Seasonal Variation of Groundwater Hardness in Mahakalapara Block, Kendrapara District, Odisha, India: A Geospatial Approach

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Abstract: **The present research involves hydrochemical analysis of 148 representative groundwater samples across the monsoonal season from quaternary alluvial aquifer system of Mahakalapara Block, coastal Kendrapara district, Odisha. The hydrogeochemical as well as the spatial analysis indicates widespread occurrences of moderately hard to hard groundwater across the entire study area with practically total absence of soft groundwater horizon. The total hardness of the subsurface water displays a distinct increase from premonsoon to postmonsoon season. The southern and western parts of the study area show a greater variation of groundwater hardness than the eastern part. This higher concentration of total hardness of subsurface water is attributed to the greater activity of Calcium and Magnesium divalent cations which seem to be originating from the underground limestone terrain upstream of the western part and from the dissolution of calcrete nodules.**

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

I. INTRODUCTION

Water Hardness is the property of water which restrains the soap leathering [1]. It is mainly the function of bivalent cations including strontium, ferrous iron, calcium, magnesium and manganous manganese [2]. However, from the point of view of predominance of ions, this trait of groundwater is chiefly attributed to the activity of calcium and magnesium cations. These ions form precipitates with soap and scales by reactions with specific anions present in the medium [4]. This is why; total hardness of groundwater is the cause of greater soap consumption and tastelessness of foods from a domestic utility perspective as well as the cause of scaling of boilers when used for industrial purpose [2].

Dissolution of limestone is the chief mechanism for the concentration of calcium and magnesium ions in groundwater [2]. Atmospheric carbon dioxide dissolved in rain water and that coming from soil and root horizon by microbial action leads to greater concentration of carbonic acid which lowers the pH of the medium. This augments the carbonate solution in the soil zone and enhances greater conversion of bicarbonates as well as sulphates, chlorides and silicates [2, 3, 4]. Thus, hard ground waters are prevalent in terrains thick toposoils overlying limestone strata [3].

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 takes into account the monsoonal spatial disposition of hard groundwater across the quaternary alluvial aquifer system of Mahakalapara administrative block of coastal Odisha (Fig. 1). The block covers an area of about 600sqkm with a perimeter of approximately 195km. It lies north of the Mahanadi River which merges with the Bay of Bengal 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 north

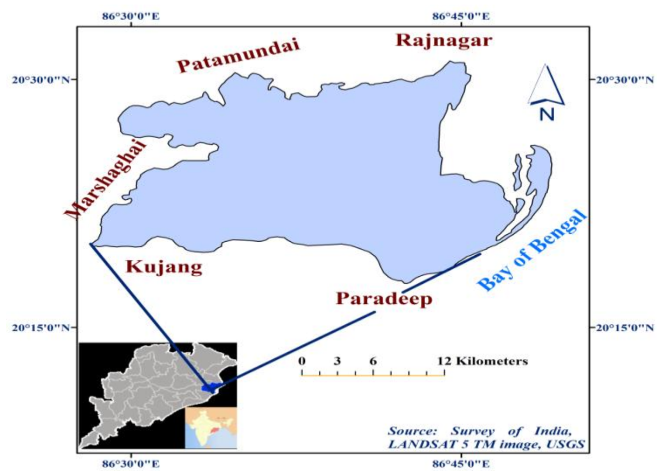

Fig. 1 Physiographic setting of the study area

west and north east 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.

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.

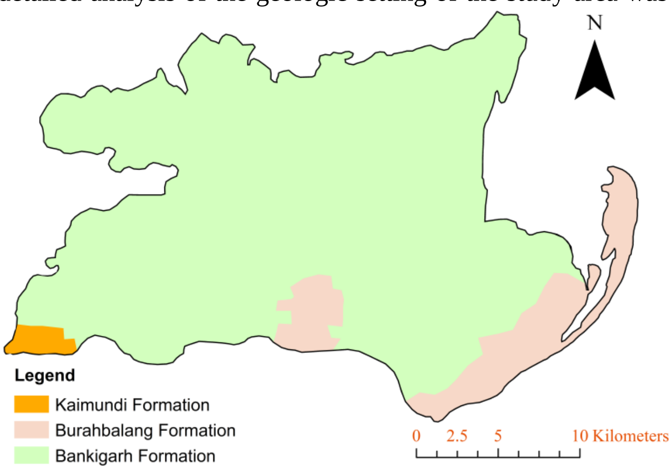

Fig. 2. Geology of the study area

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 elevation map points towards the region being very gently sloped low lying area which is generally the characteristic of coastal plains worldwide (Fig. 3a).

