Premonsoonal Spatial Distribution of Groundwater Hardness: A Case study in Mahakalapara Block, Kendrapara District, Odisha, India

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Abstract: **From the hydrochemical analysis of 89 representative groundwater samples along coastal Kendrapara district, Odisha, the current research establishes widespread occurrences of moderately hard to hard groundwater within the subsurface water bearing horizons. There exists a distinct belt of moderately hard ground water in both the Mahakalapara and Rajnagar blocks of the district whereas a specific patch of extremely hard water horizon does exist in the former block. The analysis also points to no specific interrelationship between the hardness of groundwater to that of the physical parameters including pH and electrical conductance.**

Keywords: **Aquifer, Total Hardness, SRTM, GIS, Spatial**

I. INTRODUCTION

Hardness is the characteristic of water which inhibits the leathering of soap [1]. Groundwater hardness is primarily the function of divalent cation including calcium, magnesium, strontium, ferrous iron and manganous manganese [2]. However, looking at the predominance of the ions, hardness in groundwater is cardinally contributed to the presence of calcium and magnesium cation. These ions of hard ground waters form precipitates by reaction with soap as they do also form scales by reaction with certain anions present in the water [4]. Hence, hard ground waters contribute to the greater soap consumption as well as scaling of boilers and tastelessness of foods [2].

The cardinal source of the calcium and magnesium ions in groundwater is dissolution of limestone [2]. Dissolved carbon dioxide in rain water as well as that entering the percolating rain water by microbial action in the soil and from the root zone primarily leads to higher concentration of carbonic acid groundwater which leads to further low pH conditions. This enhances the solution of insoluble carbonates in the soil zone which in limestone terrain leads to the conversion of more soluble bicarbonates as well as higher concentration of sulphates, chlorides and silicates as they pass into the subsurface water as exposed impurities once the carbonates are dissolved [2, 3, 4]. This is the reason why, hard ground waters normally originate in terrains where thick toposoils overlie limestone strata [3].

Hardness of groundwater caused due to the presence of carbonate and bicarbonate of calcium and magnesium are termed as temporary or carbonate hardness as they can be removed to some extent by simple boiling and addition of lime [4]. However, hardness caused due to the sulphates, chlorides and nitrates of calcium and magnesium are often referred to as permanent hardness as they require special softening treatment for removal of hardness [4]. This chemical property of the subsurface waters is expressed in mg/litre or p.p.m. equivalent of calcium carbonates which denotes to the calcium carbonate equivalent of calcium and magnesium ions present in water [1].

Hardness of groundwater is often directly correlated with the biological productivity as calcium and magnesium, the cardinal hardness cation contribute to productivity [2]. However, other hardness ions have a very adverse toxic effect on productivity if present in significant concentrations [2]. Although hardness and alkalinity have a positive co-relationship and in many terrains often replicate each other, it is historically easier to measure the former one [2]. However, the use of hardness as a measure of productivity has become obsolete and other indices of productivity are followed for aquatic ecosystems. But, hard water are normally referred to as soap wasting waters and are the primary cause of scum in domestic usages [2].

The present research looks into the occurrences of hard water along the eastern coast of Odisha including the Mahakalapara block along coastal Kendrapara district. The study takes into account the measured total hardness from 89 representative groundwater samples for the spatial variation of hard waters in the aforementioned block of the state [5, 6].

II. STUDY AREA

The present research deals with the aquifer system of Mahakalapara block of Odisha along the east coast of India (Fig. 1). Mahakalapara block encompasses an area of approximately 600sqkm having a perimeter of about 195km. It lies to the north of the Mahanadi River which merges with the sea in a short distance and also engulfs the total area of the concerned region within its vast expanse of floodplain. Opposite to the area of interest along the Mahanadi River, situated is the Paradeep port to the southeast side which is one of the major industrial hubs of Odisha. In contrast to Paradeep, Mahakalapara has not witnessed the development of a single industry till date and most of the population depends on the port services and agriculture for their livelihood. The study area is bounded by Kujang block of Jagatsinghpur district on south-west and Marshaghai and Rajnagar block of Kendrapara district on northwest and northeast respectively. The area has an extent of approximately 86.26^{0}E to 86.51^{0}E longitude and 20.16^{0}N to 20.31^{0}N latitude. The Bay of Bengal forms the east coast of the study area facilitating the growth of mangrove forests along the coast line.

