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MAJOR ION CHEMISTRY, HYDRO-GEOCHEMICAL STUDIES AND MAPPING OF VARIABILITY IN GROUND WATER QUALITY OF SITANADI BASIN, SOUTHERN KARNATAKA

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Abstract: The present study has been carried out for the Sitanadi basin, one of the major west flowing rivers in the west coast of Karnataka, with the objective to assess various factors controlling the groundwater chemistry. It includes water rock interaction, seasonal variations of the groundwater quality in pre and post monsoon periods and to determine its suitability for domestic use confirming to the latest water quality standards. The quality of water in Sitanadi basin is found good in all locations except very few. Soil water interaction and precipitation are the major contributors for the water quality status of the study area. Groundwater in the Sitanadi basin is acidic in nature. The dominance of cation in the study area is in the form of $Ca^+>Na^+>K^+>Mg^+$ and anion dominance is in the form of $HCO_3^->Cl^->SO_4^{2-}>NO_3^2$ in pre-monsoon season. In post-monsoon season dominance of cation in the study area is represented by $Na^+> Ca^+> Mg^+ >K^+$ and $HCO_3^-> Cl^->SO_4^{2-}>NO_3^{2-}$ is represents the dominant major anions in pre monsoon season.

Keywords: Anions; Ground water; Rock water interaction; Water quality.

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INTRODUCTION

Groundwater is the main source of water that meets the agricultural, industrial and household requirements. Population growth, socioeconomic development, technological and climate changes has increased the demand for potable water manifolds in the past few years (Alcamo et al. 2007). Water quality is defined by certain physical, chemical and biological characteristics of water. It is determined by the solutes and gases dissolved in the water as well as the matter suspended in and floating on the water (Todd and Mays 2005). Knowledge on hydrochemical characteristics is more important to assess the groundwater quality for understanding its suitability for various purposes. Investigations have reported that groundwater is highly susceptible to pollution from natural and anthropogenic factors (Jain and Sharma, 2000). In India, over exploitation of groundwater without commensurate recharge, indiscriminate use of chemicals in agriculture and residues of pollutants from pesticides and fertilizers percolating to ground in many parts of the India has resulted in deterioration of groundwater quality (Goyal *et al.,* 2010). Moreover untreated effluents from industrial and domestic sectors have also polluted the groundwater (Palaniswami and Ramulu, 1994). Aquifers in the coastal area are generally fragile and in most of the regions, the shallow aquifers are easily depleted due to over exploitation of groundwater (Chidambaram *et al.,* 2008). The water quality of the groundwater is determined predominantly by the geochemical processes, chemical and mineral composition of the aquifer rocks, residence time and other factors related to groundwater flow and addition of effluents through human interference. Continuous abstraction of water, if increases more than natural recharge, may lead to decrease in storage. The decrease in stored water in groundwater reservoir may increase the concentration of salts and consequently deteriorate its chemical quality (Jain et al., 1997). Therefore, a regular check of its chemical quality is required for assessing its suitability for different purposes and for quantitatively monitoring any future change. In the past few years the Geographic Information System (GIS) has become an efficient and effective tool in solving problems where data varies in spatial extent. Therefore it is widely used for evaluation and assessment of water quality and developing solutions for water resources related problems (Chaudhary *et al.* 1996).

Study Area: Sitanadi basin (Figure 1) is located in the west coast of peninsular India, Udupi district of Karnataka, India. It extended between 13020′ and 13035′ N latitudes and 74040′ and 75°10′ E longitude. The total geographical area of the basin is about 643.65 sq km. In Sitanadi basin, physiographical divisions consist of low land, mid-land and high land. The low land region is 2-8 km wide sandy tract running parallel to the coast. It extends up to a distance of 16 km along the river course. It has small lateritic ridges with cultivable low lands, in between small exposures of gneisses and laterite hillocks with sparse vegetation.The midland region consists of laterite ridges, mesas and also structural hills composed of gneisses with incised narrow valleys of younger cycle. High land hills comprise mostly of archaean gneisses and etavolcanics and metasediments of Dharwar super group of proterozoic age. The major lithological units of Sitanadi catchment area are banded granitic gneisses and laterites and some parts are covered by chlorite schist's. Some intrusive bodies like dolerite dykes and pegmatite veins are also noticed. Thin layer of coastal sediments is also found in the western part of the catchment. The rocks of the area belong to different periods like Archaean, Proterozoic, Cretaceous, Tertiary and Quaternary.

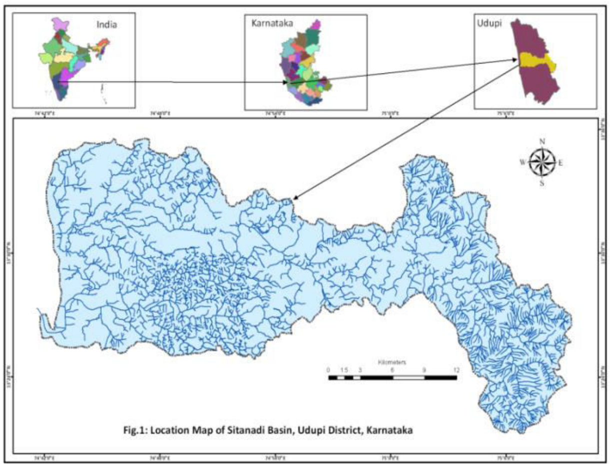

Fig.1: Location Map of Sitanadi Basin, Udupi District, Karnataka

Climate and rainfall: The Sitanadi basin has a tropical monsoon climate. March April and May are the hottest months while December and January are the coldest. However the day temperature remains high even in December and January. The maximum temperature recorded during April is about 35°C and the minimum temperature of 18.54°C in January. The rainfall in the basin is mainly due to convection and orographic. It receives an approximate average rainfall of 4832 mm and about 90% of which occurs during the monsoon period (June–September). Average maximum and minimum humidity, pan evaporation, actual sun shine and wind velocity are 96.53 % in July, 41.12% in January, 6.09 mm/day in April, 9.62 hours/day in February and 3.64 Km/h in April respectively. In the study area about 32% of the land is covered by tree groves 28% area is covered by forest land and 25% of the area is covered by agricultural land.

EXPERIMENTAL

Topographical maps of the area numbering 48K/11/NE, 48K/10/NW, 48K/14/SW, 48K/15/NW, 48K/14/SE, 48K/15/NE, 48O/2/SW and 48O/3/NW on 1:25,000 scale were collected from Survey of India department, were used for base map preparation and boundary demarcation of the study area. One liter polyethylene bottles were used for groundwater sample collection for the major ions chemical analysis. Bottles are washed well and rinsed with deionised water before sampling. The water samples from dug wells are collected at 0.5 m below the water table using standard sampling techniques. These samples are used for the analysis of major cations (Na^+, K^+, Ca^{2+}, Mg^{2+}) and major anions (Cl^-, HCO_3^-, SO_4^{2-}, NO_3^{2-}). Immediately after sampling, pH, EC, TDS in the field by a portable pH (Systronics) and an EC meter (Systronics). Sodium (Na^+), potassium (K^+), calcium (Ca^{2+}) and magnesium (Mg^{2+}) were measured using digital flame photometer (Systronics Model No. 103) and values are cross checked with titrimetric method. Bicarbonate (HCO_3^-) concentrations of the groundwater were determined by potentiometric titration method. Sulphate (SO_4^{2-}) and Nitrate (NO_3^{2-}) of the water samples were analyses using photoelectric calorimeter (Systronics, model no-112). Cl content of the water samples are measured using argentometric method. High purity analytical reagents were used throughout the study, and chemical standards for each element when necessary were prepared separately. A total of 56 open dug wells were inventoried for groundwater samples collection in Sitanadi basin (Fig.2). Two sets of groundwater samples were collected from the dug wells during pre-monsoon (PRM) and post-monsoon (POM) seasons of 2011, 2012 and 2013.

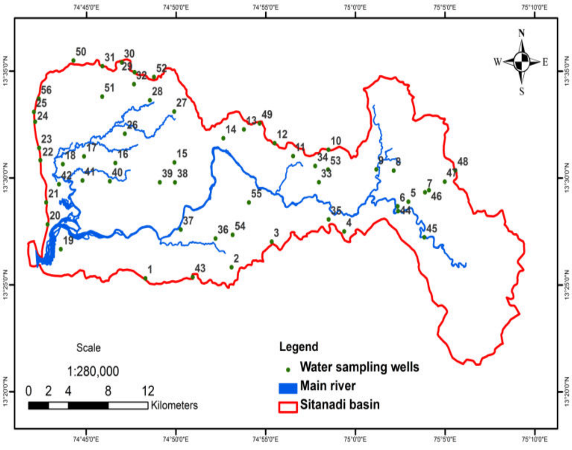

Figure.2: Location map of water sampling stations in Sitanadi basin

Preparation of Thematic Maps for Water Quality Parameters:

The boundary map of Sitanadi basin was prepared from topographical maps by digitizing in ArcGIS 9.2 software. A well location map (Fig.2) for 56 observation wells was also digitized and quality data was attached with this well location point map in the form of an attribute table. To know the spatiotemporal behavior of the groundwater quality in the study area, the point map was then opened in ArcGIS 9.2 software and Inverse Distance Weighted (IDW) point interpolation technique was used to obtain spatial distribution maps for different quality parameters (Mueller et al., 2004; Tomczak 1998; Tabios and Salas 1985). The maps were generated for both PRM and POM seasons to compare the effect of seasonal atmospheric changes on quality of water.

RESULTS AND DISCUSSION

Groundwater samples collected from the dug wells are subjected to physico-chemical analysis. Since there was not much variation in the water chemistry of two samples collected during PRM and POM, average values of each season are tabulated in Table 1 and 2.

Mechanisms of controlling the groundwater chemistry: Various factors controlling the chemistry were analyzed by Gibbs diagram, which indicates that the majority of groundwater samples were individually scattered in the precipitation dominance field (Figure 3) suggesting that base exchange processes and leaching of minerals are influencing the ground water quality (Gibbs 1970). The few samples falls in rock dominants field represents the chemical weathering or rock forming minerals are influencing the groundwater quality. In the plot few samples falling away from the zone indicate that apart from base exchange and weathering processes, other factors of natural and human intervention also play a role in the water chemistry of the Sitanadi basin.

