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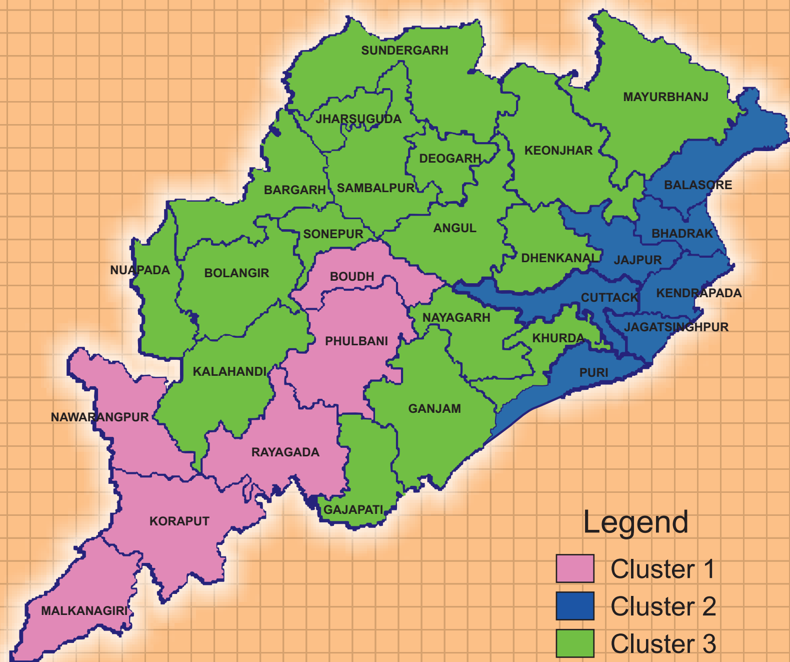

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1. INTRODUCTION

Groundwater plays a vital role in agricultural development by enhancing the productivity of other inputs and by providing assured irrigation to the farmers. Because of the land augmenting character and assured irrigation water, groundwater development has always been the priority area by the policy makers. In agriculture sector, importance of groundwater has been increasing manifold due to factors inter alia technological breakthrough in extraction technology, soft loans for installation of groundwater extraction mechanism and remunerative relative price ratio in favour of water intensive, commercial and horticultural crops. Groundwater accounts for more than 55 per cent of India's net irrigated area; however only 31 per cent of known groundwater potential has been developed hitherto. Thus, at aggregate level, there is ample opportunity to develop groundwater. However, there is a wide inter as well as intra regional disparity as far as groundwater development is concerned. In some parts of the country, such as Punjab, Western Uttar Pradesh, Gujarat, Tamil Nadu, etc., cases of groundwater over-exploitation have been noticed (GOI, 2001). On the other hand, in the Eastern part of the country, level of groundwater development is very low. The major concern at the national level nowadays is the sustainable agricultural growth through equitable development of groundwater. This requires region specific policy interventions in various aspects of groundwater development for irrigation purposes.

As groundwater extraction primarily depends on mechanical devices, reliable, economically accessible and efficient source of energy assumes a significant importance. In the Odisha state of eastern India, utilization of groundwater and energy use for the irrigation purpose is far less than other regions of similar hydro-geological and climatic situations. Further, though Odisha was one of the first few states to take initiatives in energizing the irrigation system, it lags behind in implementation due to slow pace of electrification. Alternatively, diesel/kerosene operated groundwater extraction pumps are becoming popular among the farmers. Use of these alternative sources of energy for groundwater extraction depends on various socio-economic (metered/flat rate tariff of electricity, subsidy, reliable supply, etc) and political factors. Thus, a study on different aspects of groundwater development and energy use pattern for irrigation in Odisha will provide a feedback to the policy makers to formulate suitable energy policy for the holistic and sustainable development of this precious natural resource. This, in turn, will emerge as a precursor for the development of agriculture as a whole.