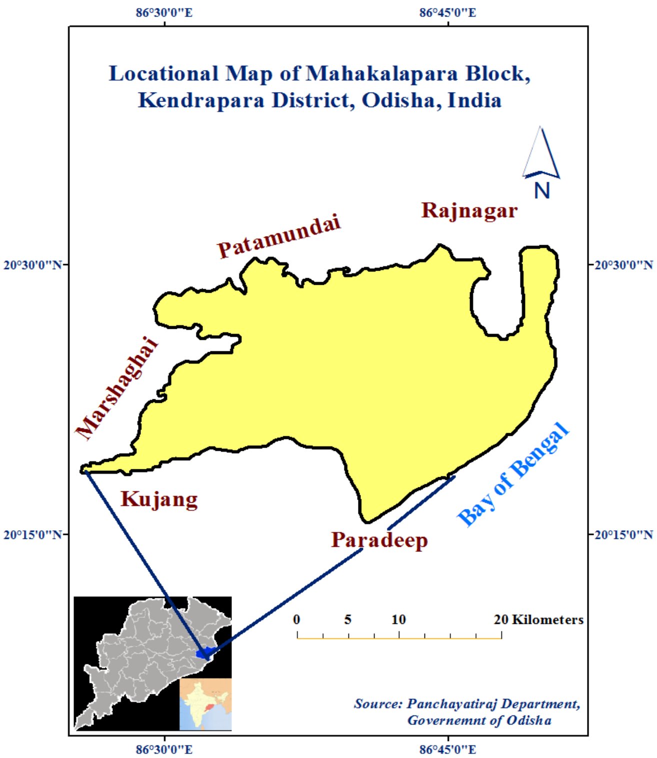

Fig. 1 Physiographic setting of the study area

III. GEOLOGY

The concentration of dissolved material in groundwater is normally greater than that of the surface waters due to their greater exposure to geologic strata [1]. The type and concentration of the salts do depend on the mineralogical characteristics of the aquifer and their solubility as well. A detailed analysis of the geologic setting of the study area was done based on the geological map which has been established by the Geological Survey of India for the state of Odisha (Fig. 2). The map displays the presence of primarily three types of geologic formations covering the Mahakalapara block including Kaimundi Formation, Burahbalang formation and the Bankigarh formation. All the three types of formations belong to the fluvial and marine type of sedimentary alluvial deposits. The Kaimundi or Sijua formation consists of hard greyish green clays with calcareous nodules. Clay is one of the common aquicludes present in the sedimentary deposits. The Bankigarh formation occupies a considerable part of the study area and consists of old sand dunes, marine clay, fluvial silt or clay and deltaic deposits. The eastern region of the study area points to the presence of two distinct belts of Burahbalang formation where the lithology is of sand silt in alternating flood plain layers, recent sand dunes and marine deposits.