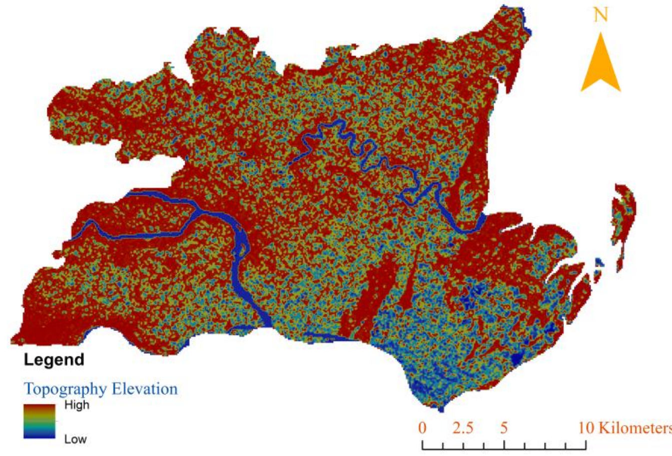

Fig. 3a. Topographic elevation of the study area

The calculated slope of the terrain from elevation values displays the gradient or inclination between two points for the water movement. Two predominant minimum and maximum slopes of 0^0 and 90^0 respectively are observed from the slope map of the terrain (Fig. 3b). 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. 3c). 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. 3d). 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.

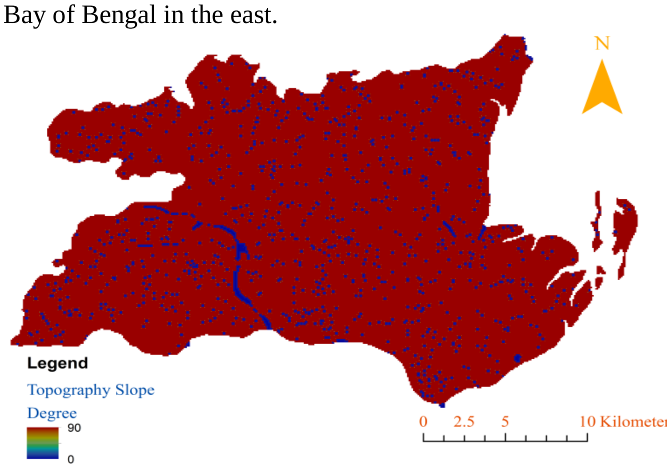

Fig. 3b. Topographic slope of the study area

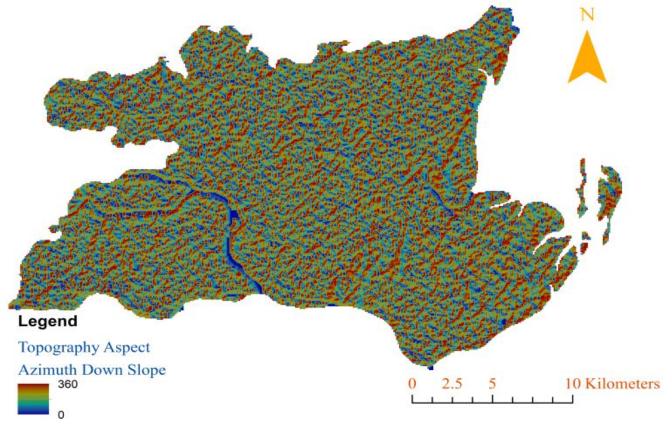

Fig. 3c. Topographic aspect of the study area

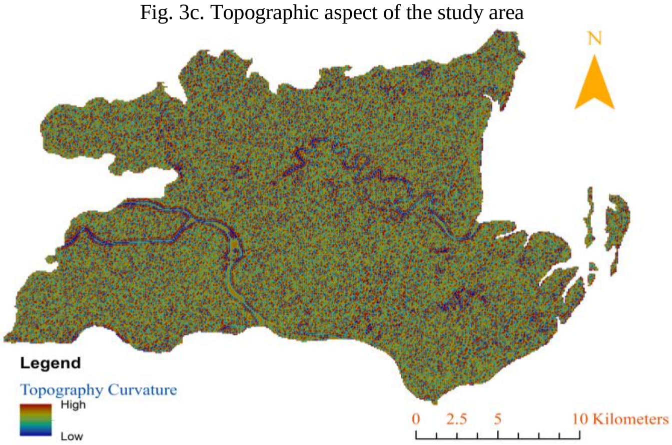

Fig. 3d. Topographic curvature of the study area

V. MATERIALS AND METHODOLOGY

Groundwater sample collection for the present study has been done in accordance with the standard methods of APHA, 1985 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 148 groundwater samples (88 premonsoon and 60 postmonsoon) from Mahakalapara block were collected across the monsoonal season of 2013 (Fig. 4).

