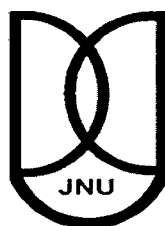


**HYDROGEOCHEMISTRY OF SUBARNREKHA RIVER,
JHARKHAND**

*Dissertation submitted to Jawaharlal Nehru University
in partial fulfilment of the degree of*
MASTER OF PHILOSOPHY

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CERTIFICATE

This is to certify that the research work embodied in this dissertation entitled
“**Hydrogeochemistry of Subarnrekha River, Jharkhand**” has been carried
out in the School of Environmental Sciences, Jawaharlal Nehru University,
New Delhi. This work is original and has not been submitted in part or full for
any other degree or diploma to any university or institute.

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CHAPTER 1

INTRODUCTION

Water is one of the principal elements which not only govern life on earth, but is one of the reasons why life exists on earth. The prosperity of nation depends on the availability of water as it influences economic, industrial and agricultural growth of mankind. Water resources are divisible into distinct categories, the surface water resource and the ground water resources. Surface water and ground water are two interdependent phases of the hydrologic cycle. Ground water supplies are generally free from suspended and organic impurities due to the natural filtration characteristics of suspended soils and organic matter (Karanth, 1989).

Among surface waters, rivers play an important role in human development and are an important natural resource. Since the advent of earliest human civilizations, man has been using the river environment for a variety of applications and most of the earliest population settlement occurred along the floodplains of rivers. Rivers provided drinking water, fertile land for agriculture, and transportation. As a result of human proximity, rivers have been considerably affected by human activities ranging from agriculture and flood control to the input of human and industrial wastes. Increasing urbanization, industrialization, rapid growth in world population and per capita utilisation of natural resources has led to a deterioration of the river environment. Thus man has manipulated hydrological cycle both quantitatively and qualitatively by interfering with the natural riverine processes at various steps either through addition of solid or liquid materials or through withdrawal of water, sediments etc.

Water is in plenty on the planet Earth. However, surface-water sources (such as rivers) only constitute about 1230 cubic Km (about 1/10,000th of one percent). The distribution of different types of water resources is given in table 1.1.

Quality of waters in India is deteriorating at very fast rate. The various reasons for the deterioration of drinking water quality in India are cited in the literature. The most important factor is over withdrawal of ground water, which has degraded water quality. It has also resulted in the presence of excessive ions like fluoride, arsenic, salinity, nitrate, iron and other heavy metals in drinking water. Other important factors, which deteriorate the water, include use of pesticides and chemical fertilizers in agriculture that leach into ground water, inadequate sewage system and treatment, industrial effluents getting mixed into water supply

Table 1.1: Earth's Water Resources

Water source	Water volume, in cubic Km	Percent of total water
Oceans	1298,432,000	97.24%
Icecaps, Glaciers	28,672,000	2.14%
Ground water	8,184,000	0.61%
Fresh-water lakes	122,880	0.009%
Inland seas	102,400	0.008%
Soil moisture	65,536	0.005%
Atmosphere	12,698	0.001%
Rivers	1228	0.0001%
Total water volume	1335,296,000	100%

(Source: Nace, U.S. Geological Survey, 1967 and the Hydrologic Cycle (Pamphlet), U.S. Geological Survey, 1984.)

Table 1.2: Water Resources of India

S. No	Items	Quantity (Cu.Km)
1.	Annual Precipitation Volume (Including snowfall)	4000
2.	Average Annual Potential flow in Rivers	1869
3.	Per Capita Water Availability (1997)	1967
4.	Estimated Utilizable Water Resources	1122
	(i) Surface Water Resources	690
	(ii) Ground Water Resources	432

(Source: Ministry of Water Resources)

Poor maintenance of water distribution pipelines further accelerates the deterioration of drinking water quality. Therefore, it has become very important to understand chemical composition of water to understand the anthropogenic impact on the water sources for the better management and to develop appropriate treatment technologies.

Besides understanding anthropogenic impact, geochemical studies of the river basin provide basic information on the weathering geochemistry of the continental mass, geochemical cycling of elements and transport of continental mass from land to the oceans. River processes form a major link in the geochemical cycling and more than 90% of the natural continental

weathered and anthropogenic materials both in dissolved and particulate phase are delivered to the oceans by rivers (Garrels et al., 1975). Thus geochemical studies of river basins are essential for understanding the exogenic cycling of elements.

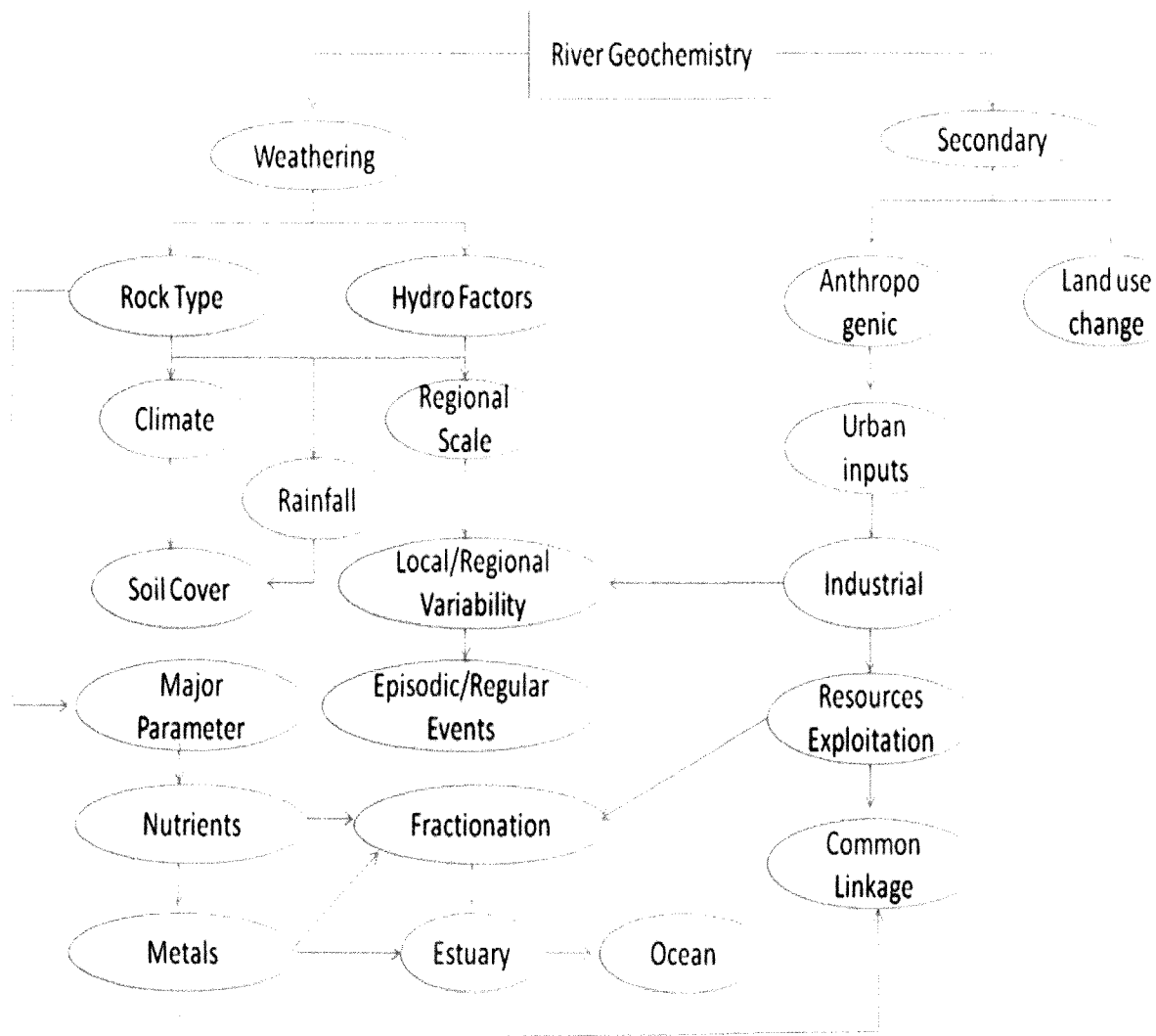


Fig 1.1: Flowchart of river geochemistry (<http://envisjnu.net/subject/river/>)

Rivers of India

India is blessed with many rivers. Out of these, fourteen are classified as major rivers comprising total catchment area of 252.8 million hectare (m.ha). Of the major rivers, the Ganga – Brahmaputra- Meghana system is the biggest with catchment area of about 110 m.ha. It covers more than 43 percent of the catchment area of all the major rivers in the country. The other major rivers with catchment area more than 10 m.ha are Indus (32.1 m.ha.), Godavari (31.3 m.ha.), Krishna, (25.9 m.ha.) and Mahanadi (14.2 m.ha). The catchment area of medium rivers is about 25 m.ha and Subarnarekha with 1.9 m.ha. catchment area is the largest river among the medium rivers in the country.

Table 1.3: River basin wise Ground Water Potential of India

S.N.	Name of Basin	Total Replenishable Ground Water Resources (Cu.Km)
1.	Brahmai with Baitarni	4.05
2.	Brahmaputra	26.55
3.	Cambai Composite	7.19
4.	Cauvery	12.30
5.	Ganga	170.99
6.	Godavari	40.65
7.	Indus	26.49
8.	Krishna	26.41
9.	Kutch & Saurashtra Composite	11.23
10.	Madras and South Tamil Nadu	18.22
11.	Mahanadi	16.46
12.	Meghna	8.52
13.	Narmada	10.83
14.	Northeast Composite	18.84
15.	Pennar	4.93
16.	Subarnrekha	1.82
17.	Tapi	8.27
18.	Western Ghat	17.69
Total		431.42

(Source: Ministry of Water Resources)

Table 1.4: Basin-wise Surface Water Potential of India (Cubic Km /year)

S.N.	Name of the River Basin	Average annual potential in river
1.	Indus (up to Border)	73.31
2.	a) Ganga	525.02
	b) Brahmaputra Barak & Others	585.60
3.	Godavari	110.54
4.	Krishna	78.12
5.	Cauvery	21.36
6.	Pennar	6.32
7.	East Flowing Rivers Between Mahanadi & Pennar	22.52
8.	East Flowing Rivers Between Pennar and Kanyakumari	16.46
9.	Mahanadi	66.88
10.	Brahmani & Baitarni	28.48
11.	Subernarekha	12.37
12.	Sabarmati	3.81
13.	Mahi	11.02
14.	West Flowing Rivers of Kutch, Sabarmati including Luni	15.10
15.	Narmada	45.64
16.	Tapi	14.88
17.	West Flowing Rivers from Tapi to Tadri	87.41
18.	West Flowing Rivers from Tadri to Kanyakumari	113.53
19.	Area of Inland drainage in Rajasthan desert	NEG.
20.	Minor River Basins Drainage into Bangladesh & Burma	31.00
Total		1869.35

(Source: Ministry of Water Resources)

Table 1.5: Catchment area and average annual yield of water in river basins of India

River Basins	Area within India (sq.km)	% of total area of India	Annual yield of water (mill.cu.mt.)	% of total yield of India	Annual flow per sq.km (cu.mt.)
Major Rivers:					
1. Ganga	861,404	26.2	468,700	25.2	442,170
2. Indus	321,289	9.8	79,500	4.3	247,441
3. Godavari	312,812	9.5	118,000	6.4	377,223
4. Krishna	258,948	7.9	62,800	3.4	243,403
5. Brahmaputra	258,008	7.8	627,000	33.7	1,081,034
6. Mahanadi	141,589	4.3	66,640	3.6	470,658
7. Narmada	98,795	3.0	54,600	2.9	552,660
8. Cauvery	87,900	2.7	20,950	1.1	237,770
9. Tapti	65,145	2.0	17,982	1.0	276,307
10. Penner	55,213	1.7	3,238	0.2	58,646
11. brahmani	39,033	1.2	18,310	1.0	202,701
12. Mahi	34,841	1.1	11,800	0.6	338,681
13. Sabarmati	21,895	0.7	3,800	0.2	173,556
14. Subarnarekha	19,296	0.6	7,940	0.4	411,484
Other Rivers	711,833	21.7	296,840	16.0	417,008
India	3,287,782	100	1,858,100	100	565,153

(Source: Central board for the prevention and control of water pollution, New Delhi.)

Previous studies

Hydro-geochemical study is a useful tool to identify processes that are responsible for groundwater chemistry. Several authors have reported about the presence of contaminants in soils (Muir & Baker, 1978) and waters (Kolpin et al., 1998) in various part of the globe and also in India (Elango et al., 2003) Detailed studies focused on the exogenic cycle of the elements were carried out on large to medium-size river systems, including the Amazon in South America, the Congo in Africa, the Ganga-Brahmaputra and the Indus in Asia, and the Huanghe in China (Sarin et al., 1989 ; Négrelet et al., 1993; Pande et al., 1994; Gaillardet et al., 1997; Zhang et al., 1990). For small catchments, the application of geochemical tools may provide constraints on runoff, on the natural and anthropogenic end-members and on their respective contributions (Ben Othmann et al., 1997; Négrelet and Deschamps, 1996).

Strontium isotope ratios are used to trace the degree of water–rock interaction and mixing processes in groundwater (Négrelet et al., 2001; Négrelet and Pauwels, 2004) while stable isotopes provide an insight into the water origin (Négrelet and Lachassagne, 2000). The aquifer is of fracture type. The chemical and isotopic compositions of waters reflect the different natural processes, i.e. mainly the weathering of rocks and soils, atmospheric inputs and anthropogenic disturbances (Drever, 1988) that contribute chemical elements to the dissolved load. Milliman (1980) pointed out that the suspended sediment load of the river depend on the various factors i.e. relief of the drainage basin, drainage basin area, Geology of drainage basin, climate and presence of lakes along the river length.

Based on preliminary chemical investigation of major Indian rivers Subramanian (1979) concluded that Indian rivers are more alkaline and about 25% more concentrated in dissolved salts than the world average river water. The comparatively high concentration of calcium and bicarbonate in Indian River systems are suggestive of intense chemical weathering in the Indian subcontinent. Drever (1982) pointed out that relief in a particular area often correlates with rock types, temperature, and vegetation. These factors are hard to separate. Subramanian (1983) after detailed studies on the Indian river system pointed out that in addition to the weathering, atmospheric contributions provide a major of certain constituents (i.e. SO₄, Cl) in Indian Rivers. For example in Godavari River basin nearly 60% of the dissolved load is atmospherically recycled (Biksham and Subramanian, 1988). The

quantification of atmospheric contribution to the river system is also reported by number of other workers Meybeck (1979); Stallard and Edmond (1983) and Sarin et al., (1989).

Undesirable and soluble constituents in the water cannot be controlled after entering the ground (Johnson 1979; Sastri, 1994). Sami (1992) has explained that leaching of surficial salts, ion-exchange processes, and residential time of groundwater in the aquifer causes the hydrogeochemical variations in the groundwater. In India and various parts of the world, numerous studies have been carried out to assess the geochemical characteristics of groundwater (Graniel et al., 1999; Umar and Sami Ahmad, 2000). Several comprehensive studies are also carried out in south India (Subba Rao et al., 1998; Elango et al., 2003; Krishnakumar, 2004; Jeevanandam et al., 2006).

Upadhyay et al. (2006) studied the heavy metals in freshly deposited sediments of the River Subarnarekha, Heavy metal distribution patterns in river sediments help in understanding the exogenic cycling of elements as well as in assessing the effect of anthropogenic influences. The detection of Hg is due to its origin in lead–zinc veins, during hydrothermal reactions Hg is entrapped (Phuong, 2005) and it is also strongly chalcophylic in nature. Banerjee and Thiagarajan (1967) during a prospecting study of the area detected Hg in rock types mica-schist, hornblende-schists, quartzite, epidiorite, quartz veins and laterites but in their studies there was no mention of its concentration detected. Sarkar et al. (2006) studied the Geo-environmental quality assessment in Jharia coalfield, India, using multivariate statistics and geographic information system. Singh et al. (2007) investigated the chemical composition of wet atmospheric precipitation over, Dhanbad.

Negrel et al. (2007) studied the Hydrogeochemical processes, mixing and isotope tracing in hard rock aquifers and surface waters from the Subarnarekha River basin. This study reports on the geochemistry of surface waters and ground waters along the Subarnarekha River system in the vicinity of the Singhbhum mining district, distinguishing between dry and wet seasons. Geochemical observations, including major ion and trace element analysis, and isotopic tracing have been carried out in the Subarnarekha River system (northeastern India) during a surface water and groundwater monitoring program aimed at evaluating impacts of mining.

The main chemical processes, which releases ions into solutions are hydrolysis, reduction, oxidation or chelation (Drever, 1988). Heavy metals are not permanently fixed on sediments and can be released back to the water column by changes in environmental conditions, such as pH, redox potential, and the presence of organic chelators (Forstner and Wittmann, 1983). Raju et.al (2009) has studied the ground water quality in the Varuna River basin, Uttar Pradesh, and found out the quality of water is suitable for irrigation purpose. The study of a relatively large number of ground water samples from a given area, offer clues to various chemical alterations undergone by the meteoric ground water, before acquiring distinct chemical characteristics. Most of the inland areas of Indian subcontinent have Ca-Mg-HCO₃ type of groundwater (Bartarya, 1993; Datta and Tyagi, 1996). The chemical alteration of the rain water depends on several factors such as soil-water interaction, dissolution of mineral species and anthropogenic activities (Faure, 1998; Subba Rao, 2001; Umar and Ahmed, 2007). Singh et. al. (2005) pointed out that the water chemistry of the reservoirs strongly reflects the dominance of continental weathering aided by atmospheric and anthropogenic activities in the catchment area.

Chemical composition of river water provides important information on the source of major ions, chemical weathering rate of basin and associated CO₂ consumption rate in the river basin which exert strong influence on climate (Berner et al., 1983; Stallard and Edmond, 1983; Gaillardet et al., 1997). Chemical weathering rate and associated CO₂ consumption are regulated by several parameters including lithology of drainage basin, runoff, temperature variation, vegetation and relief. The importance of lithology is emphasized by several authors (Meybeck, 1986; Amiotte-Suchet and Probst, 1993) who showed that basalt is more prone to weathering than the crystalline silicate rock, due to its non-crystalline structures. The chemical weathering and associated CO₂ consumption for Deccan trap regions were earlier reported by Dessert et al. (2001) and Das et al. (2005) by studying the Narmada–Tapti–Waniganga Rivers and the Krishna River systems respectively. Jha et al. (2009) estimated chemical weathering rate and associated CO₂ consumption rate of the Godavari River basin based on major ion concentration of river water, and also pointed out the role of basalt weathering on the major ion chemistry of river water.

Factors controlling water chemistry of rivers

River water derives its composition from the weathering and geochemical processes operating in the catchments and anthropogenic sources. Natural composition of river waters are essentially regulated by the breakdown of rock matrix in response to the reactive rain water containing dissolved carbon-dioxide, however deviations in natural water chemistry could be introduced by man at any stage or location in the drainage basin. The main chemical process which releases ions into solutions is hydrolysis. Hydrolysis is the chemical reaction that takes place between a mineral and water's constituents, either H^+ or OH^- . Carbonation and oxidation are the two major reactions which produce protons for chemical weathering. In carbonation reactions atmospheric CO_2 and CO_2 produced by the soil flora and fauna react with water to form weak carbonic acid (H_2CO_3). This carbonic acid is unstable and soon breakdown into HCO_3^- ions and protons (H^+) which react with the silicate and carbonate minerals and in the process release ions into solutions:



Other chemical weathering processes i.e. reduction, oxidation or chelation also release ions into solution. The relative importance of each chemical weathering process varies with the weathering materials and the conditions of the weathering environment.

Three main mechanisms controlling the water composition of the aquatic systems are atmospheric-precipitation, rock weathering and evaporation-crystallisation processes. According to Gibbs (1970), atmospheric-precipitation controlled rivers are in arid regions and these rivers are characterised by high concentration of TDS and high Na relative to Ca. The rock dominance rivers are in areas of intermediate rainfall and are characterized by values of intermediate TDS and Na/Na+Ca ratio. However, in most of the major world rivers composition is controlled by the rock weathering. Reeder et al. (1972) studied the hydrochemistry of the surface waters of the Mackenzie River basin and concluded that the salinity in the river is largely controlled by lithology, with high salinities resulting from carbonates and evaporates. Drever (1982) and Garrels and Mackenzie (1971) stress the importance of rock types in determining the chemistry of surface water. On the basis of a detailed study of Amazon River basin, Stallard and Edmond (1983) emphasized the role of geology and erosional regime as the most fundamental control on the chemistry of surface water composition, precipitation of salts, biological uptake, and cyclic salt inputs have only secondary effect on water chemistry.

However, the natural water composition of rivers may be manipulated by the human activities such as, discharge of the industrial wastes in to the rivers, multipurpose use of a single water body (agriculture, human consumption, recreation fishing, hydropower etc.) large scale settlement around the river water bodies, presence of mining/industrial activities in the catchments, problems arising due to siltation of water bodies and eutrication, which is directly attributed to over fertilization of water body by man activities usually by waste water discharge.

Subarnarekha River and its tributaries receive heavy pollutants both in dissolved and particulate forms from different sources including urban, industrial and mining sources and poses threat for water quality. Except for some studies on the water and sediment quality (Senapati and Sahu, 1996) no serious efforts has been made to understand geochemical processes and controlling factors in determining the water and sediment chemistry of the rivers. Therefore, this study has following objectives to understand the geochemical processes in the catchment and anthropogenic influences on Subarnarekha River:

Objectives of Study

1. To study the major ion chemistry of the surface water of the Subarnarekha River, reservoirs and its major tributaries.
2. To study the ground water geochemistry of the Subarnarekha River basin.
3. To study the seasonal and spatial variation in major ion chemistry of surface and sub-surface water.
4. To assess the source and mechanism controlling of the major ion chemistry of the rivers.
5. To assess the ground water quality for the domestic and agricultural uses and surface water for irrigation purposes.

CHAPTER 2
STUDY AREA

Subarnarekha ('the streak of gold') is one of the major rivers of the south Chotanagpur plateau, Jharkhand state, India. It is a rain fed river and originates from the Nagri village, Ranchi (23.4⁰N, 85.4⁰E) plateau situated 756 m above sea level. After flowing over a distance of 470 km through the state of Jharkhand, West Bengal and Orissa, it ultimately joins with the Bay of Bengal. Its catchment area comprises 18,950 km², of which 13,590 km² are situated in Jharkhand, 3200 km² in Orissa and 2160 km² in West Bengal.

Subarnarekha has an asymmetrical catchment basin, the right bank tributaries draining more than three-fourths of the total basin area and the left bank one-fourth of the basin. On the right bank there are four major tributaries, Raru, Kanchi, Karkai and Kharkai draining between them nearly half of the Subarnarekha basin, covering around 9,050 square kilometres of area. On the left side there is only one stream, Dulung, which drains an area of some 1,173 square kilometres, covering hardly 6% of the basin area.