Table 1: Physical and chemical parameters of groundwater samples in Sitanadi basin (Pre-monsoon)

Well	pH	EC	Ca^{2+}	Mg^{2+}	Na^+	K^+	HCO_3^-	SO_4^{2-}	Cl^-	NO_3^{2-}	TH	TDS
1	6.30	55.50	6.00	1.30	8.00	2.00	25.00	4.78	12.86	0.30	21.00	36.40
2	6.71	116.00	18.40	0.00	10.30	12.10	63.00	7.28	15.00	0.20	44.00	85.80
3	6.70	91.00	5.60	1.00	7.00	5.40	26.00	2.50	10.00	0.60	18.00	59.40
4	6.78	107.50	5.20	1.50	6.50	5.40	23.00	0.85	13.50	0.40	19.00	90.10

5	6.33	124.50	11.20	1.70	10.10	9.70	37.00	0.00	25.00	1.30	35.00	81.50
6	6.43	75.50	9.20	2.90	6.67	5.90	41.00	3.35	13.50	0.40	35.00	49.60
7	6.87	108.50	12.40	2.70	5.75	3.80	38.00	1.48	17.50	0.40	42.00	71.20
8	6.78	92.50	11.60	2.70	8.00	6.90	54.00	0.00	14.50	0.40	40.00	61.50
9	6.46	50.00	5.20	1.50	6.75	3.00	23.00	1.48	13.50	0.50	19.00	32.80
10	6.46	99.50	9.60	2.90	7.00	5.60	36.00	0.63	18.50	0.40	36.00	65.40
11	7.37	110.00	14.80	0.00	9.75	6.40	33.00	0.63	22.50	0.50	32.00	72.10
12	6.77	187.50	22.00	5.90	6.50	8.10	93.00	0.00	18.50	0.40	79.00	123.80
13	6.68	87.00	9.20	2.00	10.25	6.60	37.00	6.25	16.50	0.40	31.00	57.00
14	6.92	98.50	10.00	1.50	8.00	3.00	29.00	1.25	18.50	0.40	31.00	63.90
15	6.94	78.50	11.20	2.00	12.00	7.80	52.00	1.88	18.50	0.30	36.00	73.50
16	6.79	114.50	11.20	2.00	12.25	6.40	46.00	3.53	19.50	0.50	36.00	65.80
17	7.36	86.50	10.00	1.70	7.00	6.30	35.00	2.35	15.00	0.50	32.00	52.20
18	7.18	113.50	11.20	3.20	10.75	5.30	47.00	1.18	18.00	1.60	41.00	62.50
19	6.64	183.50	15.20	2.40	16.59	11.10	37.00	12.67	33.00	2.10	48.00	122.00
20	6.42	155.00	9.20	9.30	12.10	9.00	38.00	7.72	36.00	2.50	48.00	103.10
21	6.15	66.00	3.60	5.60	6.36	6.80	20.00	0.67	20.50	1.30	28.00	43.90
22	5.80	68.50	4.00	1.00	9.50	12.50	24.00	1.00	25.00	0.40	33.00	45.60
23	6.15	131.50	13.20	2.70	11.50	3.90	30.00	8.35	27.00	0.60	44.00	87.50
24	6.12	120.00	8.00	2.20	15.31	8.90	21.00	0.50	37.00	1.00	29.00	79.80
25	6.95	115.50	12.00	1.70	10.75	6.00	42.00	3.34	20.50	0.30	37.00	76.80
26	6.00	105.00	8.00	1.70	13.25	6.00	29.00	2.19	22.50	1.60	27.00	69.80
27	6.46	157.50	27.20	4.20	8.25	7.50	98.00	4.65	18.00	0.40	85.00	104.70
28	6.97	185.00	14.80	2.00	16.25	6.30	57.00	0.84	26.50	0.90	45.00	123.00
29	6.67	75.50	8.00	1.50	8.00	5.10	30.00	1.85	16.00	0.20	26.00	50.20
30	6.48	87.00	11.60	1.20	9.25	7.50	47.00	3.17	14.50	0.50	34.00	57.90
31	6.18	49.50	7.20	1.00	6.25	3.40	28.00	0.60	11.00	0.30	22.00	32.90
32	6.18	49.50	7.20	1.00	6.25	3.40	28.00	0.60	11.00	0.30	22.00	32.90
33	6.71	39.50	6.00	0.80	6.00	5.30	23.00	1.00	12.50	0.00	18.00	26.30
34	7.85	82.00	14.40	0.70	7.50	5.80	46.00	0.67	16.50	0.30	39.00	54.50
35	6.74	171.00	21.60	1.50	14.65	7.10	57.00	5.40	23.00	4.20	60.00	113.70
36	7.17	159.00	20.80	1.20	12.25	9.00	63.00	4.02	22.50	2.10	57.00	105.70
37	6.31	102.50	9.60	2.90	9.25	8.80	32.00	4.50	24.00	0.70	36.00	68.20
38	6.13	76.00	6.00	2.70	10.25	7.40	29.00	3.32	19.00	1.10	26.00	50.50
39	6.62	74.00	7.90	1.20	8.85	6.10	33.00	2.32	14.00	0.80	25.00	49.20
40	6.58	72.00	9.60	1.00	8.25	4.60	33.00	0.67	16.50	0.30	28.00	47.90
41	6.52	76.00	4.80	2.40	6.34	8.30	20.00	1.00	20.00	0.40	2.00	50.50
42	7.01	325.00	17.60	6.30	24.10	27.00	70.00	8.90	50.99	5.10	70.00	216.40
43	6.29	91.50	8.50	1.50	9.85	1.30	33.50	0.00	23.50	0.00	35.00	66.10
44	5.68	38.00	3.20	3.90	5.90	0.50	14.00	3.30	16.00	0.00	24.00	24.70
45	6.88	63.00	13.60	0.00	6.00	1.00	26.00	0.00	13.00	0.20	26.00	41.00
46	6.94	151.00	13.60	7.80	9.00	1.50	72.00	5.00	15.00	0.50	66.00	98.20
47	5.84	130.00	8.50	0.80	6.00	0.30	18.00	4.00	11.00	0.40	16.00	84.50
48	7.23	52.00	9.80	0.00	6.00	0.80	24.00	0.00	11.00	0.10	22.00	33.80
49	6.06	36.00	4.00	1.50	6.00	0.30	20.00	0.00	9.00	0.20	20.00	23.40
50	6.58	103.00	13.60	1.50	9.00	5.30	46.00	1.70	17.00	0.70	31.00	68.50
51	6.55	70.00	4.80	1.00	8.00	0.30	16.00	0.00	14.00	0.20	14.00	46.60
52	6.19	70.00	4.80	4.90	7.00	3.30	34.00	1.70	15.00	0.20	22.00	46.60

53	6.28	30.00	3.20	1.00	6.50	0.80	16.00	0.00	10.00	0.00	12.00	20.00
54	6.85	100.00	12.00	2.40	10.00	0.80	48.00	0.00	13.00	1.30	34.00	66.50
55	6.74	70.00	6.40	1.00	8.50	0.80	26.00	1.70	11.00	0.20	24.00	46.60
56	6.78	73.00	8.80	2.00	5.50	2.30	34.00	0.00	11.00	0.40	11.00	48.60

Note: All parameters are in mg/l except pH and EC (µmohs/cm)

Table 2: Physical and chemical parameters of groundwater samples in Sitanadi basin (Post-monsoon)

Well No	pH	EC	Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	HCO_3^{-}	SO_4^{2-}	Cl^{-}	NO_3^{2-}	TH	TDS
1	6.65	99.00	5.60	1.47	18.00	3.31	28.00	0.00	26.60	0.00	20.00	64.35
2	6.35	42.00	3.60	0.49	7.13	0.67	15.00	0.00	7.50	0.22	11.00	27.30
3	6.11	39.50	4.80	3.66	9.38	0.63	22.00	8.35	12.40	0.01	27.00	25.68
4	6.22	37.00	7.60	0.49	9.38	0.32	27.00	0.85	12.50	0.00	21.00	24.28
5	6.37	194.00	15.20	5.37	33.75	2.50	37.00	9.15	30.50	0.48	60.00	126.10
6	6.37	89.50	11.60	4.39	8.50	0.87	34.00	0.85	24.00	0.25	47.00	58.18
7	6.02	91.00	10.80	3.90	10.75	1.02	42.00	2.50	19.50	0.33	45.00	59.15
8	6.05	34.00	6.80	1.95	7.50	0.80	25.00	2.50	12.50	0.01	25.00	22.10
9	7.26	63.00	8.00	1.71	11.75	0.63	29.00	1.70	17.00	0.28	27.00	40.95
10	5.87	92.00	6.00	4.15	10.25	1.17	21.00	1.65	23.00	0.39	32.00	59.80
11	7.53	54.50	12.00	0.49	7.50	1.00	21.00	10.00	22.50	0.18	31.00	35.43
12	6.19	55.00	4.40	6.83	11.25	0.70	29.00	0.00	25.00	0.17	39.00	35.75
13	7.55	74.50	6.80	4.15	11.50	0.60	31.00	0.85	21.50	0.21	35.00	48.43
14	6.34	61.00	6.40	3.66	12.00	0.88	35.00	0.00	18.50	0.17	31.00	39.65
15	6.72	76.00	18.40	3.42	20.50	1.38	71.00	1.70	29.50	0.12	60.00	67.31
16	6.08	96.50	6.00	1.95	16.63	1.58	24.00	4.15	23.50	0.32	23.00	62.63
17	6.68	61.00	8.80	2.69	8.13	0.54	28.00	2.50	18.00	0.37	33.00	61.84
18	5.91	47.00	6.40	5.13	10.00	1.30	17.00	0.85	25.00	2.36	37.00	63.17
19	6.66	273.00	9.60	6.34	41.00	2.25	43.00	28.30	35.50	1.76	75.00	181.50
20	5.97	87.00	5.60	2.93	18.75	1.52	26.00	5.00	25.50	0.32	26.00	57.86
21	5.78	96.50	5.20	4.15	16.50	0.94	22.00	4.15	25.50	0.91	30.00	64.18
22	6.07	81.00	5.64	9.01	11.25	0.69	28.00	10.00	25.50	0.37	51.00	53.87
23	6.37	113.00	7.60	4.39	18.88	0.90	23.00	20.00	27.50	0.42	37.00	75.15
24	6.39	106.00	8.00	2.68	16.50	5.13	42.00	0.85	21.45	0.34	31.00	70.49
25	5.93	96.50	6.80	2.93	19.38	2.13	37.00	3.35	23.50	0.24	29.00	64.18
26	5.90	80.50	7.61	2.20	17.00	1.18	37.00	4.15	20.50	0.84	28.00	53.54
27	6.25	97.00	12.80	0.98	12.00	6.13	26.00	9.15	23.50	0.43	36.00	64.51
28	5.91	49.50	6.80	0.98	10.50	3.00	24.00	1.65	18.00	0.01	21.00	32.92
29	6.06	48.50	5.60	2.40	11.50	0.25	32.00	1.70	14.50	0.00	24.00	32.26
30	6.21	61.00	4.00	1.47	13.13	5.38	28.00	0.00	19.00	0.40	16.00	40.57
31	5.66	44.50	4.40	3.90	7.50	1.62	15.00	2.50	20.00	0.10	27.00	29.60
32	5.85	45.00	3.20	3.40	11.75	1.50	19.00	4.15	21.50	0.12	22.00	29.93
33	6.21	43.50	10.00	0.98	8.13	0.80	26.00	0.85	16.00	0.00	29.00	28.93
34	6.54	73.50	11.20	1.25	14.75	2.65	25.00	6.65	33.00	0.11	33.00	48.88
35	6.38	136.50	10.00	5.86	18.13	1.28	44.00	0.85	24.50	2.84	49.00	90.78
36	7.17	159.00	20.80	1.22	12.25	9.00	63.00	4.02	22.50	2.10	57.00	105.71
37	5.65	82.50	5.20	3.66	14.13	1.47	25.00	1.25	23.50	0.05	28.00	54.87
38	6.27	64.00	6.00	2.18	14.13	2.69	27.00	1.70	17.50	1.96	25.00	42.56
39	6.18	76.50	7.60	1.22	13.75	3.05	35.00	2.50	17.50	0.52	23.00	50.88
40	6.50	87.50	9.20	1.95	13.63	1.18	36.00	5.85	17.00	0.62	31.00	58.19
41	6.62	73.00	9.60	4.15	11.13	0.58	36.00	3.30	18.50	0.78	41.00	48.55