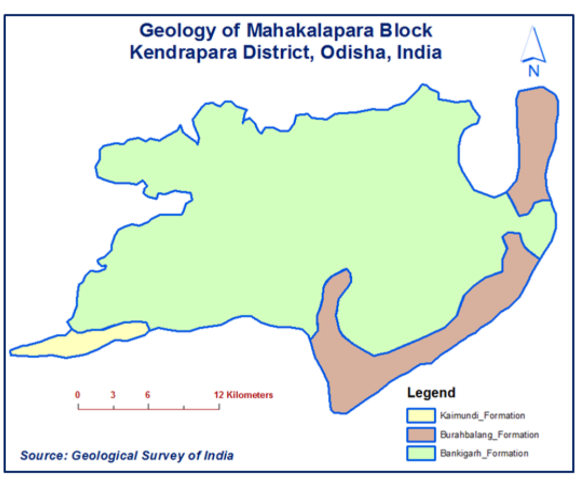

Fig. 2. Geology of the study area

IV. TOPOGRAPHY

The topographical elements of the study area are derived from the geospatial analysis of SRTM DEM in ArcGIS 10 [16]. The chief elements essential for a morphometric analysis are slope, aspect and curvature of the terrain and these were established to obtain a synoptic view of the region. The calculated slope of the terrain from elevation values displays the gradient or inclination between two points for the water movement. A peek at the elevation map points towards the region being very gently sloped low lying area which is generally the characteristic of coastal plains worldwide (Fig. 3). Two predominant minimum and maximum slopes of 0^{0} and 90^{0} respectively are observed from the slope map of the terrain (Fig. 3). The zero values are represented by the stream channels and water bodies whereas the near vertical slopes indicate flat lying areas of the terrain and the forested areas. The aspect values of Mahakalapara displays a similar view as that of the slope map having a dominant eastwardly facing topography which is clearly depictable from the physiographic setting of the study area (Fig. 3).

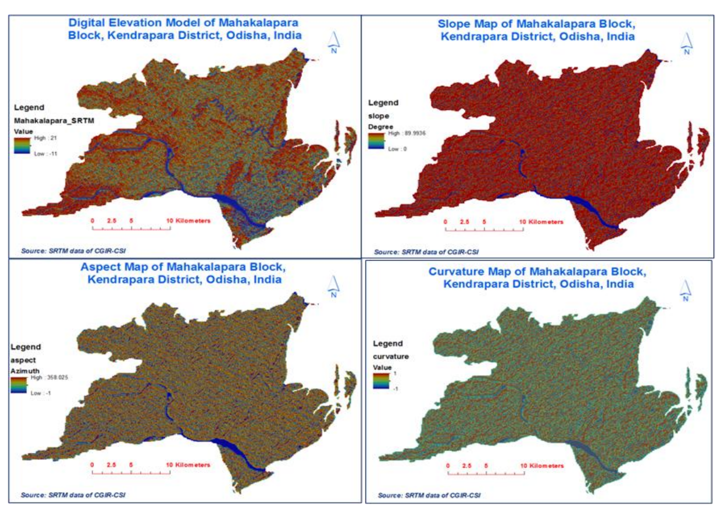

Fig. 3. Topographic elements of the study area

The morphometric element of curvature indicates the second derivative of the slope of the topography which can be interpreted in terms of acceleration or deceleration of the flow of water along the slope. This element of the terrain also gives a similar result as that of the slope and aspect of the terrain. The curvature map displays a very homogenous or isotropic nature of the region (Fig. 3). In a nut shell, the above three morphometric elements of terrain indicates a very gently sloping eastwardly facing topography merging with the Bay of Bengal in the east.

V. MATERIALS AND METHODOLOGY

Groundwater sample collection for the present study has been done in accordance with the standard methods of 1060, APHA, 1995 from the various places within the study site [9, 10, 11, 12, 13, 14, 15, 17]. The groundwater samples were collected keeping in mind the cultural set up, hydrology, geology and topography of the terrain in mind so that, they are representative of the aquifer system of concern [5, 6]. This was followed so as to find out any specific spatial pattern that exists within the study site. A total of 89 groundwater samples from Mahakalapara block were collected in June 2013 before the onset of the monsoon (Fig. 4).