An important tributary of this river is Kharkhai that originates from the neighbouring Mayurbhanj district and merges with river Subarnarekha near the city of Jamshedpur. This river and its tributary both double in stream flow during the monsoon period.

Physiography

The Subarnarekha basin occupies a region of varied physiography ranging from steep hill masses to flat coastal plain through a series of dissected plateaus and sloping plains. The following six physiographic divisions have been recognized in the Subarnarekha basin (after Mukhopadhyay, 1980).

1. Ranchi plateau: The greater part of the Ranchi plateau is made up of Chota Nagpur Granite-gneiss (550 metres above mean sea level). There is a gentle eastward slope and incised meandering of the drainage channels. The flat-topped Ajodhya hill (about 600 metres above the sea level) with two small monadnocks on its surface represents a relic of the Ranchi plateau.

2. Escarpment and plateau slopes: Along the eastern margin of the Ranchi plateau lies a great escarpment (Ganga Ghat) which has been sculptured out of the resistant rocks by

headward erosion of the Subarnarekha and its tributaries. A number of waterfalls and rapids (from 2 to 74 metres in height) characterize the escarpment. A number of springs are located on the scarps poorly jointed and impervious gneiss is overlain by fissured rocks.

3. Uplands: Wide plateau area with elevations in the range of 250 to 400 metres cover the Kolhan and Bamanghati area on the south, the Dhalbhum valley to the southeast of Dalma range, and the Barabhum and Puruliya uplands on the north. The region has moderate relief with numerous monadnocks rising 50 to 60 metres above the ground level. Some of the bare monadnocks of granite around Jhalida in the Puruliya upland have beautiful rounded shapes and these provide classical example of weathering by exfoliation (Ray, 1976; Mukhopadhyay, 1980). The upland region has thin residual soil cover with local flat silt covered patches (2 to 15 metres thick) along the valleys of the major stream, such as near Barabhum and the Rairangpur (Bamanghati) area. Parts of the surface are capped by laterite.

4. Central plains: A wide expanse of the basin south of the Porahat-Dalma range is occupied by an undulating plain land of Singhbhum with moderate to gentle slopes and with a gentle elevation in the range of 100 to 200 metres. The region has a thin soil cover and an abundance of rock outcrops as are exposed near Baharagora and Jamsola, downstream of which the plain is covered with thick bed of alluvium. From Jamsola, southeastwards, the land has steady slope dropping from a level of 100 metres down to 10 metres until the coastal plain is reached. A characteristic physiographic feature of the Singhbhum plain between Jamshedpur and Rairangpur is the presence of numerous narrow criss- cross ridges of dolerite dykes, some of which stand up to 100 metres above the granite plains.

5. Intervening hill ranges: Several hill ranges lie across the Subarnarekha basin, of which the Porahat-Dalma range (elevation 450 to 950 metres) is the most important, which runs east-west with slight northward convexity, divides the basin into two parts, Panch Pargana plain on the north and Singhbhum plain on the south, with the main river crossing the range near Chandil through a Gorge section. The Porahat- Dalma range is made up of several bands of intricately folded quartzite and mafic lavas which have resisted weathering. While much of the softer schistose rocks to the south and north have been eroded away forming the plains.

6. Coastal plain: This part of the Subarnarekha basin extends for 20 to 25 kilometres from the coast and has an elevation of less than 10 metres above mean sea level. The region is characterized by three distinct lines of low sandy ridges parallel to the shore line with flat

silty-clayey marine terraces in between. The sandy ridges are considered to represent successive positions of the beach ridges. A minor delta of the Subarnarekha which is slowly advancing seaward has developed in post-Pleistocene time.

Table 2.1: Some morphometric attributes of the Subarnarekha basin

Physiographic unit	Height (metres)	Relative relief	General slope	Drainage texture
1.Ranchi plateau	500-600	Low to moderate	Gentle	Medium & fine
2.Escarpment plateau slopes				
(a) Ganga ghat,Ajodhya hill,Dhanjori range	250-500	Moderately high to very high	Steep to moderately steep	Fine
(b) Tebo Ghat,western Sanjai,Dalma range	250-500	Moderately high to high	Very steep	Very fine
(c) Adjoining other uplands	200-450	Moderately high	Moderately steep	Fine
3. Uplands				
(a) Kolhan,Bamanghati uplands	300-450	Moderately high	Moderately steep	Fine & very fine
(b) W.Dhalbhum,Barabhum & Puruliya uplands	150-300	Moderately high to Moderately	Moderate	Medium & fine
4.General plains				
(a) Singhbhum plain		Moderate	Moderate & gentle	Fine
(b) Rarh-Medinipur plain	10-100	Low to very low	Gentle	Medium
(c) Mayurbhanj plane	150-200	Moderately high	Moderate	Medium
5. Intervening hill ranges				
(a) Porahat-Dalma	450-950	High	Moderately steep	Fine & very fine
(b) Dhanjori	450-600	High	Moderate	Fine
6. Coastal plains	Below 10	Very low	Level to gentle	Very coarse

Source: Central board for the prevention and control of water pollution, New Delhi

Geology of Subarnarekha River basin

The Subarnarekha river, flows over Precambrian terrains of Singhbhum craton in the eastern India. The prominent 200 kilometer long copper belt thrust zone of Singhbhum (extended from northern part of Mayurbhanj district through eastern and central Singhbhum to Chakradharpur and beyond) separates the Precambrian basement of the region into two distinct provinces i.e. the Singhbhum-Orissa iron ore province on the south from the Satpura province on the north. The craton consists of eight principal lithological associations.

- (1) Singhbhum granite with enclaves of older Metamorphic Tonalite Gneiss (OMTG) and Older Metamorphic Group (OMG) of sediments and volcanics
- (2) Basins of banded iron formation (BIF) fringing the Singhbhum granite
- (3) Volcanic basins, loosely termed as greenstone belts
- (4) Flysch-like sediments and volcanics of North Singhbhum orogen
- (5) Mafic dyke swarms
- (6) Kolhan basin
- (7) Newer tertiary
- (8) Alluvium

These lithological associations are described here briefly after Vaidyanadhan and Ramakrishnan, (2008):

1. The oval-shaped Singhbhum granite is a composite of several bodies, which are assigned to three phases (phase I, phase II and III). The Phases I and II are geochemically distinguished as Type-A of Singhbhum granite called SG-A (~3300-3400 Ma), and Phase III as type B (SG-B, ~3100 Ma). Broadly, Singhbhum granite belongs to granodiorite-adamellite-granite (GAG) suite, containing 3300-3400 Ma old enclaves of OMG and OMTG. Katipata (Nilgiri) granite in east, Chakradharpur granite in north and Bonai granite in the west are correlatives of Singhbhum granite. The unclassified gneisses around Pala Lahara gneiss that may also be correlated with Singhbhum granite.
2. There are three basins of iron formation fringing the Singhbhum granite to the west, east and south, called respectively as Noamundi-Koira, Gorumahisani-Badampahar

and Tonka-Daitari. They have been grouped by different authors either into a single Iron Ore Group or two major stratigraphic groups of the older Badampahar group and younger Koira group. The Daitari group is correlated by many authors with Badampur Group.

3. Isolated volcanic basins of varied ages occur in the craton and the marginal orogen. The volcanic basins overlying Singhbhum granite are the Simlipal and Dhanjori in the east, and Jagannathapur (Dungoaposi) and Malangtoli (Naukot) in the west. Dalma volcanics occur within the North Singhbhum orogen; Ongarbira volcanics overlie the Koira Group in the northwest. Dhanjori and Simlipal basins expose typical quartzite-basalt association with a basal Quartz Pebble Conglomerate (QPC). Such a lithological ensemble denoting a stable crust occurs globally in Archaean cratons after the cessation of greenstone cycles e.g., Witwatersrand-Triad of southern Africa, Circum-Superior basins of Canada, the Hamersley-Nabberu basins of Western Australia and Bababudan basin of southern India. Jagannathpur and Malangoti volcanics are weakly metamorphosed tholeiites that are believed to be younger.
4. The North Singhbhum orogen commences with a basal conglomerate on Singhbhum granite and exposes a progressively younger succession towards the north. Low-grade metasediments overlie the basal conglomerate. The major Singhbhum shear zone occurring further north is believed to have not disrupted the stratigraphy, although some authors feel that the shear zone could be a stratigraphic boundary. The shear zone is followed to the north by the flyschoid sediments of Singhbhum group consisting of the Chaibasa and Dhalbhum formation (Saha et al., 1988). The spine of the orogen is marked by the Dalma volcanic belt, which is followed to the north by a succession of fine clastics, cherts, felsic volcanics and mafic-ultramafic schists. These sediments belong to Singhbhum group of Sarkar and Saha (1983) but may belong to a younger sequence (Gupta and Basu, 2000) to be called Chandil formation. Tamar-Poropahar (-Khatra) shear zone traverses these sediments close to the northern boundary of the orogen. The irregular, intrusive contact of the northern part of the Chandil formation with Chhotanagpur Gneiss is noticed further north of the shear zone. This contact zone marks the boundary of North Singhbhum orogen against the Satpura mobile belt that is represented here by the Chhotanagpur Gneiss.

5. Dykes of never Dolerite traverse the entire craton and mark major episodes of cratonic stabilization.
6. The less deformed Kolhan basin, comparable to 'Purana' basins, unconformably overlies Singhbhum granite.
7. Alluvial formations (less than 30 metres thick) cover part of the shield area, particularly in the eastern part of Ranchi district.

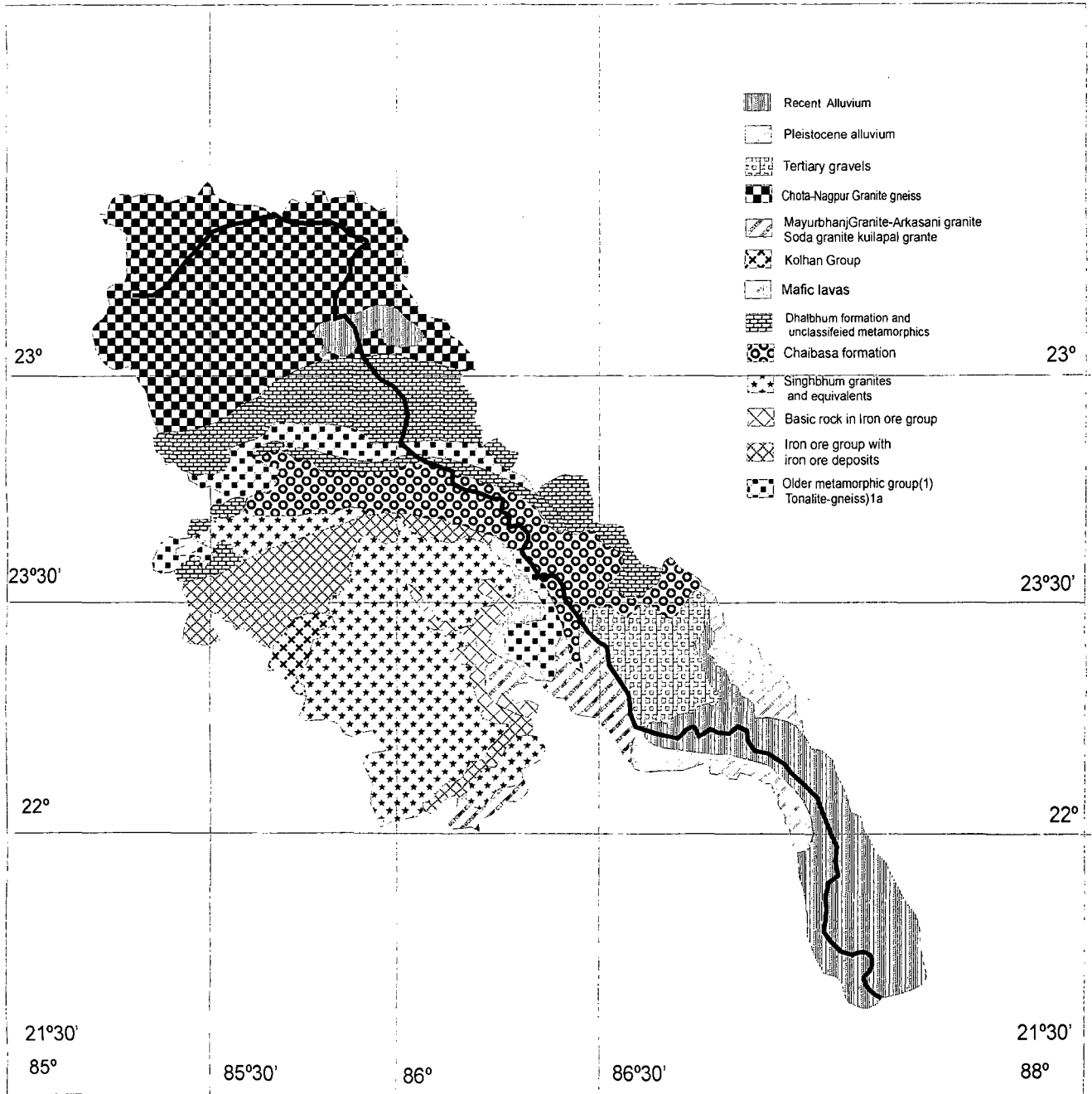


Fig 2.1 Geology of Subarnarekha River Basin

Table 2.2: Chronostratigraphic succession of the Precambrian Singhbhum rocks of Subarnarekha basin after Sarkar and Saha (1977) and Saha (1994).

Chakradharpur Granite Gneiss

Singhbhum orogeny

Newer Dolerites

Jojobatu ultrabasic intrusives

Kolhan group

Shale

Limestone

Sandstone-conglomerate

-----Unconformity-----

Singhbhum Granite (ca. 3.1 Ga)

Iron ore Orogeny

Phyllites, with volcanic

Quartzite, conglomerate bands, phyllite

Ongarbira lava flow

Several bands of orthoquartzites with minor arkose and conglomerate alternating with phyllite

-----Unconformity-----

Older Metamorphic banded gneisses and amphibolites (related to Older Metamorphic Orogeny) as relics within Singhbhum Granite

Soils of Subarnarekha River basin

Subarnarekha basin has three broad groups of soils:

1. Alluvial soils
2. Red soils
3. Latosols

In the upper basin on the plateaus and uplands of Chota Nagpur are predominant red soils, which are mostly of residual and colluvial origin, being derived from the old bed rocks. The red soils cover more than 83 % of the basin area. Further down the basin in the lower valleys and coastal plains, river borne alluvial deposits of unconsolidated materials are spread over 11% of the basin area. Remaining 4 % of the basin has cover of infertile latosols (mainly laterites).

Subarnarekha basin being located in heavy rainfall zone (1300 to 1600 mm per annum), the leaching process in the subsoil horizons is much too active all over the region. Wherever the leaching process has gone too far, especially on the flatter areas, latosols are formed, often appearing as small laterite caps or hard pans resting on clayey subsoils. Almost throughout the basin, the soil mantle is subject to heavy erosion and unless some natural protection is afforded by way of forest cover. Most of the soils are liable to be washed away, leaving the barren tracts in the Subarnarekha basin.

Table 2.3: Soils in the Subarnarekha basin and their erodibility

Soil group and subgroup	Areal extent (square Km)	% of basin area	Erosion hazard
(a) Alluvial soils	2,530	13.11	Very high
1. Coastal alluvial	288	1.49	Very high
2. Coastal sandy	59	0.31	Very high
3. Coastal saline	65	0.34	Very high
4. Older alluvial	2,118	10.98	Very high
(b) Red soils	16,086	83.36	Moderate
5. Red gravelly	739	3.82	Very high
6. Red sandy	4,623	23.96	Very high
7. Red loamy	922	4.78	High
8. Red earths	1,654	8.57	Moderate
9. Mixed red and black	1,014	2.25	Moderate
10. Red and yellow	6,134	36.97	Moderate
(c) Latosols	680	3.52	High
11. Laterite	301	1.56	High
12. Lateritic	379	1.98	High
Subarnarekha basin	19,296	100	High

(Source: Central board for the prevention and control of water pollution, New Delhi)

Vegetation of Subarnarekha River basin

More than one-fourth of Jharkhand's land area is forested. Most forests occur on the Chota Nagpur plateau; those on the plain largely have been cleared to allow cultivation of the land. The natural vegetation is deciduous forest; Chota Nagpur is rich in sal (*Shorea robusta*), a valuable hardwood. Other trees include the asan (*Terminalia tomentosa*), the leaves of which provide food for the silkworms of the sericulture industry, as well as several trees that are important in the production of lac (a resinous substance used to make varnishes). The tree

locally known as mahua (*Madhuca longifolia*) yields sweet edible flowers that are used to make liquor. Bamboo and bhabar (an Indian fibre grass; *Ischaemum angustifolium*) from Chota Nagpur supply raw materials for paper manufacture. Among the other common trees, most of which are found in the plain, are the banyan (*Ficus benghalensis*), Bo tree (or pipal; *Ficus religiosa*), and palmyra palm (*Borassus flabellifer*).

Climate and rainfall in the Subarnarekha River basin

The climate of Jharkhand is dry semi-humid to humid semi-arid types. There are three well-defined seasons in Jharkhand. The cold-weather season, from November to February, is the most pleasant part of the year. In Ranchi, the temperature in winter season usually rises from 10 °C to 20⁰ C. From March to mid-June the hot-weather season is experienced. May, the hottest month, is characterized by daily high temperatures is about 37 °C and low temperatures is 20⁰ C.

The season of the southwest monsoon, from mid-June to October, brings nearly all of the annual rainfall. The average annual rainfall on the plateau and sub-plateau region is 1400 mm. Out of this, 82.1 % rainfall is received between June to September and remaining 17.9 % during the rest of the months. The annual average rainfall received by the state is about 1400 mm, which is more than the nation average of 1170 mm. Precipitation during the winters is scanty and highly variable.

The Chotanagpur highlands have a better supply of rain than the adjoining northern and north-western plain because of several reasons. They are nearer the source of monsoon depression i.e. Bay and the delta. They are benefited by this supply both from the Bay and the Arabian Sea branches.

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CHAPTER 3
MATERIALS AND METHODS

Collection of Water samples

For geochemical analysis, water samples were collected on seasonal basis from different sampling sites of Subarnarekha River basin in 2008. This include 37 river and reservoirs water samples and 46 ground water samples collected during pre-monsoon (29th May to 3rd June), monsoon (14th August-18th August) and post-monsoon (13th December-19th December) of the year 2008. A Garmin (GPSMAP-76CSX) global positioning system (GPS) was used for location readings. One litre water sample was collected in high density polyethylene bottle from different parts of basin. The water sample was also collected from the tube well, dug well and reservoir from some selected parts of the catchment basin related to mining, industrial and urban sites for ground water quality assessment. The suspended sediments were separated by 0.45 µm Millipore membrane filter using vacuum pump before storage for further chemical analysis. Collected water samples were brought to the laboratory and stored at 4⁰C temperature in order to avoid any major chemical alteration (APHA, 1995). For cations, 100 ml samples were filtered and preserved with ultra pure nitric acid. The sampling location includes the main Subarnarekha stream and its major tributaries i.e Kanchi, Kharkai and Sankh. The ground water samples were collected from the tube well and dug well from some selected different part of the basin comprising mining, industrial and urban sites for ground water quality assessment. Following are the details of the water samples.

Table No. 3.1 Sampling locations on Subarnarekha River Basin

1. Subarnarekha River (surface water)

Location	Latitude	Longitude	Ele. (ft)	Sample Code		
				Pre monsoon	Monsoon	Postmonsoon
Hatia Bridge	N23°16.977'	E085°18.557'	2059	SB -5	SBM-5	SBP-5
Sonari	N22°50.156'	E086°09.765'	409	SB-12	SBM-12	SBP-12
Chandil	N22°58.278'	E086°01.217'	494	SB-10	SBM-10	SBP-10
Maubhandar	N22°35.562'	E086°26.782'	287	SB-13	SBM-13	SBP-13
Mango	N22°48.998'	E086°12.661'	374	SB-14	SBM-14	SBP-14
Ghatsila	N22°34.896'	E086°28.215'	291	SB-15	SBM-15	SBP-15
Musabani	N22°30.468'	E086°29.117'	222		SBM-35	SBP-35

2. Tributaries (surface water)

Location	Latitude	Longitude	Ele (ft)	Sample code		
				Premonsoon.	monsoon	Post.monsoon
Kanchi,Khuddi	N23°10.754'	E085°16.628'	1844	SB-1	SBM-1	SBP-1
Kharkai,Adityapur	N22°47.316'	E086°10.437'	391	SB-16	SBM-16	SBP-16
Kharkai, Sonari	N22°50.131'	E086°09.610'	412	SB-17	SBM-17	SBP-17
Sankh,Pampughat	N22°30.442'	E086°29.090'	231		SBM-36	SBP-36