42	7.21	283.00	13.20	7.81	32.00	5.78	69.00	9.15	38.50	5.12	65.00	102.61
43	6.61	55.00	7.60	2.19	10.38	0.44	24.00	0.85	20.59	0.05	30.00	49.25
44	6.84	45.00	4.00	3.90	7.50	0.68	18.00	5.00	17.00	0.02	26.00	29.25
45	6.71	50.00	7.60	2.20	10.38	1.08	27.00	1.70	17.50	0.20	28.00	32.50
46	6.44	70.50	10.00	2.93	8.88	1.12	36.00	1.70	16.50	0.21	37.00	45.83
47	6.16	41.00	5.60	2.93	1.20	0.25	25.00	1.70	11.50	0.00	25.00	26.65
48	7.28	59.00	7.20	0.98	13.00	0.50	32.00	3.30	12.50	0.10	23.00	39.33
49	5.83	42.00	9.60	1.46	8.13	0.75	37.00	3.30	10.50	0.00	31.00	27.30
50	6.29	112.00	11.20	1.46	19.25	1.30	40.00	1.70	24.00	0.52	34.00	74.48
51	6.75	65.00	4.80	4.39	11.25	0.68	28.00	0.00	20.00	0.10	30.00	43.23
52	5.95	64.00	11.20	4.40	5.00	0.70	32.00	5.00	17.00	0.12	46.00	42.56
53	6.96	45.00	6.40	2.40	11.75	2.33	26.00	1.70	19.00	0.00	18.00	29.93
54	6.25	94.00	8.00	3.90	14.25	2.13	38.00	1.70	18.00	1.36	26.00	62.51
55	6.18	63.00	7.20	4.39	14.50	1.73	36.00	3.30	22.00	0.06	36.00	41.90
56	6.40	69.00	4.80	4.88	16.00	5.00	34.00	11.70	18.00	0.44	32.00	45.89

Note: All parameters are in mg/l except pH and EC (µmohs/cm)

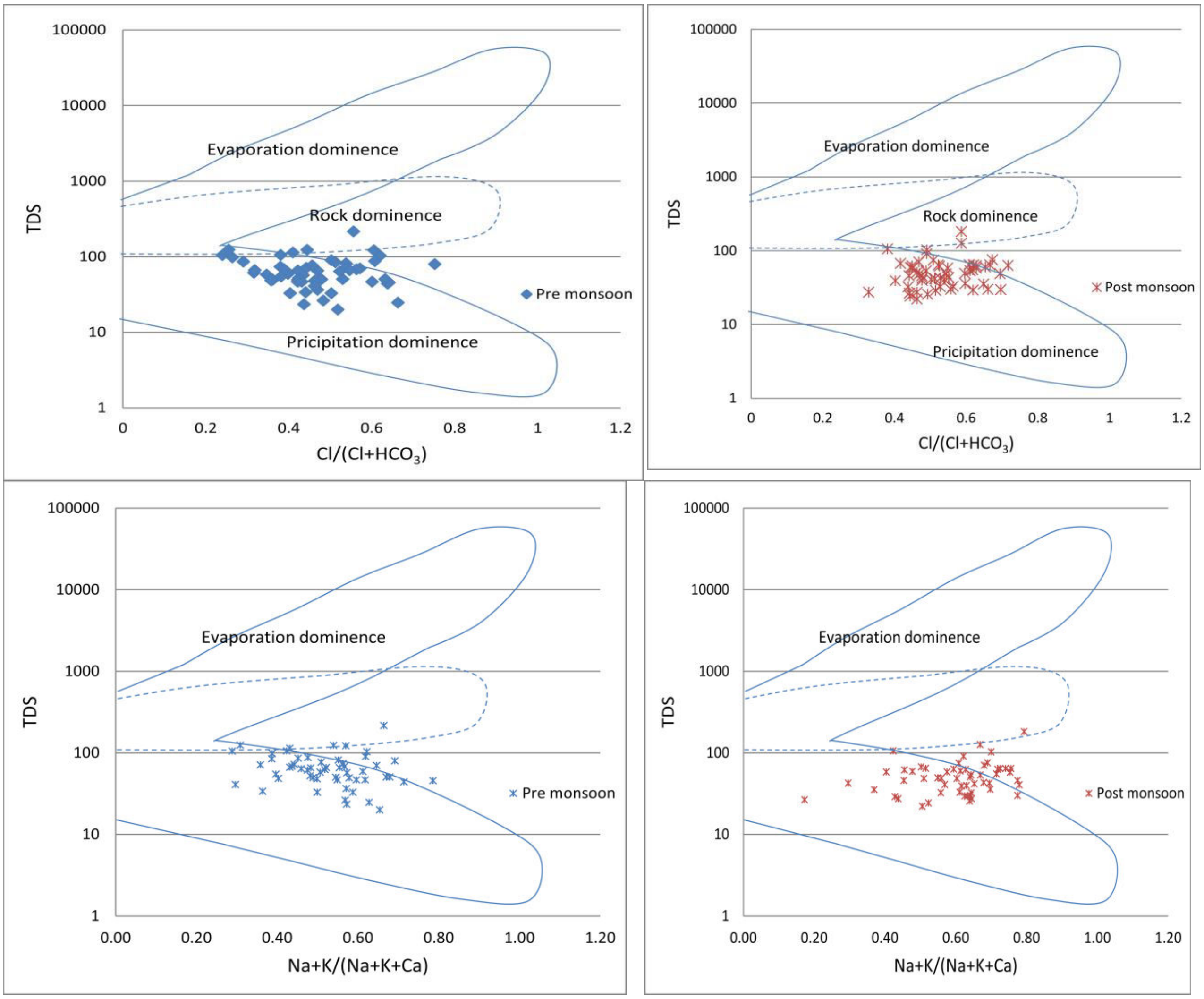

Figure 3. Gibbs plot

The plot of TDS versus Na/(Na + Ca) shows (Figure 3a) that the occurrence of sodium and calcium is due precipitation in majority of samples and in few samples is due to rock weathering process in both pre and post monsoon seasons. It justifies the results of Gibbs plot.

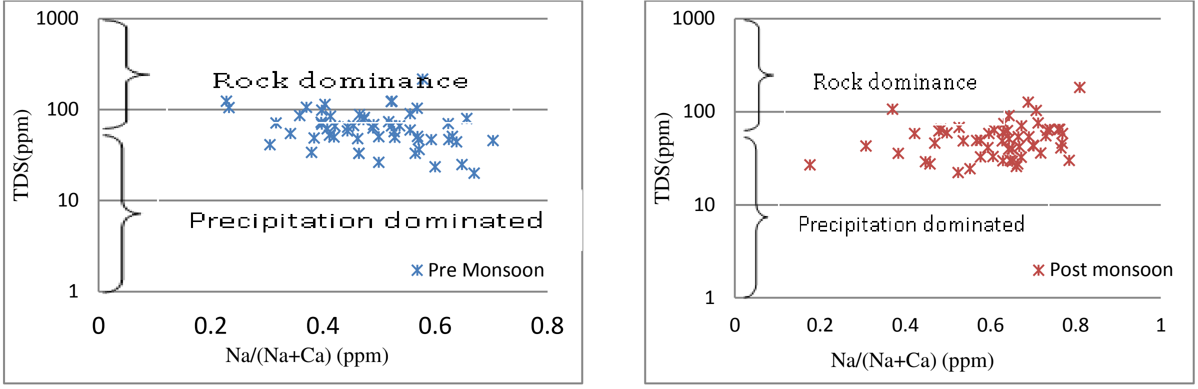

Figure 3a. Relation between Na/(Na+Ca) and TDS

A plot of the sum of the major cat-ions, minus their respective chlorides against HCO^{3-} (Figure 4) appears to corroborate the above assertion, suggesting that silicate mineral weathering does take place. Since the aquifers are sedimentary units, the presence and dissolution of carbonate and sulphate minerals might also play variable roles in the hydrochemistry. In Figure 4, although some of the points fall around the 1:1 line, most of them are above the equiline signifying the effects of cat-ion exchange and silicate mineral weathering from clay present in the study area (Raymahashay, 1986).

