Groundwater Resources, Its Mining and Crop Planning In Orissa, India

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Abstract- Groundwater being one of the most valuable resources of earth needs to be utilized properly for the healthy and economic growth of any region. The present study was carried out in Eastern part of India, where it is blessed with plenty of water resources but its utilization is very poor as compared to another part of India, which has been reflected through net cropped area, cropping intensity etc. Orissa, being one of the resource-rich States in India still struggles with low crop production and cropping intensity status. The groundwater development of the state is only 18.31 % out of total replenish able groundwater resources of 2100928 hectare meter (ha-m). Groundwater recharge being one of the most important components in the hydrologic cycle, it has to be estimated for any particular area before planning for any interventions. The natural groundwater recharge was only 22.31 % to 24.87% of the annual rainfall received in 30 districts of Orissa. The highest amount of recharge of 39.75cm was from Balasore and the lowest recharge of 26.47cm was in Rayagarh district of Orissa. However the estimation method was very crude as it is based on only rainfall of the particular area. More detail study on recharge aspects can be done under basin studies in the different region. Assessment of groundwater resources and planning for efficient use of groundwater in the agriculture sector has been planned based on crop water demand of each district of Orissa. The groundwater earmarked for irrigation is 1678038 ha-m. Considering crop water demand of 1030.5 mm (as per FAO 56 Penman-Monteith) during dry month period (November to May) the expected area to be irrigated is 1628372 ha. Since rice is dominated crop of this region even during rabi and summer season, another high-value cash crop through groundwater use is economically viable. For exploiting groundwater during rabi season, it is essential to know under-utilized and over utilized blocks of Orissa as the coefficient of variation was as high 133 % in Jagatsingpur district to as low as 1.43 % in Deogarh district. The groundwater development was a maximum of 77.61 % in Baliapal block in Balasore district. This block is dominated with summer paddy (January to April/May), which needs more frequent irrigation water for harvesting optimum yield.

***Index Terms*-** Evapotranspiration, Groundwater resources, Groundwater recharge, Sustainable water use

I. Introduction

India is the largest ground water user with estimated usages of around 250 cubic kilometer per year and occupied more than 25 % of the groundwater use at global level. Groundwater is an important source of irrigation and caters to more than 60% of the irrigated area and 85 % of the drinking water in India(Anonymous 2010). The contribution of groundwater irrigation to achieve self-sufficiency in food grains production in past three decades is phenomenal. In the coming years the groundwater utilization is likely to increase manifold for expansion of irrigated agriculture and to achieve national targets for food production. Although the groundwater is annual replenish able resource, its availability is non-uniform in space and time. Hence, precise estimation and utilization in agriculture sector is a prerequisite for planning its development. Eastern part of India is blessed with plenty of water resources. The groundwater development in the eastern region is very low as compared to national average (37 %).

Orissa State lies within latitude 17^0 48' N - 22^0 34'N and longitude 84^0 24'E - 87^0 29'E. Out of total geographical area of 155700 sq km, 118800 sq km area is suitable for groundwater exploitation (Anonymous, 2003). It has an annually replenish able net groundwater resource of 2100928 ha-m(hectare meter), out of which 122126 ha-m is committed to domestic and industrial requirements for coming 25 years. The present demand for irrigation use is estimated to be 300901 ha-m. The average stage of groundwater development is only 18.31% and there exists a further scope for creation of an additional irrigation potential of 1266002 hectare at an estimated cropping intensity of 200 %. (Pati,2007). The area covered by hard rock and alluvium is 86444-sq.km and 32356-sq km, respectively. The major portion (about 85%) of the state covered by hard rock area are normally compact and rendered groundwater bearing only when it is fractured and weathered. Some of the districts of the western part of Orissa are experiencing recurring drought conditions due to the erratic distribution of rainfall. With these natural conditions, mono-cropping is practiced in most of the districts with a cropping intensity of hardly 158%, leaving huge cultivated area fallow during the dry season.

It is predominantly an agriculture state drained by major river Mahanadi, Brahmani, Baitrani , Subarnarekha , Rushikulya Vamasdhara , Nagavalli, Indravati and Machhakund with drainage area ranges from 3746 sq km to 65579 sq km and annual water flows from 637 million cubic meters to 51061 million cubic meters (Anonymous, 1988).The coastal tract of Orissa forms a narrow linear belt extending from the border of West Bengal to the Chilka Lake lying to the South West of Puri town and includes the newly formed districts of Balasore, Bhadrak, Jajpur, Kendrapara, Cuttack, Jagatsinghpur, Puri, and Khurda.

The major source of irrigation in almost all parts of Orissa is by canal system. Increasing problems of water logging in irrigation commands are mainly due to an imbalance in different water balance components in a particular area. It is caused both by natural and manmade (cultivation of paddy during the wet and dry season) conditions. Among natural causes, heavy rainfall is one of the most important factors, which is responsible for increasing the water level in the farmers' field. In deltaic command areas like the State Orissa, water logging is a serious problem, which needs to be monitored properly. From a recent study conducted by Orissa Remote Sensing Application Centre, Bhubaneswar (Anonymous, 1993), it appears that about 0.84 lakh ha area is affected by water logging situation in Orissa. Reappraisal hydro-geological surveys in Mahanadi Delta Command Stage-I and II indicate an area of 4680 sq. km under water-logging conditions i.e. having the depth to water table within 2 m from land surface in the post monsoon period. The area shrinks to 484 sq. km in pre- monsoon period (Das, 1994).

Rainfall is the principal source of recharge to the groundwater body. Besides rainfall, canals, streams, ponds, springs etc also plays an important role in improving groundwater level. The annual groundwater recharge is the sum total of monsoon recharge and non-monsoon recharge. Geographical area, infiltration index and specific yields are the governing parameters to determine the availability of groundwater in an aquifer (Karanth, 1990). Orissa falls under sub-humid coastal ecosystem in eighteen and nineteen agro-ecological regions of India and receives an average (1901-1950) annual rainfall of 1492.8 mm in 73.4 rainy days. Out of this, 1300.9 mm (87.1%) is received during June-October, 101.6 mm (6.8%) during November to March and rest of 90.3mm (6.1%) during April and May. The reference evapotranspiration for the nineteen-agro ecological region of India varies from 800-1900 mm. The annual rainfall ranged as low as <150 mm in a cold arid climate of Himalaya ranges to as high as 1600- 2000 mm in hot per-humid region of Andaman and Nicobar Island (Sehgal et. al., 1992). Keeping this in view, the present study was carried out to assess the availability of groundwater for irrigation use so that cropped area could be increased especially during the dry season. Actual cropped area, water requirement of different crops has been considered for the analysis. This has been presented through few case studies conducted in different areas of Orissa state.

II. MATERIAL AND METHOD

The assessment of block-wise groundwater potential has been carried out up to 31.3.2004 by the department of Groundwater Survey and Investigation, Government of Orissa and Central Groundwater Board, Bhubaneswar as per the Groundwater Estimation Committee Norm 1997, Ministry of Water Resources, Govt. of India. Based on groundwater development, the statistical measures like standard deviation, the coefficient of variation were estimated to assess the variability within districts. The districts of Orissa have been divided into semi-consolidated, consolidated and unconsolidated geological formations(Photo plate no.1).

