Identification of fresh groundwater areas in the Central Godavari Delta region, Andhra Pradesh, India – an integrated approach

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Groundwater is vital and dependable source of water for drinking, agriculture and industries. The Central Godavari Delta of East Godavari district, Andhra Pradesh, is composed of alluvium wherein fresh and saline pockets exist together in close proximity. The present study is to identify freshwater pockets using geomorphological, land-use/land-cover, geophysical and geochemical analysis. Groundwater samples are analysed for electrical conductivity which revealed that about 35% of area is occupied by freshwater pockets in the north western and eastern parts. Vertical electrical sounding data inferred that resistivities less than 5 ohm-m is clay/sand with saline water; 5–10 ohm-m sandy clay and 10–75 ohm-m corresponds to freshwater zone. Freshwater pockets at depths greater than 8 m observed in northern part and shallower depths in southern parts. This integrated study proved successful in identification of fresh groundwater pockets in the delta region.

Keywords: Delta regions, electrical conductivity, fresh groundwater zones, geomorphology, vertical electrical sounding.

EXCESSIVE extraction of fresh groundwater in the delta regions induces stress on fresh groundwater systems due to the intrusion of invasion of saline water on the overlying freshwater aquifers. The Central Godavari Delta in Andhra Pradesh, India, is one such region where freshwater aquifers are being affected by saline water intrusion as a result of anthropogenic activities[1–4]. This is a matter of concern for most of the coastal areas, as it can affect drinking water supply and agriculture. Keeping this in mind, we made an effort to identify pockets of fresh groundwater in the deltaic region through an integrated geomorphological, land-use/land-cover (LULC), geological, hydrogeological, geophysical and groundwater geochemical quality study.

Remote sensing imageries are useful in mapping different hydrogeological units and detection of specific features[5–7]. The surface features relating to geologic, geomorphologic and land cover can be derived by interpretation of the satellite imageries, and thus hydrogeological information can be obtained.

The Central Godavari Delta area is underlain by the Recent to Sub-Recent alluvium comprising sand, gravel, clay and silt. The soils in the area are mainly deltaic alluvial soil and coastal sand. Groundwater occurs under phreatic conditions. It is mostly developed by dug wells, filter points and tube wells. Depth to water level varies from less than 1 to 3 mbgl.

Geophysical surveys using electrical resistivity method play a major role in delineating freshwater and saline-water zones/pockets in the coastal environment[8–10]. Electrical resistivity method is useful to study the nature of the subsurface formations. It is commonly employed in the field of groundwater exploration for its efficacy in detecting the groundwater-bearing zones, identifying the lithology and determining the depth and thickness of detectable geo-electrical layers, apart from water quality. Therefore, vertical electrical sounding (VES) was carried out at 120 locations in the study area. The collected VES data were interpreted to obtain the resistivity and thickness of subsurface freshwater/saline-water zones.

To determine water quality, electrical conductivity (EC) and total dissolved solids (TDS) were measured from water samples collected in the study area, following the standard methods of APHA[11]. By integrating the geomorphological, LULC, geochemical and geophysical data, fresh groundwater zones/pockets have been demarcated.

Study area

The study area forms the southwestern part of the Central Godavari Delta. It comprises five mandals, namely Razolu, Malikipuram, Mamidikuduru, P. Gannavaram and Sakhinetipalli covering an area of 380 sq. km (Figure 1). The area is bound by rivers Vasishta Godavari in the west and Vainateyam Godavari in the east. The important soil groups are deltaic alluvial soil and coastal sand.

Geomorphology

Geomorphologically, the area is occupied by deltaic and coastal plains[12]. The altitude varies from 2 to 15 m amsl.