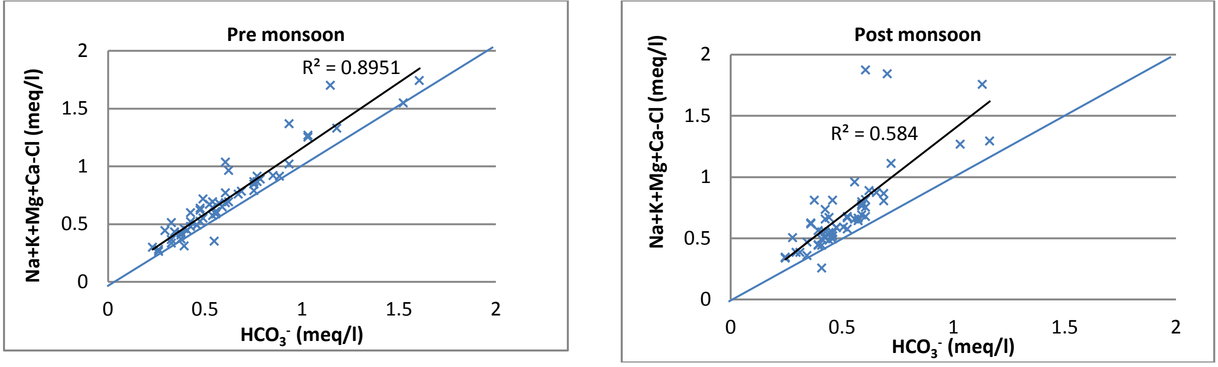

Figure 4. Relationship between HCO3- and $Na^{+}+K^{+}+Mg^{2+}+Ca^{2+}-Cl^{-}$ in pre and post monsoon

The Na+– Cl- relationship has often been used to identify the mechanisms for acquiring salinity in semi-arid regions (Magaritz *et al.* 1981; Dixon and Chiswell 1992; Sami 1992). A parallel enrichment in Na+ and Cl- indicates dissolution of chloride salts or reconcentration processes by evaporation (Sami, 1992).The dissolution of halite (NaCl) in water release equal concentrations of Na+ and Cl- into the solution. A good correlation (0.708) in PRM indicates halite sources are the major contributors for Na+ and a moderate correlation (0.55) between Na+ and Cl- in POM groundwater samples suggest that with halite as a major source along with other sources are contributes Na+ in the study area (Figure 5). The sodium versus chloride (Fig.5) plot indicates that most of the pre-monsoon samples lie slightly above the equiline. Na+ concentration is being reduced by ion-exchange in PRM and excess Na+ contribution is from clay in POM in the study area. Hence Na+ and Cl- does not increases simultaneously.

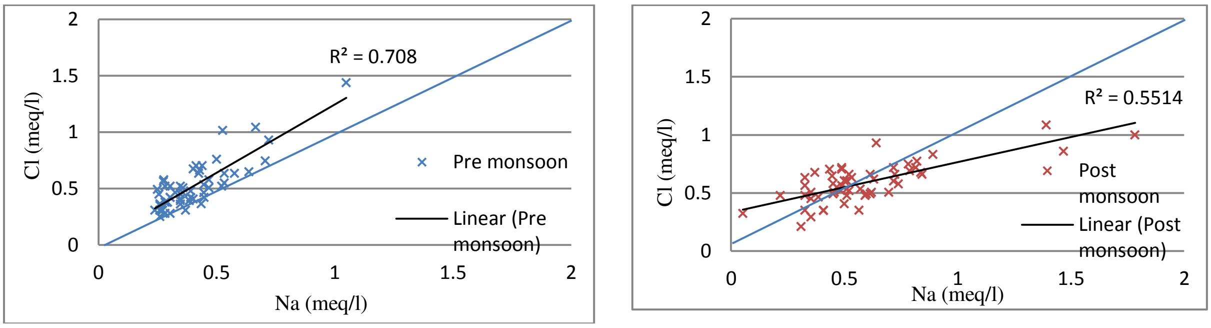

Figure 5 Relation between Na+ and Cl^-

Those samples with a value of Na+/Cl- ratio higher than 1 also show a deficit in Ca2+ + Mg2+, and this is consistent with a Ca2+ - Na+ cation exchange process which leads to a softening of the water (Hidalgo et al. 1995; Hidalgo and Cruz-Sanjulian 2001). Ca2+ and Mg2+ can exchange Na+ sorbed on the exchangeable sites of the clay minerals, resulting in the decrease of Ca2+ and Mg2+ and the increase of Na+ in ground waters. In the study area only 7 (12%) water samples shows Na+/Cl- ratio more than 1 in PRM season and in POM season in 28 (50%) water samples shows Na+/Cl- ratio more than 1. The increase in Na+/Cl- ratio in POM may be due to leaching of clay minerals present in the study area. The atmospheric inputs can also be assessed by considering the ratio of elements to chloride, due to the abundant concentration of Cl- in the ocean and its low level in most rocks. For the study area, the average Na+/Cl- ratio is 0.80 and 0.99 and K+/Cl- ratio is 0.26 and 0.08 in PRM and POM respectively. In PRM the average value of Na+/Cl- is comparatively less and in POM the average value is significantly high with the standard value of 0.85 expected from marine aerosols. It indicates that in PRM season Cl- is predominantly from atmospheric precipitation and in POM, Cl- is also from other sources besides atmospheric precipitation. The observed high average K+/Cl- ratios compared with the standard value of 0.01 expected from marine aerosols, indicate contributions of chloride from other sources in addition to atmospheric precipitation to the observed ion budgets (Zhang et al. 1995, Divya Dudeja *et al.,* 2011).

Water/rock interaction and human activities control the hydrogeochemical characteristics of groundwater. Variation in TDS in groundwater may be related to land use and also to pollution (Jalali 2009). Cl-, SO42-, NO3- and Na+ ions are mostly derived from agricultural fertilizers, animal wastes and industrial and municipal sewage (Jalali 2009). Correlation of these ions with TDS can be used to indicate the influence of human activities on the water chemistry (Han and Liu 2004). The Na+ concentrations show an a good correlation with TDS in POM season compared to a moderate correlation in PRM season (Figure 6).It justifies the leaching of clay minerals in POM and it may be due to the anthropogenic sources such as sewage, household waste etc (Choi *et al.* 2005). No other ions shows good correlation with TDS indicates that there are no other major sources of pollution in the study area.

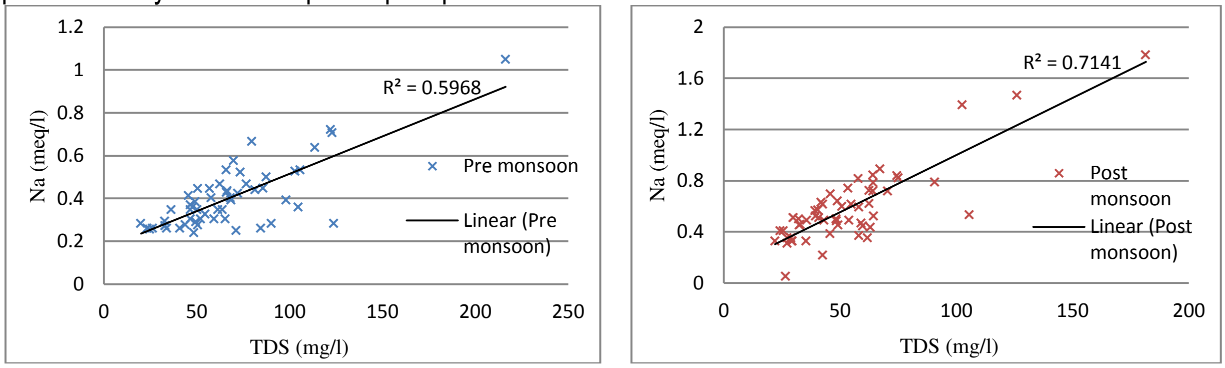

Figure 6. Relation between TDS and Na^+

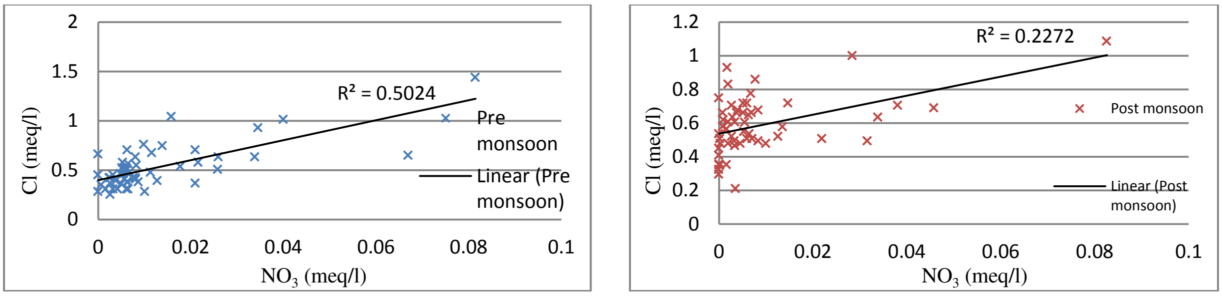

Figure 7. Relation between NO^{3-} and Cl$^-$

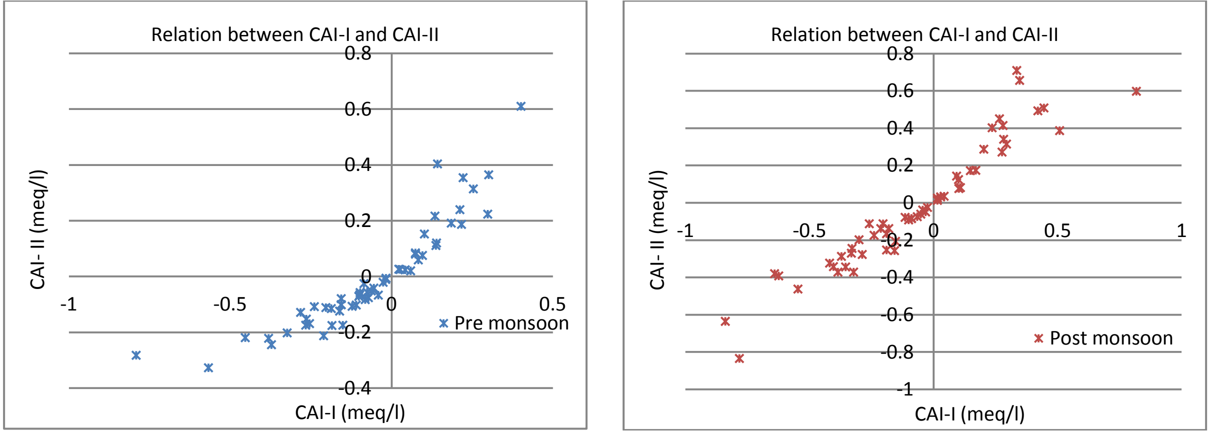

Figure 8. Relation between CAI-I and CAI-II

Higher correlation between Cl$^-$ and NO^{3-} above 0.35, indicate common source and input from anthropogenic activities (Back and Hanshaw 1966; Piskin 1973; Ritter and Chirnside 1984; Pacheco and Cabrera 1997). In the study area positive correlation between Cl- and NO^{3-} (r = 0.50) (Figure 7) in PRM and a poor correlation (0.23) (Figure 7) in POM have been observed. It suggesting that the same source for these ions in PRM and it may be agriculture. A poor correlation in POM may be due to dilution of groundwater and leaching of aquifers leads to contribution of Cl- from the other sources also into groundwater.