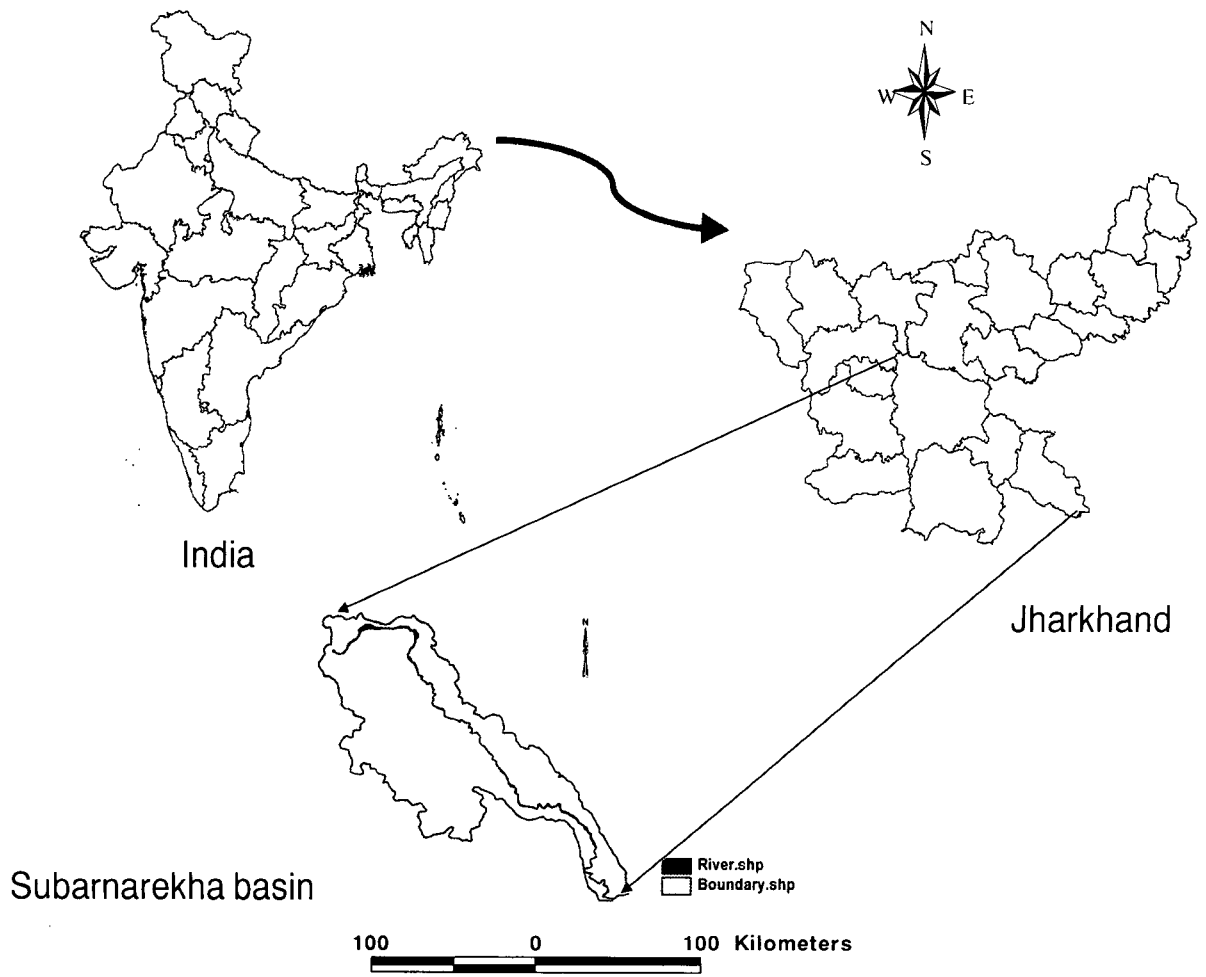
3. Reservoir

Location	Latitude	Longitude	Ele (ft)	Sample Code		
				Pre monsoon	Monsoon	Post monsoon
Durwa Dam	N23°17.648'	E085°15.532'	2219	SB-3	SBM-3	SBP-3
Chandil Dam	N22°58.564'	E086°01.430'	582	SB-11	SBM-11	SBP-11

4. Ground water

Location	Latitude	Longitude	Ele (ft)	Sample Code		
				Pre monsoon	Monsoon	Post monsoon
Hatia Bridge	N23°17.210'	E085°18.584'	2101	SB-4	SBM-4	SBP-4
Khuddi	N23°10.731'	E085°16.596'	1852	SB-7	SBM-7	SBP-7
Tatanagar	N22°46.344'	E086°11.731'	825	SB-18	SBM-18	SBP-18
Adityapur	N22°47.306'	E086°10.322'	430	SB-19	SBM-19	SBP-19
Sakchi	N22°48.421'	E086°12.373'	469	SB-20	SBM-20	SBP-20
Govindpur	N22°45.537'	E086°15.101'	564	SB-21	SBM-21	SBP-21
Mango	N22°49.113'	E086°12.706'	410	SB-22	SBM-22	SBP-22
Jugsalai	N22°46.525'	E086°11.281'	833	SB-23	SBM-23	SBP-23
Jaduguda	N22°39.663'	E086°20.829'	357	SB-24	SBM-24	SBP-24
Mushabani	N22°30.713'	E086°27.443'	378	SB-25	SBM-25	SBP-25
Maubhandar	N22°35.47'	E086°26.703'	309	SB-26	SBM-26	SBP-26
Ghatsila	N22°34.896'	E086°28.215'	291	SB-27	SBM-27	SBP-27
Chakulia(dug well)	N22°28.837'	E086°43.253'	394	SB-28	SBM-28	SBP-28
Chandil	N22°58.370'	E086°01.429'	518	SB-29	SBM-29	SBP-29
Kandra	N22°51.009'	E086°03.024'	596	SB-30	SBM-30	SBP-30
Saraikela	N22°42.125'	E08°55.905'	605	SB-32	SBM-32	SBP-32
Chaibasa	N22°46.420'	E085°48.968'	750	SB-33	SBM-33	SBP-33
Chakradharpur	N22°40.376'	E085°37.885'	731	SB-34	SBM-34	SBP-34
Chakulia	N22°28.749'	E086°43.252'	418	SB-37	SBM-37	SBP-37

(a)



(b)

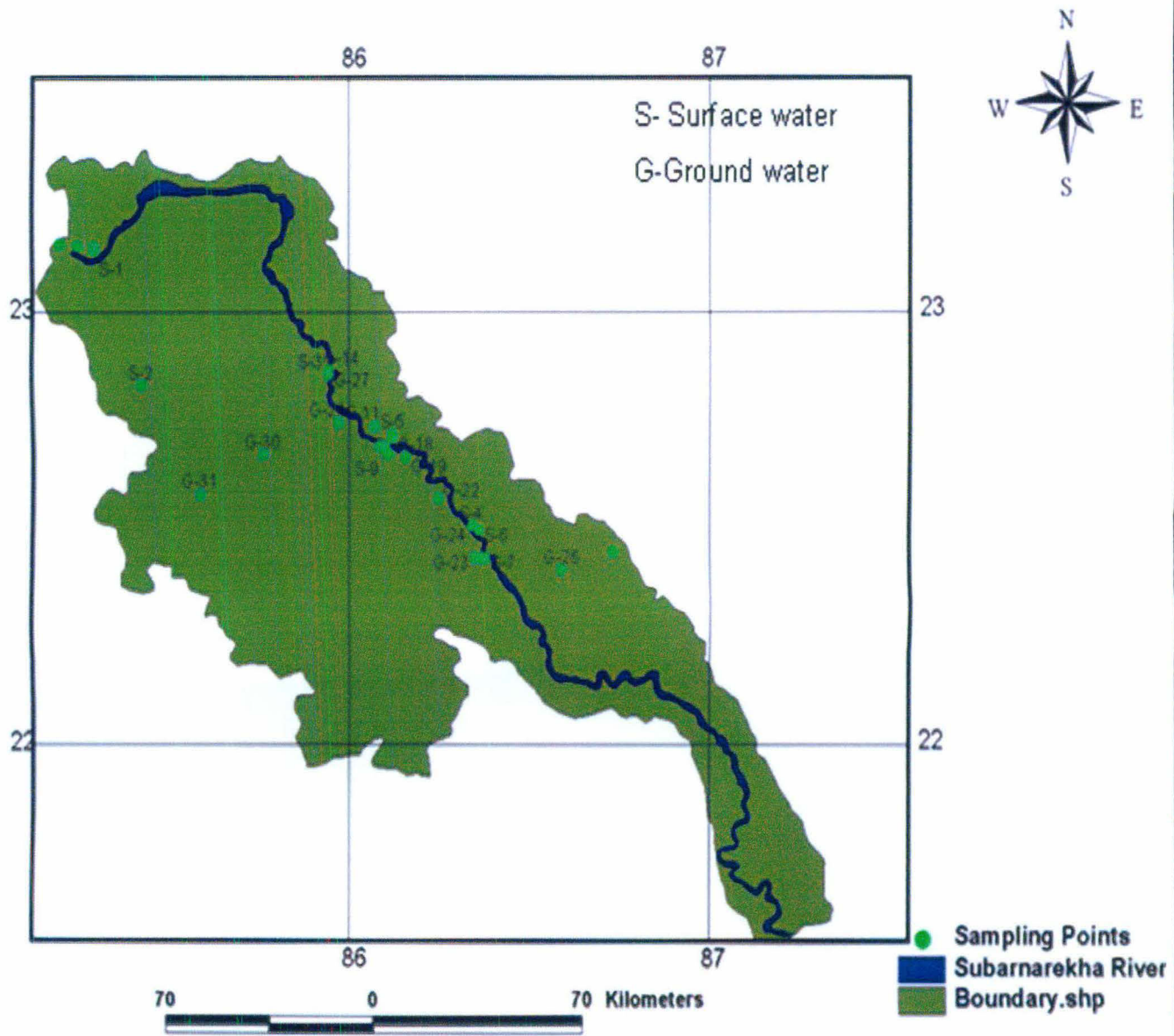


Fig 3.1: Location map of Subarnarekha River basin (a&b)

Water Analysis

Separation of Suspended Sediments: Suspended sediments were separated from the water samples in the laboratory by using 0.45 μm Millipore membrane filters of 47 mm diameter. Vacuum pump was used to for faster filtration. Weight of the suspended sediment was found out by weighing the filters before filtration and subtracting this weight from the weight of the filter with sediment after the filtration. Before taking the weight of the sediment on the filter paper, it was kept for one week in dessicator to remove moisture from the sediment. Volume of the samples was measured by glass measuring cylinder. Total suspended matter was calculated for one litre water samples from the volume of filtered water and the weight of the sediment.

pH Measurement: pH is an important parameter, which is used to identify the type of effluent. The pH scale is a series of numbers, these numbers express the degree of acidity or alkalinity of a solution, as contrasted with the total quality of acid or base in some substances as found by acid – base titrations, the term pH was introduced by Sorensen,

$$\text{pH} = -\log [\text{H}^+]$$

pH is a measure of H^+ , the hydrogen ion concentration, which determines the acidic or basic quality of water solution. At 25°C, when $\text{pH} < 7$, a water solution is acidic, when $\text{pH} = 7$, a water solution is neutral, when $\text{pH} > 7$, a water solution is basic.

pH of collected water sample was measured by Consort microcomputer ion meter. Before measuring the pH of water samples, the electrode was immersed for 10 hours in 0.1 N HCl, to make it stable. After rinsing the electrode with distilled water the instrument was calibrated with a buffer solution of pH 4.0 and 9.2. After that the electrode was immersed in samples and pH of each sample was recorded. The samples were stirred well during measurement to provide homogeneity.

Electrical Conductivity (E.C.): Electrical conductivity was measured by using Consort pH and Conductivity Meter. It provides measurement of electrical conductivity by a cell consisting of two platinum electrodes to which an alternating potential is applied. The corresponding is proportional to conductivity of ionic solution in which the cell is applied. For EC measurement, the instrument was calibrated and set for 0.01M KCl standard. The conductivity was measured in $\mu\text{S}/\text{cm}$ for water samples.

Bicarbonate (HCO_3): Bicarbonate was determined by potentiometric titration method. Standards of HCO_3 were prepared for required concentration from chemical salt NaHCO_3 . 50 ml of each standard and samples were titrated against 0.03 N HCl. pH 4.5 is taken as the endpoint of the reaction. A graph was plotted for standard concentrations against the volume of HCl consumed. The concentrations of the samples were determined from the graph plotted for standards.

Dissolved Silica (H_4SiO_4): The dissolved silica was determined by Molybdosilicate method (APHA, 1995), 20 ml of each standard and samples were pipetted out in to a 100 ml volumetric flask and 10 ml of ammonium molybdate solution (prepared by dissolving 2 gm of ammonium molybdate in 10 ml distilled water and 6 ml of conc. HCl and volume was made to 100 ml) and 15 ml of reducing agent (prepared by mixing 100 ml of metol sulphite solution, 60 ml 10% oxalic acid and 120 ml of 25% H_2SO_4 and the volume was made upto 300 ml) were added. The samples were stirred well and kept for three hours to complete the reaction. The optical density was measured for standard and water samples at 812 nm by using UV/VIS Spectrophotometer.

Major Anions: Major anions (F, Cl, NO_3 , and SO_4) were analyzed on ion chromatograph (Dionex Dx-120) using anions AS12A/AG12 columns coupled to an anion self-regenerating suppressor (ASRS) in recycle mode. A combination of Na_2CO_3 and NaHCO_3 was used as an eluent maintained at flow rate of 1.15 ml min^{-1} . Eluent solution for anion analysis was prepared by stock solution of 0.5 M sodium carbonate (Na_2CO_3) and 0.5 M sodium bicarbonate (NaHCO_3) as follows:

1. 0.5M Sodium Carbonate (Na_2CO_3) Stock Solution: 5.98 gm of Na_2CO_3 were dissolved in de-ionized water and diluted it up to 100ml.
2. 0.5M Sodium Bicarbonate (NaHCO_3) Stock Solution: 4.2 gm NaHCO_3 was dissolved in de-ionized water and diluted it up to 100ml.

5.4 ml of 0.5M sodium carbonate solution and 0.6ml of 0.5M sodium bicarbonate (NaHCO_3) solution were mixed and diluted to 1000 ml with water for preparation of eluent for anion analysis.

Major Cations: Major cations (Ca, Mg, Na, K and NH_4) were measured by ion chromatograph by using cation column (CS12A/CS12G) and cation self-regenerating suppressor (CSRS) in recycle mode. The eluent used for cation analysis was prepared by

diluting 22 ml of 1N sulphuric acid (H_2SO_4) in 1-liter of de-ionized water. 1N H_2SO_4 was prepared by mixing of 27.76 ml of concentrated sulphuric acid with 1 litre of de-ionized water. Analysis of major cations of some samples was repeated on ICP-OES to monitor the accuracy of the analysis.

The analytical precision was maintained by running the known standard after every 15 samples. An overall precision, expressed as percent relative standard deviation (RSD) was obtained for the entire samples. Analytical precision for cations (Ca^{2+} , Mg^{2+} , Na^+ and K^+) and anions (F^- , Cl^- , NO_3^- and SO_4^{2-}) were within 10%.

CHAPTER 4
RESULTS AND DISCUSSION

RESULTS AND DISCUSSION

The surface and ground water samples has been collected from different sampling sites of Subarnarekha River basin and analysed for pH, EC, TDS, major cations (Ca, Mg, Na, K) and anions (F, Cl, HCO₃, SO₄). The geochemical characteristics of the surface and ground waters are given in Tables 4.1-4.6 and the results are discussed in the following paragraphs:

pH, EC and TDS:

The physicochemical characteristics of surface water of Subarnarekha River basin during pre-monsoon, monsoon and post-monsoon seasons are given in Tables 4.1-4.3. The pH was slightly alkaline in nature and its value varied from 7.2 to 8.1 in pre-monsoon, 6.9 to 7.6 in monsoon and 6.9 to 8.5 in post-monsoon. In monsoon, pH was relatively low, which may be due to the addition of low pH water from atmospheric precipitation. An increase in pH suggests that dissolution has been enhanced due to high interaction between rainwater and soil and rocks (Subramanian and Saxena, 1983). The Electrical conductivity (EC) which is a measurement of the ionic strength of solutions varies from 86 to 352 $\mu\text{S}/\text{cm}$ (average 237 $\mu\text{S}/\text{cm}$) in pre-monsoon, 68 to 195 $\mu\text{S}/\text{cm}$ (average 136 $\mu\text{S}/\text{cm}$) in monsoon and 67 to 361 $\mu\text{S}/\text{cm}$ (average 241 $\mu\text{S}/\text{cm}$) in post-monsoon. Total dissolved solids (TDS) of river water sample varies from 60 to 279 mg/l with the average being 191 mg/l in pre-monsoon, 55 to 154 mg/l (average 115 mg/l) in monsoon and 55 to 301 mg/l (average 199 mg/l) in post-monsoon seasons.

The pH of ground water samples was slightly acidic to alkaline and its value varies from 6.7 to 8.3, 5.9 to 7.8 and 5.3 to 7.5 during pre-monsoon, monsoon and post-monsoon respectively with the average value of 7.9, 7.0 and 6.8 (Tables 4.4-4.6). The EC varies from 342 to 2290 $\mu\text{S}/\text{cm}$ with the average being 961 $\mu\text{S}/\text{cm}$ in pre-monsoon, from 324 to 3120 $\mu\text{S}/\text{cm}$ (average 1019 $\mu\text{S}/\text{cm}$) in monsoon and from 252 to 3090 $\mu\text{S}/\text{cm}$ (average 944 $\mu\text{S}/\text{cm}$) in post-monsoon. TDS of ground water samples of Subarnarekha River basin varies from 303 to 1736 mg/l (average 804 mg/l) in pre-monsoon, from 246 to 2677 mg/l (average 865 mg/l) in monsoon and from 215 to 2545 mg/l (average 755 mg/l) in the post-monsoon season.

Table 4.1: Physico-chemical characteristics of surface water of Subarnarekha River basin during pre-monsoon season

S.N.	Code	pH	EC	TDS	F	Cl	HCO ₃ ⁻	SO ₄ ²⁻	NO ₃	H ₄ SiO ₄	Ca ²⁺	Mg ²⁺	Na ⁺	K ⁺	TZ ⁻	TZ ⁺	%Na	SAR
1	SB5	7.2	215	150	1.20	17.9	72.8	5.6	10.2	7.0	16.9	4.7	11.7	1.8	2.0	1.8	31.1	0.6
2	SB12	7.8	266	222	0.46	23.8	108.3	15.1	7.4	17.4	22.7	8.0	16.1	3.2	2.9	2.6	30.4	0.7
3	SB10	7.6	164	146	0.54	11.9	81.5	4.1	1.3	14.6	14.5	5.3	10.6	1.8	1.8	1.7	30.3	0.6
4	SB13	7.6	334	272	1.36	47.3	101.2	31.5	6.5	16.0	32.1	8.1	21.5	6.5	3.8	3.4	32.7	0.9
5	SB14	7.7	242	182	0.47	16.2	93.6	11.3	2.8	16.5	16.8	7.6	14.1	2.5	2.3	2.1	31.6	0.7
6	SB15	7.4	352	279	1.05	27.4	116.8	37.9	10.4	16.1	32.6	8.3	21.8	6.4	3.7	3.4	32.5	0.9
7	SB1	7.7	271	239	0.51	19.5	138.8	4.2	3.6	18.9	20.7	7.6	21.8	3.8	3.0	2.7	38.7	1.0
8	SB16	7.7	218	171	0.42	16.9	85.4	9.9	4.7	16.2	18.1	5.9	10.7	2.5	2.2	1.9	27.5	0.6
9	SB17	7.6	298	231	0.52	26.8	112.1	16.7	2.3	17.8	31.8	9.3	10.6	3.5	3.0	2.9	19.0	0.4
10	SB3	8.1	86	60	0.35	6.0	31.9	2.5	1.4	2.6	7.7	2.8	3.9	1.2	0.8	0.8	24.5	0.3
11	SB11	7.6	165	147	0.50	11.9	81.5	4.5	1.6	14.2	14.6	5.4	10.8	1.6	1.8	1.7	30.4	0.6
Maximum		8.1	352	279	1.36	47.3	138.8	37.9	10.4	18.9	32.6	9.3	21.8	6.5	3.8	3.4	38.7	1.0
Minimum		7.2	86	60	0.35	6.0	31.9	2.5	1.3	2.6	7.7	2.8	3.9	1.2	0.8	0.8	19.0	0.3
Average		7.6	237	191	0.67	20.5	93.1	13.0	4.7	14.3	20.8	6.6	13.9	3.2	2.5	2.3	29.9	0.7
Standard Dev.		0.2	79.0	65.2	0.4	11.0	27.9	11.8	3.4	5.0	8.2	2.0	5.8	1.8	0.9	0.8	5.0	0.2

Unit: All parameters are in mg/l, except pH, %Na, EC (µS/cm), SAR, TZ, and TZ⁺ (meq/l)

Table 4.2: Physico-chemical characteristics of surface water of Subarnarekha River basin during monsoon season

S.N.	Code	pH	EC	TDS	F	Cl	HCO ₃ ⁻	SO ₄ ²⁻	NO ₃	H ₄ SiO ₄	Ca ²⁺	Mg ²⁺	Na ⁺	K ⁺	TZ	TZ ⁺	%Na	SAR
1	SBM5	7.1	195	154	0.35	16.4	70.1	11.4	8.4	11.6	18.5	4.8	9.6	2.6	2.0	1.8	26.7	0.5
2	SBM12	7.5	150	125	0.22	4.5	73.9	3.6	2.4	13.9	15.8	4.6	5.6	0.9	1.5	1.4	18.6	0.3
3	SBM10	7.2	120	104	0.28	6.3	51.0	4.1	3.3	16.5	11.5	3.3	6.2	1.4	1.2	1.2	26.6	0.4
4	SBM13	7.5	150	133	0.40	6.6	70.1	5.7	2.3	16.8	18.3	5.1	6.5	1.3	1.5	1.6	19.1	0.3
5	SBM14	7.4	152	128	0.25	5.4	73.9	4.2	2.4	14.7	15.4	4.5	5.8	1.2	1.5	1.4	19.8	0.3
6	SBM15	7.5	156	135	0.42	7.8	73.9	6.2	2.6	15.6	15.1	4.5	6.8	1.5	1.6	1.5	22.8	0.4
7	SBM35	7.5	151	129	0.34	6.1	70.1	5.9	3.6	15.0	15.0	4.8	6.4	1.5	1.5	1.5	21.6	0.4
8	SBM1	6.9	68	65	0.40	3.4	28.0	2.2	5.1	12.4	7.5	2.4	3.3	0.7	0.7	0.7	22.4	0.3
9	SBM16	7.6	158	134	0.31	4.8	81.5	3.3	1.9	14.6	16.4	4.9	5.8	1.0	1.6	1.5	18.6	0.3
10	SBM17	7.5	150	130	0.25	4.8	77.7	3.9	2.4	9.4	19.7	5.4	5.7	1.0	1.5	1.7	16.1	0.3
11	SBM36	7.4	132	121	0.18	3.1	70.1	3.0	1.6	18.3	14.3	6.6	3.4	0.7	1.3	1.4	11.5	0.2
12	SBM3	6.9	70	55	0.49	4.7	24.3	3.2	3.0	7.4	6.2	2.1	2.6	1.1	0.7	0.6	22.9	0.2
13	SBM11	7.3	122	85	0.41	4.3	44.6	4.3	1.0	12.7	9.0	1.5	5.8	1.5	1.0	0.9	33.6	0.5
Maximum		7.6	195	154	0.49	16.4	81.5	11.4	8.4	18.3	19.7	6.6	9.6	2.6	2.0	1.8	33.6	0.5
Minimum		6.9	68	55	0.18	3.1	24.3	2.2	1.0	7.4	6.2	1.5	2.6	0.7	0.7	0.6	11.5	0.2
Average		7.3	136	115	0.33	6.0	62.2	4.7	3.1	13.8	14.0	4.2	5.6	1.3	1.4	1.3	21.6	0.3
Standard Dev.		0.2	35.2	29.4	0.1	3.4	19.0	2.3	1.9	3.0	4.3	1.5	1.8	0.5	0.4	0.4	5.5	0.1

Unit: All parameters are in mg/l, except pH, %Na, EC (μS/cm), SAR, TZ, and TZ⁺ (meq/l)

Table 4.3: Physico-chemical characteristics of surface water of Subarnarekha River basin during post-monsoon season