2. BACKGROUND

Literature related to groundwater development and energy use in irrigation in Odisha as well as different parts of the country has been reviewed. The studies revealed the increasing dominance of groundwater as a source of irrigation in the nation. Of the addition to net irrigated area of about 29.75 million hectares between 1970 and 2007, groundwater accounted for 24.02 million hectares (80%). On an average, between 2000-01 and 2006-07, about 61% of the irrigation in the country was sourced from groundwater. The share of surface water has declined from 60% in the 1950s to 30% in the first decade of the 21st century. The most dramatic change in the groundwater scenario in India is that the share of tube wells in irrigated areas rose from a mere 1% in 1960-61 to 40% in 2006-07. By now, tube wells have become the largest single source of irrigation water in India (Shankar, et al. 2011). Though only 58 per cent of the total groundwater has been developed in the country, there existed wide spatial variation in its development. In many parts of the country such as Punjab, Haryana, Rajasthan, Tamil Nadu, groundwater development is more than sustainable level (CGWB, 2010). A more recent assessment by NASA showed that during 2002 to 2008, three states (Punjab, Haryana and Rajasthan) together lost about 109 km^3 of water due to decline in water table to the extent of 0.33 metres per annum (Rodell et al 2009). On the other hand, in Eastern region, groundwater development is less than 50 per cent. In Odisha, groundwater development is only 26 per cent (Govt. of Odisha, 2010) with wide variability across different districts due to geological and socio-economic constraints. Lack of development of groundwater has been thought to be the most important reason for stagnating agriculture in Eastern India (Dhawan, 1982). The major foodgrains producing states of Haryana, Punjab and Rajasthan in Northwest India are overexploited to the tune of 109-145%. On the other hand, there is large scope for developing and utilizing groundwater for irrigation in the poverty-ridden eastern states of Assam, Bihar, Chhattisgarh, Jharkhand, Odisha and West Bengal since 58-82 % groundwater remains underdeveloped and unutilized for irrigation. India's food security will be ensured through the second green revolution in the high productivity potential eastern states (Sharma, 2009). Groundwater irrigation has the potential of unleashing unprecedented agrarian boom in Eastern India. However, due to a multitude of policy differences coupled with varying agrarian structures, the beneficial impact of groundwater has not been realized equally everywhere (Ballabh et al, 2002). Swain et al. (2009) attempted to analyze the process of regional agricultural development in the State of Odisha and identify the determinants of differential agricultural growth. The results showed that four coastal districts (Balasore, Cuttack, Puri, and Ganjam) and two districts of central table land area (Sambalpur and Bolangir) are agriculturally more advanced than other districts in the three references years over three decades (1980-81 to 1998-99). The agricultural success of four coastal districts is due to well-developed irrigation facilities and vast tracts of plain and fertile land comprising alluvial soil. The crux of the groundwater challenge in India is that there is extreme overexploitation of the resource in some parts of the country coexisting with relatively low levels of extraction in others (Shankar et. al., 2011). Along with the development of groundwater irrigation, the contribution of groundwater irrigation to the overall agricultural growth is estimated to have increased significantly in India. Apart from directly benefiting the farmers having own groundwater structures, the emergence of groundwater market has also benefited millions of non-well owning farmers (Moorthy, 2008). Energy plays an important role in groundwater extraction and various studies examined its relationship with groundwater development and suggested that reliable electricity supply has a potential for efficient use of groundwater. The studies have ascertained the impact of power tariff in the farm sector on efficiency, equity and sustainability in groundwater use, and its overall socio-economic viability thereof (Singh, 2008). Overall, the empirical evidences reinforce the fact that the raising power tariff in the farm sector would be socio-economically viable to achieve efficiency, equity and sustainability in groundwater use. Sethi et al (2006) developed models to allocate available land and water resources optimally on seasonal basis so as to maximize the net annual return in Balasore district of Odisha, considering net irrigation water requirement of crops as stochastic variable. The study reveals that 40% deviation of the existing cropping pattern is the optimal that satisfies the minimum food requirement and maintain geo-hydrological balance of the basin. The sensitivity analysis of conjunctive use of surface water and groundwater shows that 20% surface water and 30% groundwater availability as the optimum water allocation level. The proposed cropping and water resources allocation policies of the developed models were found to be socioeconomically acceptable that maintained the balance of the entire system, considering all the constraints and restrictions imposed. The National Water Policy calls for the conjunctive use of all the available water resources. These are rainwater, river and surface water sources, groundwater, sea water and recycled waste water. The conjunctive use of ground and surface water can help to improve cropping intensity by using surface and rainwater during *kharif* and groundwater during *rabi* and summer seasons. Integrated water resources management is vital for maximizing the benefits of the available irrigation water.