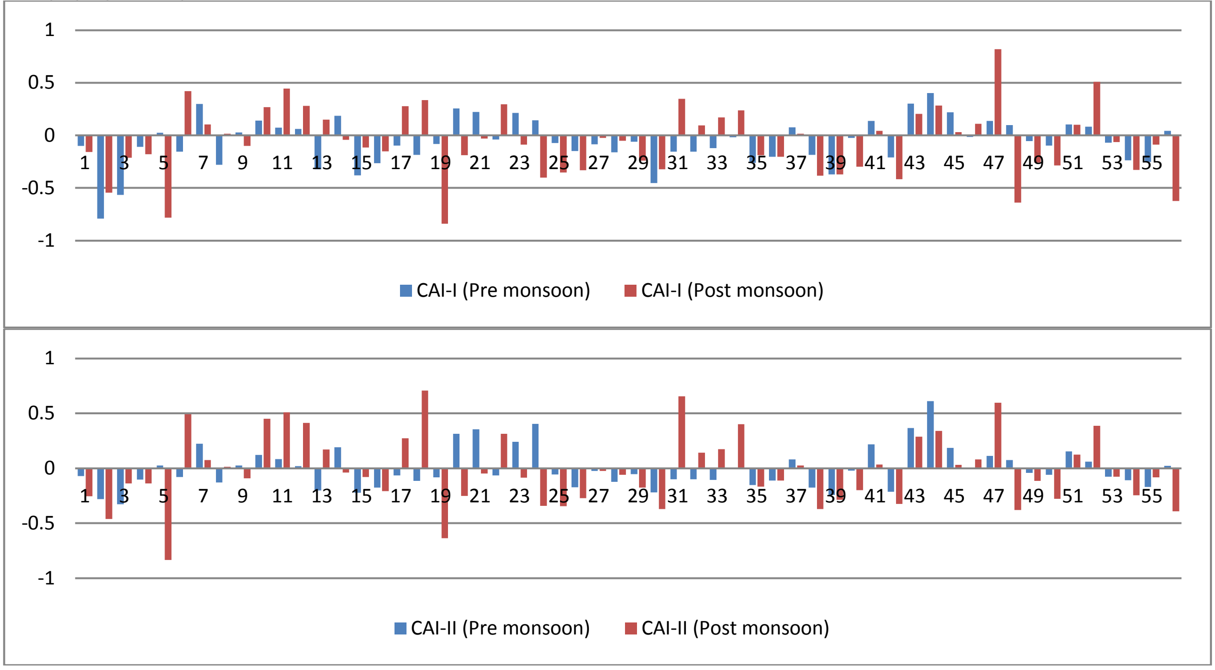

Figure 9. Bar diagram of Chloro Alkaline Indices (CAI) 1 and 2 for the pre and post-monsoon season

Ion exchange process: The ion exchange between the groundwater and its host environment during residence or travel of groundwater can be understood by studying the Schoeller index (SI) (1965) also known as chloro-alkaline index (CAI-I and CAI-II). If Na+ and K+ in water are exchanged with Mg2+ and Ca2+, the value of SI will be positive, indicative of base exchange reaction (chloro-alkaline equilibrium). The negative values of SI indicate chloro-alkaline disequilibrium and the reaction is known as cation–anion exchange reaction (Schoeller 1965). Groundwater with a base-exchange reaction, in which the alkaline earths has been exchanged for Na+ ions (HCO3>Ca+Mg) may be referred to as base exchange softened water, and those in which the Na+ ions have been exchanged for alkaline earths (Ca++Mg>HCO3) may be referred to as base exchange hardened water (Schoeller 1965). All the sampling sites where the values of SI are positive have high concentration of HCO3- than alkaline earths indicating exchange of Na+ ions for alkaline earths and the water as base exchange softened water. The chloro-alkaline index (CAI-I and CAI-II) values of the study area range from (average, -0.08) and (average, -0.05), respectively. If cat-ion exchange occurs between Ca2+ and Mg2+ in the host rock and K+ and Na+ in the water, both indices are expected to be positive. On the other hand, if both indices are negative, it indicates a reverse cat-ion exchange (Schoeller 1965; Kumar et al., 2007). Fig.8 shows that the samples are distributed on both +ve and –ve side. Positive values indicate cat-ion exchange takes place between Ca2+ and Mg2+ in the host rock and K+ and Na+ in the water. If indices are negative, it indicates a reverse cat-ion exchange.

CAI-I and II values of the samples in the study area indicate that 35 groundwater samples show a negative ratio depicting the type of base exchange and 21 groundwater samples indicate positive ratio in both PRM and POM respectively. Cat-ion exchange takes place in the study area because of presence of clay that is being formed in the wake of silicate mineral weathering. Figure 9 for the groundwater samples of Sitanadi basin suggests a significant switch over between the processes of ion and reverse ion exchange on seasonal basis. It is clearly visible from the fig.9 there is reverse ion-exchange dominant with 62.5% and 59% samples in PRM and POM seasons respectively, with the exceptions of few samples. However, about 21% samples show ion-exchange in both the seasons and 43% sampling location exhibits reverse-ion exchange in both the seasons (Fig.9). Fig.8 shows that most of the samples indicate negative values for both indices, in PRM suggesting reverse ion exchange in the system. Cat-ion exchange is feasible when exchange sites such as clay minerals are known to be present. Previous studies (Acheampong and Hess 1998; Yidana et al. 2008b) suggest that clay minerals are being formed in the wake of silicate mineral weathering. A plot of (Mg2++Ca2+) against (HCO3- + SO42-) was used to assess the effects of carbonate and sulfate mineral dissolution in the system. Data points that all along or close to the 1:1 line are attributed to carbonate and sulfate mineral weathering. Those that fall above the 1:1 line resulted from the effects of the reverse ion exchange processes in the system. Data points that fall below the equiline are deemed to have also resulted from the dissolution of carbonates and sulfates. In Fig.10, although some of the points fall around the 1:1 line, most of them are above the equiline signifying the effects of cat-ion exchange and silicate mineral weathering. The plot of Ca2+ + Mg2+ versus SO42- + HCO3- (Fig.10) of the study area shows that most of the groundwater samples of the post-monsoon found above the 1:1 line indicating ion exchange except few samples which do indicate reverse-ion exchange but extent is very less. While in pre-monsoon it is evenly distributed on both sides of the equiline. In Ca2++ Mg2+ versus SO42- +HCO3- scatter diagram (Figure 10), the points falling along the equiline suggests that these ions have been resulted from weathering of carbonates and silicates (Datta et al. 1996; Rajmohan and Elango 2004;Kumar et al. 2006) of clay predominately present in the area . In the study area most of the points placed above the 1:1 line indicating silicate weathering of clay minerals.

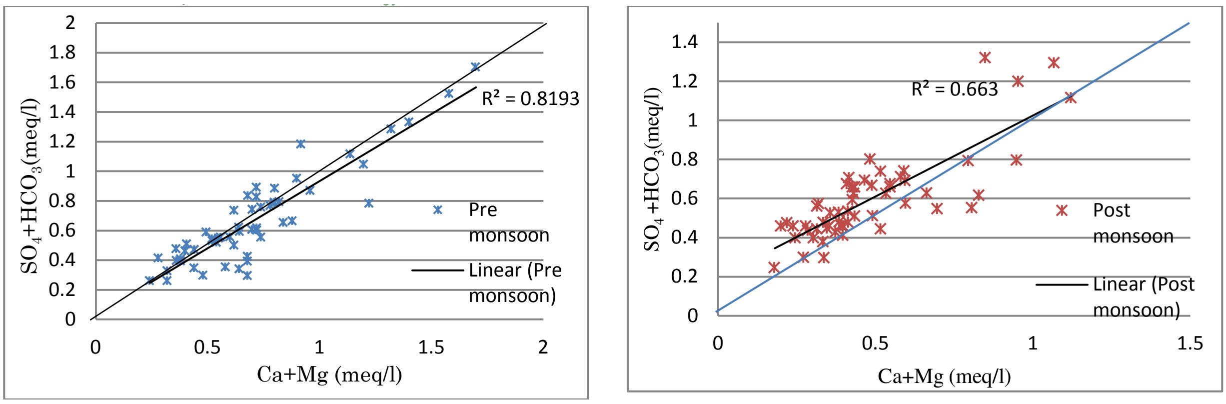

Figure 10. Relation between Ca^{2+} + Mg^{2+} and SO_4^{2-} + HCO_3^-

Evaporation: In general, it is expected that the evaporation process would cause an increase in concentrations of all chemical parameters in water. If the evaporation process is dominant, assuming that no mineral species are precipitated, the Na^+/Cl^- ratio would be unchanged (Jankowski and Acworth 1997). Hence, the plot of Na^+/Cl^- versus EC would give a horizontal line, which would then be an effective indicator of concentration by evaporation and evapotranspiration. The trend of EC versus Na^+/Cl^- scatter diagram (Fig.11) of the groundwater samples shows that the trend line is inclined, which indicates that evaporation may not be the major geochemical process controlling the chemistry of groundwater.