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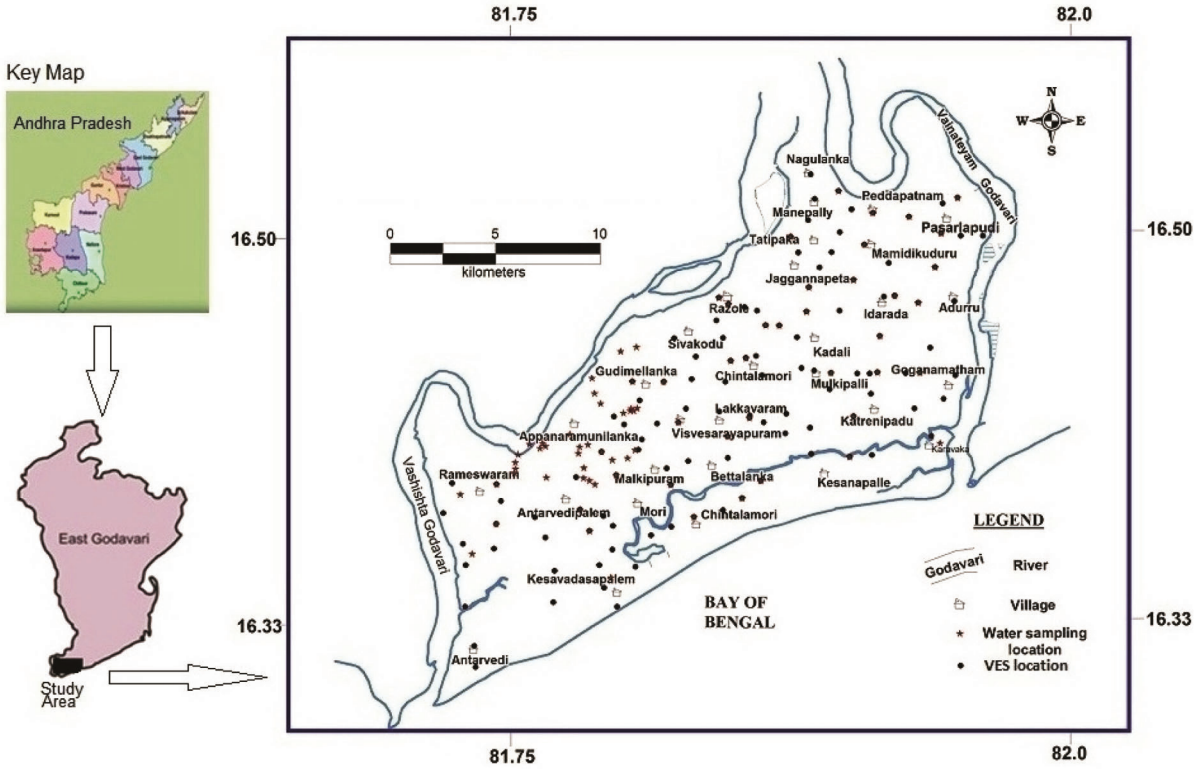

Figure 1. Location map of the Central Godavari Delta region, East Godavari district, Andhra Pradesh, India.

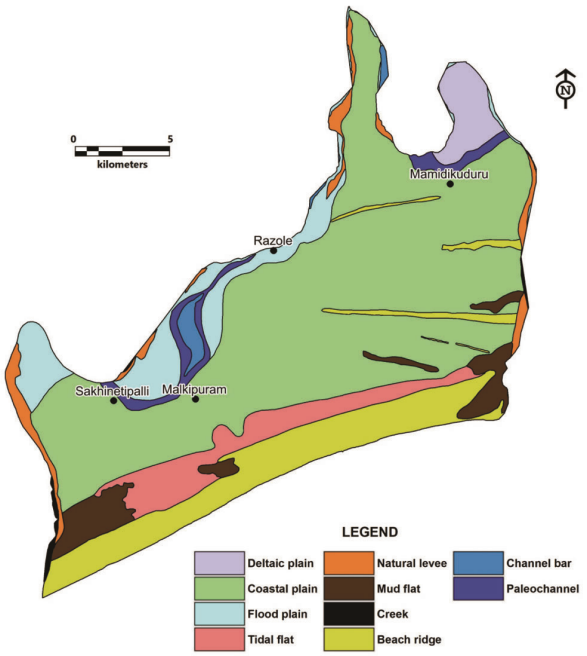

Figure 2. Geomorphology of the Central Godavari Delta region. (Source: Geological Survey of India, Hyderabad.)

The landforms are mainly fluvial. Remote-sensing observations and geomorphological maps prepared by the Geological Survey of India provide a synoptic view of the features in the terrain (Figure 2). Nageswara Rao[13] reported that the Godavari delta plain is divided into two typical landform assemblages: the upper fluvial plain with palaeo distributary courses and natural levees, and the lower beach-ridge plain with beach ridges, mangrove swamps and mudflats. Delta plain, coastal plain, flood plain, beach ridge, tidal flat, mud flat, natural levee, creek, channel bar and palaeochannels are observed in the study area.

Geology

The geological formations occurring in the study area are the Recent to sub-Recent alluvial deposits. In this area, the width of the delta across the coast is 9 km between Rameswaram and Antarvedi, and 15 km between Nagulanka and Kesanapalli. The extent of the delta along the coast is about 25 km. The alluvium comprises intercalations of clay, sand and gravel of variable thickness.