3. DATA AND METHODOLOGY

The study is primarily based on secondary data on different hydro-geological, socio-economic and energy use aspects collected from published sources of various Government departments such as Central Groundwater Board (Bhubaneswar), Directorate of Groundwater Survey & Investigation (Government of Odisha), Ministry of Water Resources (Minor Irrigation Census), Directorate of Economics and Statistics, etc. To provide a meaningful interpretation of the data, tabular, multivariate and econometric analyses have been done. Tabular analysis has been done to examine spatial and temporal groundwater development, sector-wise utilization, irrigation potential created and utilized and constraints analysis. Further, log-linear regression analysis has been done to establish relationship between groundwater development and agricultural income in Odisha as follows;

$$\text{Log}(Y) = c + b^{x}\,\text{Log}(X) + e \qquad \ldots (1)$$

where,

Y= per hectare net district domestic product from agriculture (Rs/ha)
c = intercept to be estimated
b= regression coefficient to be estimated
X= groundwater development (%)
e =unobserved error term

The regression coefficients were estimated using Ordinary Least Square (OLS) technique. Thereafter, partial correlation coefficients (ρ) were estimated to identify the factors affecting groundwater development and their inter-relationship.

$$\textit{Correlation coeff.} \quad (\rho) = \frac{\sum_i (x_i - \bar{x}_i)(y_i - \bar{y}_i)}{\sqrt{\sum_i (x_i - \bar{x}_i)^2 (y_i - \bar{y}_i)^2}} \qquad \ldots (2)$$

It is to be noted that correlation coefficient provide information about the nature of the inter-relationship between two variables. To know the extent of influence of the associated factors on the groundwater development, regression analysis using block level data (210 out of 314 blocks for which uniform data was available) was also attempted in which groundwater development was regressed with discharge, wells (no.), draw-down and geology. To differentiate consolidated (hard-rock), semi consolidated and non-consolidated (alluvial geology), dummy variable technique was used. Blocks falling under alluvial areas were taken as a base category (represented by intercept in the regression) and the groundwater development in hard rock and semi-consolidated blocks was compared with alluvial blocks using the estimated coefficients.

Groundwater development in Odisha exhibits wide inter-regional variations due to varied hydro-geological conditions, agro-climatic features, infrastructure and other socio-economic constraints. Therefore, an attempt was made to delineate regions of similar hydro-geological properties and infrastructure development using k-means cluster (multivariate) analysis. Groundwater development (%), discharge (litre/second), draw-down (m), villages electrified (%) and seasonal water fluctuation (meter) variables were considered for cluster analysis. Cluster analysis is an exploratory data analysis tool which aims at sorting different objects into groups in a way that the degree of association between two objects is minimal if they belong to the same group and maximal otherwise. Cluster analysis is used to discover structures in data but without providing an explanation/interpretation why they exist. K-means cluster analysis is an algorithm to classify or group objects based on attributes/features into k number of group, k is positive integer number. The grouping is done by minimizing the sum of squares of distances between data and the corresponding cluster centroid. In k-means cluster analysis, first number of cluster K is determined and cetroid or centre of these clusters is assumed. Any random objects as the initial centroids or the first k objects can serve as the initial centroids. Then the k-means algorithm will do the following three steps until convergence.

1. Determine the centroid coordinate
2. Determine the distance of each object to the centroids
3. Group the objects based on minimum distance (find the closest centroid)

Distance between each object and centroid is obtained by estimating Euclidean distance [distance(x,y) = $\{\Sigma_i (x_i - y_i)^2\}^{½}$] which the geometric distance in the multidimensional space. The procedure is repeated till the convergence criterion is obtained. The convergence criterion represents a proportion of the minimum distance between initial cluster centers, so it must be greater than 0 but not greater than 1. If the criterion equals 0.02, for example, iteration ceases when a complete iteration does not move any of the cluster centers by a distance of more than 2% of the smallest distance between any initial cluster centers.

The districts of Odisha have been divided into three distinct clusters and comparative analyses of different aspects of groundwater development and utilization have been done across these clusters. An attempt was also made to quantify the variations in aquifer properties and groundwater development within each cluster by estimating coefficient of variation (CV) as follows;

$$Coefficient\ of\ Variation\ (CV) = \frac{Standard\ Deviation}{Mean} \times 100 \qquad ...(3)$$

The long-run sustainability of groundwater resources in the state was examined by analyzing the trend (increasing/decreasing/no change) in water table (1997 to 2009) for each administrative block (314) in both pre-monsoon and post-monsoon season by fitting the time-series regression functions. In the time–series analysis, water table depth was regressed with the time variable after examining the stationarity condition of the time series. The coefficients (intercept and slope) were estimated using OLS (Ordinary Least Square) technique. The sign (+/-), significance level and value of slope variable in the function indicate the direction and rate of change in the water table during the period under consideration.