Estimation of groundwater recharge:

Groundwater recharge is a key component in a hydrologic system. Major factors that affect the ground water recharge are climatic, hydrological and geomorphologic like topography, soil and vegetation. Common methods for estimating ground-water recharge are empirical formulae (rainfall analysis), water budget, water table fluctuation, soil moisture balance technique. These methods produce estimates over various time and space scales and encompass a wide range of complexity and expense. Different methods were followed on the estimation of groundwater recharge (Simmers 1988,1997; Sharma,1989; Lerner et. al. 1990; and Scanlon et. al. 2002). But it is extremely difficult to assess the accuracy of any method. For this reason, it is highly beneficial to apply multiple methods of estimation and hope for some consistency in results even though consistency, by itself, should not be taken as an indication of accuracy (Healy and Cook, 2002). Based on the studies undertaken by different scientists and organizations regarding the correlation of ground water level fluctuation and rainfall, some empirical relationships have been developed for computation of natural recharge to groundwater from rainfall. A different approach to estimating natural groundwater recharge in India was documented by (Kumar, 1977).

In the present study, annual rainfall data of 15 years (1993 to 2004) was collected. As per Chaturvedi(1973), ground-water recharge was calculated (when rainfall exceeds 40cm) as,

$R = 1.35(P-14)^{0.5}$ --(1)

Where, R is net recharge due to precipitation during the year in inches and P is annual precipitation.

As per Amritsar formula, $R = 2.5(P-0.6)^{0.5}$ -- (2)

Where, recharge (R) & precipitation (P) both measured in inches.

As per Krishna Rao (1970) ground water recharge in limited climatologically homogeneous areas can be defined as

$R = K(P-X)$ --(3)

Relation used for different parts of country for areas with P above 2000 mm is

$R = 0.35(P-600)$ ---(4)

Where, R & P are expressed in millimeters.

Estimation of crop water requirements:

The district- wise monthly evaporative demand was calculated as per the globally accepted method of FAO 56 - Penman-Monteith (Allen et al, 1998). All the aerodynamic and radiation terms and the additional physical factors that are surface resistance (70 s m^{-1}, crop height 0.12 m, and albedo 0.23) was considered for calculating monthly ETo rate. The following Penman-Monteith equation was used for computing ETo.

Where,

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T+273} U_2 (e_s - e_a)}{\Delta + \gamma (1 + 0.34 U_2)}$$

ET_0 = reference evapotranspiration, mm/day
Δ = slope of vapor pressure curve (kPa /^{0} C)
R_n = net radiation (MJ/m^2/day)
G = soil heat flux density (MJ/m^2/day)
γ = psychrometric constant (0.0671 kPa /^{0} C)
T = mean daily temperature at 2 m height

U_2 = the wind speed at 2 m height (m/s)
e_s = saturation vapour pressure (kPa)
e_a = actual vapour pressure(kPa)
e_s-e_a = saturation vapour pressure deficit (kPa).

The monthly reference ETo was calculated by using software of "**World Water and Climate Atlas" of International Water Management Institute, Sri Lanka.** Then considering the major crop-growing season, where sufficient water is not available during dry season, the monthly reference ETo of the month November to May was summed up and total crop ET demand was computed.

General Crop Scenario of Orissa:

Paddy is dominated crop of this state. Out of 89.60-lakh ha gross cropped area, 44.5 lakh ha (50 % area) is in paddy, 22% in pulses, 9% in oilseeds, 7 % in vegetables, 5% in other cereals and rest area is in sugarcane, fibre crops, spices. In case of paddy crop, 3.14 lakh ha area is in rabi /summer season. Since this crop is being grown under semi-aquatic condition with canal water, shallow tube well and deep tube well water, requires highest amount of irrigation water for its growth. So based on exiting cropping pattern, suggestion is made to improve cropping pattern by high value crops with groundwater use.

Studies on Ground water Fluctuation: In distributory no. 5 of Patmundai canal (Mahanadi Delta II), 61 observation wells in irrigation command of 751 ha area was selected to monitor ground water level throughout the year at 15 days interval to assess the impact of canal irrigation and rainfall. It was monitored during 2007-08 to 2009-10 but the details of this study has been shown season -wise for better explanation.

III. RESULTS AND DISCUSSION

Block wise Groundwater Development and overall groundwater draft :

The gross annual draft with respect to total assessed groundwater resources has been worked out as stage of groundwater development for all districts of the state. Table 1 showed that an alluvium area has more groundwater development status than hard rock areas. Among that Balasore districts has highest groundwater development status (47.46%) followed by Bhadrak (42.25%) and Jajpur (35.83%). Lowest development was recorded in Malkangiri, which may be due to economic status of the region. So overall there is a vast scope to use groundwater for irrigation in order to increase irrigated area and the crop production in this state. Survey reports showed that 52 % farmers of this state are having land holding less than one hectare, which prevails them to afford bore wells and there is no such cohesiveness to form society or water users association within farmers groups (State Economy Report, 1999). Hence maximum number of dug wells is being used for irrigation purposes.

The block wise groundwater development reveals that there is lot of variation on groundwater utilization as it is expressed by coefficient of variation. Highest variation within a block was recorded in Jagatsinghpur district. This district is located in coastal belt of Orissa and due to bad quality groundwater (saline water) within block; it has not been exploited uniformly. In other district of Orissa, the variation is not substantial (Table 2). With respect to district wise groundwater development, it is maximum in Balasore. The irrigated area in this district is 125350 ha during rainy season and 91100 ha during winter season (2006-07). Total shallow tube well in this district is 2180 in number out of total of 6866 in the state. So the major chunk of shallow tube well is developed in this district alone. These types of shallow tube well are quite feasible in coastal district of Orissa. In Jagatsingpur and Jajpur districts shallow tube wells are available in good numbers (1238 and 1399 in numbers, respectively) and thus irrigated area is reasonably more as compared to other districts of state.

Proposed area to be irrigated from groundwater resources:

Based on available groundwater resources for irrigation and water required to grow the crops during dry months period, the district-wise cropped area has been considered and water requirement has been estimated with ET of the crop. The amount of water required for special needs, percolation, conveyance loss etc has not been taken into account. Navalawala (1991) has reported that about 71 % of the applied water from the reservoir is lost in different segments (canal, distributory, minor and field channel) and only 29 % is effectively reached to the farmers' field where the final user is benefited. This loss component varies from location to location. Table 2 reveals that if the allocated groundwater for irrigation is fully extracted then about 16.28 lakh ha area can be brought under irrigation over the present irrigated area of 11.54 lakh ha during the winter season. If this proposed area is fully irrigated then total irrigated area would be around 27.82 lakh ha in a dry month period. The statistical data showed that the farmers are keeping their land fallow after harvest of rainy season crops or they grow low water requirement crops like black gram and green gram on residual soil moisture and harvest very low crop yield (0.43 t/ha black gram and 0.41 t/ha green gram). Under such circumstances, exploitation of groundwater gives a lot of benefits to the farmers for which development of groundwater structures are most essential.

Estimation of groundwater recharge:

For estimating natural recharge by rainfall data, three methods were used i.e. Chaturvedi formula, Amritsar formula and Krishna Rao formula. The results (Table 3) showed that the amount of rainfall recharged into groundwater was as low as 26.47cm in Rayagarh district to as high as 39.75cm in Balasore district. The percentage groundwater recharge was 22.31 % to 24.87% of the annual rainfall received in 30 districts of Orissa. Among three methods used for estimating rainfall recharge Amritsar formula showed very high value as compared to other two methods. This amount of rainwater recharge can be used very effectively during the winter season as most of the winter crop requires water during late crop growth period (February and March). During initial stages, the crop extracts residual soil moisture for its growth.