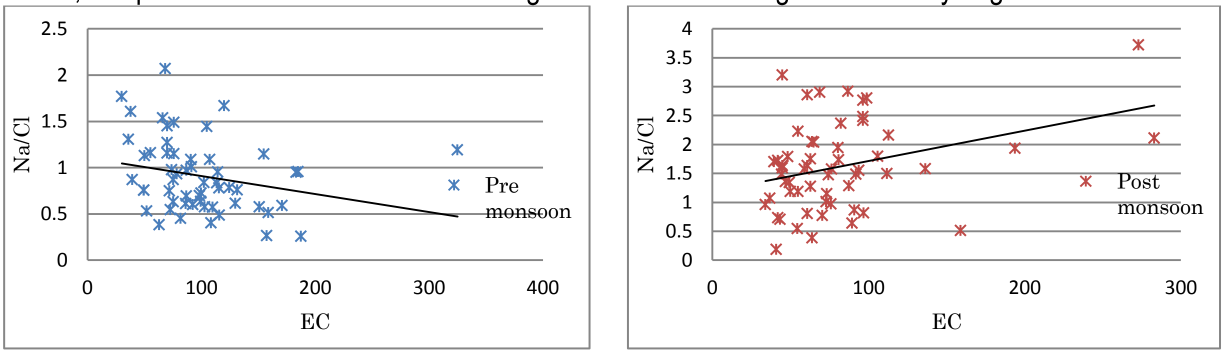

Figure 11. Plot of Na^+/Cl^- ratio versus electrical conductivity (EC)

Geochemical Classification of groundwater: For geochemical classification of groundwater in Sitanadi basin and to study hydro chemical processes, geochemical data were plotted on Chadha diagram (1999) for PRM and POM seasons (Fig.12). The plot shows that majority of groundwater in PRM fall under the subdivision of alkaline earths exceed alkali metals and weak acidic anions exceed strong acidic anions (Ca-Mg-HCO_3 water type). In POM samples, groundwater recharge during wet season has taken place and hence shows variation in the water types (Table 3).

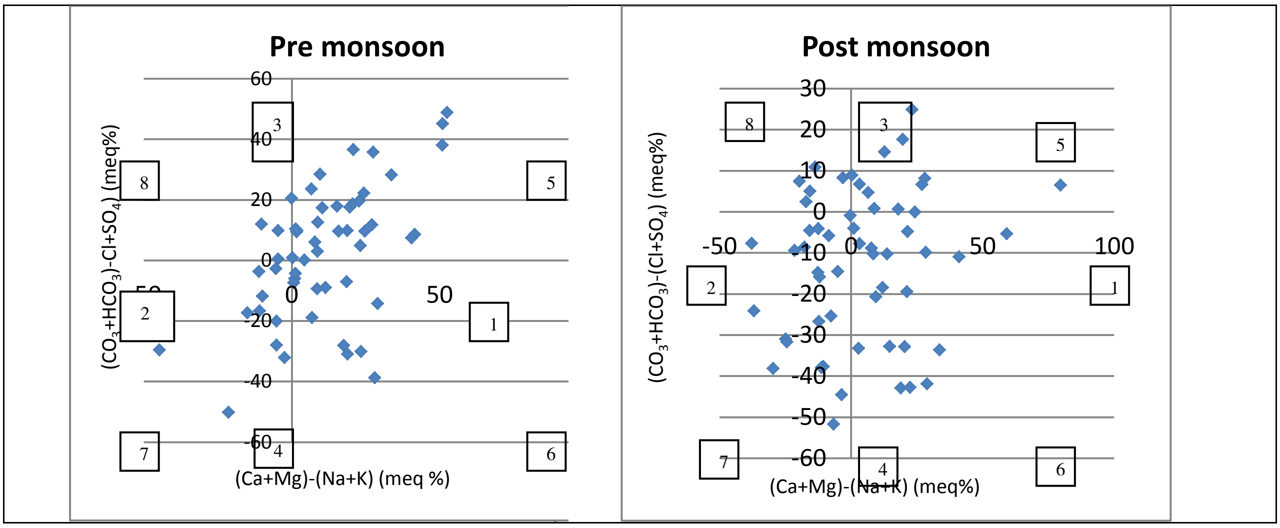

Figure 12. Geochemical classification and hydrochemical parameters of groundwater (Chadha, 1999)

Table 3: Geochemical classification of groundwater type in Sitanadi basin

S.No.	**Water Type**	**Well number**	
		Pre-monsoon	**Post-monsoon**
1	Alkaline earths exceed alkali metals.	1,2,5,6,7,8,9,10,11,12,13,14,16,17,18,20,21,23,25,27,28,29,30,31,32,34,35,36,40,45,46,48,49,50,52,54,55,56,37,43,44,47	3,4,6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 17, 18, 22, 23, 27, 33, 35, 36, 41, 43, 44, 45, 46, 47, 49, 51, 52, 54, 55
2	Alkali metals exceed alkaline earths.	3,4, 15, 19, 22, 24, 26, 33, 38,39, 41, 42,51,53	1,2,5,16,19,20,21,24,25,26, 28,29,30, 31, 32, 34, 37, 38,39, 40,42,48, 50, 53, 56
3	Weak acidic anions exceed strong acidic anions.	2, 3, 6, 7, 8, 10, 12, 13, 15, 16, 17, 18, 25, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 38, 39, 40, 41, 42, 45, 46, 48, 49, 50, 51, 52, 53, 54, 55, 56	2, 4, 7, 8, 14, 15, 24, 29, 35, 36, 39, 46, 47, 48, 49, 54
4	Strong acidic anions exceed weak acidic anions.	1, 4, 5, 9, 11, 14, 19, 20, 21, 22, 23, 24, 26, 37, 43, 44, 47	1,3,5,6,9,10,11,12,13,16,17, 18, 19, 20, 21, 22, 23, 25,26,27, 28, 30, 32, 33, 34,37,38,40,41, 42, 43, 44, 45,50,51,52,53,55, 56
5	Alkaline earths and weak acidic anions exceed both alkali metals and strong acidic anions, respectively. Such water has temporary hardness. The positions of data points in this domain represent Ca_2^+–Mg_2^+–HCO_3^- water type.	2, 6, 7, 8, 10, 12, 13, 16, 17, 18, 25, 27, 28, 29, 30, 31, 32, 34, 35, 36, 40, 45, 46, 48, 49, 50, 52, 54, 55, 56	4, 7, 8, 14, 15, 35, 36, 46, 47, 49, 54
6	Alkaline earths exceed alkali metals and strong acidic anions exceed weak acidic anions. Such water has permanent hardness and does not deposit residual sodium carbonate in irrigation use. The positions of data points in this domain represent Ca_2^+–Mg_2^+–Cl^- - type of waters.	1, 5, 9, 11, 14, 20, 21, 23, 37, 43, 44, 47	3, 6, 9, 10, 11, 12, 13, 17, 18, 22, 23, 27, 31, 33, 41, 43, 44, 45, 51, 52, 55

7	Alkali metals exceed alkaline earths and strong acidic anions exceed weak acidic anions. Such water generally creates salinity problems both in irrigation and drinking uses. The positions of data points in this domain represent Na+ –Cl^- type and Na^+ – SO_4^{2-} - type of waters.	4, 19, 22, 24, 26, 38, 41, 42, 51, 53	1, 5, 16, 19, 20, 21, 25, 26, 28, 30, 32, 34, 37, 38, 40, 42, 50, 53, 56
8	Alkali metals exceed alkaline earths and weak acidic anions exceed strong acidic anions. Such waters deposit residual sodium carbonate in irrigation use and cause foaming problems. The positions of data points in this region represent Na+ –HCO3- - type waters. This type of water results from the dissolution of carbonates and the weathering of silicate minerals in the aquifer material.	3, 15, 33, 39	2, 24, 29, 39, 48

Evaluation of groundwater for drinking purpose: The statistical summary of water quality parameters determined during the period of investigation are computed and shown in Table 4. Hydrogen ion concentration was measured in terms of pH.

Although pH usually has no direct impact on health of consumers, it is one of the most important operational water quality parameters (Gulshan and others, 2011). pH in the study area was found acidic in nature. It varies between 5.68 to 7.85 and 5.65 to 7.55 having mean value of 6.60 and 6.36 in the PRM and POM respectively in the study period. A major part of the basin is forested (25% of the total area) and thickly vegetated (60% of the total area) that produce surplus soil CO2 by root respiration and by organic decay (Calmels et al. 2006), makes the water in acidic pH range. Mean pH value 6.60 in PRM and 6.36 in POM also indicates that dissolved carbonates are predominantly present in the form of HCO3- (Adams et al.2001). The pH of water is mainly governed by the dissociation of H2CO3 (H+) and by the hydrolysis of bicarbonate (OH-). The catchment is rich with clay, drainage of Sulphuric acid may significantly contribute to acidity of water in the Sitanadi basin (Hounslow, 1995). As per BIS standards the suitable range of pH for domestic use is 6.5 to 8.5 which reveal that about 26 (46.5%) samples in PRM and 36 (64%) samples in POM are not suitable for domestic use having less than 6.5 pH value in Sitanadi basin. EC is an indirect measure of ionic strength and mineralization of natural water. EC ranges from 30 to 325 with a mean value of 100 in PRM season and varies from 34 to 283 with a mean value 81.05 in (Table 4) POM season. Due to dilution of water in POM season the concentration of minerals in water reduces and hence the mean value of EC is also reduced. TDS refers to any minerals, salts, metals, cat-ions and anions dissolved in water. It is reported that TDS levels less than 600 mg/l is considered to be good and concentration greater than 1000 mg/l decreases the palatability of the drinking water (WHO 2008). Values of TDS in the study area varied between 19.95 to 216 and 22.10 to 181.50 with an average value of 66.64 mg/l and 53.48 mg/l (Table 4) in the PRM and POM respectively. TDS values (Table 1 and 2) shows that whole study area had desirable to permissible concentration of TDS in groundwater both in PRM and POM period. Decreased mean value of TDS after precipitation indicates dilution of salts. Hardness is a very important property of water from its domestic application point of view (Goyal et al. 2010). The acceptable limit for TH as per BIS norms is 300 mg/l which may be extended upto 600 mg/l. Analysis reveals that water in the study area is soft in general and average hardness remains almost same both in PRM and POM seasons (Table 4). Both EC and TDS have high SD compared to other parameters in PRM as well as POM suggesting that water chemistry is not homogeneous in the study area and regulated by distinguished processes (Kleinman and others, 2011).