The energy use aspects of groundwater irrigation were studied by examining the trend in electricity consumption for agriculture purpose, distribution of groundwater structures across alternative sources of energy and cost of groundwater extraction using alternative energy sources (Diesel/Electricity) in different clusters. The steps involved in estimation of cost of per cubic meter groundwater extraction are as follows;

1. Estimation of average horse power (hp) of the pumps used in groundwater structures (Shallow Tubewells/Deep Tubewells/Dugwells) across different clusters. Average horse power (hp) was estimated by weighted average using the recent (4^{th}) Minor Irrigation (MI) census data. Thereafter, average hp was expressed in terms of Energy (Kilowatt) by multiplying with the factor 0.746. For man/animal operated dugwells, 0.28 KW {(average of 0.06 (male), 0.048 (female) and 0.746 (drought animal)} energy was used (Srivastava, N.S.L., 2002).

2. Estimation of "total head" using following formula;

   $$\text{Total Head (m)} = \text{Water table (m)} + \text{draw down(m)} + \text{friction loss} \quad \text{... (4)}$$

   10 per cent of the water table and draw down was taken as friction loss. Average water table and draw down for each cluster was estimated using the data collected from Central Groundwater Board and Directorate of Survey & Investigation (Government of Odisha).

3. Estimation of average groundwater draft (l./sec.) using following formula;

   $$Groundwater\ Darft\ (l./Sec.) = \frac{hp \times 75 \times pump\ efficiency}{Total\ Head\ (m)} \quad \text{... (5)}$$

   Pump efficiency was assumed as 40%. Thereafter, groundwater extraction in the full year was estimated using the information such as number of pumping days in monsoon and non-monsoon seasons and average pumping hours/day. The number of pumping days in monsoon and non-monsoon season were taken as 50 and 120, respectively (Directorate of Groundwater survey & Investigation, Govt. of Odisha). Average pumping hours/day for different groundwater structures were calculated by weighted average using recent (4^{th}) Minor Irrigation (MI) census data.

4. Estimation of energy consumed to lift one cubic meter of groundwater (KWhr/cum). For diesel operated pumps, it was found from the farmers'

response that 1 hp pump consumes about 0.25 liter diesel in one hour. Thereafter, energy was expressed in monetary terms (Rs/cum.) by multiplying with Rs.45 per liter for diesel and Rs 1.10 per Unit (KW) for electricity.

5. Estimation of total annual amortized cost of groundwater structure (Shallow Tubewell/Deep Tubewells/Dugwell) as sum of total amortized digging cost, total amortized pump cost and maintenance cost.

$$A = \frac{CB \times (1+i)^{n} \times i}{(1+i)^{n} - 1} \quad \text{...(6)}$$

where,

A = amortized cost of digging/pump (Rs.)

CB= initial Cost digging/pump (Rs.)

i = interest rate (6%)

n = life of groundwater structure

For cluster 1 and cluster 3 (Hard rock areas), average life of groundwater structure was taken as 15 years, while for cluster 2 (Alluvial/coastal) average life of groundwater structure was taken as 20 years. Average life of pump was taken as 10 years. Annual maintenance cost was taken as 5 % and 1% of pump cost for diesel and electric operated pumps, respectively.

6. Estimation of total cost of per cubic meter groundwater extraction (Rs/cum) as sum of total annual amortized cost (Rs/cum) and energy cost (Rs/cum).

Thereafter, the share of alternative sources of energy (diesel/electricity) in total groundwater extraction cost was examined across different clusters and groundwater structures and implication of government subsidy on these energy sources was diagnosed.

As agriculture is the major consumer of groundwater resources, its performance was examined in different clusters by estimating agriculture development index (ADI) as following;

$$ADI = \frac{\sum_{i=1}^{m} X_{ij}}{\sum_{i=1}^{m} i} \times 100 \quad \text{... (7)}$$

Where, ADI is agriculture development index which is average (with equal weight to all the indicators) of i^{th} indicator for j^{th} district. Agriculture coverage (share of agricultural area in total geographical area), irrigation coverage (share of gross irrigated area in gross cropped area), cropping intensity (net sown area/gross sown area), paddy yield, groundwater development and fertilizer consumption (kg/ha) were taken as the individual indicators to estimate composite agriculture development index in each cluster. Index for individual indicator was calculated as follows;

$$X_{ij} = \frac{(Y_{ij} - min.Y_{ij})}{(max.Y_{ij} - min.Y_{ij})} \quad ...(8)$$

where Y_{ij} is the i^{th} indicator for j^{th} district. Inter-cluster variations in agricultural performance were examined and inferences were drawn.