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.

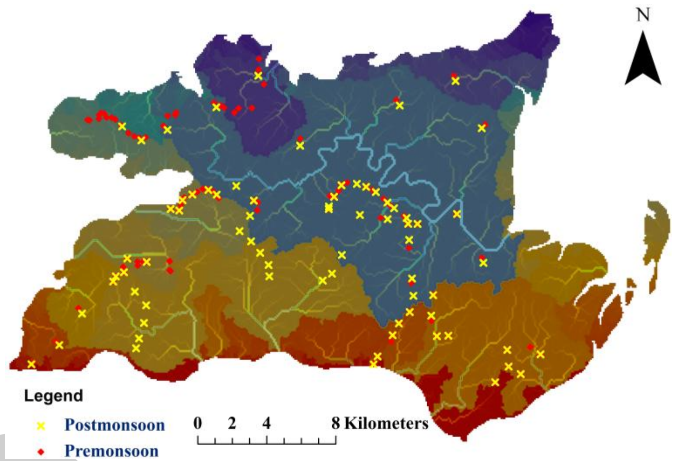

Fig. 4. Groundwater Sampling Locations of Study Area

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 for premonsoon period of Mahakalapara block found out to be between 65mg/l to 925mg/l. Out of the 88 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. However, there is a distinct increase in TH activity

TABLE 1. TOTAL HARDNESS OF GROUNDWATER SAMPLES OF THE STUDY AREA

Sample No.	TH (mg/l)	Sample No.	TH (mg/l)
MPT-101	170	2MPT-1	250
MPT-102	140	2MPT-2	195
MPT-103	120	2MPT-3	145
MPT-104	120	2MPT-4	90
MPT-105	90	2MPT-5	195
MPT-106	135	2MPT-6	155
MPT-107	110	2MPT-7	135
MPT-108	100	2MPT-8	615
MPT-109	140	2MPT-9	1635
MPT-110	110	2MPT-10	750
MPT-111	110	2MPT-11	545
MPT-112	155	2MPT-12	1250
MPT-113	160	2MPT-13	1175
MPT-114	140	2MPT-14	1085
MPT-115	65	2MPT-15	715
MPT-116	260	2MPT-16	750
MPT-117	165	2MPT-17	565
MPT-118	135	2MPT-18	660
MPT-119	170	2MPT-19	1240
MPT-120	150	2MPT-20	515
MPT-121	140	2MPT-21	1600
MPT-122	85	2MPT-22	410
MPT-123	155	2MPT-23	970
MPT-124	170	2MPT-24	320
MPT-125	140	2MPT-25	290
MPT-126	100	2MPT-26	210
MPT-127	160	2MPT-27	230
MPT-128	145	2MPT-28	225
MPT-129	245	2MPT-29	245
MPT-130	530	2MPT-30	300
MPT-131	470	2MPT-31	200
MPT-132	520	2MPT-32	235
MPT-133	365	2MPT-33	190
MPT-134	510	2MPT-34	185
MPT-135	140	2MPT-35	240
MPT-136	280	2MPT-36	290
MPT-137	405	2MPT-37	250
MPT-138	200	2MPT-38	250
MPT-139	270	2MPT-39	280
MPT-140	370	2MPT-40	150
MPT-141	360	2MPT-41	250
MPT-142	410	2MPT-42	570
MPT-143	145	2MPT-43	220
MPT-144	170	2MPT-44	390
MPT-145	110	2MPT-45	185
MPT-146	130	2MPT-46	145
MPT-147	80	2MPT-47	195
MPT-148	140	2MPT-48	315
MPT-149	145	2MPT-49	260
MPT-150	155	2MPT-50	350
MPT-151	105	2MPT-51	250
MPT-152	210	2MPT-52	190
MPT-153	140	2MPT-53	420
MPT-154	180	2MPT-54	620
MPT-155	140	2MPT-55	410
MPT-156	140	2MPT-56	290
MPT-157	240	2MPT-57	580
MPT-158	240	2MPT-58	500
MPT-159	100	2MPT-59	530
MPT-160	120	2MPT-60	160
MPT-161	205		
MPT-162	160		
MPT-163	120		
MPT-164	130		
MPT-165	90		
MPT-166	110		
MPT-167	195		
MPT-168	95		
MPT-169	90		
MPT-170	100		
MPT-171	100		
MPT-172	170		
MPT-173	150		
MPT-174	120		
MPT-175	175		
MPT-176	275		
MPT-177	285		
MPT-178	925		
MPT-179	330		
MPT-180	260		
MPT-181	355		
MPT-182	260		
MPT-183	730		
MPT-184	390		
MPT-185	400		
MPT-186	170		
MPT-187	155		
MPT-188	160		

during post monsoon period with no sample belong to the soft water category. Out of the 60 samples collected during this period 4 samples (6.7%) are moderately hard and 28 samples each (46.7%) belong to hard and very hard category.