The dominance of cat-ion in the study area is Ca^+>Na^+>K^+>Mg^+ in PRM season. The dominant cat$^-$ ion is Ca^+ , which has a mean concentration of 10.29 mg/l (Fig.13) (Table 3), followed by Na+ with mean concentration of 9.16 mg/l and then K^+ and Mg^+ which have mean concentration of 5.62 and 2.21 mg/l respectively. In 53.5% of ground water samples Ca^+ is dominant cation, in 41% and 5.5% of ground water sample Na^+ and K^+ are in dominant respectively. In anion dominance is HCO_3^->Cl^->SO_4^{2-}>NO_3^2. HCO_3 – is the major an-ion (Fig.13) (Table 3), having mean concentration of 37.51 mg/l followed by Cl-, SO42- and $NO_3^{2-}$with mean concentration of 18.35, 2.44 and 0.73 mg/l respectively. HCO_3^- is dominant in 91% followed by Cl- in 9% of water samples in PRM season. In POM season dominance of cat-ion in the study area are Na+> Ca+> Mg+ >K+ (Fig.13) (Table 3). The dominant cat-ion is Na+, which has a mean concentration of 13.44 mg/l (Table 3), followed by Ca+ with mean concentration of 8.03 mg/l and then Mg+ and K+ which have mean concentration of 3.14 and 1.77 mg/l respectively. In 78.5% of ground water samples Na+ is in dominant cation and in 21.5% of ground water sample Ca+ is in dominant. In POM season also anion dominance is HCO_3^->Cl^->SO_4^{2-}>$NO_3^{2,}$ HCO_3 – is the major anion (Fig.13) (Table 3), having mean concentration of 31.37 mg/l followed by Cl-, SO42- and NO_3^2 with mean concentration of 20.76, 3.95 and 0.52 mg/l respectively. HCO_3^- is dominant in 86% followed by Cl^- in 14% of water samples in POM season. The higher concentration of HCO_3^- can come from soil CO_2 or from the bacterial degradation of organic contamination.

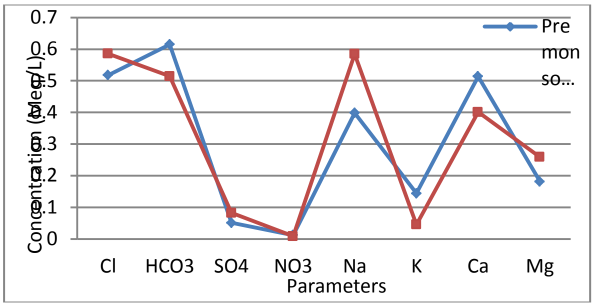

Figure 13. Schoeller diagram of the groundwater samples taken from the study area

High concentration of Na+ and Cl^- in groundwater is due to impact of saline water and base exchange reaction (Freeze and cherry, 1979). Granitic rocks of the study area can be considered as significant contributors of Mg_2+ to groundwater. Two factors are responsible for the scarcity of potassium in groundwater, one being the resistance to potassium minerals to decomposition by weathering (Golditch 1938) and the other is fixation of potassium in clay minerals formed due to weathering, while higher sodium is often recorded in the groundwater. Mean value of Ca+, HCO_3^- ,K^+ and NO_3^{2-} decreased from PRM to POM seasons due to dilution of these minerals in POM. Mean value of Mg^+, Na^+, SO_4^{2-}, and Cl^- increased from PRM to POM season due to leaching of minerals from soil and ion exchange process with percolating rainwater. The groundwater samples are analyzed for their suitability for drinking purpose based on Durfor and Becker (1964), Davis and DeWiest (1966), Sawyer and McCarthy (1967) and Freeze and cherry (1979) (Table 5). By Sawyer and McCarthy (1967) and Durfor and Becker (1964) methods of classification it is found that the samples in the study area fall into two classes namely soft and moderate. Whereas by other two type of classification they belongs to a single class namely desirable (Davis and DeWiest, 1966), and fresh water type (Freeze and Cherry, 1979). From this, it is very clear that the groundwater in the study area is fit for drinking purpose.

Table 5: Classification of groundwater for drinking purpose based on TDS and TH in Sitanadi basin

Range	Classification	Number of Samples		Percentage of samples	
		Pre monsoon	Post monsoon	Pre monsoon	Post monsoon
Groundwater classification based on TDS(mg/l)					

Based on total hardness (mg/l) as CaCO3 after Durfor and Becker (1964)					
0-60	Soft	52	54	92.8	96.4
61-120	Moderate	4	2	7.2	3.6
121-180	Hard	Nil	Nil	0	0
>180	Very hard	Nil	Nil	0	0
Based on total hardness (mg/l) as CaCO3 after Sawyer and McCarthy (1967)					
<75	Soft	54	55	96.4	98.21
5-150	Moderately hard	2	1	3.6	1.97
150-300	Hard	Nil	Nil	0	0
>300	Very hard	Nil	Nil	0	0
Devis and DeWiest (1966)					
<500	Desirable for drinking	56	56	100	100
500-1000	Permissible for drinking	Nil	Nil	Nil	Nil
1000-3000	Useful for irrigation	Nil	Nil	Nil	Nil
>3000	Unfit for drinking and irrigation.	Nil	Nil	Nil	Nil
Freeze and cherry (1979)					
<1000	Fresh water type	56	56	100	100
1,000-10,000	Brackish water	Nil	Nil	Nil	Nil
10,000-100000	Saline water	Nil	Nil	Nil	Nil
>100000	Brain water	Nil	Nil	Nil	Nil

The groundwater samples were classified according to WHO and Indian drinking water quality standards (Table 6). According to this classification it is found that majority of the samples fall within the maximum allowable limits indicating they are fit for drinking purpose.

Spatial distribution of water quality parameters: Spatial distribution maps of geochemical data prepared for the study area are shown in Figures13 to 18. The EC content in groundwater samples in PRM and POM seasons varies from 30 to 325 and 34 to 283 µmohs/cm respectively (Figure 14, Table 1 and 2). Increase of EC values during PRM season in the 150-200 class intervals is observed. This may be due to high rate of evaporation taking place in the study area where the groundwater table is shallow. The Ca+ content in groundwater samples in PRM and POM seasons varies from 3.2 to 27.2 and 3.2 to 20.80 mg/l respectively (Figure 15, Table 1 and 2). Though there is not much variation in the range of Ca+ content in PRM and POM seasons, there is an increase in calcium content in groundwater samples of POM season. This may due to leaching of soil/fertilizers during rainy season.

Table 6: Classification of groundwater for drinking purpose based on WHO and BIS in Sitanadi basin

Parameters	WHO (1993)				BIS (1998) (IS Code 10500:1991)			
	Desirable limit	Max. allowable limit	Samples exceeding max. allowable limit		Desirable limit	Max. allowable limit	Samples exceeding max. allowable limit	
			PRM	POM			PRM	POM
pH	7.0-8.5	9.2	Nil	Nil	6.5 –8.5	6.5 – 9.2	23	36
EC	200	4000	1 (42)	2(42,19)	-----	3000	Nil	Nil
Ca+	75	200	Nil	Nil	75	200	Nil	Nil
Mg+	30	150	Nil	Nil	30	100	Nil	Nil

Na^+	50	200	Nil	Nil		200	Nil	Nil
K^+	10	12	3(2,22,42)	Nil	10		4 (2,19,22,42)	Nil
$HCO_3^-+CO_3^-$	300	600	Nil	Nil	300	600	Nil	Nil
SO_4^{2-}	200	400	Nil	Nil	200	400	Nil	Nil
Cl^-	200	600	Nil	Nil	250	1000	Nil	Nil
NO_3^-	45	----	Nil	Nil	45	100	Nil	Nil
TH	100	500	Nil	Nil	300	600	Nil	Nil
TDS	500	1500	Nil	Nil	500	2000	Nil	Nil

The Na^+ content in groundwater samples in PRM and POM seasons varies from 5.50 to 24.10 and 1.20 to 41.00 mg/l respectively (Figure 16, Table 5.1 and 5.2). The concentration of Na^+ is low during POM monsoon may be due to dilution of groundwater because of high rainfall in the region. The K^+ content in groundwater samples in PRM and POM seasons varies from 0.3 to 27 and 0.25 to 9 mg/l respectively (Figure 17, Table 5.1 and 5.2). The concentration of K^+ is low during POM monsoon may be due to dilution of groundwater because of high rainfall in the region. The HCO_3^- content in groundwater samples in PRM and POM seasons varies from 14.00 to 98.00 and 15.00 to 71.00 mg/l respectively (Figure 18, Table 5.1 and 5.2). The HCO_3^- content in PRM is slightly higher than the POM season at few locations only due to anthropogenic activity. The Cl^- content in groundwater samples in PRM and POM seasons varies from 9.00 to 50.99 and 9.50 to 38.50 mg/l respectively (Figure 19, Table 1 and 2). Though the concentration does not very much, there is an increase in chloride content in groundwater samples of POM season. This may again due to leaching of soil/fertilizers during rainy season.