4. RESULTS AND DISCUSSION

4.1. Different Aspects of Groundwater Development in Odisha

4.1.1. Status of Groundwater Resources in Odisha

Gross groundwater recharge has been estimated as 17.77 billion cubic meter (BCM) in Odisha through different sources (Table 1). Rainfall contributes 71 per cent in gross groundwater recharge. With 1.09 BCM of natural groundwater losses, net groundwater availability in Odisha is 16.69 BCM. Out of this, only 4.36 BCM groundwater is drafted with irrigation sector extracting the highest (79.6 per cent). Thus, overall groundwater development in Odisha stands only 26.14 per cent. However, there exists wide variability in its development across different districts ranging from 8.76 per cent in Malkangiri to 55 per cent in Bhadrak due to varying hydro-geological and socio-economic conditions. Among the 314 blocks, groundwater development in 23 coastal blocks is more than 50 per cent. At the same time, in 25 hard rock blocks, groundwater development in less than 10 per cent. Further, 36 and 6 coastal blocks are partially and fully affected by salinity problem, respectively. Block-wise categorization into four quartile classes revealed that in 75 per cent of the total blocks, groundwater development is less than 34 per cent and most of the blocks, where groundwater development is better, fall in coastal belt of the state (Figure 1). For future, after reserving groundwater for industry and domestic uses for the next 25 years, 1.19 BCM and 0.84 BCM groundwater is available for creation of additional irrigation potential at 100 per cent and 70 per cent level of groundwater development, respectively.

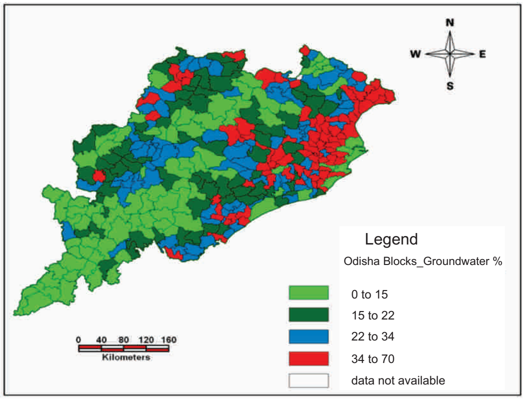

Figure 1: Block-wise groundwater development (%) in Odisha

Table 1. Status of groundwater resources in Odisha in 2009-10

Particulars	Value
Gross Groundwater recharge (BCM)	17.77
Natural Groundwater losses (BCM)	1.09
Net Groundwater resources (BCM)	16.69
Groundwater Draft (BCM)	4.36
Irrigation	3.47 (79.6)
Domestic	0.74 (16.99)
Industry	0.15 (3.41)
Groundwater Development (%)	26.14
Maximum	55 (Bhadrak)
Minimum	8.76 (Malkangiri)

Figures within parentheses includes share in total groundwater draft
Source: Directorate of Groundwater Survey and Investigation, Government of Odisha, 2011

4.1.2. Groundwater irrigation-agricultural income linkage in Odisha

Although groundwater constitutes a small share (6.14 %) in gross irrigated area (GIA) in Odisha, it bears a positive relationship with the agricultural income. Estimated log-linear regression function revealed that about a quarter (R^2) of the agricultural income (Rs/ha) is dependent on groundwater (Table 2). The elasticity of agricultural productivity with respect to groundwater development (estimated coefficient) was positive (0.598) and significant at 1% level of significance, indicating improvement in groundwater development will increase the agricultural income in the state. It has been estimated that 47.75 per cent of the total ultimate irrigation potential (8.8 Mha) in Odisha can be developed using groundwater and till now only 13 per cent (5.5 lakh ha) of the Ultimate Irrigation Potential (UIP) has been created using groundwater resources. Thus, there is enough scope for improving agricultural income in the state through sustainable groundwater development.