Hydrogeology

Hydrogeological studies show that the area has unconsolidated formations comprising deltaic and river alluvial deposits with windblown sands. Groundwater occurs under phreatic conditions. It is mostly developed by dug wells, filter points and tube wells.

Table 1. Water sampling locations with electrical conductivity (EC) and total dissolved solids (TDS) in the Central Godavari Delta region, East Godavari district, Andhra Pradesh, India

Location/village	Longitude	Latitude	EC (µS/cm)	TDS (mg/l)
Pothumatla	81.8489	16.4499	795	388
Razolu	81.8436	16.477	950	512
IrIsumanda	81.8572	16.4255	1690	846
Sivakodu	81.8189	16.4409	1595	854
Gudimellanka	81.8049	16.441	1412	738
Tekisettipalem	81.7912	16.4109	947	468
Antarvedipalem	81.7815	16.3861	941	471
Sringavarapadu	81.7858	16.377	926	468
Malikipuram	81.7977	16.4009	1938	1025
Kattimanda	81.8221	16.3967	1955	965
Chintalamori	81.8324	16.383	972	484
Padamatipalem	81.8623	16.3985	1800	928
Chintalapalli	81.8557	16.4511	588	294
Mulkapalli	81.8936	16.4447	1005	502
Goganamatam	81.9333	16.4448	1312	654
Ponamanda	81.9144	16.445	1990	999
Kadali	81.8705	16.4649	573	286
Adavipalem	81.8645	16.4651	1625	839
B. Savaram	81.8479	16.4742	1010	502
Vegivaripalem	81.8828	16.4709	1596	825
Geddada	81.8837	16.4814	1580	785
Nagaram	81.9086	16.4996	2854	1496
Mamidikuduru	81.9286	16.5116	1699	869
Pasarlapudi	81.9502	16.5198	1758	845
Kothumeraka	81.9428	16.5046	1956	956
Peddapatnam	81.9124	16.5132	1532	754
Manepalli	81.897	16.5226	957	475
Tatipaka	81.8757	16.503	2958	1470
Aduru	81.9326	16.4747	2469	1270
Komarada	81.9222	16.4777	1826	925
Idarada	81.9037	16.4846	2996	1501
Lakkavaram	81.8475	16.4175	1395	747
Chinnada	81.9155	16.4605	2998	1548
Sakhinetipalli	81.7442	16.3969	696	351
Merakapalem	81.9037	16.4261	496	249
Kesanapalli	81.902	16.4088	881	440
Sivakodu	81.8067	16.4559	1933	971
Sivakodu–Dindiborder	81.7997	16.454	564	281
Sivakodu–Dindi	81.7869	16.4425	775	386
Ramarajulanka	81.788	16.436	476	237
Ramarajulanka	81.7907	16.4317	470	240
Appanaramunilanka	81.785	16.414	1178	591
Appanaramunilanka	81.777	16.4185	1589	796
Ramarajulanka	81.8009	16.4276	3999	2000
Gudimellanka	81.8041	16.4285	765	380
Gudimellanka	81.8043	16.4295	1320	652
Gudimellanka	81.8054	16.4285	880	440
Gudimellanka	81.807	16.4296	1781	896
Malikipuram	81.8061	16.4117	738	357
Malikipuram	81.8028	16.4082	2010	1006
Malikipuram–Tekisettipalem border	81.796	16.4075	741	374
Antarvedipalem	81.783	16.3997	1593	797
Antarvedipalem	81.7857	16.3986	397	198
Chinnapalem	81.7881	16.3969	3170	1586
Tekisettipalem–Sundarivarimerakapalem	81.7832	16.4041	1114	557
Sundarivarimerakapalem	81.7808	16.4103	3999	2000
Sundarivarimerakapalem	81.7813	16.413	2580	1271
Kothalanka	81.766	16.4133	2286	1147
Kothalanka	81.759	16.4143	576	284
Kothalanka	81.7636	16.4125	2247	1121

(*Contd*)

Table 1. (*Contd*)

Location/village	Longitude	Latitude	EC (μS/cm)	TDS (mg/l)
Kothalanka	81.7647	16.4147	3170	1608
Sakhinetipalli	81.7665	16.4	537	266
Sakhinetipalli	81.7539	16.4098	3485	1752
Sakhinetipalli	81.7526	16.4064	3999	2000
Sakhinetipalli	81.7527	16.4036	759	380
Sakhinetipalli	81.7521	16.4019	1253	618
Sakhinetipalli	81.7529	16.413	2652	1326
Antarvedi	81.73333	16.3672	3100	1600
Karvaka	81.9424	16.4147	6830	3701
Rameshwaram	81.7281	16.3926	572	316
Kesavadaspalem	81.7954	16.3571	6030	3457

Figure 3. Land-use/land-cover map of the Central Godavari Delta region.