S.N.	Code	pH	EC	TDS	F ⁻	Cl ⁻	HCO ₃ ⁻	SO ₄ ²⁻	NO ₃ ⁻	H ₄ SiO ₄	Ca ²⁺	Mg ²⁺	Na ⁺	K ⁺	TZ ⁻	TZ ⁺	%Na	SAR
1	SBP5	6.9	152	120	0.77	15.8	58.9	7.6	2.1	9.7	14.7	3.4	5.8	1.7	1.6	1.3	22.5	0.4
2	SBP12	7.6	301	254	0.38	19.5	132.8	19.5	1.4	20.1	26.7	9.2	19.8	4.7	3.2	3.1	31.9	0.8
3	SBP10	7.7	157	130	0.38	7.9	72.1	3.3	1.1	18.2	14.7	4.8	6.0	1.5	1.5	1.4	21.0	0.3
4	SBP13	8.5	342	279	0.62	35.5	116.9	33.3	9.6	15.3	29.1	9.7	22.3	6.6	3.8	3.4	33.6	0.9
5	SBP14	8.5	268	210	0.36	19.5	109.4	14.6	2.3	18.4	24.3	8.3	9.0	4.2	2.7	2.4	20.9	0.4
6	SBP15	8.1	361	301	1.06	19.5	143.8	40.3	9.9	15.4	30.4	9.9	23.5	6.8	4.0	3.5	33.8	0.9
7	SBP35	7.5	327	259	1.20	16.7	121.7	36.9	7.4	16.0	29.2	9.9	13.2	7.0	3.4	3.0	24.9	0.5
8	SBP1	8.4	146	138	0.28	7.3	78.6	3.8	1.7	15.7	16.0	5.1	6.8	3.2	1.6	1.6	23.5	0.4
9	SBP16	8.3	330	271	0.26	17.8	153.8	20.7	1.1	21.6	29.3	11.7	10.5	4.0	3.5	3.0	18.7	0.4
10	SBP17	8.0	290	233	0.30	18.8	121.3	17.5	1.3	19.4	30.0	10.3	9.6	4.4	2.9	2.9	18.5	0.4
11	SBP36	7.2	237	206	0.22	7.6	123.6	5.1	1.1	27.5	21.5	11.2	6.4	2.2	2.4	2.3	14.4	0.3
12	SBP3	8.1	67	55	0.34	4.9	26.4	2.5	1.2	6.3	6.4	2.3	3.2	1.2	0.7	0.7	25.1	0.3
13	SBP11	7.6	159	137	0.37	7.6	80.3	3.9	0.9	13.9	15.4	5.0	6.1	3.4	1.6	1.5	23.0	0.3
Maximum		8.5	361	301	1.20	35.5	153.8	40.3	9.9	27.5	30.4	11.7	23.5	7.0	4.0	3.5	33.8	0.9
Minimum		6.9	67	55	0.22	4.9	26.4	2.5	0.9	6.3	6.4	2.3	3.2	1.2	0.7	0.7	14.4	0.3
Average		7.9	241	199	0.50	15.3	103.0	16.1	3.2	16.7	22.1	7.8	10.9	3.9	2.5	2.3	24.0	0.5
Stand. Dev.		0.5	94.7	75.9	0.3	8.3	36.9	13.5	3.4	5.3	7.9	3.2	6.8	2.0	1.0	0.9	6.0	0.2

Unit: All parameters are in mg/l, except pH, %Na, EC (μ S/cm), SAR, TZ, and TZ⁺ (meq/l)

Table 4.4: Physico-chemical characteristics of ground water of Subarnarekha River basin during pre-monsoon season

S.N.	Code	pH	EC	TDS	F ⁻	Cl ⁻	HCO ₃ ⁻	SO ₄ ²⁻	NO ₃ ⁻	H ₄ SiO ₄	Ca ²⁺	Mg ²⁺	Na ⁺	K ⁺	TZ ⁻	TZ ⁺	%Na	SAR
1	SB4	7.7	964	693	0.10	128.4	173.2	76.9	88.5	33.8	100.2	16.0	66.1	9.7	9.50	9.44	33.1	1.6
2	SB7	8.1	342	312	1.74	16.4	183.8	1.3	0.4	36.2	44.7	5.1	20.8	1.5	3.60	3.60	26.2	0.8
3	SB18	7.6	888	810	0.38	103.8	238.2	162.3	51.9	39.2	156.6	36.6	19.0	2.3	11.07	11.71	7.6	0.4
4	SB19	7.9	625	541	0.37	161.8	131.2	68.7	5.7	34.0	76.9	36.6	22.6	3.4	8.26	7.92	13.5	0.5
5	SB20	8.0	550	482	0.24	115.7	200.0	16.8	0.4	35.4	85.0	14.8	11.2	2.2	6.91	6.00	9.1	0.3
6	SB21	7.6	2290	1736	0.60	277.0	291.7	505.7	158.6	45.3	312.6	98.1	42.2	4.6	25.71	25.62	7.6	0.5
7	SB22	8.1	1063	823	0.50	213.6	275.8	58.2	32.6	42.0	135.3	36.4	27.6	1.5	12.31	10.98	11.3	0.5
8	SB23	8.1	772	625	0.65	161.7	135.0	80.6	38.8	38.4	118.9	27.7	19.8	3.3	9.11	9.16	10.3	0.4
9	SB24	7.7	1070	963	0.65	218.6	154.1	172.1	95.8	40.7	238.7	17.9	22.6	2.2	13.85	14.43	7.2	0.4
10	SB25	7.7	1246	1008	0.60	284.5	222.9	91.1	96.7	33.3	203.2	60.5	10.5	4.3	15.17	15.68	3.6	0.2
11	SB26	7.8	1093	995	1.11	76.5	272.6	341.1	24.0	41.4	154.8	36.3	43.7	3.5	14.17	12.70	15.7	0.8
12	SB27	8.3	813	653	1.73	17.2	375.3	74.4	10.3	46.2	64.6	49.7	13.0	1.0	8.44	7.90	7.5	0.3
13	SB28	6.7	444	303	0.17	16.6	159.5	0.8	13.4	21.8	43.6	9.6	34.8	2.4	3.32	4.54	34.7	1.2
14	SB29	8.2	527	474	0.38	53.7	268.8	4.5	1.1	38.6	90.8	8.1	4.8	3.7	6.05	5.50	5.5	0.1
15	SB30	7.9	1121	1007	0.18	215.8	219.1	151.9	83.9	38.4	246.4	38.2	11.9	1.5	14.20	15.99	3.5	0.2
16	SB32	8.1	1788	1576	0.41	503.7	230.6	214.6	93.5	33.5	327.8	60.2	111.6	0.5	23.98	26.18	18.6	1.5
17	SB33	8.1	1091	908	1.02	288.9	169.4	56.2	79.9	39.3	214.8	33.9	22.9	1.2	13.44	14.54	7.1	0.4
18	SB34	8.3	604	560	0.27	123.7	203.8	31.3	10.1	36.6	114.3	21.5	16.8	1.1	7.66	8.23	9.2	0.4
Maximum		8.3	2290	1736	1.74	503.7	375.3	505.7	158.6	46.2	327.8	98.1	111.6	9.7	25.7	26.2	34.7	1.6
Minimum		6.7	342	303	0.10	16.4	131.2	0.8	0.4	21.8	43.6	5.1	4.8	0.5	3.3	3.6	3.5	0.1
Average		7.9	961	804	0.62	165.4	216.9	117.2	49.2	37.5	151.6	33.7	29.0	2.8	11.5	11.7	12.8	0.6
Standard Dev.		0.4	480.5	385.2	0.5	123.7	63.1	130.4	46.2	5.4	87.4	23.0	25.4	2.1	6.0	6.4	9.5	0.4

Unit: All parameters are in mg/l, except pH, %Na, EC (μS/cm), SAR, TZ⁻, and TZ⁺ (meq/l)

Table 4.5: Physico-chemical characteristics of ground water of Subarnarekha River basin during monsoon season

S.N.	Code	pH	EC	TDS	F ⁻	Cl ⁻	HCO ₃ ⁻	SO ₄ ²⁻	NO ₃ ⁻	H ₄ SiO ₄	Ca ²⁺	Mg ²⁺	Na ⁺	K ⁺	TZ ⁻	TZ ⁺	%Na	SAR
1	SBM4	6.4	1348	900	0.09	157.0	324.7	35.4	86.3	43.1	133.9	22.1	88.1	9.7	11.9	12.6	32.4	1.9
2	SBM7	6.0	324	270	0.44	31.3	131.2	9.4	2.4	37.0	27.9	5.9	23.7	0.8	3.3	2.9	35.9	1.1
3	SBM18	7.3	1259	1143	0.92	113.3	465.3	138.8	51.4	49.1	256.8	36.2	29.3	2.1	14.6	17.1	7.8	0.5
4	SBM19	7.8	647	550	0.43	120.9	209.4	44.0	9.9	28.1	83.3	17.7	34.0	2.4	7.9	7.2	21.6	0.9
5	SBM20	7.3	570	501	0.26	122.6	196.2	17.8	0.2	44.1	84.0	16.3	16.6	2.7	7.1	6.3	12.5	0.4
6	SBM21	7.3	3120	2677	0.72	387.9	525.8	675.8	264.6	58.5	425.7	178.9	155.1	3.7	37.9	42.8	16.0	1.6
7	SBM22	7.2	1210	1099	0.91	253.5	312.4	90.7	100.4	53.5	153.8	54.5	77.9	1.4	15.8	15.6	22.0	1.4
8	SBM23	7.3	1228	1126	1.02	210.6	387.2	117.1	63.7	44.5	179.9	33.8	85.6	2.9	15.8	15.6	24.4	1.5
9	SBM24	7.4	397	359	0.63	15.2	203.8	16.5	2.0	36.9	62.1	11.0	10.3	0.5	4.2	4.5	10.4	0.3
10	SBM25	7.4	1159	937	0.76	166.4	333.7	62.3	75.4	42.0	172.4	62.0	17.6	4.7	12.7	14.6	6.1	0.3
11	SBM26	7.4	1069	903	1.07	56.8	241.6	318.1	13.1	46.9	110.7	35.3	76.4	3.2	12.5	11.8	28.8	1.6
12	SBM27	7.6	850	703	1.44	13.1	387.6	84.3	7.3	59.1	61.5	59.8	27.9	1.2	8.7	9.2	13.5	0.6
13	SBM28	5.9	468	317	0.07	24.2	137.7	6.6	17.8	24.8	51.8	9.3	39.3	5.6	3.4	5.2	35.6	1.3
14	SBM29	6.6	536	478	0.40	45.1	276.4	5.7	0.8	47.8	72.5	9.3	15.6	4.4	6.0	5.2	15.3	0.5
15	SBM30	7.0	1126	1028	0.38	212.5	249.7	138.1	92.8	46.1	219.1	47.1	20.6	1.9	14.5	15.7	6.0	0.3
16	SBM32	7.2	1608	1410	0.46	353.6	382.9	139.6	66.0	41.0	254.8	66.4	103.8	1.5	20.2	22.7	20.0	1.5
17	SBM33	6.9	1235	1011	0.33	280.5	356.8	25.9	10.0	49.1	218.5	23.0	45.3	1.3	14.5	14.8	13.5	0.8
18	SBM34	7.2	862	782	0.22	146.0	315.6	44.0	21.5	47.3	132.2	27.2	46.5	1.3	10.6	10.9	18.9	1.0
19	SBM37	6.5	336	246	0.18	40.5	117.9	9.3	2.3	13.4	23.5	6.0	28.2	4.5	3.3	3.0	44.6	1.3
Maximum		7.8	3120	2677	1.44	387.9	525.8	675.8	264.6	59.1	425.7	178.9	155.1	9.7	37.9	42.8	44.6	1.9
Minimum		5.9	324	246	0.07	13.1	117.9	5.7	0.2	13.4	23.5	5.9	10.3	0.5	3.3	2.9	6.0	0.3
Average		7.0	1019	865	0.57	144.8	292.4	104.2	46.7	42.8	143.4	38.0	49.6	2.9	11.8	12.5	20.3	1.0
Standard Dev.		0.5	639.2	555.0	0.4	114.2	112.4	158.0	63.5	11.2	100.4	39.4	38.3	2.2	8.1	9.2	11.0	0.5

Unit: All parameters are in mg/l, except pH, %Na, EC (μS/cm), SAR, TZ⁻, and TZ⁺ (meq/l)

Table 4.6: Physico-chemical characteristics of ground water of Subarnarekha River basin during post-monsoon season

S.N.	Code	pH	EC	TDS	F ⁻	Cl ⁻	HCO ₃ ⁻	SO ₄ ²⁻	NO ₃ ⁻	H ₄ SiO ₄	Ca ²⁺	Mg ²⁺	Na ⁺	K ⁺	TZ ⁻	TZ ⁺	%Na	SAR
1	SBP4	6.8	1239	874	0.17	109.5	284.1	99.5	121.7	39.2	121.2	20.8	59.4	18.2	11.8	10.8	28.2	1.3
2	SBP7	7.1	290	222	1.01	12.5	123.8	1.0	0.3	32.8	33.3	4.3	11.0	2.1	2.5	2.6	20.9	0.5
3	SBP18	7.0	924	794	0.34	56.8	295.8	167.9	50.0	39.2	121.5	36.6	21.2	5.0	10.8	10.1	10.4	0.4
4	SBP19	7.3	751	604	0.83	115.2	243.8	55.2	9.8	37.9	72.2	26.6	39.0	3.1	8.6	7.6	23.4	1.0
5	SBP20	7.3	524	413	0.18	105.4	172.7	7.2	0.2	31.4	66.7	15.0	12.1	2.6	6.0	5.1	11.5	0.3
6	SBP21	6.8	3090	2545	0.69	357.0	511.6	712.6	248.7	55.2	389.9	142.9	118.7	7.8	37.3	36.6	14.7	1.3
7	SBP22	7.1	1129	871	0.51	212.8	279.9	62.9	76.9	44.3	96.8	42.1	53.8	1.3	13.2	10.7	22.3	1.1
8	SBP23	7.0	1104	920	0.46	187.9	312.4	95.4	55.3	43.4	136.8	28.1	57.1	2.7	13.3	11.7	21.8	1.2
9	SBP24	7.5	342	285	0.62	12.0	176.5	6.1	1.1	26.2	43.7	9.9	6.9	1.5	3.4	3.3	10.2	0.2
10	SBP25	6.7	1225	988	0.56	276.7	274.5	84.3	92.3	29.2	153.7	56.7	15.7	4.2	15.6	13.1	6.0	0.3
11	SBP26	6.9	1040	832	1.34	70.3	216.9	295.2	18.4	42.9	93.5	33.3	56.8	3.2	12.1	10.0	25.6	1.3
12	SBP27	7.00	870	687	1.51	12.9	339.4	110.3	0.7	55.8	55.6	64.4	44.6	1.9	8.3	10.1	19.8	1.0
13	SBP28	5.3	408	278	0.14	24.2	132.5	1.0	11.6	24.8	39.6	9.6	29.4	5.0	3.1	4.2	33.7	1.1
14	SBP29	6.5	252	223	0.54	8.7	117.4	2.6	1.0	47.2	27.4	4.5	9.8	3.7	2.3	2.3	23.0	0.5
15	SBP30	6.2	1103	942	0.16	189.9	217.8	180.0	95.7	36.9	159.7	41.8	19.5	1.1	14.2	12.3	7.1	0.4
16	SBP32	6.6	1563	1291	0.48	313.8	362.8	168.2	61.2	32.4	216.8	52.5	81.0	1.5	19.3	18.7	19.0	1.3
17	SBP33	6.6	1026	746	0.16	241.8	217.6	31.1	14.6	44.9	142.7	20.2	31.0	2.1	11.3	10.2	13.8	0.6
18	SBP34	6.7	747	613	0.24	125.8	256.9	39.1	10.1	36.7	86.9	22.6	32.3	2.1	8.7	7.7	19.0	0.8
19	SBP37	6.1	308	215	0.18	32.7	105.7	7.9	3.2	13.0	21.5	6.2	20.5	3.7	2.9	2.6	38.4	1.0
Maximum		7.5	3090	2545	1.51	357.0	511.6	712.6	248.7	55.8	389.9	142.9	118.7	18.2	37.3	36.6	38.4	1.3
Minimum		5.3	252	215	0.14	8.7	105.7	1.0	0.2	13.0	21.5	4.3	6.9	1.1	2.3	2.3	6.0	0.2
Average		6.8	944	755	0.53	129.8	244.3	112.0	45.9	37.5	109.4	33.6	37.9	3.8	10.8	10.0	19.4	0.8
Standard Dev.		0.5	644.4	533.1	0.4	110.6	100.0	165.6	62.5	10.4	86.1	32.0	28.5	3.9	8.1	7.8	8.6	0.4

Unit: All parameters are in mg/l, except pH, %Na, EC (μS/cm), SAR, TZ⁻, and TZ⁺ (meq/l)

Major ion chemistry

Calcium is the most dominant cation in surface water of the Subarnarekha River basin. Weathering of carbonate and silicate minerals are the major contributor of Ca^{2+} in the river water. On an average Ca^{2+} constitute 45% of the total cations (TZ^+) in equivalent unit and its concentration ranges from 7.7 to 32.6 mg/l during pre-monsoon. In monsoon season, calcium constitute 53% of the TZ^+ and its concentration ranges from 6.2 to 19.7 mg/l, while during post-monsoon, it contributed about 48% to the TZ^+ and the concentration ranges from 6.4 to 30.4 mg/l. Na^+ is the next dominant cation after Ca^{2+} in pre-monsoon and account for 26% of the TZ^+ . Sodium concentration ranges from 3.9 to 21.8 mg/l in pre-monsoon. During monsoon and post-monsoon, concentration of sodium varies from 2.6-9.6 mg/l and 3.2-23.3 mg/l and accounting for 19% and 20% of the TZ^+ respectively. Concentration of other two cations i.e. Mg^{+2} and K^+ ranges between 2.8-9.3 mg/l, and 1.2-6.5 mg/l respectively in pre-monsoon, 1.5-6.6 mg/l and 0.7-2.6 mg/l in monsoon and 2.3- 11.7 mg/l and 1.2-7.0 mg/l in post-monsoon seasons. The major cations follow a trend of $\text{Ca}^{2+} > \text{Na}^+ > \text{Mg}^{+2} > \text{K}^+$.

Bicarbonate (HCO_3^-) is the most dominant anion in the river water, accounting 63%, 75% and 69% of the total cations (TZ^+) respectively in pre-monsoon, monsoon and post-monsoon seasons. Concentration of bicarbonate varies between 31.9-138.8 mg/l (pre-monsoon), 24.3-81.5 mg/l (monsoon) and 26.4 - 153.8 mg/l (post-monsoon). Bicarbonate in river water is mainly contributed from weathering reactions and decomposition of organic matter (Jha et al., 2009). Bicarbonate is followed by Cl^- which accounts for 22% of the TZ^- and its concentration range from 6.0 to 47.3 mg/l during pre-monsoon season and 3.1 to 16.4 mg/l (13% of TZ^-) in monsoon. But in post-monsoon, bicarbonate is followed by SO_4^{2-} which accounts for 11% of the total anion (TZ^-) and ranges from 2.5 to 40.3 mg/l. Cl^- ions do not participate in weathering reactions and thus behave conservatively through the hydrological cycle. Cl^- originates from rain inputs (seasalt aerosols) and human activities (Negrel et al, 2007). Concentration of SO_4^{2-} , NO_3^- and F^- ranges between 2.5-37.9 mg/l, 1.3-10.4mg/l and 0.35-1.36 mg/l in pre-monsoon, 2.2-11.4 mg/l, 1.0-8.4 mg/l and 0.18-0.49 mg/l in monsoon respectively. However, in post-monsoon concentration of Cl^- , NO_3^- and F^- ranges between 4.9-35.5 mg/l, 0.9-9.9 mg/l and 0.22-1.20 mg/l respectively. The anions for pre-monsoon and monsoon seasons are arranged in decreasing order as $\text{HCO}_3^- > \text{Cl}^- > \text{SO}_4^{2-} > \text{NO}_3^- > \text{F}^-$ and during post-monsoon as $\text{HCO}_3^- > \text{SO}_4^{2-} > \text{Cl}^- > \text{NO}_3^- > \text{F}^-$.

Calcium is also the dominant cation in ground water of the Subarnarekha River basin. In ground water, concentration of calcium varied from 43.6-327.8 mg/l in pre-monsoon,

constituting 64% of the Total Cations (TZ⁺). During monsoon, calcium accounts for 57% of the TZ⁺, and its concentration ranges from 23.5 to 425.7 mg/l. The concentration of same ion during post-monsoon varies between 21.5-389.9 mg/l and contributing 55% of the TZ⁺. Magnesium was the next dominant cation after Ca⁺ accounted for 23% of the TZ⁺ and its concentration range from 5.1-98.1 mg/l in pre-monsoon. Calcium and magnesium ions present in ground water is particularly derived from leaching of limestone, dolomites, gypsum, and anhydrites, whereas the Ca⁺ is also derived from cation exchange process (Garrels, 1976). During monsoon and post-monsoon seasons, Na⁺ was the next dominant cation, accounting 19% and 18% of the TZ⁺ and its concentration ranges from 10.3-155.1 mg/l and 6.9-118.7 mg/l respectively. The possible source of sodium concentration in groundwater is dissolution of rock salts and weathering of sodium bearing minerals. If the halite dissolution process is responsible for the sodium, Na/Cl ratio should be approximately 1, whereas the Na/Cl ratio greater than 1 typically indicates that the sodium was released from silicate weathering (Meyback, 1987). In the present study, Na/Cl ratio is less than 1 (i.e. 0.8) in the predominant groundwater samples, making one to conclude that the significant reduction of Na concentration may be due to ion exchange process. The increase in HCO₃⁻ concentration compared to Na⁺ concentration in the groundwater indicates the dominance of silicate weathering process, it is well supported by a high concentration of HCO₃⁻ (Elango et al., 2003). Potassium ion concentration in the groundwater also comes from the above said process. Concentration of other two cations i.e. Na⁺ and K⁺ ranges between 4.8-111.6 mg/l, and 0.5-9.7 mg/l respectively in pre-monsoon. In monsoon and post-monsoon Mg⁺ and K⁺ concentration ranges from 5.9-178.9 mg/l, 0.5-9.7 mg/l and 4.3-142.9 mg/l, 1.1-18.2 mg/l respectively. The major cations follow trend Ca²⁺>Mg⁺>Na⁺>K⁺ in pre-monsoon and Ca²⁺>Na⁺>Mg²⁺>K⁺ in monsoon and post-monsoon.