Estimation of evaporative demand and supply scenario of Orissa:

The computed reference evapotranspiration (annual evaporative demand) of Orissa is 1658 mm, whereas total annual water supply through rainfall is 1492.8 mm. Thus there was annual water deficit of only 9.94 % (165 mm). Though the water availability through rainfall alone was sufficient to fulfill crop water demand for two crop seasons, but due to its uneven distribution, the farmers of this state have been growing only one crop in most of the districts. As far as the season- wise crop water demand and supply are concerned, on an average of all thirty districts, there was a surplus of 106.55 % during wet season and deficit of 83.7 % and 76.9 % during winter (Nov. to March) and dry season(April to May), respectively. During winter and summer (dry season), the amount of rainfall was only 101.6 mm in 6.2 rainy days and 90.3 mm in 7.0 rainy days, respectively, which is not enough to fulfill water needs of the crop for more than fifteen days period (Table 4). So it is important to make utilization of excess rainwater of wet season effectively. This excess water can be recharged into the ground by various recharged techniques wherever it is feasible. This recharged groundwater can be further exploited during dry season i.e winter and summer season and the cropping intensity and irrigated area can be increased as there is a substantial deficit of water exists during winter and summer season.

Crop water requirement of rice:

The annual water available through rainfall is 23.36 million ha-m and the evaporative demand is 25.68 million ha-m. Thus there was a deficit of 2.32 million ha-m in the state (Table-5). The state is having sufficient amount of water through the rain but the cropping intensity is hardly 158 % with paddy as dominated crop. Out of total cropped area of 8.64 million ha, 4.5 million ha (52%) area is under paddy alone. Paddy consumes more water than other cereals, pulse and oilseed crops. So it may be feasible to take up pulse and oilseed crop instead of paddy in upland and medium land condition during the wet season, where the total cultivated area of upland and medium land is 0.53 and 0.48 million hectares respectively. Similarly during the winter season, the vegetable cash crops can be taken up for more economic return. During summer season, farmers of Sambalpur and Bargarh districts have been growing paddy and consumed substantial amount of available water from Hirakud Irrigation project, CCA of 157018 hectares, (Anonymous, 1998).

Geological formation and aquifer characteristics of Orissa:

The particular feature of the aquifer plays a major role in the further exploitation of groundwater. Based on aquifer nature and water bearing zone and water yield potential, the construction of open wells, shallow tube well, deep tube wells are decided in the particular districts or in the block level. Accordingly planning on a large scale is made at the state level for executing groundwater structures. During 1999-2000, a number of shallow tubes well were 17297(Anonymous 2006-07). This has been increased to 61751 in 2006-2007. Similarly number of bore well in above year was 1668 and now it is increased to 6768. These numbers can be increased further if state government provides an incentive or increase networking of electricity in rural areas as farmers can not afford to use diesel pump or kerosene operated pump on a large scale. In agriculture sector power consumption is very low. During 1990-91 power consumption in the agriculture sector was 229 million units which was only 4.7 % of the total power consumption of 4901 million units in the state. This consumption pattern has further declined and during 2006-07, it was 130 million units (1.4%) of the total consumption of 9288 million units. So to exploit groundwater during rabi and summer season for irrigation purpose it is highly essential to divert more energy towards agriculture sector as most of the electrical pumps are not functioning properly due to the low power supply. The district-wise and state wise features of the aquifer represent the water status is given in Table 6.

Few Case Studies on Use of Groundwater to Increase the Cropping Intensity:

Crop performance and economic return with tube well and open well irrigation water (Patmundai canal):

In distributory 5 of Patmundai canal (Mahanadi Delta I), shallow tube well and two open wells was made in tail reach of the distributory and irrigations were provided to different crops in tube well command area in which 18 farmers were involved. This project was funded by the Ministry of Water Resources, Govt. of India (INCID letter no. 21/102/2006-R & D/ 2337-48, dated: Oct. 2006) and it was implemented in the command area of the above distributory on participatory mode. In open well command area the farmers covered 2.4 ha area during 2007-08 and cultivated different paddy varieties during the rainy season and obtained the net return of 152.64 to 307.8 US$/ha (1 US dollar =Rs 40.50 as in August 2008) with four different short and medium duration varieties grown with tube well irrigation water. The paddy yield was 3.54 t/ha to 4.87 t/ha. After that two farmers had grown different vegetable crops namely onion, tomato, chilli, potato, brinjal and lady's finger. They obtained the net return of US$ 429.26/ha from lady's finger, US$ 1041.68/ha from tomato, US$ 848.77/ha from potato, US$ 1003.1 /ha from onion, US$ 3998.0/ha from brinjal, US$ 460.44/ha from the chilli. But those farmers who had taken green gram on residual soil moisture after harvest of paddy, they obtained only US$ 62.37/ha to US$ 143.2/ha. The yield of a green gram was only 281 kg/ha to 450 kg/ha, which was quite low. If two irrigations i.e. one before sowing and another at 25-30 days after sowing is provided then farmer may harvest 1000-1200 kg/ha green gram yield but due to several social/ economical constraints they are not irrigating their field crops though the ground water level is at shallow depth.

In open well command of 0.21 ha area, the farmers had taken 3 crops (Jute in May to August, paddy on August 20- November end and onion there after till March) and harvested very good crop yield and obtained very high net return. The net return in three hundred percent cropping system was US$ 1667.5/ha, (US$ 334.5 from jute, US$ 221.7 from paddy and US$ 1111.3/ha from onion).it is thus inferred that , exploitation of ground water in coastal region is highly feasible as the depletion of ground water is replenished quickly during rainy season as it is observed through ground water fluctuation data(Table 7). In rural areas, the electricity network is available at the village level . If the farmers want to take up at the farm site where the irrigation is to be given for raising field crops then the farmers have to bear the cost for stretching the power supply from village to the farm, which is next to impossible to the individual farmers. With the results, the consumption of power to the farm level is drastically reduced though the power supply is regular throughout the day. The statistical figures of power consumption of Orissa state reveals that during 1999-2000, 3.87 % of the total consumption (5603 MU) was used in irrigation and agriculture sector . During 2003-2004 power consumption in this sector has drastically reduced and found only 1.84 % of the total consumption.So it requires huge investment to develop infrastructure by the government to create power network at village level and farm sites where irrigation is to be given to the field crops . With regards to cost of irrigation through electric motor pump and diesel pump, certainly the irrigation cost through diesel pump is higher than electric pump but the farmers have been compelled to use diesel pump due to inadequate networking of the power at farm site and hence in most of the area, the ground water exploitation is low.

Groundwater Fluctuation of Command Area:

Year 2007-2008:

The groundwater fluctuations were monitored during canal on and off period in 61 observation wells which were scattered in 12 villages to assess the influence of groundwater level and recharge of groundwater in selected distributory. The canal water was released on 12. 07. 2007 and continued up to 21. 11. 2007 for *kharif* season crop and 12. 01. 2008 to 31. 01. 2008 for *rabi* season crops. The results revealed that one week before releasing canal water, the water table in head reach area ranged from 2.43 m to 4.40 m. The corresponding value in middle reach was 3.18m to 4.26m. But in tail reach villages the groundwater table was at shallow depth and ranged between 2.3m to 3.32m. After harvest of *kharif* season paddy crop, canal water was released on 12.1.2008 and continued only up to 31. 01.2008 for *rabi* crops. But during this *rabi* season, canal water was available only for 19 days due to receipt of good amount of rainfall.