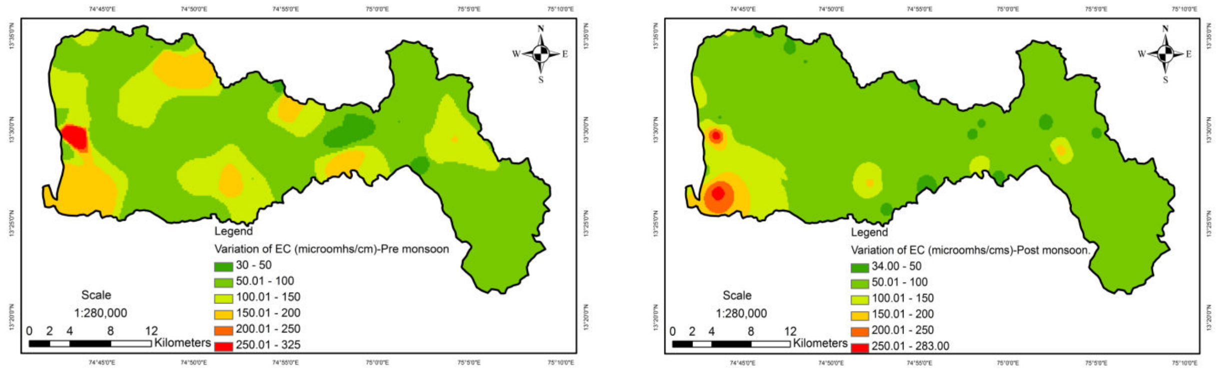

Figure 14: Spatial variation of EC (μmhos/cm) in Pre-monsoon and Post-monsoon season

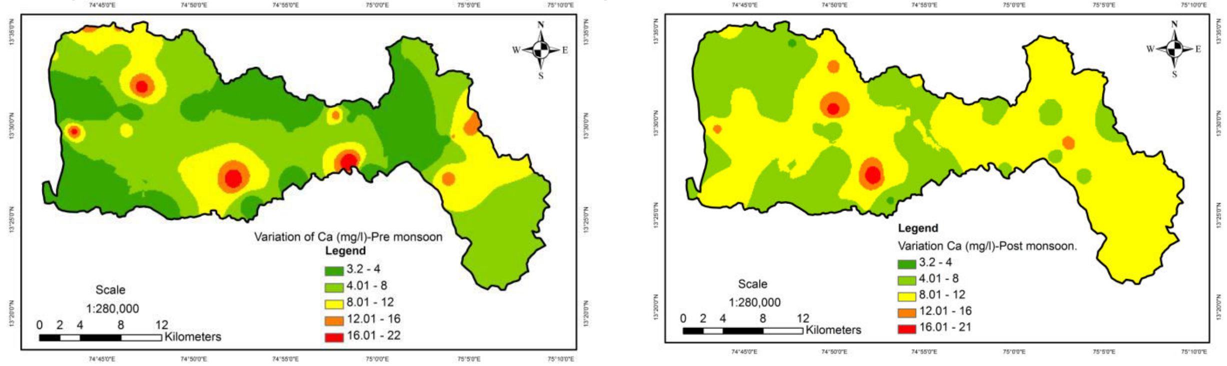

Figure 15: Spatial variation of Calcium (mg/l) in Pre-monsoon and Post-monsoon season

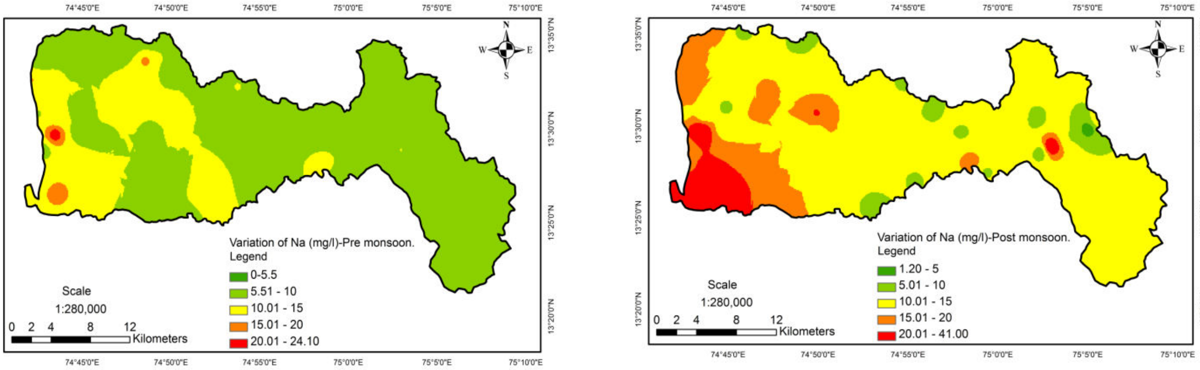

Figure 16: Spatial variation of Sodium (mg/l) in Pre-monsoon and Post-monsoon season

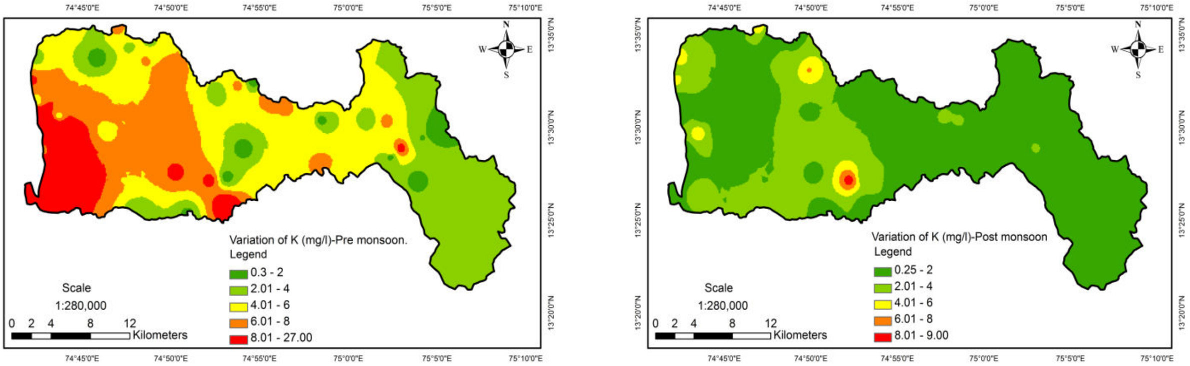

Figure 17: Spatial variation of Potassium (mg/l) in Pre-monsoon and Post-monsoon season

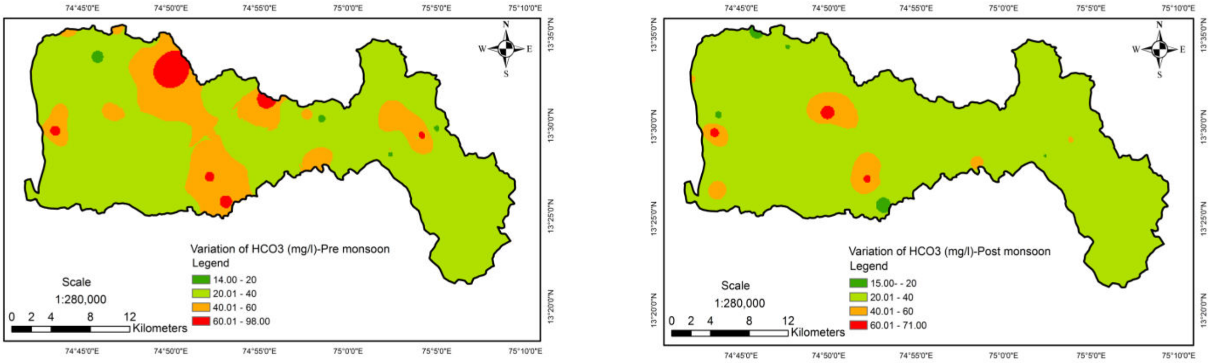

Figure 18: Spatial variation of HCO3 (mg/l) in Pre-monsoon and Post-monsoon season

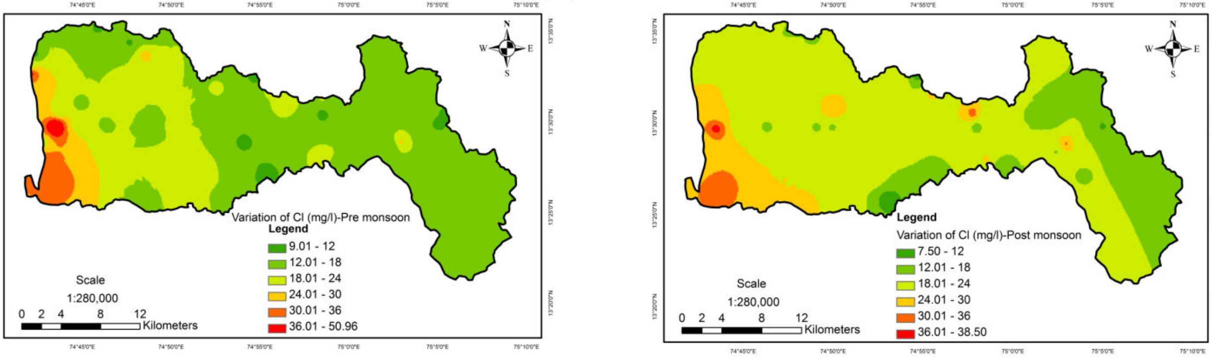

Figure 19: Spatial variation of Chloride (mg/l) in Pre-monsoon and Post-monsoon season

CONCLUSION

Various factors controlling the chemistry were analyzed by Gibbs diagram, which indicates that the majority of groundwater samples were individually scattered in the precipitation dominance field suggesting that base Exchange processes and leaching of minerals are influencing the ground water quality. The few samples falls in rock dominants field and falls away from the field represents the chemical weathering or rock forming minerals apart from base exchange and weathering processes along with other factors also play a role in the water chemistry of the Sitanadi basin. The clay predominantly parent in the region is the prime contributor for the status of the water quality along with atmospheric precipitation, rock-water interaction and anthropogenic sources. The dominance of cation in the study area is $Ca^{+}>Na^{+}>K^{+}>Mg^{+}$ in PRM season. In anion dominance is $HCO_3^{-}>Cl^{-}>SO_4^{2-}>NO_3^{2}$. HCO_3^{-} in PRM season. In POM season dominance of cation in the study area are $Na^{+}> Ca^{+}> Mg^{+} >K^{+}$ .In POM season also $HCO_3^{-}> Cl^{-}>SO_4^{2-}>NO_3^{2-}$. HCO_3^{-} are the dominate major anion. Both EC and TDS have high SD compared to other parameters in PRM as well as POM suggesting that water chemistry is not homogeneous in the study area and regulated by distinguished processes. By Sawyer and McCarthy (1967) and Durfor and Becker (1964) methods of classification it is found that the samples in the study area fall into two classes namely soft and moderate. Whereas by other two type of classification they belongs to a single class namely desirable, and fresh water type. From this, it is very clear that the groundwater in the study area is fit for drinking purpose. According to this classification it is found that majority of the samples fall within the maximum allowable limits indicating they are fit for drinking purpose. Spatial variations maps in the pre and post monsoon seasons are prepared to show the seasonal variations in the concentrations of various parameters using GIS software.

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