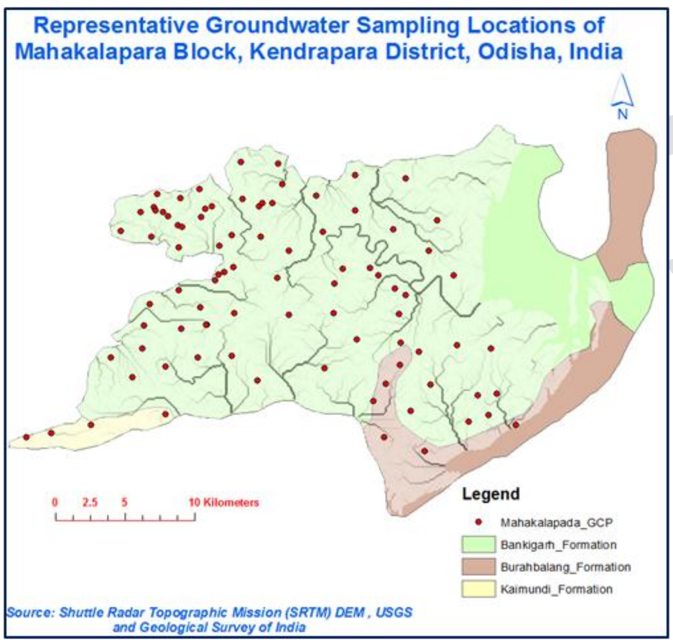

Fig. 4. Groundwater Sampling Locations of Study Area

The samples were collected in 300ml low density poly-ethylene narrow mouth bottle (conforming to USP Class IV) with leak-proof and air tight lid. Before collecting the samples from the required source, certain amount of water was first pumped out (in spite of the concern tube well being an active public tube well) so that fresh drawn down groundwater is collected (not stored water). Collector's hand was properly washed and the sampling bottles were rinsed with same water for few seconds before collecting the water samples. During the collection of water samples the location of the site was identified by GPS device (GARMIN NUVI 250) [5, 6]. The labelling of the samples was done in such a manner so that it clearly demonstrates the system (e.g. well or tube-well or bore well), sampling site and sample number. The date and time of the sampling was also noted down during the collection of the samples. As soon as the samples were collected, they were labelled and capped and packaged in foam box that was used exclusively for this purpose.

Physical parameters like pH, Electrical Conductance (EC) were measured on the spot by Systronics Water analyzer 371 and total dissolved Solid (TDS) was calculated by multiplying a factor of 0.64 to the corresponding EC values. Total hardness (TH) of the groundwater samples were estimated by titration with the chelating agent ethylenediaminetetraacetic acid (EDTA). EDTA forms stable complex ions with divalent cation as below illustrated explanation for calcium:

$$Ca^{2+} + EDTA = Ca.EDTA$$

Thus every molecule of EDTA will form complex with one divalent metal cation which in turn points to one mole of EDTA consumed being equal to 1 mole of $CaC0_3$ equivalence of TH. The titration procedure uses ammonia buffer and Erochrom Black Tea (EBT) as reagent solutions. The calculated TH concentrations of the collected groundwater samples are given in Table 1.

VI. RESULTS AND DISCUSSION

Groundwater is classified as soft when the TH concentration is below 75mg/l, moderately hard when it is between 75mg/l to 150mg/l, hard if TH is between 150mg/l to 300mg/l and very hard when the TH value is greater than 300mg/l [3, 4]. From the hydrochemical analysis the range of the hardness values of groundwater samples of Mahakalapara block found out to be between 65mg/l to 925mg/l. Out of the 89 representative groundwater samples collected, only one displayed a hardness value below 75mg/l whereas, 41 samples have TH values between 75mg/l to 150mg/l, 31 samples ranged between 150mg/l to 300mg/l and 26 of them displayed values exceeding 300mg/l. Hence 1.12% of the samples belong to the soft water category, 46.07% belong to moderately hard category, 34.83% come within hard water category and 29.21% of the samples are very hard waters.

To determine the spatial distribution of the different groundwater types, the hardness concentration of the samples were analyzed in a GIS environment (Fig. 2). Arc GIS 10 was used to spatially interpolate the TH concentrations of collected groundwater samples. Digital Elevation Model (DEMs) was created for each water type (where the concentration is displayed as elevation) to know the lateral variation of the groundwater hardness (Fig. 5). As displayed from the DEM, moderately hard groundwater occurs in a NW-SE trending zone which almost divides the Mahakalapara block into two halves of hard water zones. Extremely hard groundwater has a distinctive patch in the western part of the Mahakalapara block. As found out from the hydrochemical analysis as well as that displayed in the DEM the study area is almost devoid of soft groundwater (only one sample) horizons and the water type mainly falls within the hard water category.