During canal off period, groundwater table depth went to deeper depth rapidly till on-set of monsoon i.e. up to13. 01. 2008 to 04. 04. 2008 as good amount of rainfall influenced rise in groundwater table depth in most of the observation wells, either located in head reach and middle reach of the command area. In tail reach villages the groundwater table was at shallow depth due to influence of drainage water in Gobri Nala from Kendrapara distributory as well as distributory 5 of Patmundai canal. The detail statistical analysis of the groundwater table fluctuations is given in Table 5, which clearly indicates abundant source of groundwater at shallow depth even in tail reach of irrigation command.

The groundwater fluctuation data was further categorized into pre-monsoon (March-May), monsoon (June-October) & post monsoon (November to February). It has been observed that the groundwater table during pre-monsoon & post monsoon period was at shallow depth. In pre-monsoon (March-May) period, canal water was available in January end which has helped to raise groundwater level & hence it was 1.89 m. In post monsoon period it was also 1.98m. But in monsoon period it was 3.18m. This high value was found in June & July months where rain water recharge was found to be less. But in August onward groundwater level was rising at faster rate. The coefficient of variation is maximum of 48.40% during pre monsoon period (March – May) followed by post monsoon (June to October), in which the coefficient of variation was 34.59%. In these periods, the farmers have utilized groundwater for irrigating *rabi*/summer crops wherever the bore wells & open wells were available during post monsoon period. The coefficient of variation was very low i.e. 26.71% (Table 7). This could be due to recharge of groundwater by rainfall and anal water supply

Year 2008-2009

The data on groundwater fluctuations showed that the groundwater table during the month of May was at deeper depth because of dry month and no canal water supply was available. Thereafter due to receipt of rainfall and release of canal water, the groundwater table remained at shallow depth. During the post monsoon season also the groundwater table depth was at shallow depth because of release of canal water in the month of January 2009 and continued up to February 2009.

Year 2009-2010

The groundwater fluctuation data of whole command area was analyzed and categorized as pre-monsoon (March-May2009), monsoon (June- October2009), and post monsoon (November 2009-February 2010). The data on groundwater fluctuations showed that the groundwater table during the month of May was at deeper depth, thereafter due to receipt of rainfall and release of canal water, the groundwater table remained at shallow depth. During the post monsoon season also the groundwater table depth was at shallow depth because of release of canal water in the month of January 2010 and continued up to February 2010. The detail statistical analysis of the groundwater table fluctuations is given in Table 7, which clearly indicates abundant source of groundwater at shallow depth even in tail reach of .irrigation command.

Rainwater Harvesting and groundwater use during Rabi/Summer:

The rain water harvesting project was initiated by Indian Institute of water management, Bhubaneswar in 2005 in Keonjhar district of Orissa state and completed in February 2006 with 4 ponds (cap. 3000-4000m^3). In this project, the series of wells (8 wells) were constructed along with drainage nala and the stored water in wells was used during rabi season for vegetable crops. These structures were developed in the watershed area of 68 ha, in which the beneficiaries of three villages were involved. Due to which the cropping intensity has been increased at the substantial level. The results on water use, economic return of different vegetable crop is given here.

After harvest of rainy season paddy in October- November 2007, farmers took vegetable crops during winter 2007-2008 and summer 2008 (January – February to the onset of monsoon). The results on water efficiency, crop yield, the net return of the vegetable crops grown with recharged rain water of open well and water flow from drainage-nala reveals that 10 farmers had grown the bhindi crop and obtained, on an average of US$ 344.6/ha net return. The irrigation water applied by them was 36.5cm (26.4cm to 65.3cm) and the crop yield was 2.6 t/ha (range 1.22 to 6.0 t/ha). The irrigation water efficiency was 69.1 kg/ha-cm (ranges 36.1 to 133.0 kg/ha-cm). In case of bitter gourd where nine farmers had grown with open well water, they obtained net return of US$ 390.4/ha (US$ 129.1 to US$ 718.7/ha); irrigation water use was 35.3cm (25.2cm to 51.6cm), crop yield was 1.85t/ha (range1.0 t/ha to 2.84 t/ha) and the irrigation water use efficiency was 54.7 kg/ha-cm (30.9 to 96.5 kg/ha-cm). Thirteen farmers took ridge gourd after harvest of rainy season paddy crop and harvested on an average of 4.75 t/ha fruit yield (range 1.87-9.37 t/ha). They got a net return of US$ 650.0/ha (US$ 288.9 to US $ 1180/ha). During crop growth period they applied 38.64cm irrigation water (24.3cm to 65.3cm) and the water use efficiency was 123.2kg/ha-cm (79.1-219.1 kg/ha-cm). Brinjal is also highly dominated crop of this area and farmers invariably grow brinjal crop with irrigation water. In the watershed area, eight farmers took brinjal crop and harvested 6.33t/ha (2.5t/ha to 22.0 t/ha). They got the net return of US $ 857.1/ha (US$ 126.2/ha to US$ 2824.7/ha). They applied irrigation water to the extent of 38.8cm (25.3cm to 46.9cm). The water use efficiency was 157.3 kg/ha-cm (57.0-541.1kg/ha-cm).

Farmers took tomato crop and harvested fruit yield of 8.77 t/ha (3.25t/ha-32.5 t/ha). The net return was US$ 577.8/ha (US$ 216.0 to US$ 2407.4/ha), the irrigation water efficiency was 240.3 kg/ha-cm. Potato is also dominated crop and being a short duration requires very less water. About 10 farmers took potato crop and harvested 4.80t/ha potato yield. They got a net return of US$ 374.6/ha. The irrigation water applied was 30.4cm and irrigation water use efficiency was 163.7 kg/ha-cm. Onion crop was taken by 15 farmers and got onion yield on an average of 3.09t/ha, the water applied was 31.3cm and water use efficiency was 58.0kg/ha-cm. The net profit from onion cultivation was US$ 330.2/ha. The chilli, garlic, cucumber, cauliflower were also taken by the farmers from open well water. In case of chilli crop, the farmers got net profit of US$ 428.3/ha, from garlic US $ 487.3/ha, from cucumber US$ 533.8/ha and from cauliflower US$ 471.6/ha. During winter the sunflower, spinach, pumpkin, cowpea were also grown with open well water. So with the help of harvested rainwater, the cropping intensity was increased at greater extent. Earlier they were not taking winter vegetable crops due to lack of water but with development of open well, the farmers are growing winter crops and earning their livelihood.