HCO₃ and Cl are the dominant anions in ground water followed by SO₄²⁻, NO₃⁻ & F⁻. Concentrations of HCO₃⁻ and Cl⁻ during pre-monsoon vary from 131.2 to 375.3 mg/l and 16.4 to 165.4 mg/l, and account for 39% and 38% of the total anion (TZ⁻) in equivalent unit, respectively. During monsoon, its concentration ranges between 117.9 to 525.8 mg/l, 13.1 to 387.9 mg/l, and account for 49% and 32% of the TZ⁻, respectively. In post-monsoon it range between 105.7 to 511.6 mg/l and 8.7 to 357.0 mg/l, and account for 48% and 31% of the total anion (TZ⁻) respectively. The bicarbonate concentration in groundwater is derived from carbonate weathering as well as dissolution of carbonic acid in the aquifers (Jeevanandam et al., 2006) The natural process such as weathering, dissolution of salt deposits, and irrigation drainage return flow are responsible for chloride content in the groundwater, which is

supported by Cl/HCO₃ ratio of 0.4 to 3.0 (Luszczynski and Swarzenski, 1996). In the present study Cl/HCO₃ ratio varies between 0.8 - 1.4.

Concentration of SO₄²⁻, NO₃⁻ and F⁻ ranges between 0.8-505.7 mg/l, 0.4-158.6 mg/l and 0.10-1.74 mg/l, respectively in pre-monsoon, 5.7-675.8 mg/l, 0.2-264.6 mg/l and 0.07-1.44 mg/l in monsoon and 1.0-712.6 mg/l, 0.2-248.7 mg/l and 0.14-1.51 mg/l, respectively in post-monsoon season. Sulphate ion concentrations are probably derived from weathering of sulphate and gypsum-bearing sedimentary rocks (Elango et al., 2003; Jeevanandam et al., 2006). Nitrates are extremely soluble in water and can move easily through soil into the drinking water supply (Saba et al., 2006). The fertilizers and domestic wastes are the main sources of nitrogen-containing compounds and they are converted to nitrates in the soil. The anions for all seasons are arranged in decreasing order as HCO₃⁻ > Cl⁻ > SO₄²⁻ > NO₃⁻ > F⁻.

Seasonal and spatial variation in ionic concentration

Seasonal data of major ion chemistry of surface water shows that average EC is minimum in monsoon (136 µS/cm) and maximum (241 µS/cm) in post-monsoon season. TDS, Ca, K, Mg, HCO₃, SO₄, and H₄SiO₄ followed a similar trend as EC, i.e., the lower concentrations in monsoon and higher concentrations during pre and post-monsoon periods (Fig. 4.1). Na⁺, NO₃⁻, F⁻ and Cl⁻ have trends of the higher concentrations during pre-monsoon than the post-monsoon season.

In ground water samples average concentration EC is minimum (944 µS/cm) in post-monsoon and maximum (1019 µS/cm) during monsoon season. Similar trend is followed by TDS, Mg, and H₄SiO₄ i.e. the lowest average concentration in pre-monsoon and higher concentration in monsoon season. However the average concentration of Na⁺ and HCO₃⁻ are found minimum in pre-monsoon and maximum during monsoon season. Ca²⁺ average concentration is minimum (109.4 mg/l) in post-monsoon and maximum (151.6 mg/l) during pre-monsoon season. NO₃, F⁻ and Cl⁻ follow the same trend as Ca²⁺. Average concentration of K⁺ is minimum (2.8 mg/l) in pre-monsoon and maximum (3.8 mg/l) in post-monsoon (Fig.4.2).

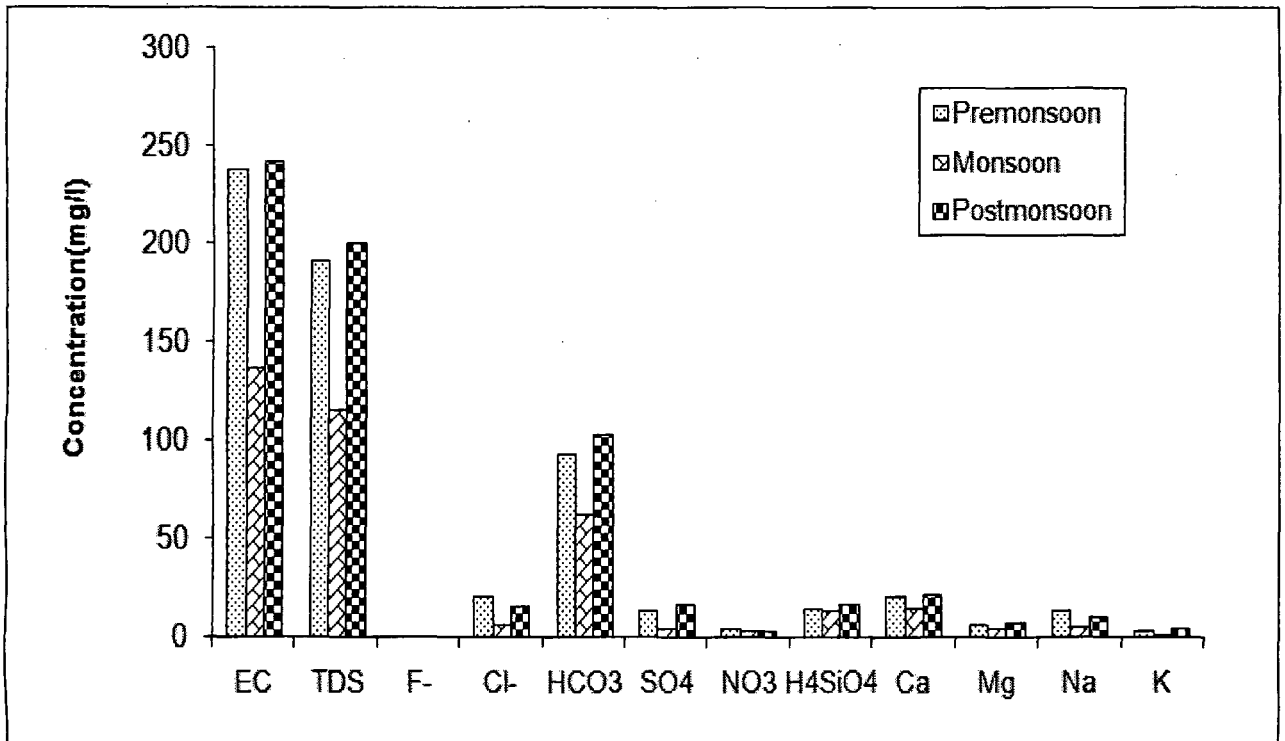


Fig 4.1: Seasonal variation in EC, TDS and major ion concentration in surface water of Subarnarekha River basin.

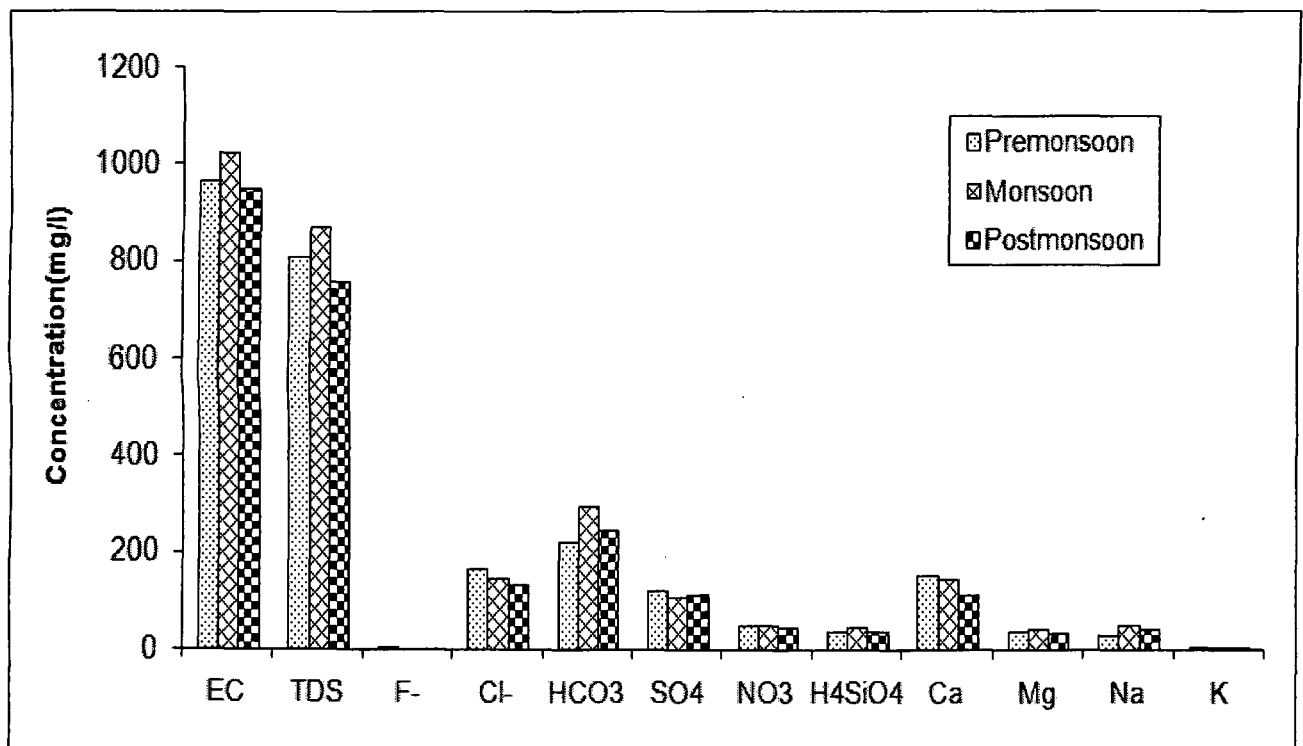


Fig 4.2: Seasonal variation in EC, TDS and major ion concentration in ground water of Subarnarekha River basin.

magnesium indicate the dissolution of magnesium-poor calcite. Silica is derived either from dissolution of siliceous microfossils that are abundant within carbonate rocks surrounding the area, or from weathering of silicates in overlying soils and clastic units. Sodium and potassium are probably derived from atmospheric inputs plus ion-exchange in soils and clastic rock units. Chloride is probably derived solely from atmospheric inputs. Sulfate is likely derived from atmospheric inputs, pyrite oxidation, or dissolution of minor gypsum fracture fillings that occur in drier parts of Subarnarekha River basin and presumably in similar settings throughout the aquifer.

The correlation matrix observed for groundwater in pre-monsoon shows that pH is negatively correlated with almost all the parameters thus depicting the dissolution as the process for governing the concentration of all the cations and anions in the study area. The dissolution of CO₂ in water causes increase in total carbonate and a decrease in pH which is well explained by negative correlation of pH. This explains that electrical conductivity is higher in the area due to Na, Cl, Mg, Sulphate and K. The most common sources of elevated sodium levels in groundwater are erosion of salt deposits and sodium bearing rock minerals, irrigation and precipitation leaching through soils high in sodium, infiltration of leachate from landfills or industrial sites.

The fluoride shows nearly moderate (in pre & post-monsoon) to good correlation with dissolved silica. Some amphiboles as hornblende & micas contain fluoride which has replaced part of hydroxide, since the fluoride has similar charge & size for F⁻ & OH⁻, substitution of fluoride or hydroxyl ions at mineral surface is an obvious possibility.

It was observed that the correlation of chloride and nitrate in all the seasons was nearly the same i.e. 0.71 in pre-monsoon, 0.74 in monsoon & 0.72 in post-monsoon indicating the source of nitrate same as source of chloride. It was also observed that the nitrate concentration (the value range from 0.2-265mg/l) was very high than the limit prescribed by WHO 50mg/l that indicates that the source of nitrate is not anthropogenic but is geogenic. Most nitrate contamination sources are easily defined, particularly if there is a single known source such as a cattle feed lot, but in some areas – particularly rural locations that have been urbanized, distinguishing between human (anthropogenic) and natural (geogenic) sources is somewhat more complicated. Sources of anthropogenic nitrate contamination to groundwater are septic systems, sanitary sewage effluent releases, domestic animal wastes, and home and farm usage of nitrogen fertilizer. Nitrate contamination also occurs from the degradation of cyanide (CN⁻) an industrial pollutant, particularly common to

historic gasworks sites. The geogenic sources include those that are desert-derived such as Desert deposits (which also contain natural perchlorate); caliche and Playa Lake evaporate deposits, and desert vadose zone soils. Motzer (2006) reported that naturally occurring vadose zone nitrogen reservoir had the potential to become mobilized thereby leaching large amounts of nitrate to groundwater.

It was also observed from the correlation table that sulphate showed positive correlation with Mg, Ca and was negatively correlated with sodium in pre-monsoon but in monsoon and post-monsoon season it showed good correlation with Na, Ca & Mg depicting that in the monsoon and post-monsoon the halite dissolution was the main process for controlling the chemistry of water and as the dissolution dominate nitrate also showed good correlation with Na, Ca & Mg which was not the case in pre-monsoon showing the ion exchange process dominated the NO_3^- ion chemistry with Na, Ca & Mg. Ca & Mg showed strong correlation in all the seasons for groundwater depicting the influence of weathering in the area. Bicarbonate showed strong correlation with sulphate, nitrate, calcium, sodium, magnesium and dissolved silica showing the process of leaching to be dominant. The chloride had strong correlation with calcium, sodium, magnesium in pre-monsoon and with calcium, sodium, magnesium, sulphate, nitrate & bicarbonate in monsoon and post-monsoon thus precipitation process is the only reason for its strong correlation.

Correlation Matrix and Geochemical Process in Surface water

The high correlation of EC in pre-monsoon with all major ions due to significant amount of dissolved salt was observed at all sites. High EC is attributed to the high salinity and high mineral content. It also corresponds to the highest concentrations of dominant ions which are result of ion exchange & solubilisation in the aquifer. The high level of major cations (Na, Ca and Mg) and concentration of major anions Cl^- and SO_4 in surface water and an increase in EC is consistent with other study (Zacheus and Martikainen, 1997). High correlation of all major cations i.e. Ca, Mg, Na, K with Cl^- and SO_4 in pre-monsoon as well as in post-monsoon can be attributed to presence of dolomite, limestone in the area which is undergoing ion-exchange process. Nitrate was strongly correlated with Na, K in pre-monsoon with K in monsoon but in post-monsoon it was observed that it was in good correlation with Na, K and dissolved silica which shows that in post-monsoon hydrolysis process was dominant and it lead to ion exchange with cations such as Na and K. Dissolved silica showed strong correlation with Ca, Mg, Na, K in pre-monsoon depicting that the samples belonged to the area with predominant silicate weathering which in post-monsoon showed strong correlation

with Ca & Mg which are not as mobile as Na and K. So, Na and K went with ion-exchange process during dissolution and Na and K also showed strong correlation with each other in all the seasons in surface water which also justifies the above process.

The dissolution of carbonate rocks proceeds more rapidly than silicate breakdown and is the likely mechanism of solute acquisition. The quantification of solution products of silicate weathering is difficult because of the incongruent dissolution (Sarin et al., 1989). The relative proportions of the various ions in solution depend on their relative abundance in the host rock and on their solubility. Sources of dissolved ions in the Subarnarekha River basin can be evaluated by looking at associations among ions. A parametric correlation analysis for values of all measured parameters is given in Table 4.7 and 4.8.

The Gibbs diagram is widely used to establish the relationship of water composition and aquifer lithological characteristics. Three distinct fields such as precipitation dominance, evaporation dominance and rock-water interaction dominance areas are shown in the Gibbs diagram. Gibbs (1970) plot also places of the surface water and ground water in the region of rock dominance, indicating that rock weathering is a primary factor controlling the water composition (Fig. 4.3 and 4.4). The distribution of the sampling points suggests that the major ion chemistry of the surface water and groundwater seems to be controlled by chemical weathering of rock forming minerals and anthropogenic activities.

Table 4.7a: Correlation matrix of surface water sample in pre-monsoon (n=11)

	pH	EC	TDS	F	Cl	HCO ₃	SO ₄	NO ₃	H ₄ SiO ₄	Ca	Mg	Na	K
pH	1.00												
EC	-0.47	1.00											
TDS	-0.39	0.98	1.00										
F	-0.70	0.54	0.47	1.00									
Cl	-0.34	0.85	0.83	0.70	1.00								
HCO₃	-0.30	0.82	0.89	0.15	0.54	1.00							
SO₄	-0.32	0.83	0.78	0.62	0.81	0.44	1.00						
NO₃	-0.66	0.58	0.49	0.73	0.48	0.27	0.59	1.00					
H₄SiO₄	-0.13	0.69	0.78	-0.07	0.47	0.88	0.37	0.01	1.00				
Ca	-0.44	0.95	0.92	0.54	0.87	0.72	0.86	0.48	0.61	1.00			
Mg	-0.26	0.90	0.92	0.19	0.71	0.88	0.65	0.26	0.86	0.87	1.00		
Na	-0.32	0.84	0.90	0.52	0.71	0.83	0.66	0.53	0.64	0.70	0.71	1.00	
K	-0.27	0.90	0.90	0.62	0.88	0.65	0.92	0.53	0.51	0.89	0.72	0.85	1.00

Table 4.7b: Correlation matrix of surface water sample in monsoon (n=13)

	pH	EC	TDS	F	Cl	HCO ₃	SO ₄	NO ₃	H ₄ SiO ₄	Ca	Mg	Na	K
pH	1												
EC	0.70	1.00											
TDS	0.76	0.97	1.00										
F	-0.54	-0.40	-0.49	1.00									
Cl	-0.10	0.61	0.52	0.17	1.00								
HCO₃	0.91	0.89	0.95	-0.60	0.24	1.00							
SO₄	0.03	0.69	0.59	0.17	0.97	0.33	1.00						
NO₃	-0.50	0.18	0.14	0.20	0.79	-0.14	0.69	1.00					
H₄SiO₄	0.52	0.32	0.43	-0.43	-0.10	0.45	-0.02	-0.28	1.00				
Ca	0.77	0.89	0.95	-0.50	0.41	0.93	0.48	0.09	0.28	1.00			
Mg	0.70	0.67	0.81	-0.66	0.16	0.84	0.23	-0.03	0.49	0.83	1.00		
Na	0.36	0.85	0.76	-0.04	0.83	0.56	0.87	0.46	0.16	0.66	0.27	1.00	
K	-0.10	0.54	0.39	0.31	0.92	0.13	0.94	0.64	-0.13	0.26	-0.07	0.84	1.00

Table 4.7c: Correlation matrix of surface water sample in post-monsoon (n=13)

	pH	EC	TDS	F	Cl	HCO ₃	SO ₄	NO ₃	H ₄ SiO ₄	Ca	Mg	Na	K
pH	1.00												
EC	0.24	1.00											
TDS	0.25	0.99	1.00										
F	-0.21	0.40	0.37	1.00									
Cl	0.35	0.77	0.74	0.35	1.00								
HCO₃	0.18	0.94	0.95	0.17	0.55	1.00							
SO₄	0.25	0.88	0.86	0.73	0.75	0.69	1.00						
NO₃	0.24	0.61	0.60	0.79	0.66	0.37	0.87	1.00					
H₄SiO₄	-0.04	0.51	0.55	-0.33	0.09	0.72	0.09	-0.15	1.00				
Ca	0.25	0.98	0.98	0.33	0.74	0.94	0.83	0.53	0.55	1.00			
Mg	0.18	0.90	0.92	0.10	0.54	0.96	0.65	0.35	0.77	0.91	1.00		
Na	0.28	0.81	0.83	0.50	0.79	0.67	0.86	0.78	0.15	0.75	0.58	1.00	
K	0.34	0.86	0.86	0.62	0.73	0.71	0.94	0.81	0.15	0.84	0.65	0.84	1.00

Table 4.8a: Correlation matrix of ground water in pre-monsoon (n=18)

	pH	EC	TDS	F	Cl	HCO ₃	SO ₄	NO ₃	H ₄ SiO ₄	Ca	Mg	Na	K
pH	1.00												
EC	-0.08	1.00											
TDS	-0.02	0.98	1.00										
F	0.34	-0.08	-0.07	1.00									
Cl	0.13	0.76	0.79	-0.26	1.00								
HCO ₃	0.23	0.33	0.32	0.37	-0.08	1.00							
SO ₄	-0.19	0.84	0.84	0.04	0.40	0.35	1.00						
NO ₃	-0.24	0.88	0.85	-0.19	0.71	0.03	0.67	1.00					
H ₄ SiO ₄	0.56	0.38	0.39	0.47	0.05	0.61	0.46	0.21	1.00				
Ca	-0.01	0.89	0.94	-0.17	0.86	0.12	0.71	0.86	0.29	1.00			
Mg	-0.03	0.88	0.85	0.07	0.60	0.47	0.76	0.68	0.42	0.70	1.00		
Na	-0.12	0.53	0.54	-0.16	0.56	-0.02	0.39	0.40	-0.21	0.45	0.29	1.00	
K	-0.29	0.11	0.01	-0.31	-0.12	-0.16	0.15	0.29	-0.13	-0.10	0.00	0.17	1.00

Table 4.8b: Correlation matrix of ground water in monsoon (n=19)

	pH	EC	TDS	F	Cl	HCO ₃	SO ₄	NO ₃	H ₄ SiO ₄	Ca	Mg	Na	K
pH	1.00												
EC	0.30	1.00											
TDS	0.36	0.99	1.00										
F	0.60	0.25	0.30	1.00									
Cl	0.27	0.83	0.84	0.00	1.00								
HCO ₃	0.47	0.82	0.84	0.49	0.65	1.00							
SO ₄	0.31	0.86	0.87	0.36	0.54	0.59	1.00						
NO ₃	0.16	0.92	0.91	0.15	0.74	0.65	0.81	1.00					
H ₄ SiO ₄	0.42	0.58	0.60	0.57	0.42	0.75	0.47	0.44	1.00				
Ca	0.33	0.94	0.95	0.19	0.86	0.83	0.75	0.84	0.55	1.00			
Mg	0.37	0.92	0.92	0.38	0.69	0.73	0.89	0.90	0.56	0.82	1.00		
Na	0.11	0.84	0.82	0.15	0.72	0.59	0.75	0.76	0.35	0.68	0.72	1.00	
K	-0.43	0.11	0.00	-0.38	-0.07	-0.05	0.01	0.20	-0.25	-0.05	-0.03	0.21	1.00

Table 4.8c: Correlation matrix of ground water in post-monsoon (n=19)

	pH	EC	TDS	F	Cl	HCO ₃	SO ₄	NO ₃	H ₄ SiO ₄	Ca	Mg	Na	K
pH	1.00												
EC	0.06	1.00											
TDS	0.07	1.00	1.00										
F	0.43	0.07	0.08	1.00									
Cl	0.01	0.82	0.81	-0.21	1.00								
HCO ₃	0.25	0.91	0.91	0.20	0.70	1.00							
SO ₄	0.05	0.90	0.91	0.25	0.55	0.77	1.00						
NO ₃	-0.03	0.91	0.90	-0.12	0.72	0.76	0.82	1.00					
H ₄ SiO ₄	0.31	0.52	0.52	0.45	0.27	0.61	0.51	0.37	1.00				
Ca	0.02	0.97	0.98	-0.06	0.86	0.85	0.86	0.89	0.43	1.00			
Mg	0.09	0.92	0.93	0.27	0.68	0.89	0.89	0.82	0.55	0.87	1.00		
Na	0.02	0.87	0.86	0.19	0.63	0.83	0.79	0.72	0.51	0.78	0.77	1.00	
K	-0.10	0.30	0.25	-0.22	0.03	0.22	0.24	0.49	0.09	0.22	0.13	0.32	1.00