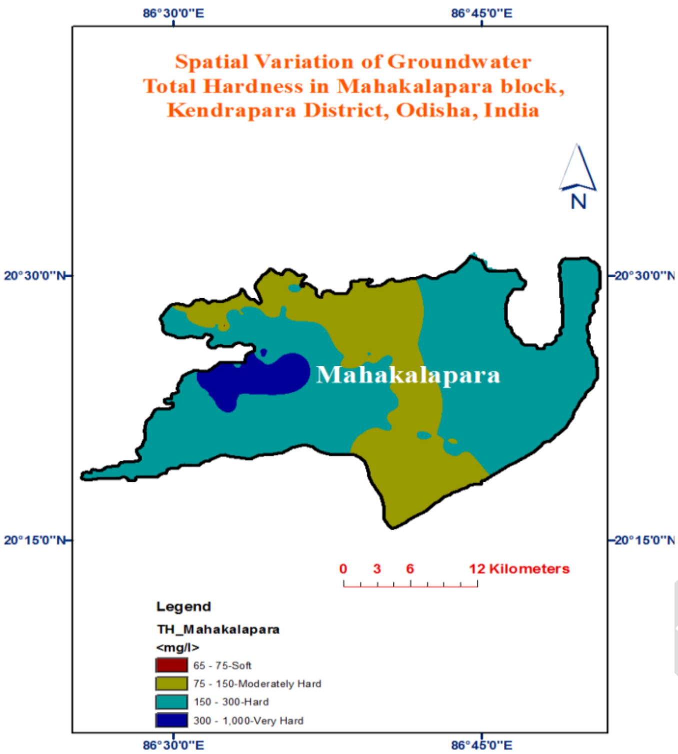

Fig. 5. Spatial variation of groundwater types in the study Area

This lateral occurrence assumes greater significance in future as the area is still to witness any significant industrialization and hence the type of industry that can be thought of to be set up. Analysis of the correlation of TH values with that of pH and EC values displayed no significant interrelationship (Table 2).

VII. CONCLUSION

The present research looks into the sptial distribution of hardness of groundwater in the coastal kendrapara district. Analysis of the 89 representative groundwater samples from the area displays the wide spread occurrence of moderately had to hard groundwater types along this coastal belt of the state. The hardness concentration of the subsurface waters also does not display any significant interrelationship with the physical parameters such as pH and EC. These findings hold greater future scope regarding the type of industry to be chosen for this backward region.

ACKNOWLEDGEMENT

The authors sincerely acknowledge the support provided by the department of Geology, Utkal University for providing field and laboratory equipments as well as lab chemicals for carrying out the various field and laboratory analysis related to this research. The authors also sincerely