IV. CONCLUSION

- There is substantial variation on groundwater use within block due to several socio-economic as well as geological constraints. In coastal district of Orissa, the groundwater development is comparatively more than non-coastal district.
- In all district of Orissa, the evaporative demand (ETo) is greater than water supply through rain except in district of Mayurbhanj, the water availability through rainfall exceeded total water demand by 109.62 mm. Under such excess water supply condition, conservation of rainwater through various water recharge techniques is necessary. When season wise crop evaporative demand and availability of rainwater as supply is concerned, in most of the districts, the availability of water during wet season (June to October) through rainwater is quite high than the crop evaporative demand.
- This excess water can be recharged in to the groundwater by various techniques wherever the groundwater recharge technique is feasible. This recharged water can be reutilized for crop growth during dry season that is rabi and summer and the cropping intensity and irrigated area can be increased as there is substantial deficit of water exists in these seasons.
- In some of the coastal districts of Orissa, groundwater is available at shallow depth however the exploitation is very low as irrigation through canal particularly in Mahanadi delta I and II has good irrigation net work and hence the shallow dug wells are in limited numbers.
- In Western Orissa, canal irrigation source is available from Hirakud project (CCA 1,57,018 ha) and hence the shallow dug wells are limited numbers in Sambalpur and Bargarh. Maximum numbers of shallow dug wells were found in Ganjam district followed by Angul. Similarly maximum numbers of medium deep tube wells were dominated in Balasore district and hence the groundwater development is quite high as compared to rest of the districts of Orissa.
- In existing rice based cropping system, high value and more remunerative crops are introduced, and then the income of the farmers can be further enhanced.
- In Orissa, irrigation through canal network is limited due to a limited number of major, medium and minor irrigation projects. Further development of new irrigation projects also needs a lot of investments and more time to complete the project work. Under such condition, it is essential to make an assessment of water resources available from all sources to make efficient utilization of available water in crop production.

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Table-1 Statistical analysis of block wise groundwater development (%) of Orissa.

District	No. of block	Mean	Maximum	Minimum	Standard deviation (%)	CV %
Anugul	8	17.49	8.48	32.81	9.44	53.98
Balasore	12	47.46	22.38	77.61	16.38	34.52
Baragarh	12	14.32	9.39	25.17	4.51	31.50
Bhadrak	7	42.25	23.84	73.82	17.00	40.23
Bolangir	14	16.77	12.75	25.46	3.56	21.26
Boudh	3	16.69	12.56	30.68	10.44	62.54
Cuttack	14	18.64	6.79	46.25	11.50	61.71
Deogarh	3	11.43	9.87	12.72	1.43	12.47
Dhenkanal	8	15.94	6.75	29.6	8.55	53.61
Gajapati	7	18.24	6.14	37.08	11.24	61.61
Ganjam	22	25.47	13.14	51.48	10.38	40.76
Jagatsinghpur	8	14.57	5.16	59.64	19.40	133.18
Jajpur	10	35.83	14.04	59.86	15.98	44.59
Jharsuguda	5	26.45	13.97	39.78	10.25	38.76
Kalahandi	13	14.25	5.83	29.17	6.71	47.07
Kandhamal	12	10.64	5.04	19.77	4.96	46.66
Kendrapara	9	31.88	10.51	64.99	26.52	83.17
Keonjhar	13	13.29	3.05	40.96	11.34	85.32

Khurda	10	13.82	4.39	26.56	7.73	55.96
Koraput	14	6.65	3.88	18.41	4.00	72.31
Malkangiri	7	6.02	3.08	13.7	3.00	60.41
Mayurbhanja	26	21.71	7.21	50.98	11.04	50.83
Nupada	5	15.89	8.99	31.45	9.59	60.34
Nayagarh	8	15.52	5.16	48.93	15.12	97.41
Nawarangapur	10	11.17	6.91	16.68	3.06	27.39
Puri	11	10.51	3.72	16.88	4.02	38.29
Rayagada	11	12.74	6.93	33.15	8.11	63.67
Sambalpur	9	10.39	7.29	17.29	3.68	35.37
Sonepur	6	11.23	7.29	18.29	4.42	39.34
Sundergarh	17	15.37	3.73	38.07	11.62	75.58

Table-2 Groundwater resources available in Orissa as on 31.3.2004 and area to be irrigated

District	Groundwater resources assessed (ham)	Balance resources for irrigation use (ham)	Annual ET demand (m)	ET demand during Nov.-May (m)	Expected area to be irrigated (ha)
Angul	86673	70317	1.703	1.073	65515
Balasore	99882	50198	1.607	0.993	50557
Bargarh	56076	47059	1.733	1.082	43489
Bhadrak	51210	27087	1.609	0.995	27231
Bolangir	71348	58044	1.736	1.090	53276
Boudh	36974	30265	1.729	1.082	27974
Cuttack	105366	83984	1.723	1.083	77540
Deogarh	21224	18579	1.687	1.056	17600
Dhenkanal	65192	53673	1.712	1.079	49766
Gajpati	27756	22475	1.659	0.991	22679
Ganjam	113800	81858	1.607	0.961	85180

Jagatsingpur	139697	118335	1.645	1.014	116701
Jajpur	58999	35604	1.646	1.089	32754
Jharsuguda	17266	12684	1.689	1.045	12142
Kalahandi	89520	72948	1.682	1.061	68818
Kendrapala	32147	21451	1.611	1.012	21207
Keonjhar	132284	113353	1.561	0.981	11556
Khurda	90184	73914	1.666	1.028	71873
Koraput	82135	75222	1.544	0.972	77373
Malkangiri	32880	30685	1.710	1.059	28985
Mayurbhanj	152066	117334	1.538	0.942	124533
Nawapara	36730	30500	1.722	1.084	28136
Nawarangpur	48101	41030	1.647	1.016	40393
Nayagarh	51430	42930	1.606	1.016	42266
Puri	88351	78106	1.608	0.958	81550
Phulbani	62397	55068	1.589	1.010	54501
Rayagarh	62883	53864	1.650	1.027	52428
Samabalpur	66337	58950	1.706	1.063	55455
Sonepur	29943	25920	1.733	1.085	23885
Sundargarh	92077	76601	1.675	1.041	73619
State Total	2100928	1678038	1.658	1.031	1628372

Table 3. Estimation of natural recharge based on annual rainfall of Orissa

District	Mean rainfall, cm	Recharge, cm (Chaturvedi's formula)	Recharge, cm (Amritsar formula)	Recharge, cm (Krishna Rao formula)	Average recharge, cm	Mean recharge as % of rainfall
Anugul	132.10	20.62	45.27	25.24	30.37	22.99
Balasore	178.19	25.07	52.81	41.37	39.75	22.31
Baragarh	123.14	19.61	43.66	22.10	28.46	23.11

Bhadrak	150.18	22.35	48.25	31.56	34.05	22.68
Bolangir	112.81	19.14	43.26	21.75	28.05	24.87
Boudh	124.83	19.63	43.79	22.74	28.72	23.01
Cuttack	143.45	21.69	47.14	29.21	32.68	22.78
Deogarh	132.21	20.62	45.25	25.27	30.38	22.98
Dhenkanal	139.67	21.35	46.62	27.88	31.95	22.88
Gajapati	127.16	19.92	44.44	23.51	29.29	23.03
Ganjam	123.24	19.50	43.76	22.13	28.46	23.10
Jagatsinghpur	145.40	21.72	47.34	29.89	32.98	22.69
Jajpur	154.98	22.78	49.01	33.24	35.01	22.59
Jharsuguda	130.21	20.13	44.71	24.57	29.80	22.89
Kalahandi	154.72	22.73	48.83	33.15	34.90	22.56
Kandhamal	158.85	23.27	49.73	34.60	35.87	22.58
Kendrapara	145.87	21.71	47.35	30.06	33.04	22.65
Keonjhar	125.14	20.02	44.19	22.80	29.00	23.18
Khurda	144.48	21.73	47.31	29.57	32.87	22.75
Koraput	136.93	21.28	46.33	26.92	31.51	23.01
Malkangiri	145.21	22.00	47.53	29.82	33.12	22.81
Mayurbhanja	143.03	21.89	47.33	29.06	32.76	22.90
Nawarangapur	142.52	21.81	47.20	28.88	32.63	22.90
Nayagarh	131.31	20.36	45.10	24.96	30.14	22.95
Nupada	100.56	16.83	39.39	14.20	23.47	23.34
Puri	143.02	21.44	46.98	29.06	32.49	22.72
Rayagada	113.65	18.56	42.07	18.78	26.47	23.29
Sambalpur	135.95	20.93	45.84	26.58	31.12	22.89
Sonepur	135.26	20.76	45.63	26.34	30.91	22.85
Sundergarh	131.78	20.69	45.28	25.12	30.36	23.04