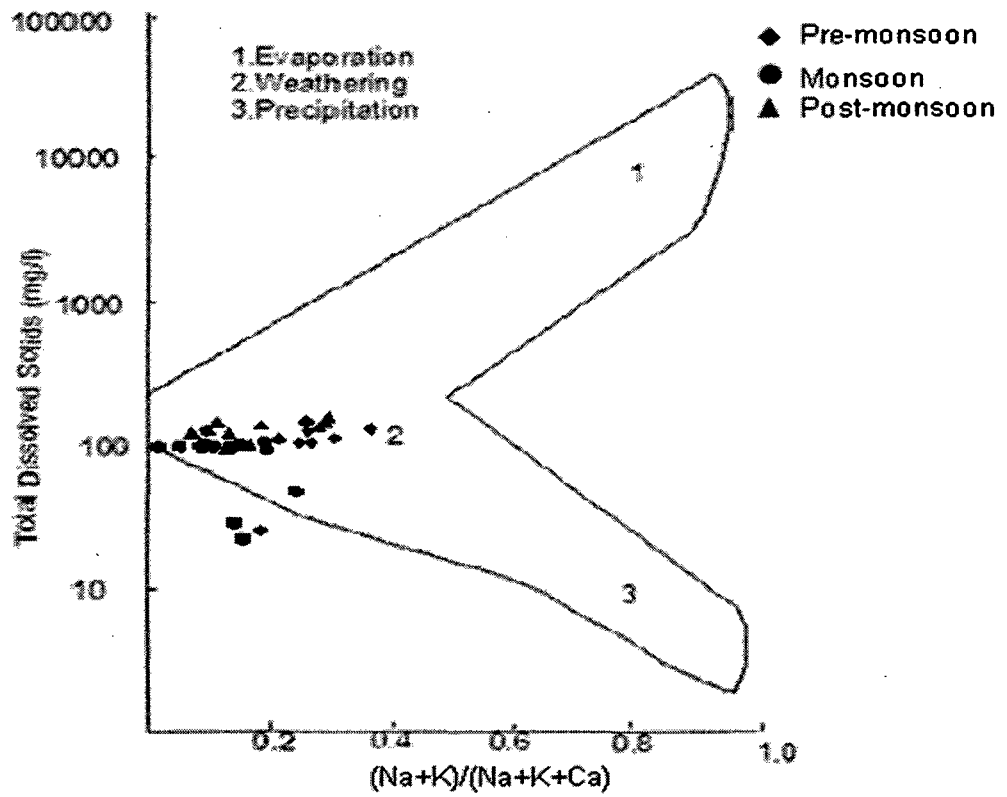


Fig 4.3: Gibbs diagram for controlling factor of surface water quality

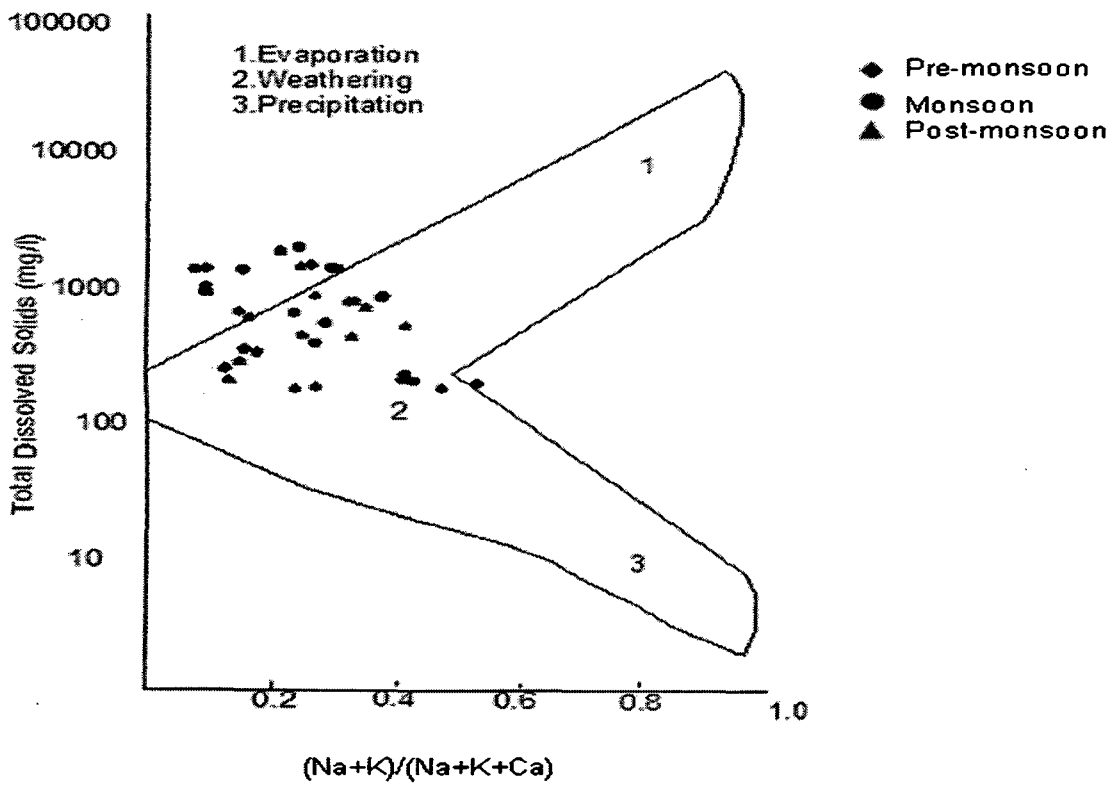
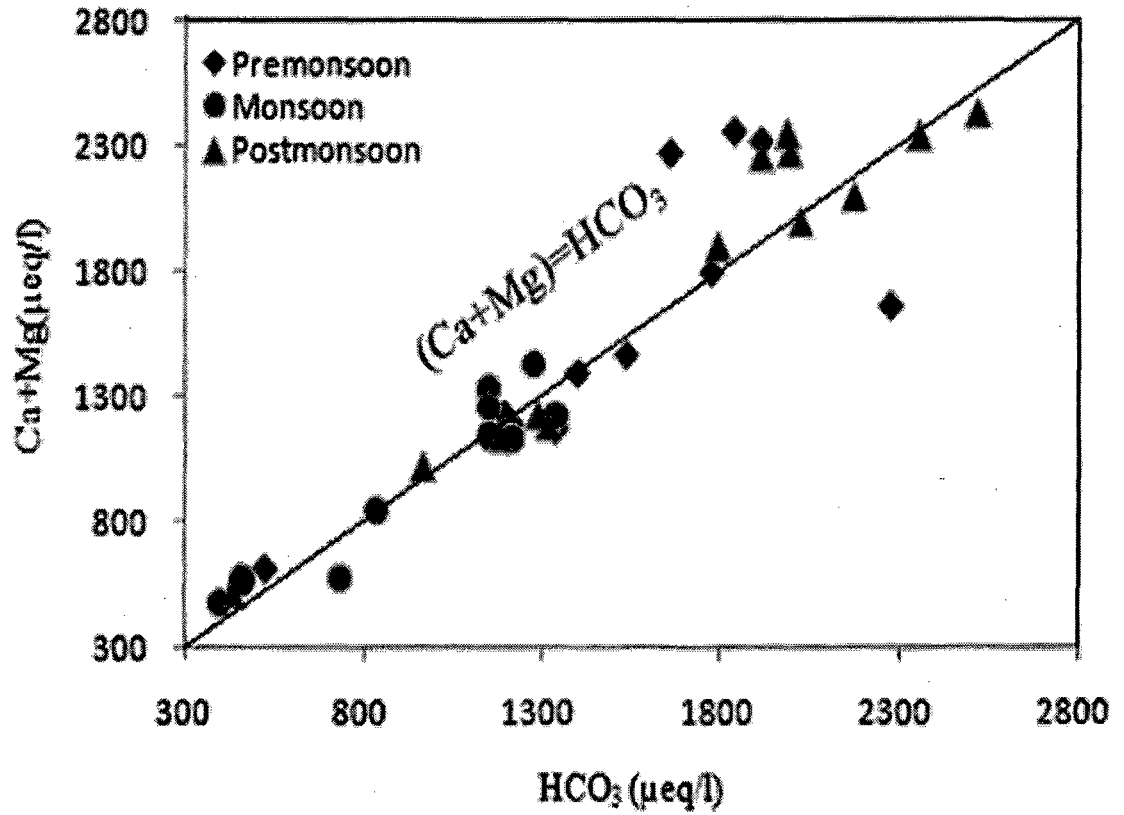


Fig 4.4: Gibbs diagram for controlling factor of groundwater quality

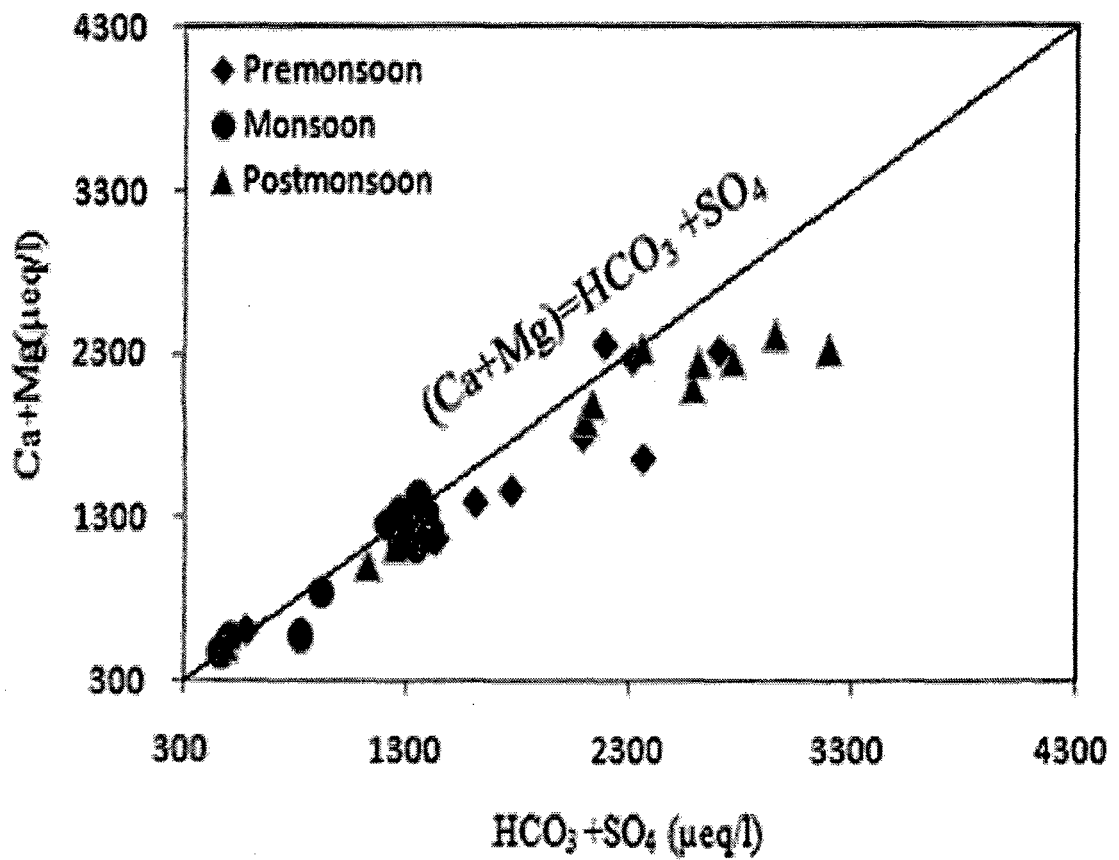
The plot of (Ca+Mg) vs. HCO_3^- marks the upper limit of HCO_3^- input from weathering of carbonates (Stallard and Edmond, 1983). This plot for Subarnarekha water samples shows that few samples lie above the equiline [(Ca+Mg) = HCO_3^-]. These higher value points have to be balanced by other anions (Fig. 4.5a). The points fall along the equiline, can result from both carbonate weathering and silicate weathering. However, difficult to calculate from each weathering processes separately. The plot of (Ca+Mg) vs. ($\text{HCO}_3^- + \text{SO}_4^{2-}$) shows better relationship and suggests that the required anion for high (Ca+Mg) is contributed by sulphate and chloride (Fig. 4.5b). The sulphate in aquatic system may be contributed from the weathering of sulphur bearing minerals like gypsum and pyrite. The plot of (Ca+Mg) vs. TZ^+ show that plotted points falls along the equiline, indicating significant contribution from the (Ca+Mg) to the total cation (TZ^+) balance. The deviation of plotted points from the equiline at higher concentration indicates increasing contribution of alkalis (Na+K) from the weathering of silicate minerals (Fig. 4.5c).

The scatter diagram of (Ca+Mg) vs. HCO_3^- for ground water show that most of the sample points fall above the equiline, shows that in most of the samples the (Ca+Mg) content is excess of HCO_3^- , suggesting that excess of (Ca+Mg) in these waters should be balanced by SO_4^{2-} and Cl (Fig. 4.6a). The plot of (Ca+Mg) vs. ($\text{HCO}_3^- + \text{SO}_4^{2-}$) shows that most of the samples are falling above the equiline (Fig. 4.6b). It is indicating that the carbonate weathering is the dominant process for supply of the calcium ions to the ground water. In addition to silicate weathering, the carbonate weathering process is also contributor for the increase of calcium ions in the ground water. The plot of the (Ca+Mg) vs. TZ^+ shows that most of the plots approach equiline (Fig. 4.6c). The relatively high contribution of (Ca+Mg) to the total cations, the high (Ca+Mg)/(Na+K) ratio (5.72), and the low (Na+K)/ TZ^+ ratio (0.2) indicate that carbonate weathering is the major source of solutes in these waters.

(a)



(b)



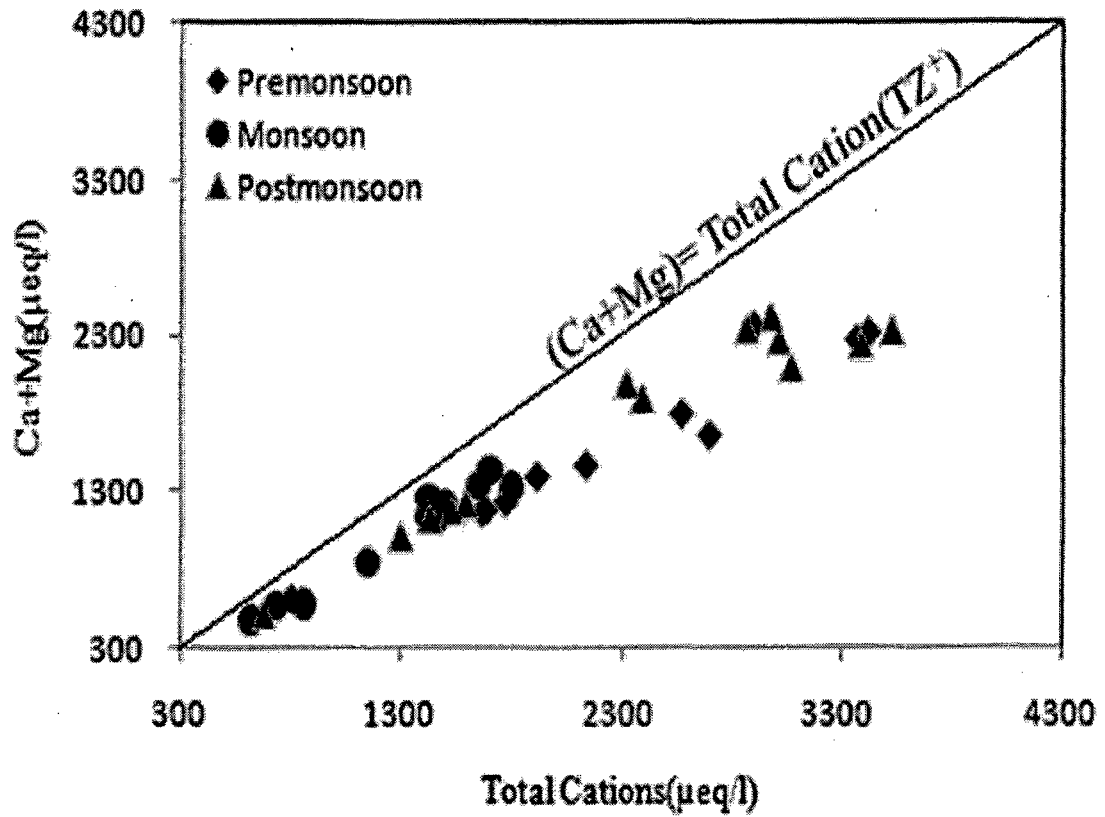
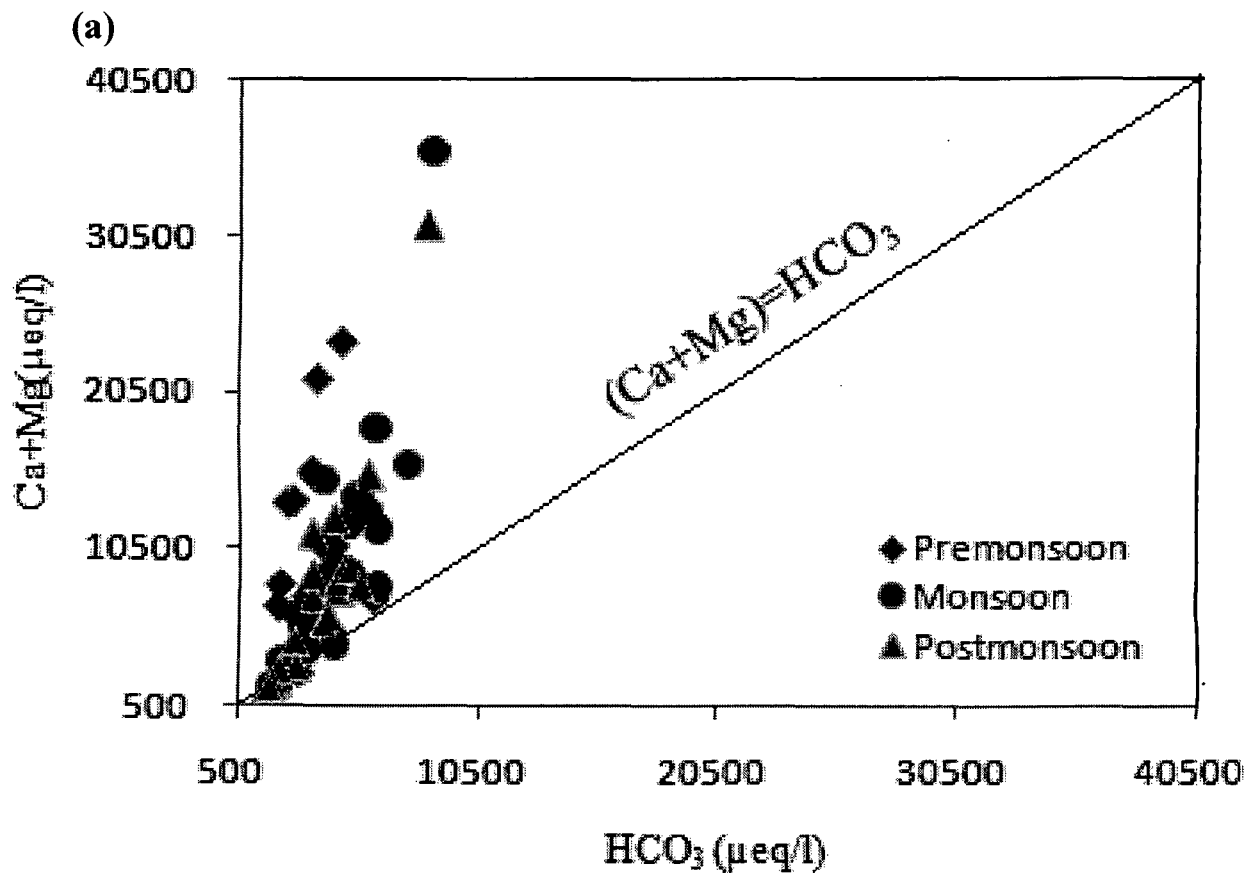


Fig 4.5: Scatter diagram of surface water between (a) $\text{Ca}+\text{Mg}$ vs. HCO_3 , (b) $\text{Ca}+\text{Mg}$ vs. HCO_3+SO_4 and (c) $\text{Ca}+\text{Mg}$ vs. Total Cations