TABLE 1. TOTAL HARDNESS OF GROUNDWATER SAMPLES OF MAHAKALAPARA BLOCKS, ODISHA, INDIA

Mahakalapara Block				
Sample No.	PH	EC(μs/cm)	TDS(mg/l)	TH(mg/l)
MPT-101	7.2	1070	684.80	170
MPT-102	7.32	887	567.68	140
MPT-103	6.92	893	571.52	120
MPT-104	7.1	876	560.64	120
MPT-105	7.1	788	504.32	90
MPT-106	6.87	834	533.76	135
MPT-107	6.83	809	517.76	110
MPT-108	6.89	816	522.24	100
MPT-109	7.15	912	583.68	140
MPT-110	7.1	862	551.68	110
MPT-111	7.13	976	624.64	110
MPT-112	7.23	1200	768.00	155
MPT-113	6.92	1130	723.20	160
MPT-114	7.13	868	555.52	140
MPT-115	7.2	962	615.68	65
MPT-116	7.29	1070	684.80	260
MPT-117	7.2	1530	979.20	165
MPT-118	7.21	1100	704.00	135
MPT-119	7.28	1370	876.80	170
MPT-120	7.38	1770	1132.80	150
MPT-121	7.47	1260	806.40	140
MPT-122	7.32	1130	723.20	85
MPT-123	7.35	1470	940.80	155
MPT-124	7.44	3070	1964.80	170
MPT-125	7.3	2930	1875.20	140
MPT-126	7.55	891	570.24	100
MPT-127	7.28	1810	1158.40	160
MPT-128	7.41	944	604.16	145
MPT-129	7.08	3050	1952.00	245
MPT-130	6.85	6100	3904.00	530
MPT-131	7.08	5600	3584.00	470
MPT-132	6.78	3640	2329.60	520
MPT-133	6.84	3270	2092.80	365
MPT-134	6.83	9470	6060.80	510
MPT-135	7.31	2670	1708.80	140
MPT-136	6.37	2230	1427.20	280
MPT-137	6.52	4530	2899.20	405
MPT-138	6.94	1630	1043.20	200
MPT-139	7.31	3280	2099.20	270
MPT-140	6.83	6200	3968.00	370
MPT-141	6.75	6360	4070.40	360
MPT-142	6.68	6820	4364.80	410
MPT-143	7.43	2430	1555.20	145
MPT-144	7.5	3910	2502.40	170
MPT-145	7.54	2780	1779.20	110
MPT-146	7.5	3140	2009.60	130
MPT-147	7.7	2250	1440.00	80
MPT-148	7.51	2610	1670.40	140
MPT-149	7.6	2390	1529.60	145
MPT-150	7.68	2190	1401.60	155
MPT-151	7.78	1700	1088.00	105
MPT-152	7.55	5660	3622.40	210
MPT-153	7.67	4060	2598.40	140
MPT-154	7.56	5200	3328.00	180
MPT-155	7.62	4820	3084.80	140
MPT-156	6.45	1930	1235.20	140
MPT-157	7.69	5170	3308.80	240
MPT-158	7.1	2620	1676.80	240
MPT-159	6.78	580	371.20	100
MPT-160	7.3	1490	953.60	120
MPT-161	6.95	2190	1401.60	205
MPT-162	7.9	3300	2112.00	160
MPT-163	7.68	3330	2131.20	120
MPT-164	7.78	3490	2233.60	130
MPT-165	7.33	490	313.60	90
MPT-166	7.65	4200	2688.00	110
MPT-167	7.6	400	256.00	195
MPT-168	7.28	1370	876.80	95
MPT-169	7.35	750	480.00	90
MPT-170	7.34	1410	902.40	100
MPT-171	7.24	650	416.00	100
MPT-172	7.06	791	506.24	170
MPT-173	7.18	5080	3251.20	150
MPT-174	7.57	3420	2188.80	120
MPT-175	7.31	4660	2982.40	175
MPT-176	6.61	1420	908.80	275
MPT-177	7.26	1180	755.20	285
MPT-178	6.26	7330	4691.20	925
MPT-179	6.54	1990	1273.60	330
MPT-180	6.6	787	503.68	260
MPT-181	6.5	2010	1286.40	355
MPT-182	6.56	1690	1081.60	260
MPT-183	6.36	3760	2406.40	730
MPT-184	6.64	2270	1452.80	390
MPT-185	6.36	3650	2336.00	400
MPT-186	6.79	891	570.24	170
MPT-187	6.72	982	628.48	155
MPT-188	6.78	1120	716.80	160
MPT-189	6.86	2610	1670.40	475

TABLE 2. CORRELATION BETWEEN DIFFERENT HYDRO-CHEMICAL PARAMETERS OF GROUNDWATER SAMPLES

	PH	EC(μs/cm)	TDS(mg/l)	TH(mg/l)
PH	1.00			
EC(μs/cm)	-0.06	1.00		
TDS(mg/l)	-0.06	1.00	1.00	
TH(mg/l)	-0.60	0.60	0.60	1.00

thank Dr. R. N. Hota, Mr. Satyanath Mohapatra, Mrs. Susmita Sahu and Mr. Prafulla Kumar Mohapatra for their kind support and cooperation during various stages of this research.