Rainfall and recharge were based on the data (1993-2004)

Table-4. Season- wise water demand (ETo) and supply through rainfall

District	ETo , mm			Rainfall, mm			Deficit/surplus, mm		
	June to Oct.	Nov. to March	April to May	June to Oct.	Nov. to March	April to May	June to Oct.	Nov. to March	April to May
Angul[s*]	630.0	619.0	454.3	1238.1	94.7	88.3	608.1	-524.3	-366.0
Balasore[u]	614.4	592.1	400.8	1278.7	131.5	158.1	664.3	-460.6	-242.7
Bargarh[c]	651.1	592.3	489.8	1405.1	73.4	48.5	754.1	-518.9	-441.3
Bhadrak[u]	614.4	593.9	400.8	1278.7	131.5	158.1	664.3	-462.4	-242.7
Bolangir[c]	646.6	611.0	478.5	1330.1	65.6	47.8	683.5	-545.4	-430.7
Boudh[c]	647.6	612.9	469.0	1391.2	104.4	101.5	743.6	-508.5	-367.5
Cuttack[u]	639.7	654.8	428.3	1266.5	114.1	120.7	626.8	-540.7	-307.6
Deogarh[c]	631.7	587.2	468.4	1405.1	73.4	48.5	773.4	-513.8	-419.9
Dhenkanal[c]	633.1	639.5	439.0	1238.1	94.7	88.3	605.0	-544.8	-350.7
Gajpati[c*]	668.1	618.6	372.5	1042.6	133.9	119.1	374.5	-484.7	-253.4
Ganjam[c]	646.1	603.9	357.2	1042.6	133.9	119.1	396.5	-470.0	-238.1
Jagatsingpur[u]	630.7	626.8	387.4	1266.5	114.1	120.7	635.8	-512.7	-266.7
Jajpur[u*]	626.9	614.2	404.5	1266.5	114.1	120.7	639.6	-500.1	-283.8
Jharsuguda[c*]	644.1	568.8	475.8	1405.1	73.4	48.5	761.0	-495.4	-427.3
Kalahandi[c]	621.1	611.9	448.6	1259.2	61.6	57.4	638.2	-550.3	-391.2
Kendrapara[u]	599.4	588.7	422.8	1266.5	114.1	120.7	667.1	-474.6	-302.1
Keonjhar[c]	580.5	562.7	418.2	1282.3	120	132.2	701.8	-442.7	-286.0
Khurda[s*]	637.9	634.6	393.8	1229.8	125.3	94	591.9	-509.3	-299.8
Koraput[c]	571.44	581.43	390.77	1315.8	77.6	128.4	744.4	-503.8	-262.4
Malkangiri[c]	651.01	631.76	426.89	1315.8	77.6	128.4	664.8	-554.2	-298.5
Mayurbhanj[c*]	596.01	545.39	396.8	1383	121.2	144	787.0	-424.2	-252.8
Nawapara[c]	638.09	598.71	485.29	1259.2	61.6	57.4	621.1	-537.1	-427.9
Nawarangpur[c]	590.63	596.9	418.84	1315.8	77.6	128.4	725.2	-519.3	-290.4
Nayagarh[c]	631.16	618.48	397.21	1229.8	125.3	94	598.6	-493.2	-303.2

Phulbani[c]	597.5	585.7	424.7	1391.2	104.4	101.5	793.7	-481.3	-323.2
Puri[u]	631.52	608.24	349.53	1229.8	125.3	94	598.3	-482.9	-255.5
Rayagarh[c]	622.54	617.08	410.31	1315.8	77.6	128.4	693.3	-539.5	-281.9
Sambalpur[c]	643.15	584.81	478.21	1405.1	73.4	48.5	762.0	-511.4	-429.7
Sonepur[c]	647.84	610.05	475.14	1330.1	65.6	47.8	682.3	-544.5	-427.3
Sundergarh[c*]	634.05	616.43	424.08	1488.2	97.3	61.2	854.2	-519.1	-362.9

S-Semi-consolidated, U-Unconsolidated, C-Consolidated geological formation, * more than 80% of the area is covered under particular geological formation

Table 5: District-wise crop evaporative demand of rice in Orissa

District	Geographical area (000, ha)	Annual rain water, ham	Annual ETo, ham	ETo demand in wet season, ham	ETo demand in winter season, ham	ETo demands in autumn season, ham	ETo demand in summer season, ham	Total ETo demand in rice, ham
Angul	635	902399	1081608	68040	53234	12125	3492	136891
Balasore	371	581839	598694	136397	130486	2171	15911	290361
Bargarh	583	890241	1010432	156903	152475	30415	45219	385012
Bhadrak	279	437556	448933	105062	100965	545	11919	218491
Bolangir	655	945493	1137126	125966	70343	43391	2443	242143
Boudh	344	549402	594941	44683	35548	6126	1438	87794
Cuttack	392	588510	675322	78039	87741	10410	7361	183550
Deogarh	278	424506	469039	29056	17028	9088	3040	58212
Dhenkanal	460	653706	787341	77875	65225	11842	3098	158040
Gajpati	381	493624	632159	26057	23506	600	346	50510
Ganjam	870	1127172	1398281	173954	160640	1761	187	336543
Jagatsingpur	174	261226	286202	63697	59544	3455	5670	132366
Jajpur	289	433876	475576	93411	78618	11792	4958	190470
Jharsuguda	220	335940	345176	34781	16494	13279	827	64976
Kalahandi	820	1130124	1378879	140978	122178	42905	2723	308785
Kendrapara	257	385834	422418	105484	76082	4085	7834	195002

Keonjhar	830	1273635	1264903	124805	83230	30273	1972	240280
Khurda	289	418790	488786	75384	72047	661	4298	152391
Koraput	838	1275268	1293570	61144	58644	15944	2733	138465
Malkangiri	612	931342	1046312	55336	61846	6362	25	123569
Mayurbhanj	1042	1717424	1602804	199663	147255	33392	3429	384967
Nawapara	341	469966	587233	66999	53756	21380	483	142618
Nawarangpur	519	8789814	854715	94043	86753	23919	233	204948
Nayagarh	396	573844	669755	73310	68044	2646	1987	145987
Puri	760	1213796	1222034	35254	24600	8942	392	69187
Phulbani	306	443425	486323	89044	84545	1175	16463	191228
Rayagarh	759	1155046	1252297	36730	31471	4470	1123	73794
Samabalpur	671	1024617	1144840	84896	51463	23575	16742	176676
Sonepur	229	330562	396864	61545	46364	10493	19193	137595
Sundargarh	971	1598946	1625998	147734	78903	59180	2401	288217