Table 2. Results of regression analysis between agricultural income and groundwater development in Odisha

Particular	Estimates
Constant	8.569*
	(0.631)
Groundwater development (log)	0.598*
	(0.199)
R^2	0.244
No. of observations	30

Dependent variable: Per hectare net district domestic product from agriculture (Rs/ha) in logarithmic form
*significant at 1% degree of significance
Figures within parentheses are standard errors of estimated coefficients

4.1.3. Factors affecting groundwater development in Odisha

The development of groundwater resources in a location is outcome of a complex set of inter-related hydro-geological, socio-economic, agriculture and infrastructure related factors. To identify major factors affecting groundwater development in Odisha, partial correlation coefficient was estimated using district level data. The variables such as discharge and draw-down were taken as proxy for hydro-geological conditions, while electrified villages (%), per capita income (net district domestic product) and fertilizer consumption (kg/ha) were taken as proxy for infrastructure development, economic conditions of the farmers and level of input use in agriculture, respectively. The estimated correlation coefficient between groundwater development and other variables was significant and positive except for draw-down (Table 3).

Table 3. The estimated correlation coefficient between groundwater development and other factors

Variables	GWD	Per capita income	Electricity	Discharge	Drawdown	Fertilizer
GW dev.	1.00	0.38*	0.63**	0.81**	-0.53**	0.48**
Per capita income	0.38*	1.00	0.48**	0.29	-0.27	0.13
Electricity	0.64**	0.48**	1.00	0.52**	-0.41*	0.43*
Discharge	0.81**	0.29	0.52**	1.00	-0.71**	0.49**
Drawdown	-0.53**	-0.27	-0.41*	-0.71**	1.00	-0.21
Fertilizer	0.48**	0.13	0.43*	0.49**	-0.21	1.00

*. Correlation is significant at the 0.05 level (2-tailed).
**. Correlation is significant at the 0.01 level (2-tailed).

The correlation coefficient between discharge and groundwater development was 0.81 which indicated that the areas with high discharge (lit/sec) are conducive for groundwater development. On the other hand, high draw-down affects the groundwater extraction negatively as shown by negative correlation coefficient between groundwater development and draw down (-0.53). The installation of groundwater structure primarily involves private investment. Therefore, income of the farmers was found to be an important determinant (positive correlation coefficient) of the groundwater development in Odisha. Similarly, availability of electricity was found to be positively affecting groundwater development as shown by high and positive correlation coefficient. Moreover, positive correlation coefficient between groundwater development and fertilizer consumption indicated that irrigation and fertilizer consumption are complement to each other. The assured availability of irrigation induces farmers to apply more fertilizer to maximize farm profit. It is to be noted that per hectare fertilizer consumption in the state (54 kg/ha) was less than half of the national average (118 kg/ha) in TE 2008-09. Thus, assured irrigation through groundwater development has the potential to improve fertilizer consumption and therefore agricultural productivity in Odisha.

The correlation coefficient indicates nature of relationship between two variables. To know the extent of influence of these variables, regression analysis was done using block level data (Table 4). It is to be noted that per capita income, electrified villages and fertilizer consumption could not be taken as explanatory variables in regression analysis due to unavailability of consistent data.

Table 4. Estimated parameters of regression analysis

Variables	Estimated Parameter
Constant	41.191*
	(4.195)
Discharge	0.209*
	(0.071)
Consolidated (Hardrock) geology	-18.956*
	(2.978)
Semi-consolidated geology	-11.311*
	(4.054)
Wells	7.261E-03*
	(0.001)
Draw down	-9.149E-02
	(0.087)
No. of observations	210
R^2	0.58

Dependent variable: groundwater development
*significant at 1% level of significance
Figures within parentheses are standard error of the estimated parameters

From the estimated parameters, it was found that groundwater development in consolidated and semi-consolidated areas are significantly lower by 18 and 11 per cent than alluvial region of the state. The groundwater development in alluvial areas is represented through the intercept value of the regression. The positive coefficient of discharge and negative coefficient of draw-down indicated that groundwater recharge activities in the areas of low discharge and high draw-down would improve the groundwater development.

4.1.4. Classification of districts using K-means clustering technique

Odisha exhibits wide inter-regional variability in hydro-geological properties and socio-economic conditions leading to differential groundwater development across different regions. Therefore, multivariate (K-means clustering technique) analysis was used to classify districts, exhibiting similarity in attributes (groundwater development, discharge, drawdown, electrified villages and water level fluctuation), into 3 distinct clusters (Figure 2).