Water levels in this alluvium are generally close to the land surface, being generally less than 3 mbgl. The drilling depth of tube wells tapping sand, sandy clay and gravel deposits ranges from 3 to 11 mbgl, but is generally within 6 mbgl.

Land use/land cover

The prepared LULC maps and satellite images obtained from the National Remote Sensing Centre, Hyderabad based on satellite data of 2011–12 were studied in conjunction with the Survey of India topographic maps on the same scale. The four main LULC classes such as built-up land (35 sq. km), agricultural land (270 sq. km), wastelands (4 sq. km) and water bodies (70 sq. km) were delineated using standard visual interpretation techniques based on the image characteristics like tone, texture, shape, colour, association, background, etc. The land-use pattern indicates that the area is mostly agrarian. It is criss-crossed by the canal network of the Central Godavari Delta Irrigation System, catering to the irrigation needs during both *kharif* and *rabi* seasons. The crops grown are paddy and other cereals, coconut, banana, sugarcane, pulses, green pepper (chilli), fruits and vegetables. Paddy is the main crop in the area. Figure 3 shows the LULC map of the study area.

Methodology

Remote sensing data were used for the preparation of various thematic maps such as geological, geomorphological, LULC maps, etc. These maps were used for identifying the different hydrogeological units in the study area. Geophysical surveys employing electrical resistivity methods were carried out to identify the characteristic features of subsurface formations. VES surveys were conducted to determine the layer parameters, viz. resistivity and thickness of the subsurface formations. Different lithological layers at depths exhibit different values of resistivity and thickness. Therefore, the alluvium consisting of intercalations of clay, sand, gravel and pebble beds possesses different resistivities. The high or low values of formational resistivity depend on the porosity influenced by grain size, water content, water quality, etc. There exists sufficient resistivity contrast between freshwater-bearing and saline water-bearing formations.

Groundwater samples were collected from 75 locations and analysed for EC and TDS. Table 1 shows the water sampling locations along with EC and TDS values. A total of 120 VES surveys were conducted and the data for each VES interpreted both manually and using the IPI2Win software to obtain the resistivity and thickness of subsurface

Table 2. Lithologs of piezometric wells/shallow wells

Site/village	Longitude	Latitude	Depth drilled (mbgl)	Lithology	Depth range (mbgl)	Thickness (m)
Sakhinetipalli	81.7574	16.404	12	Topsoil sand with clay (40%) – brown, clay–brownish, sand–fine, brown, yellow	0–6	6
				Sand with clay (30%) – brown, clay–brownish, sand–fine, brown, yellow	6–12	6
Antarvedi	81.7348	16.3327	4.5	Fine sand with clay	0–3	3
				Clayey fine sand	3–4.5	1.5
Razole	81.8367	16.475	7.9	Topsoil sand – medium	0–3	3
				Coarse sand	3–7.9	4.9
Katrenipadu	81.9146	16.4344	12	Medium-grained sands	0–3	3
				Fine-grained sand with intercalations of clay	3–9	6
Lakkavaram	81.8338	16.4191	18	Topsoil fine sand	0–3	3
				Coarse-grained sand	3–15	12
				Sandy clay	15–18	3
Malikipuram	81.7978	16.4046	12	Medium-grained sand	0–6	6
				Coarse sand	6–12	6
Mamidikuduru	81.924	16.506	15	Loamy sandy soil with occurrence of pebbles and gravel	0–3	3
				Sandy clay with occurrence of pebbles	3–6	3
				Clayey sand with occurrence of pebbles	6–9	3
				Fine-grained sand with intercalations of clay	9–15	6
Pasarlapudi	81.9616	16.5034	8.7	Topsoil fine sand, clay	0–3	3
				Medium-grained sand with intercalations of clay	3–8.7	5.7

Source: Central Ground Water Board (CGWB), Southern Region (SR), Hyderabad and Andhra Pradesh State Ground Water Department.