Table 6:Aquifer characteristics of different districts of Orissa

District	Aquifer characteristics		
	No. of exploratory bore well	Transmissivity (m^2/day)	Storavity (x 10^{-4})
Angul		2.84-34.75	4.50
Balasore	36	60-1160	1.30-21.00 (4)
Bhadrak	43	6-1786	0.45-72.40 (17)
Cuttack	38	10.54-12873	0.02-49.0 (16)
Jagatsingpur	11	388-9360	0.03-2.50 (5)
Jajpur	24	55.88-4650	1.50-133.0 (14)
Kalahandi	Not available	Not available	4.10-4.90 (2)
Kendrapala	17	110.0-7445	1.60-19.80 (9)
Keonjhar	Not available	Not available	1.55-5.39 (8)
Khurda	3	75.26-258.0	Not available

Koraput	Not available	Not available	2.21-8.00 (3)
Nayagarh	Not available	Not available	1.10-8.00
Puri	20	34.10-14688.0	0.03-145.0 (10)
Samabalpur	Not available	Not available	1.06-7.73 (3)

Figures in brackets are no. of observations, Source: Groundwater Resources of Orissa, Directorate of Groundwater Survey and Investigation, Orissa, 2001

Table 7. Statistical analysis of water table depth (in meter)

Parameters	**2007-08**			**2008-09**			**2009-2010**		
	Mar-May (Pre-monsoon) m	June-Oct (Monsoon), m	Nov-Feb (Post monsoon),m	Mar-May (Pre-monsoon), m	June-Oct (Monsoon)	Nov-Feb (Post monsoon)	Mar-May (Pre-monsoon)	June-Oct (Monsoon)	Nov-Feb (Post monsoon)
Mean	3.18	1.89	1.98	2.04	1.91	3.23	2.73	2.10	2.08
Maximum	5.98	5.01	3.4	5.53	4.60	5.93	5.02	3.58	5.26
Minimum	0.73	0.25	0.66	0.69	0.28	0.76	0.61	0.69	0.26
SD (m)	1.10	0.92	0.53	0.55	0.86	1.12	0.95	0.61	1.02
CV %	34.59	9.2	26.71	27.0	45.02	34.7	34.8	29.1	49.0