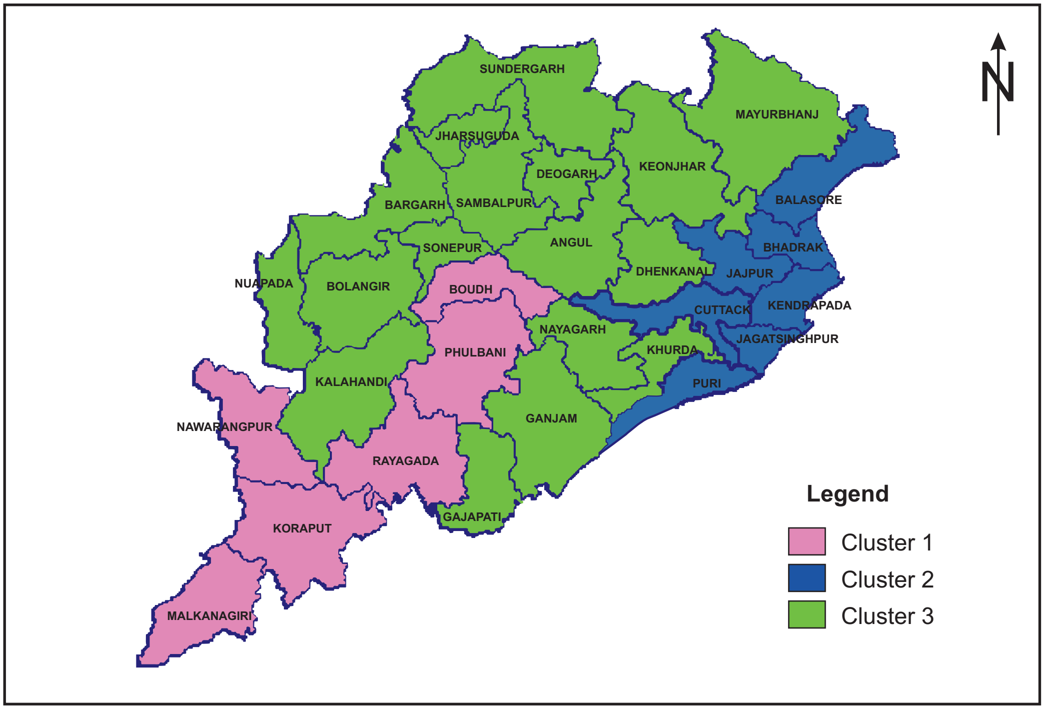

Figure 2. Classification of districts using K-means clustering analysis

The aquifer properties, infrastructure development (villages electrified taken as proxy) and number of districts in each cluster are given in table 5. Mean values of the attributes in each cluster was found to be significantly different from each other except water level fluctuation as shown by the analysis of variance (Table 6). Groundwater development was found to be highest (42.90 %) in cluster2 and least (14.23 %) in cluster 1. It is to be noted that cluster2 exhibited more favourable aquifer properties (highest discharge rate, least drawdown and least water level fluctuation) and infrastructure development (highest electrified villages) as compared to other clusters. On the other hand, mean values of aquifer properties and infrastructure development in cluster1 was unfavourable leading to least (14.23%) groundwater development in the districts included in this cluster. Further, all the 7 districts of cluster 2 are located in coastal/alluvial region (with favourable aquifer properties) of the state, while all the 6 districts of cluster 1 are located in hard rock (with unfavourable aquifer properties) region of the state. However, favorable/unfavourable aquifer properties were found to be complemented by the better/least infrastructure development (electrified villages) for groundwater development in the respective regions. Thus, improvement in infrastructure related to groundwater can play a crucial role in its development especially in less developed regions of the state. Groundwater development in cluster3 containing 17 districts was 24.37 per cent.