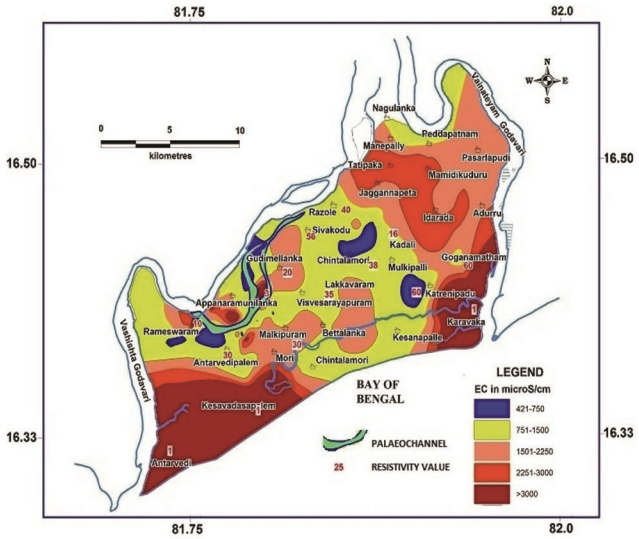

Figure 4. Electrical conductivity-cum-resistivity map of the Central Godavari Delta region.

formations. Resistivity in freshwater zones is more in comparison to that in saline water zones. A map depicting EC and resistivity values was prepared (Figure 4) showing EC distribution in the area. Lithologs of piezometer wells or shallow wells in the area corroborate the freshwater zones that are identified (Table 2). A contour map showing the depth of freshwater zones along with locations of piezometer wells was also prepared (Figure 5).

Results and discussion

The recorded EC values ranged from 397 to 6830 µS/cm in the study area. The EC map revealed that about 35% of the study area is occupied by the freshwater zone. Isolated low EC pockets were also observed in the central part of the study area. In the southeast and southwest corners high EC/TDS patches were observed, indicating saline-water zones where the water is unsuitable for agriculture. The area around Antarvedipalem recorded 397 µS/cm EC indicating freshwater, whereas near Karavaka EC of 6830 µS/cm was recorded indicating saline water.

The interpreted VES results indicate the occurrence of 3–4 layers of subsurface formation. Freshwater zones were delineated at 36 locations with thickness of the aquifer varying from 4 to 26 m characterized by resistivity values from 10 to 75 ohm-m (Table 3). The thickness of the freshwater zone was maximum at Tatipaka and B. Savaram near Razolu and its surroundings. The regions south of Rameswaram, Chintalamori, Chintalapalli, Katrenipadu and Adurru lying between the Vashista Godavari and Vainateyam Godavari rivers are mostly an admixture of fine-grained sand and clay with saline water. Water from these formations is being tapped by shallow open/dug wells for domestic purposes. The depth of the wells tapping sand, sandy clay and gravel deposits ranges from 3 to 11 mbgl, but is generally less than 6 mbgl.

EC-cum-resistivity map also revealed that high EC values were recorded in the southwestern and southeastern

Table 3. Depth of freshwater zones/pockets in the Central Godavari Delta region

Location/village	Longitude	Latitude	Depth/thickness of freshwater zone (mbgl)	Resistivity of freshwater zone (ohm-m)
Pothumatla	81.8489	16.4499	6.6	38
Razolu	81.8436	16.477	12	40
Irisumanda	81.8572	16.4255	4	75
Sivakodu	81.8189	16.4409	3.9	56
Gudimellanka	81.8049	16.441	8	20
Tekisettipalem	81.7912	16.4109	7.5	24
Antarvedipalem	81.7815	16.3861	4	30
Sringavarapadu	81.7858	16.377	5.5	30
Malikipuram	81.7977	16.4009	8	30
Kattimanda	81.8221	16.3967	7.1	23
Chintalamori	81.8324	16.383	4.2	38
Padamatipalem	81.8623	16.3985	5.3	40
Chintalapalli	81.8557	16.4511	9.3	42
Mulkapalli	81.8936	16.4447	8.5	20
Goganamatam	81.9333	16.4448	4.4	60
Ponamanda	81.9144	16.445	12	12
Kadali	81.8705	16.4649	9	16
Adavipalem	81.8645	16.4651	10	25
B. Savaram	81.8479	16.4742	21	30
Vegivaripalem	81.8828	16.4709	5.7	15
Geddada	81.8837	16.4814	5.5	27
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Pasarlapudi	81.9502	16.5198	12.8	20
Kothumeraka	81.9428	16.5046	11	24
Peddapatnam	81.9124	16.5132	10	25
Manepalli	81.897	16.5226	10	15
Tatipaka	81.8757	16.503	26	15–50
Aduru	81.9326	16.4747	8	25
Komarada	81.9222	16.4777	5	22
Idarada	81.9037	16.4846	15	15
Lakkavaram	81.8475	16.4175	8	35
Chinnada	81.9155	16.4605	4.5	14
Sakhinetipalli	81.7442	16.3969	4.5	10
Merakapalem	81.9037	16.4261	4.7	61
Kesanapalli	81.902	16.4088	6.1	55