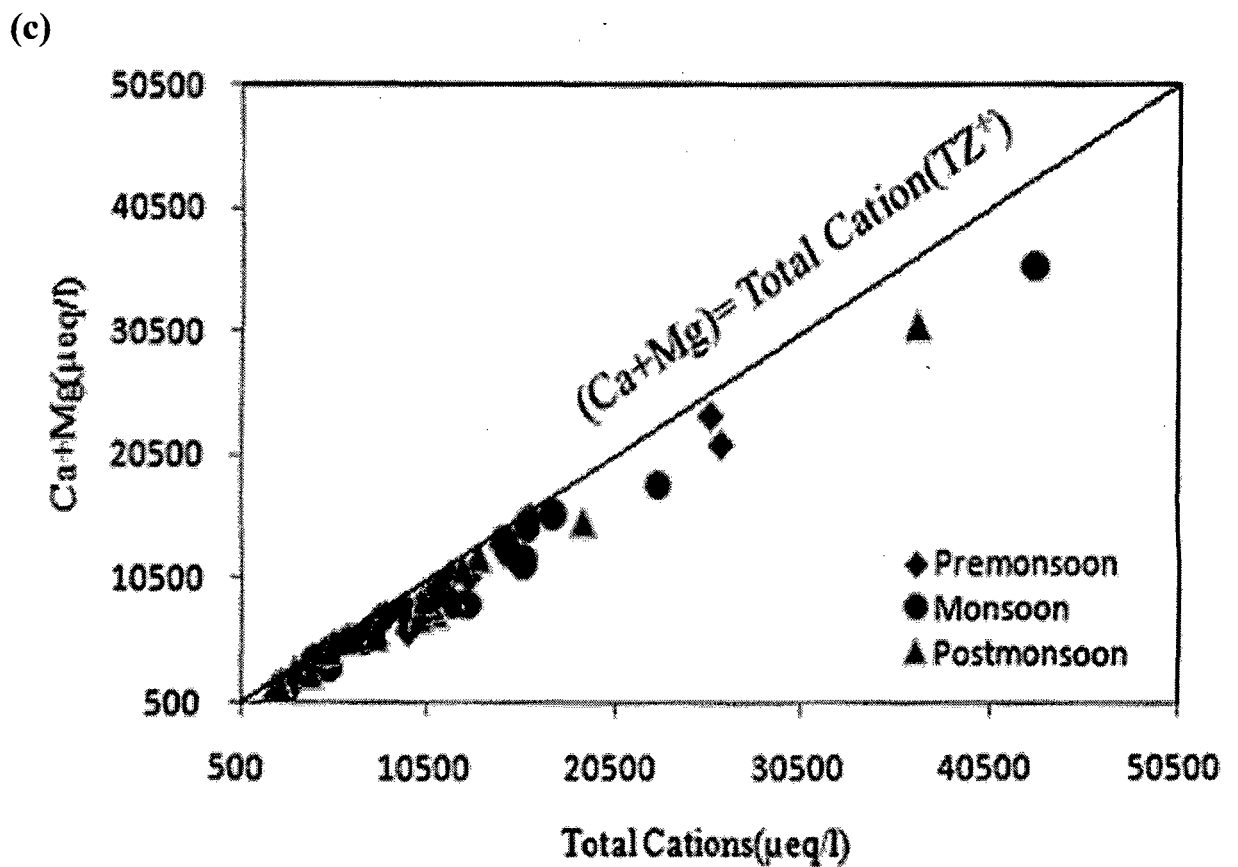
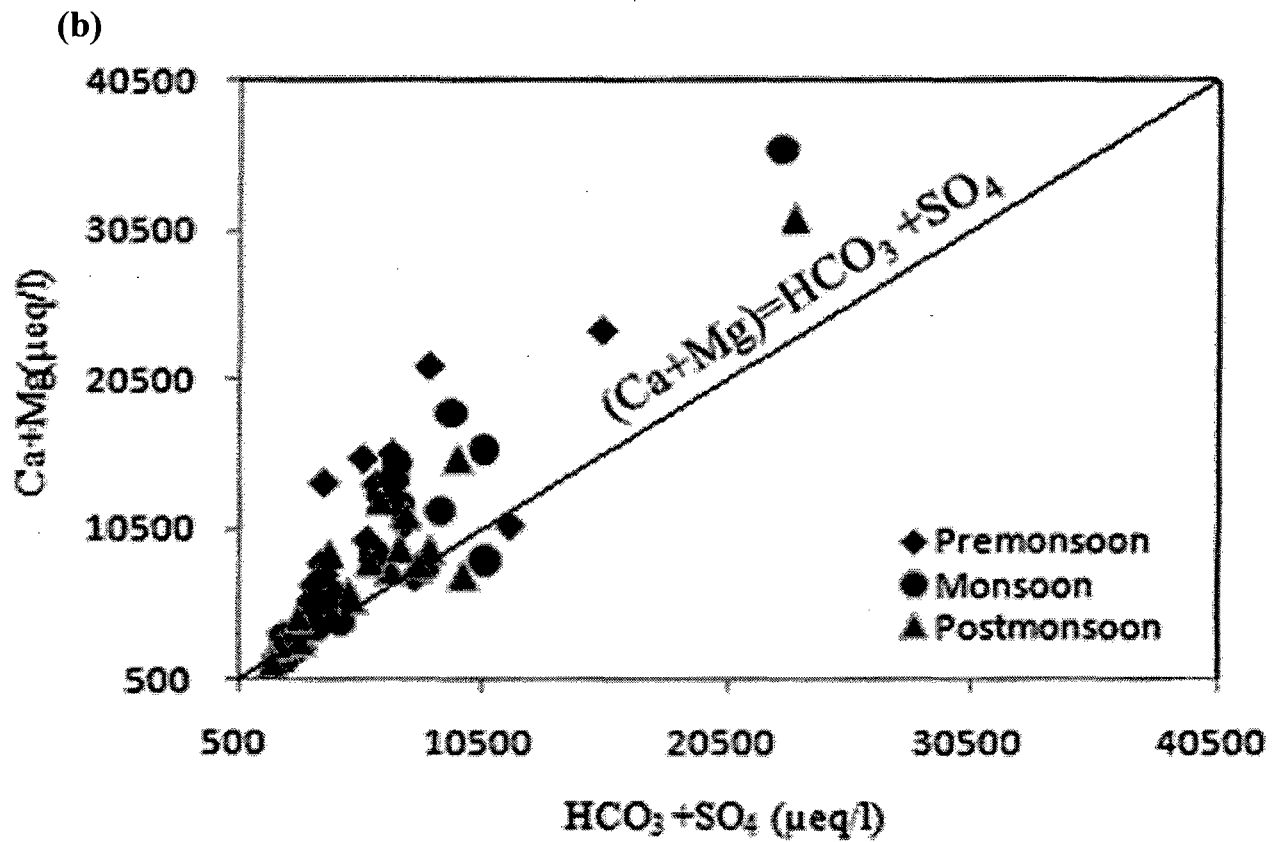


Fig 4.6: Scatter diagram of groundwater between (a) Ca+Mg vs. HCO₃, (b) Ca+Mg vs. HCO₃+ SO₄ and (c) Ca+Mg vs. Total Cations

Hydrochemical facies can be classified on the basis of dominant ions using the Piper's trilinear diagram (Piper 1944). Piper trilinear diagram shows that Ca-HCO₃, mixed Ca-Na-HCO₃ and Na-Cl type are domination hydrochemical facies (Fig. 4.7 and 4.8). It is also suggested that silicate weathering domination and rock-water interaction are the primary factors in increasing the major ion concentration in the groundwater (Jeevanandam et al., 2006). The diamond shaped field between the two triangles is used to represent the composition of water with respect to both cations and anions. All the samples of surface water are Ca-HCO₃ type. But in ground water sample 55% fall in Ca-Cl type, 27% fall in Ca-HCO₃ type, 11% fall in Ca-SO₄ type, 5% sample fall in Mg-HCO₃ type, and remaining 2% ground water sample fall in Na-Cl type. So that maximum ground water samples are Ca-Cl type.

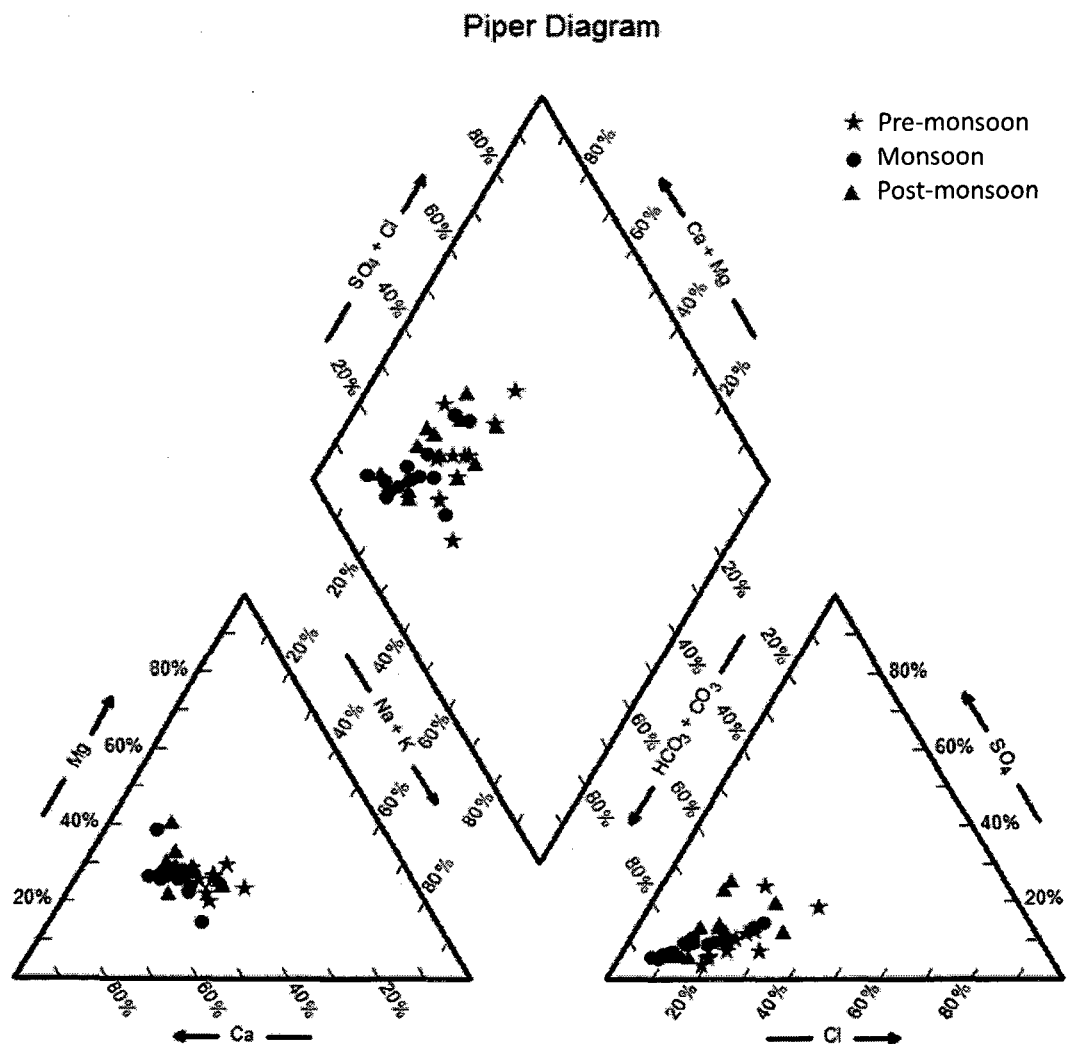


Fig 4.7: Piper trilinear diagram for hydrogeochemical facies (surface water)

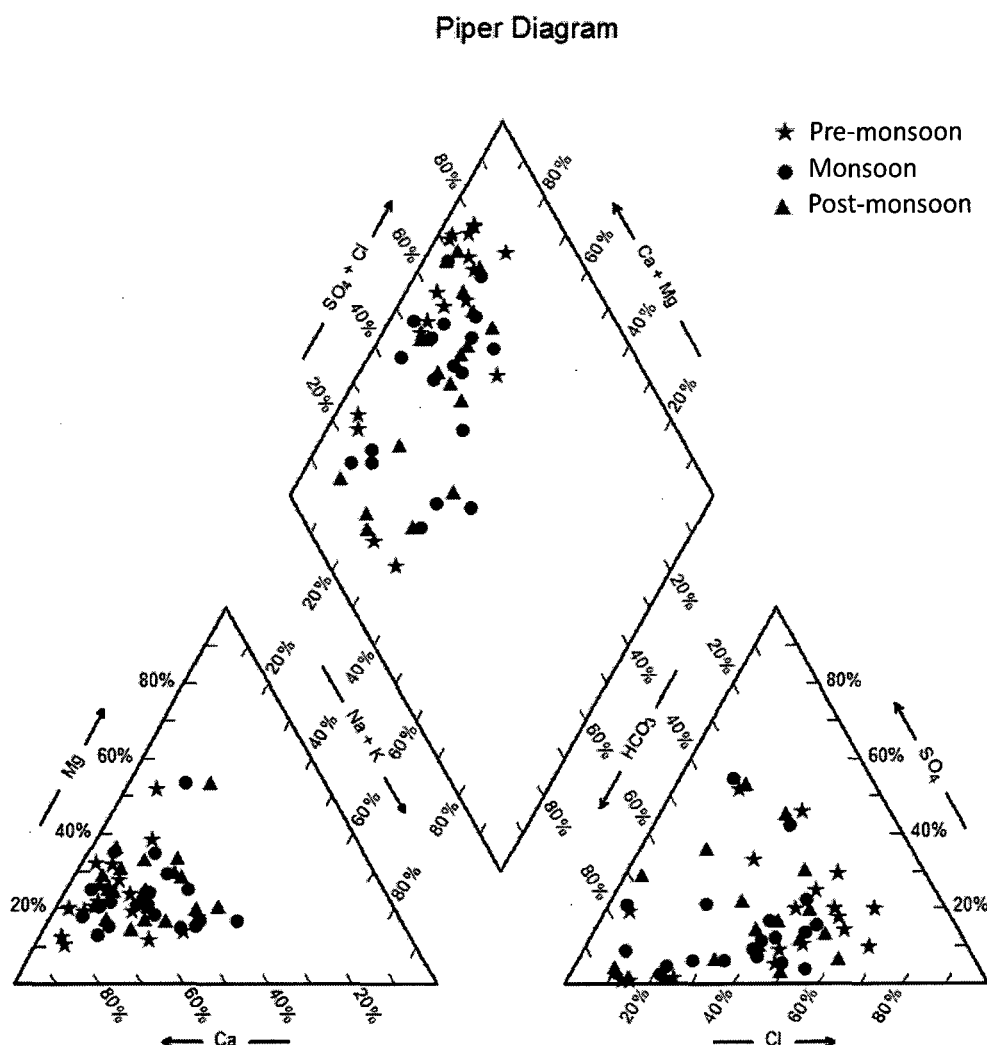
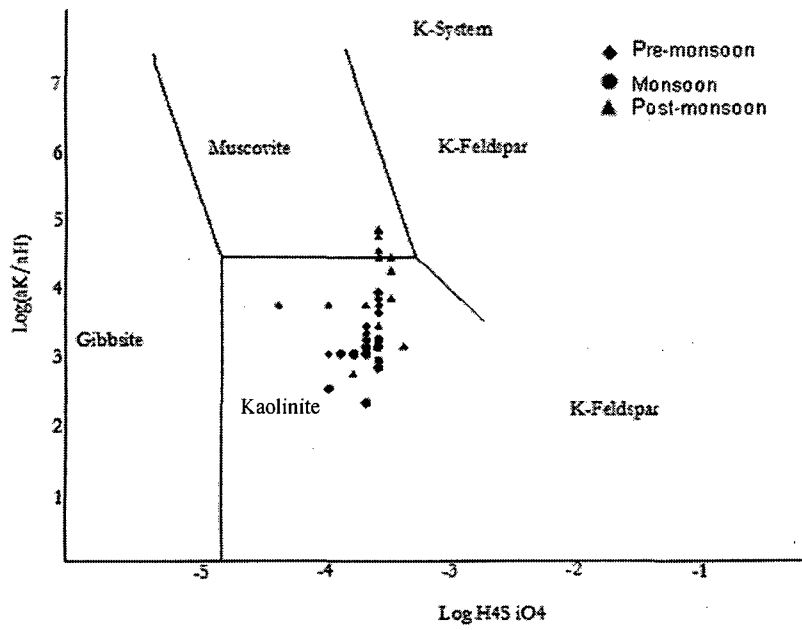


Fig 4.8: Piper trilinear diagram for hydrogeochemical facies (ground water)

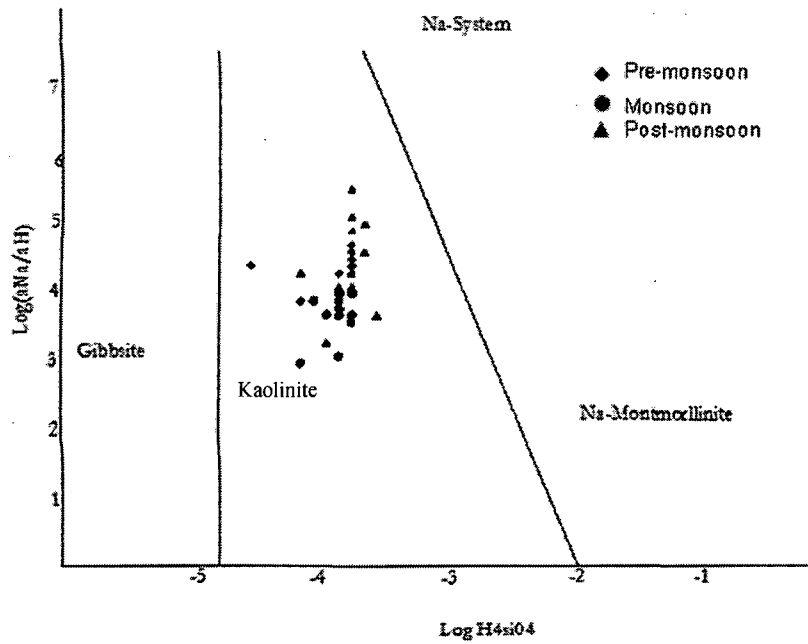
Stability diagram for silicate system

The plot of K-Na silicate systems (Garrels and Christ, 1965) is shown in (Fig 4.9 and 4.10). The plot of mineral stability diagram for the silicate system shows that Kaolinite is a stable mineral in the Subarnarekha River water environment with reference to potassium, sodium, calcium, and magnesium systems. Garrels and Mackenzie (1971) and Subramanian (1979) have shown that the plot of river water will generally fall in kaolinite region. In the stability diagram of Ca-system, the water composition plot near the kaolinite-Ca montmorillonite boundary, and in the Mg-aluminium silicate system, all the plotted points fall near the kaolinite-chlorite boundary. Similar types of pattern are found in groundwater samples. In Na-system, the water composition plots near the Na-montmorillonite boundary.

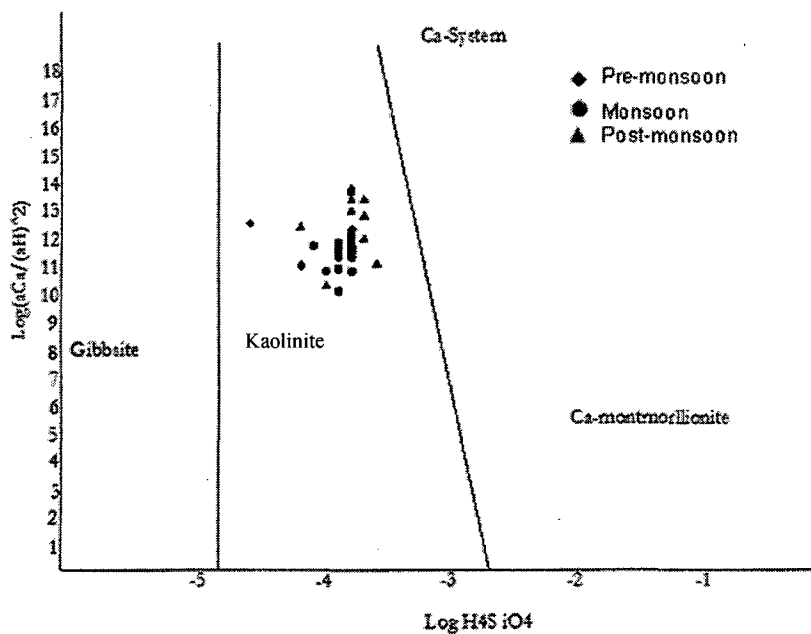
(a)



(b)



(c)



(d)

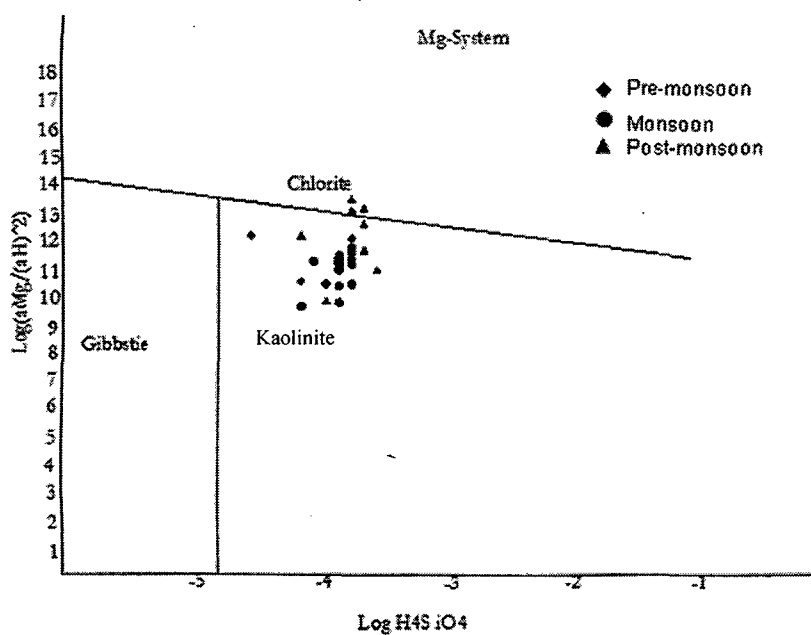
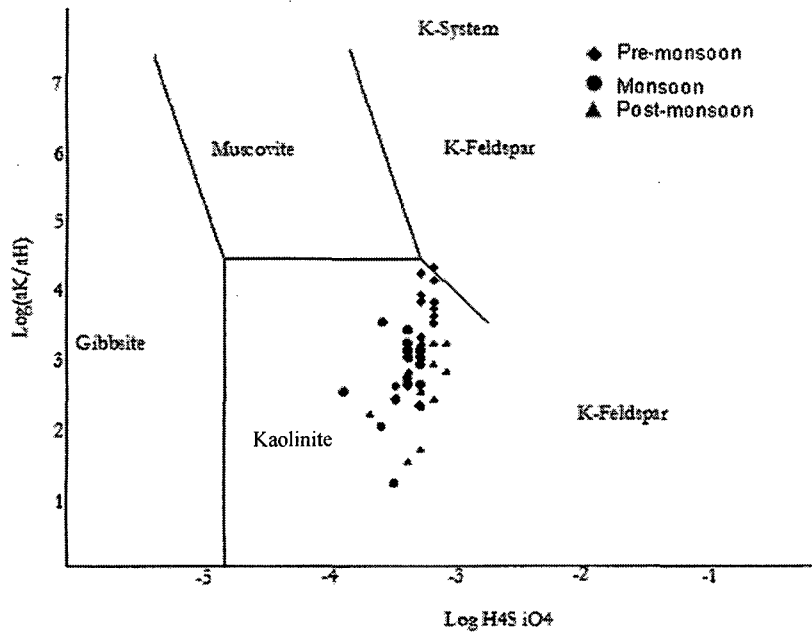
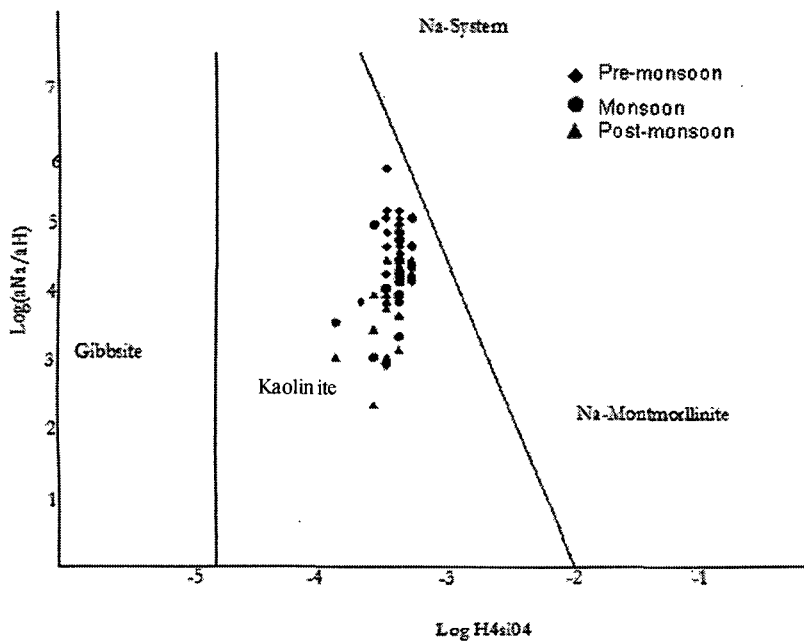


