25.12

Table 5: Classification of irrigation water quality based on SAR value

SAR	Water class	Quality of water	Samples
<10	Low sodium water (S1)	Excellent	All samples
10-18	Medium sodium water (S2)	Good	
18-26	High sodium water (S3)	permissible	
>26	Very high sodium water (S4)	Doubtful-unsuitable	

Table 6: Classification of irrigation water based on SO_4^{2-}, Na^+, % and Cl^-,

SO_4^{2-} (mg/l)	Cl^- (mg/l)	(Na^+ %)	Quality of water	Samples
<192	<142	<20	Excellent	All samples
192-336	142-249	20-40	Good	
336-575	249-426	40-60	Permissible	
575-960	426-710	60-80	Doubtful	
>950	>710	>80	Unsuitable	

Table 7: Quality classification of irrigation water based on Magnesium Hazard (MH)(Szabolcs and Darab, 1964)

Magnesium Hazard (%)	Quality of water	Samples category
<50	Suitable	All samples
>50	Harmful	

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