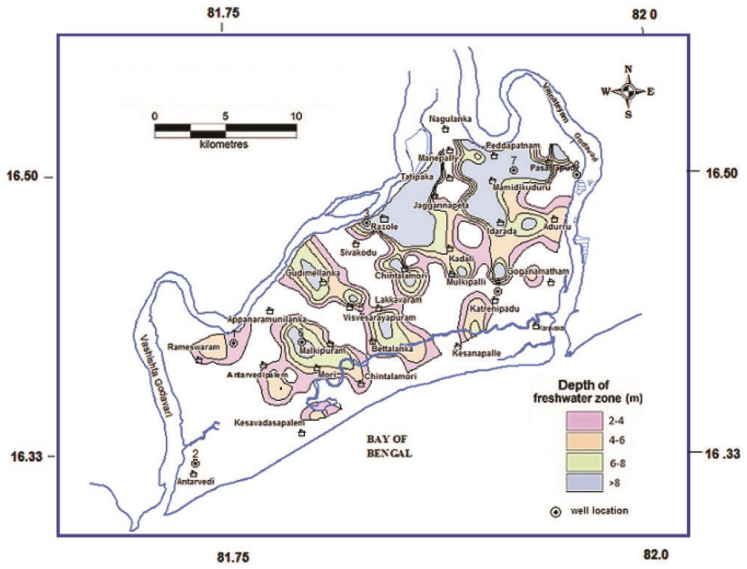

Figure 5. Depth of freshwater zones in the Central Godavari Delta region.

parts of the study area. Areas with moderate EC were observed in the northeastern part and low EC in the northern, central and northwestern parts of the study area. Low EC with high resistivity of 30 ohm-m at Antarvedipalem and high EC with low resistivity of 1 ohm-m at Karavaka were recorded. The recorded low EC values in the northwestern part support the interpretation of the presence of a palaeochannel. This palaeochannel is bounded by zones with high EC values. High EC values are expected in low resistivity areas. In order to determine aquifer parameters like transmissivity, hydraulic conductivity and storativity the Central Ground Water Board conducted pumping tests in the wells constructed in the study area. It was found that the yields of these wells varied from 23 to 90 m^3/h, whereas transmissivity (T) and storativity (S) varied from 250 to 6500 m^2/day and 3.14×10^{-3} to 5.5×10^{-4} respectively.

It is inferred that resistivity less than 5 ohm-m is attributable to clay/sand with saline water. Sandy clay with saline water is characterized by a resistivity range 5–10 ohm-m. In contrast, resistivities are in the range 10–75 ohm-m in areas where sand or sandy clay is found with freshwater.

Conclusion

The present study has been carried out to delineate the potential zones of fresh groundwater in the Central Godavari Delta. It is an integrated study of geomorphology, LULC mapping, geology, hydrogeology, geochemistry and electrical resistivity geophysics.

The EC map revealed that about 35% of the study area is occupied by freshwater. The recorded low EC/TDS values in the northwestern part of the area confirmed the presence of a palaeochannel in the area. The high EC/TDS patches observed in the southeast and southwest corners indicate that the groundwater is saline and unsuitable for agriculture.

At most places, high EC values were recorded with low resistivity values and vice versa. Thus, using VES, EC of the area may be estimated in regions where there are no wells. Since water quality plays an important role in agriculture, estimation of EC through VES plays a vital role in the selection of areas for agricultural production.

The contour map of depth of freshwater zones/pockets showed maximum depth greater than 8 m in northern part, intermediate depths less than 8 m in the middle and minimum/zero in southern part of the study area. It was also observed that the freshwater zones delineated were invariably top layers. Lithologs of shallow wells in the area also confirmed the same. Thus it is inferred that resistivity less than 5 ohm-m is attributable to clay/sand with saline water and sandy clay. Resistivity range 10–75 ohm-m corresponds to sand or sandy clay with freshwater.

Thus, the present study shows the successful application of an integrated approach for the identification of fresh groundwater pockets in the Central Godavari Delta region.

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