Fig 4.9: Stability diagram of surface water for silicate system (a, b, c, & d)

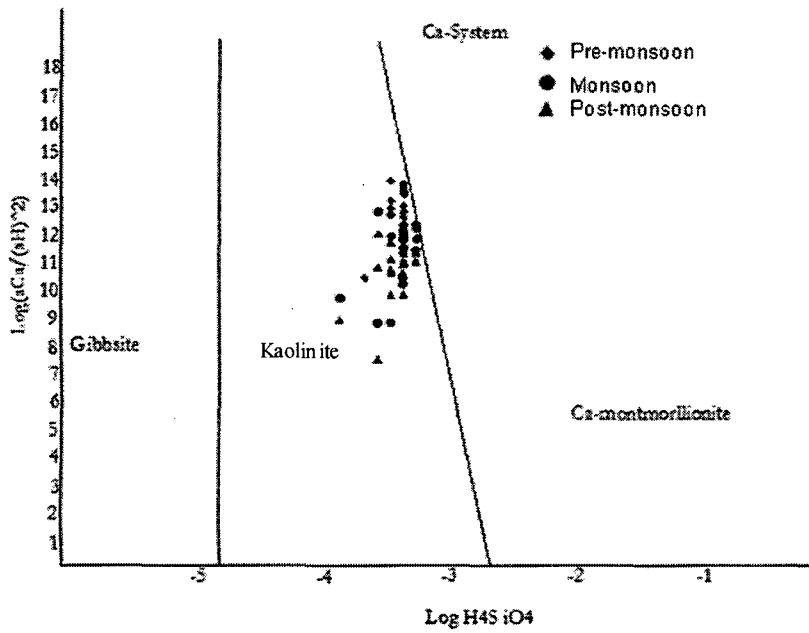
(a)



(b)



(c)



(d)

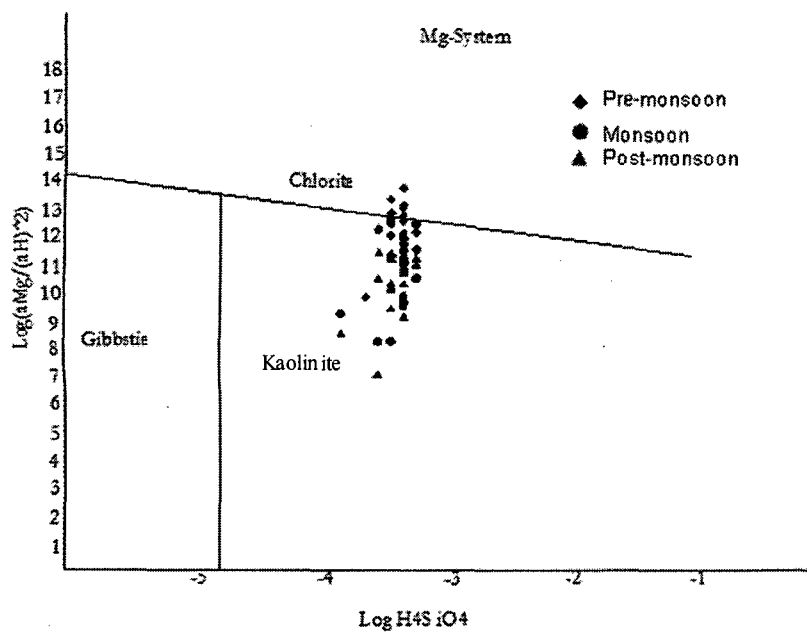


Fig 4.10: Stability diagram of groundwater for silicate system (a, b, c, & d)

Water Quality Assessment

The data obtained by chemical analyses were evaluated in terms of suitability for drinking and general domestic use, irrigation, livestock and industrial use.

(a) Suitability for drinking and general domestic use:

To assess the suitability for drinking and public health, the hydrochemical parameters of the groundwater of the study area were compared with the prescribed limits of WHO (1997) and Indian standard for drinking water (BIS 1991). The data mentioned in Table 4.9 show that most of the parameters are exceeding the desirable limits of WHO (1997) and BIS (1991) in a number of samples, though it is within the maximum permissible limits in most samples. The EC and concentration of TDS is more than the desirable limits of 750 $\mu\text{S}/\text{cm}$ and 500 mg/l, respectively. The higher EC and TDS values may cause a gastrointestinal irritation in the consumers. The TH of the analysed water samples varies between 79 and 1800 mg/l (Avg. 481 mg/l) in tube wells, indicating soft to very hard types of water. Hardness of the water is attributable to the presence of alkaline earths, i.e., Ca and Mg. The data indicate that the Govindpur (1800 mg/l) tube well have TH beyond the safe limit of 600 mg/l for drinking water (BIS 1991). Hardness has no known adverse effect on health but it can prevent formation of lather with soap and increases the boiling point of water.

Table 4.9: Range in values of geochemical parameters in ground water and WHO (1997) and Indian Standards (IS-10500) for drinking water

Parameters	Range	Mean	WHO (1997)		BIS (1991) IS:10500	
			Max. Desirable	Highest Permissible	Max. Desirable	Highest Permissible
pH	5.3-8.3	7.2	7.0-8.5	6.5-9.2	6.5-8.5	8.5-9.2
EC	252-3120	975	750	1500	-	-
TDS	214-2677	808	500	1500	500	2000
HCO ₃	106-526	252	200	600	200	600
SO ₄	0.8-712	111	200	600	200	400
Cl	8.7-504	146	250	600	250	1000
NO ₃	0.2-265	47	-	50	45	100
F	0.1-1.7	0.6	0.6-0.9	1.5	1.0	1.5
Ca	21.5-426	134	75	200	75	200
Mg	4.3-179	35	30	150	30	100
Na	4.8-155	39	50	200	-	-
K	0.5-18.2	3.2	100	200	-	-
TH	79.1-1800	481	100	500	300	600

Unit: mg/l, except pH and EC

The high TH may cause encrustation on water supply distribution systems. There is some suggestive evidence that long term consumption of extremely hard water might lead to an increased incidence of urolithiasis, anencephaly, parental mortality, some types of cancer and cardio-vascular disorders (Agrawal and Jagetia 1997; Durvey et al., 1991). The recommended limit for sodium concentration in drinking water is 200 mg/l. A higher sodium intake may cause hypertension, congenial heart diseases and kidney problems. Concentrations of sodium are within the prescribed limit of 200 mg/l in 99% of the analysed groundwater samples. Concentration of Ca, Mg and K is also found within the highest permissible limits except Govindpur tube well which is having higher concentration of Ca (426 mg/l). The concentration of HCO₃ and Cl in all samples is within permissible limit.

(b) Suitability for livestock

Water for livestock should be of high quality to prevent livestock diseases, salt imbalance, or poisoning by toxic constituents. Most of the water quality variables for livestock are the same as for human drinking-water resources although the total permissible levels of total suspended solids and salinity may be higher. Irrigation canals, ponds, rivers, reservoirs and groundwater may serve as water supplies for livestock. The data in Ayers and Wescot (1985) and Shuval et al. (1986) indicate that water having salinity <1,500 mg/l and Mg <250 mg/l is suitable for drinking by most livestock. Surface and groundwater of the area meet these standards and are suitable for livestock with some exceptions.

(c) Suitability for irrigation uses

(i) Alkali and Salinity Hazard (SAR)

Excessive sodium content in water renders it unsuitable for soils containing exchangeable calcium and magnesium ions. The exchange capacity of water is expressed by SAR (sodium absorption ratio).

$$\text{SAR} = \frac{\text{Na}}{\left[\frac{\text{Ca} + \text{Mg}}{2}\right]^{0.5}}$$

Water with high sodium content may produce harmful levels of sodium in most soils and requires special water and soil management practices, like application of gypsum. Water high in bicarbonates and relatively low in calcium is also known to be hazardous for irrigation (Richards, 1954). Higher EC in water creates a saline soil. Whereas salt content in

irrigation water causes an increase in soil solution osmotic pressure (Thorne and Peterson 1954). EC and sodium concentration are very important in classifying irrigation water. The total concentration of soluble salts in irrigation water can be expressed for the purpose of classification of irrigation water as low (EC = <250 $\mu\text{S}/\text{cm}$), medium (250–750 $\mu\text{S}/\text{cm}$), high (750–2,250 $\mu\text{S}/\text{cm}$) and very high (2,250– 5,000 $\mu\text{S}/\text{cm}$) salinity zone (Richards, 1954).

The calculated value of SAR in the surface water ranges from 0.3 to 1.0 in the pre-monsoon, 0.2-0.5 in the monsoon season and 0.3-0.9 in the post-monsoon season. The plot of data on the US salinity diagram (Fig.4.11) in which the EC is taken as salinity hazard and SAR as alkalinity hazard, shows that most of the surface water samples fall in the category C1S1 and a few samples in C2S1, indicating low to medium salinity and low sodium water which can be used for irrigation in most soil and crops with little danger of development of exchangeable sodium and salinity. In ground water the SAR value ranges from 0.1 to 1.6 in the pre-monsoon, 0.3-1.9 in the monsoon season and 0.2-1.3 in the post-monsoon.

The plot of ground water data on the US salinity diagram shows that the ground water samples fall in the category C2S1 and C3S1, indicating medium to high salinity and low alkalinity (Fig.4.12). This water is more suitable for plants with good salt tolerance. High saline water cannot be used on soils with restricted drainage and requires special management for salinity control. The soil must be permeable, drainage must be adequate, irrigation water must be applied in excess to provide considerable leaching and salt tolerant crops/plants should be selected for such region. Low sodium (alkali) water can be used for irrigation on almost all soils with little danger of the development of harmful levels of exchangeable sodium. Medium sodium water can be an appreciable sodium hazard in fine textured soils having high cation exchange capacity especially under low leaching conditions. This water can be used on coarse textured or organic soils with good permeability (Karanth, 1987).

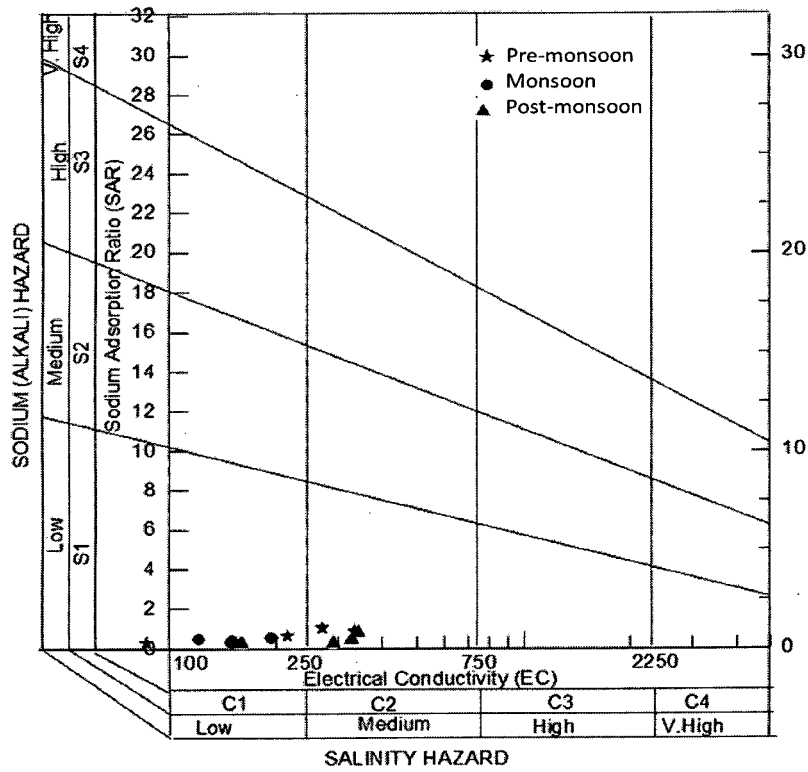


Fig 4.11: USSL salinity diagram of surface water for classification of irrigation water (after Richards 1954)

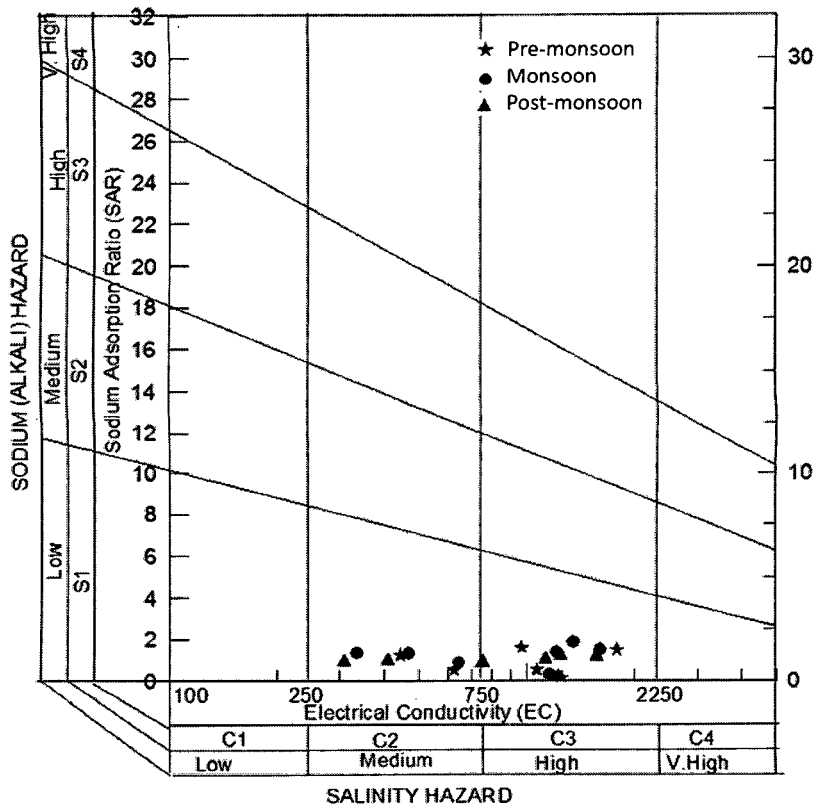


Fig 4.12: USSL salinity diagram of groundwater for classification of irrigation water (after Richards 1954)

(ii) Sodium percentage (Na %):

Sodium concentration is important in classifying irrigation water because sodium reacts with soil to reduce its permeability. Excess sodium in waters produces undesirable effects of changing soil properties and reducing soil permeability (Kelley, 1951). The Na% is calculated using the formula given below, where all the concentrations in meq/l.

$$\text{Na\%} = \frac{\text{Na}^+}{(\text{Ca}^+ + \text{Mg}^{2+} + \text{Na}^+ + \text{K}^+)} \times 100$$

The Wilcox (1955) diagram is relating sodium percentage and electrical conductivity (Fig. 4.13). The sodium percentage in the surface water ranges from 19.0% to 38.7 % in pre-monsoon, 11.5% to 33.6% in monsoon and 14.4% to 33.8 % in post-monsoon season. As per the BIS (bureau of Indian Standard), maximum sodium of 60% is recommended for irrigation water. The plot of surface water samples on the Wilcox diagram fall in the categories of excellent to good region.

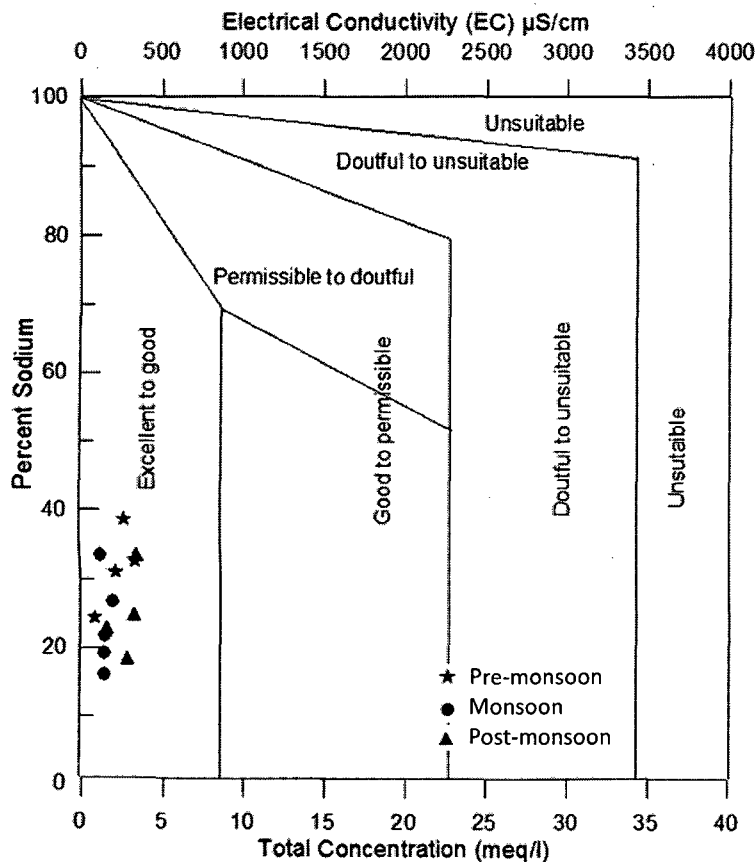


Fig. 4.13: Plot of %Na vs. EC in surface water (Wilcox 1955)

The sodium percentage in the ground water ranges from 3.5% to 34.7% in pre-monsoon, 6.0% to 44.6% in monsoon and 6.0% to 38.4 % in post-monsoon season. The plot of surface water samples on the Wilcox diagram (Fig 4.14) fall in the categories of excellent to good and good to permissible for irrigation purposes. So water of Subarnarekha River basin is suitable for irrigation purpose.

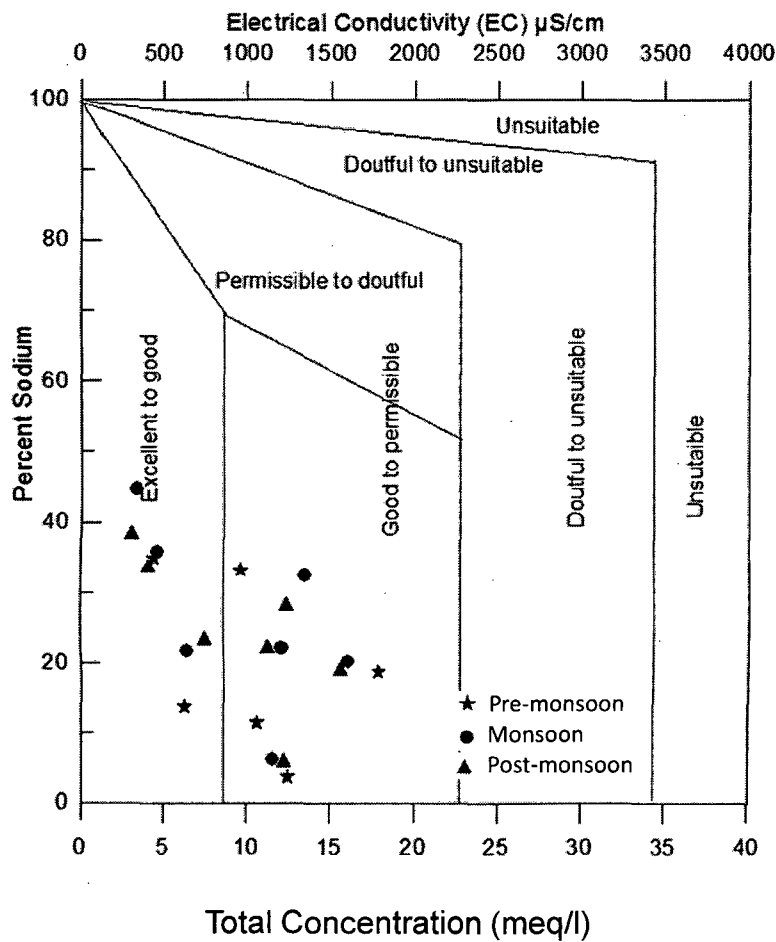


Fig. 4.14: Plot of %Na vs. EC in ground water (Wilcox 1955)

CHAPTER 5
CONCLUSIONS

CONCLUSIONS

To achieve the objectives of the present study, 37 samples from surface (river and reservoirs) and 46 samples from ground water resources (tube well and dug wells) were collected from different sampling sites of the Subarnarekha River basin during pre-monsoon, monsoon and post-monsoon seasons in 2008. The collected samples were analysed for pH, conductivity, TDS, major cations (Ca, Mg, Na and K), major anions (HCO_3 , F, Cl, SO_4 and NO_3) and dissolved silica. The analytical data were evaluated in terms of the chemical characteristics of the water resources of the Subarnarekha River basin and its suitability for drinking and irrigation uses. For assessing the suitability of drinking water, the water quality data of the analysed samples were compared with the prescribed drinking water standard of WHO and BIS (IS:10500). The parameters like %Na and SAR were calculated for assessment of water for the irrigation uses. The following are the major findings of the present study:

- ❖ The pH value of the analysed water samples shows that the surface and ground water of the Subarnarekha River basin are neutral to alkaline in nature.
- ❖ The major ion chemistry of the surface water and groundwater seems to be controlled by chemical weathering of rocks and anthropogenic activities.
- ❖ Groundwater chemistry reveals that natural weathering process involving carbonate and silicate weathering is responsible for the groundwater quality of the region.
- ❖ Leaching of nitrate containing fertilizers and biological oxidation of organic nitrate is responsible for the contribution of NO_3 in the groundwater.
- ❖ All the samples of surface water are Ca- HCO_3 type. But in ground water samples, 55% fall in Ca-Cl type, 27% in Ca- HCO_3 type, 11% Ca- SO_4 type, 5% Mg- HCO_3 type and remaining 2% in Na-Cl type. Therefore, maximum ground water samples are Ca-Cl type.

- ❖ The water quality of Subarnarekha River basin has all parameters such as TDS, EC, pH, major cations and anions are within permissible limit of WHO (1993) and BIS (1991) except at few sites. Concentration of TDS, NO₃ and Ca of ground water at Govindpur location has higher than permissible limit. TDS concentration at this site varies from 2677 mg/l in pre-monsoon to 2545 mg/l in post-monsoon season, higher than the BIS maximum permissible limit of 2000 mg/l (BIS 1993).
- ❖ Sodium concentration is important in classifying irrigation water because sodium reacts with soil to reduce its permeability. On the basis of SAR and Na % values, water of Subarnarekha River basin is suitable for irrigation purpose. However, the higher salinity in some samples restricts its suitability for irrigation uses.
- ❖ Kaolinite is a stable mineral in the Subarnarekha River water environment.

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