To determine the spatial distribution of the different groundwater types, the hardness concentration of the samples were analyzed in a GIS environment. Arc GIS 10 was used to spatially interpolate the TH concentrations of collected groundwater samples. Digital Elevation Models (DEMs) were created for each water type (where the concentration is displayed as elevation) to know the lateral variation of the groundwater hardness (Fig. 5).

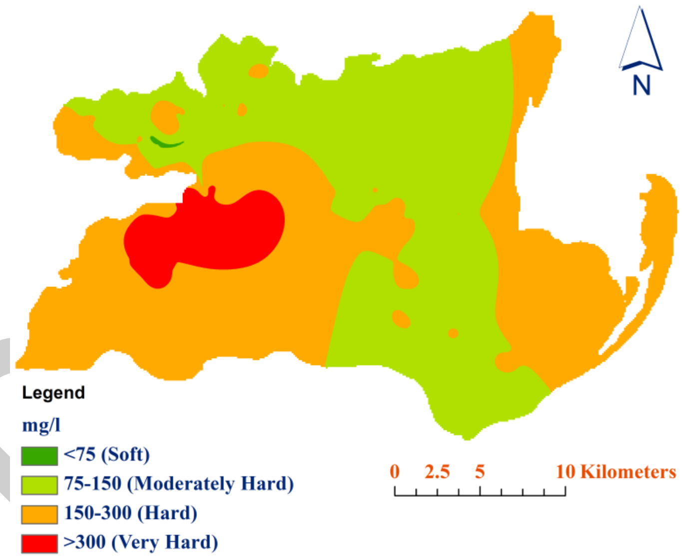

Fig. 5a. Premonsoon disposition of groundwater types in the study Area

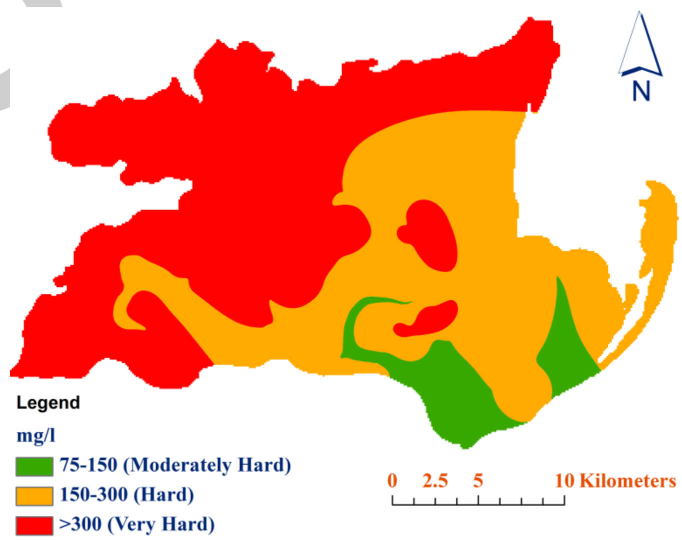

Fig. 5b. Postmonsoon disposition of groundwater types in the study Area

As displayed from the DEM, during premonsoon season 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. But, in line with the hydrochemical analysis, during postmonsoon period majority portion of the study area belong to the hard and very hard category with the western part displaying a prominent excess hardness of subsurface water. Primarily, there seems to be a general increase in the TH of groundwater across the western and southern part of the study region. This greater concentration of TH points towards a higher dissolution reaction postmonsoon. There is reported presence of molluscan lime stone at a depth range from 145m to 292m upstream of the western margin of the study site [18]. Hence, this horizon of limestone terrain as well as the calcareous nodules of the alluvial deposit is the potential contributors of TH within the unsaturated subsurface horizon.

VII. CONCLUSION

The present article explains the lateral disposition of hard groundwater in the coastal Kendrapara district across the monsoonal period of 2013. Analysis of the 148 representative groundwater samples from the area displays a general occurrence of moderately had to hard groundwater regimes across the entire study area. The TH activity also indicates a significant increase during postmonsoon especially along the western and southern part of the region. The increase in TH activity can be attributed to the presence of molluscan limestone upstream along the western part of the study area as well as from the calcareous nodules of the alluvium. 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.

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