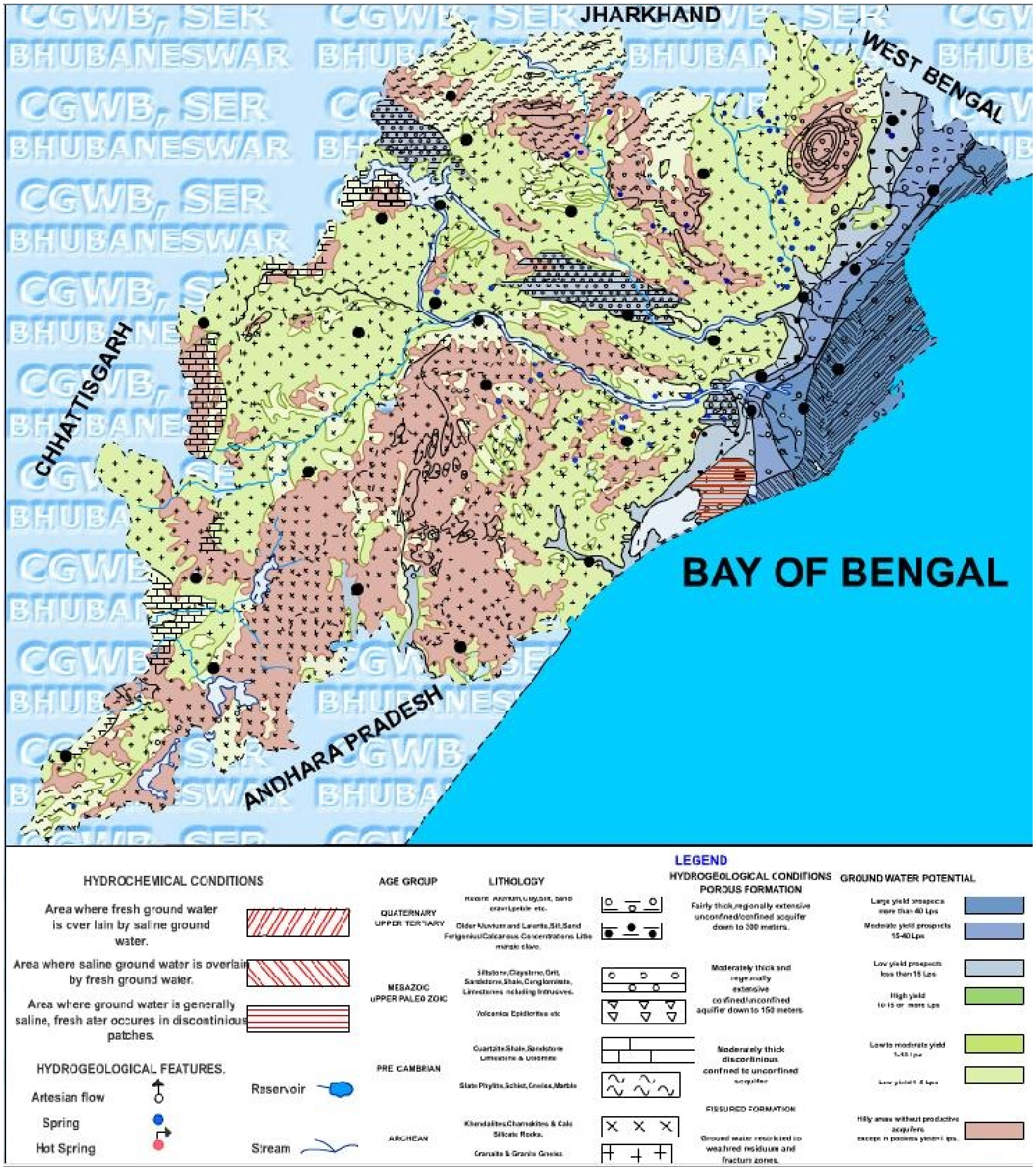

Photo Plate no. 1: Hydrogeology of Orissa

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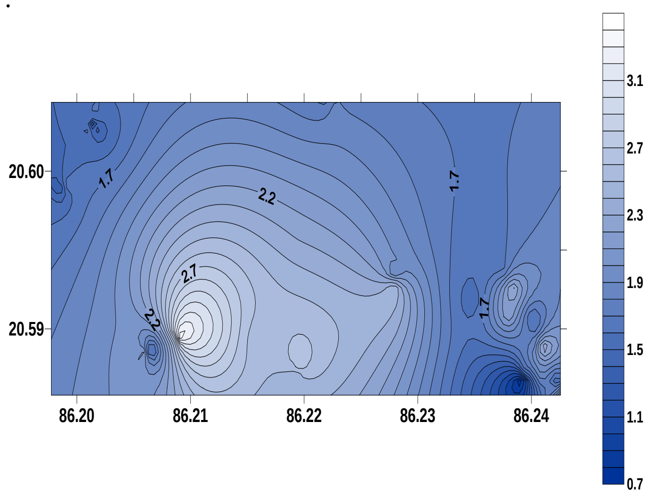
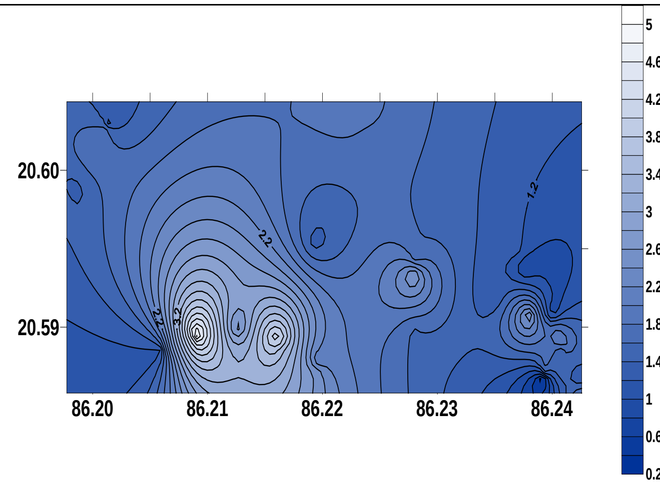
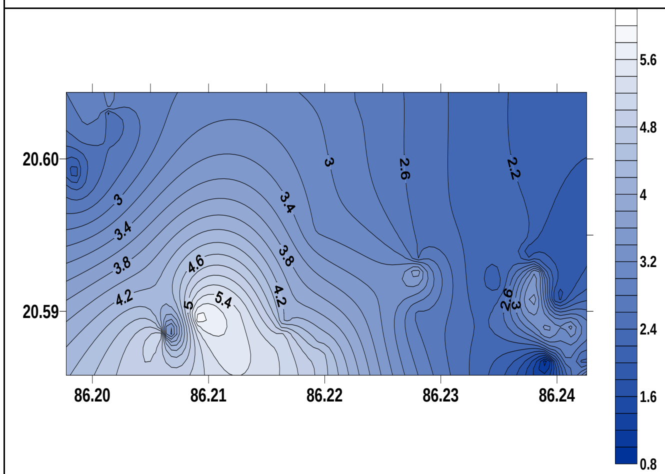
Fig.1 Ground water Fluctuations in canal command during study period



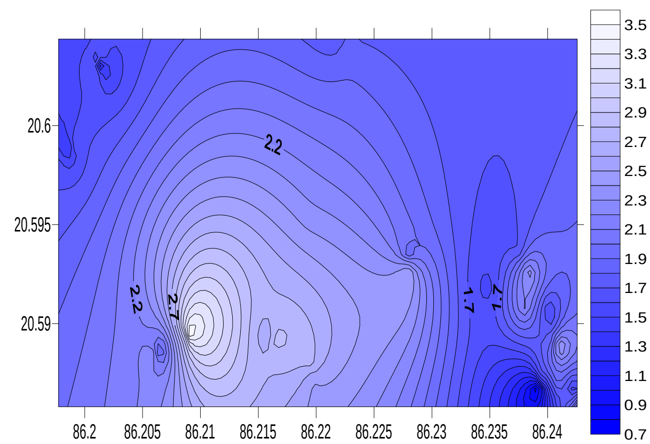
Contour map of groundwater table depth during monsoon periods (June 2007 -October 2007)



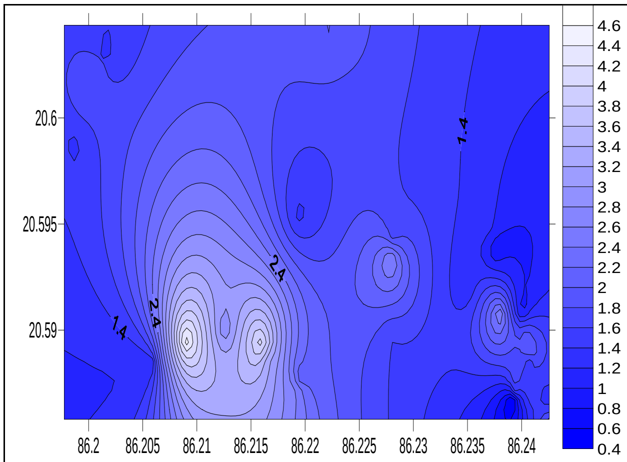
Contour map of groundwater table depth during post monsoon periods (November 2007 -Feb 2008)



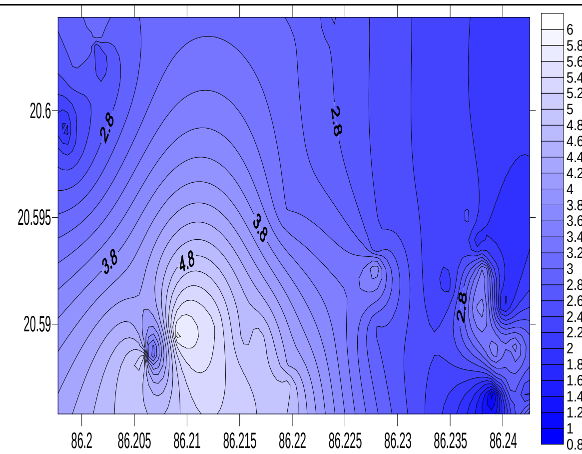
Contour map of March 2008 -May2008



Contour map of June 2008- Oct. 2008



Contour map for November 2008 –February 2009



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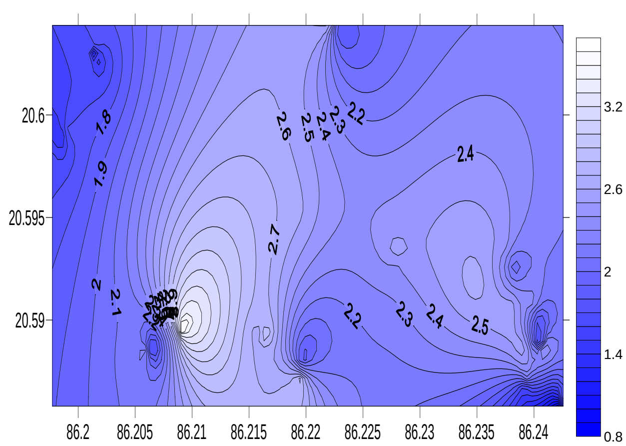
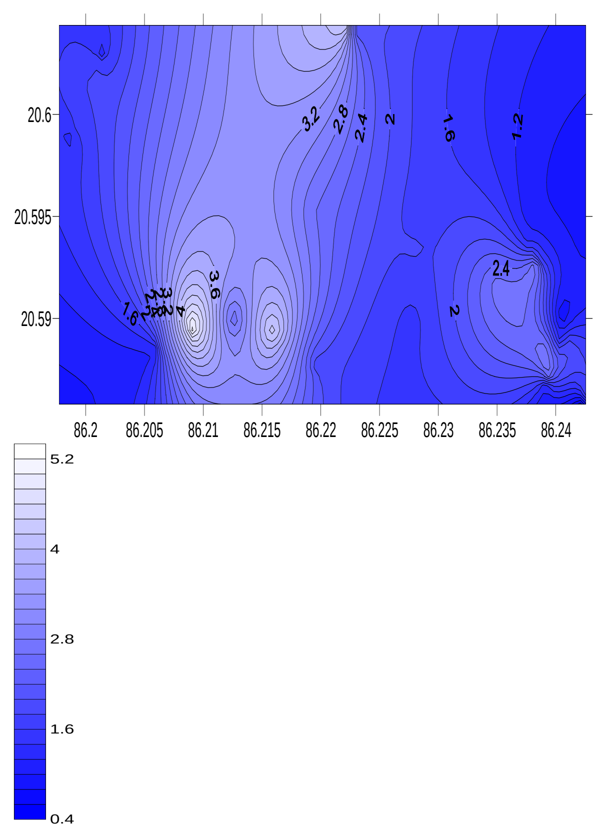


Water table fluctuation during June 2009-October 2009



Water table fluctuation during November 2009-February 2010