REFERENCES

[1] Birdie G.S. and Birdie J.S., (2010), Water Supply and Sanitary Engineering. Eighth Edition. Dhanpat Rai Publishing Company.
[2] Boyd, C. E. (2000), Water quality. Kluwer Academic Publishers
[3] Todd, D.K., (2001), Ground water hydrology, 2nd edition
[4] Garg, S. K. (2009), Water supply engineering. Khanna Publishers
[5] Das P. P. and Sahoo H. K., (2014). Designing Representative Groundwater Sampling of Mahakalapara Block, Kedrapara District, Odisha: A Comprehensive Hydro-geologic Analysis by GIS Approach. International Journal of Latest Technology in Engineering, Management and Applied Sciences, Vol. III, Issue X, pp – 63-68.
[6] Das P. P. and Sahoo H. K., (2014). A Geospatial Evaluation of SRTM DEM for Representative Groundwater Sampling of Rajnagar Block, Odisha, India. International Journal of Emerging Technology and Advanced Engineering, Vol. 4, Issue 11, pp. 95-103. Sundaray D., Sahoo T., Biswal S., Das P. P. and sahoo. S. (2014), Spatial Interpolation of Iron Contaminationaround the industrial belts of eastern Odisha. International Journal of Latest Technology in Engineering, Management and Applied Sciences, Vol. III, Issue IX, pp – 49-57.
[7] Kar, D.K., and Sahoo, H.K., (2012), Hydrogeochemical Evaluation and groundwater pollution studies around Kalinganagar industrial complex, Jajpur District, Odisha, Environmental Geochemistry, Vol -15, No.1, pp 25-30.
[8] Edzwald J. K. (1999), Water Quality and Treatment: A handbook of Drinking Water. Sixth edition, McGraw-Hill Companies.
[9] U.S. Geological Survey, (1977), National Handbook of Recommended Methods for Water-Data Acquisition. USGS Office of Water Data Coordination, Reston, Virginia.
[10] Wood, W. W., (1976), Guidelines for Collection and Field Analysis of Groundwater Samples for Selected Unstable Constituents. *In:* U.S. Geological Survey Techniques for Water Resources Investigations, Book 1, Chapter D-2.
[11] Scalf, M. R., J. F. McNabb, W. J. Dunlap, R. L. Cosby, and J. Fryberger., (1981), Manual of Ground-Water Quality Sampling Procedures. National Water Well Association, Worthington, Ohio.
[12] Brass, H. J., M. A. Feige, T. Halloran, J. W. Mellow, D. Munch, and R. F. Thomas., (1977), The National Organic Monitoring Survey: Sampling and Analyses for Purgeable Organic Compounds. *In:* Drinking Water Quality Enhancement through Source Protection (R.B. Pojasek, cd.), Ann Arbor Science Publishers, Ann Arbor, Michigan.
[13] Tinlin, R. M., ed. 1976. Monitoring Groundwater Quality: Illustrative Examples. EPA 600/4-76-036, USEPA, Environmental Monitoring and Support Laboratory, Office of Research and Development, Las Vegas, Nevada.
[14] Barcelona M. J., Gibb J. P., Helfrich J. A. and Garske E. E., (1985), Practical Guide for Groundwater Sampling Illinois State Water Survey Champaign, Illinois, ISWS Contract Report 374.
[15] Claassen, H. C., (1982), Guidelines and Techniques for Obtaining Water Samples That Accurately Represent the Water Chemistry of an Aquifer. U.S. Geological Survey, Open-File Report 82-1024, Lake, Colorado, 49 pp.
[16] http://srtm.csi.cgiar.org/SELECTION/inputCoord.asp
[17] Gibb, J. P., R. M. Schuller, and R. A. Griffin., (1981), Procedures for the Collection of Representative Water Quality Data from Monitoring Wells. Cooperative Groundwater Report 7, Illinois state Water Survey and Illinois State Geological Survey, Champaign, Illinois.