Table 5. Cluster-wise aquifer properties and infrastructure development (mean values)

Variables	Cluster 1	Cluster 2	Cluster 3
Groundwater development (%)	14.23	42.90	24.37
Discharge (litre/second)	3.07	35.37	5.21
Drawdown (meter)	21.89	10.44	20.27
Villages electrified (%)	11.88	88.32	69.15
seasonal water level fluctuation (meter)	2.72	2.20	2.315
No. of districts	6	7	17

Districts categorized under cluster1 and cluster3 have hard rock geology, while districts in cluster2 fall in alluvial/coastal belt of Odisha. The favourable aquifer properties (high discharge, low draw-down and high water level) in coastal areas (cluster2) also results in comparatively low energy requirement to lift the groundwater. However, these areas are hydrologically sensitive to sea-water intrusion and 42 coastal blocks are already partially or fully affected by the salinity problem. Hence, safe pumping options should be followed in order to use the groundwater on sustainable basis in coastal areas. On the other hand, in hard rock region (cluster1 and cluster3), Poor groundwater development is primarily due to low discharge, high draw-down and heterogeneity in aquifer properties within the small areas. The unfavorable hydro-geological conditions also results in higher energy requirement to extract groundwater in these areas. Thus, the associated problems and therefore strategies for the sustainable groundwater development in different hydro-geological settings (hard rock/coastal) would be different.

Table 6. Analysis of variance (ANOVA) in cluster analysis

Variables	Cluster		Error		F	Sig.
	Mean Square	df	Mean Square	df		
Groundwater Development	1430.76	2	52.35	27	27.33	0.00
Discharge	2542.67	2	19.08	27	133.26	0.00
Draw down	288.02	2	16.23	27	17.74	0.00
Villages electrified	10394.53	2	144.32	27	72.02	0.00
Water level fluctuation	0.49	2	.25	27	1.95	0.16

Note: The F tests should be used only for descriptive purposes because the clusters have been chosen to maximize the differences among cases in different clusters. The observed significance levels are not corrected for this and thus cannot be interpreted as tests of the hypothesis that the cluster means are equal.

4.1.5. Inter-cluster and intra-cluster variations in groundwater development

Out of the 16.69 BCM of net groundwater reserve, cluster3 endows 9.47 BCM groundwater reserve as it contains largest number (186) of administrative blocks of the state (Table 7). Similarly, cluster3 dominates in total groundwater draft. Further, there exists wide variability in groundwater resources and its utilization in the state as well as different cluster. Estimated coefficient of variation (CV) for net groundwater resources for the state was 45 per cent ranging from 38 per cent in cluster3 to 57 per cent in cluster2. The estimated CV for total groundwater draft for the state was 80 per cent ranging from 51 per cent in cluster3 to 67 per cent in cluster2. High CV in cluster2 was primarily due to presence of saline affected area in which groundwater draft is very less. Among different sectors, irrigation was the dominant user of groundwater in all the clusters. However, the use of groundwater for domestic purpose was more pronounced in cluster1 and cluster3 as compared to cluster2. In cluster2, about 87 per cent of the total groundwater draft is used for irrigation purpose.

Table 7. Groundwater resources, draft and its development within each cluster

Particulars	Cluster1	Cluster2	Cluster3	Odisha
Net Ground water resources (BCM)	3.17	4.06	9.47	16.69
	(44)	(57)	(38)	(45)
Groundwater Draft (BCM)	0.40	1.68	2.28	4.36
	(59)	(67)	(51)	(80)
Irrigation (% of total draft)	67.83	86.81	76.50	79.6
Domestic (% of total draft)	26.01	10.76	20.00	16.99
Industrial (% of total draft)	6.15	2.43	3.50	3.41
Groundwater development (%)	14.23	42.90	24.37	26.14
	(42)	(39)	(43)	(54)
No. of blocks	57	71	186	314

Figures within parentheses are coefficient of variation (CV) estimated using block level data

The development of groundwater exhibits wide inter-cluster as well as intra-cluster variations. The groundwater development ranges from 14.23 per cent in cluster1 to 42.90 per cent in cluster2 with the overall development of 26.14 per cent in the state. Temporally, groundwater development in Odisha has increased from 15 per cent in 1999 to 26 per cent in 2009 (Figure 3). The increasing trend in groundwater development was found in all the clusters. Groundwater development has increased from 9 per cent to 14 per cent in cluster1, from 23 to 43 per cent in cluster2 and 13 to 24 per cent in cluster3 during 1999 to 2009. However, the rate of increase in groundwater development was highest in cluster3 (90%) followed by cluster2 (83%) and cluster1 (59%). Further, high value of estimated coefficient variation using block level data for the state (54%) indicated wide variability in groundwater development.

Variability in hard rock areas (cluster1 and cluster3) was found to be higher than alluvial/coastal areas (cluster2) due to unfavourable hydro-geological conditions in the former areas.

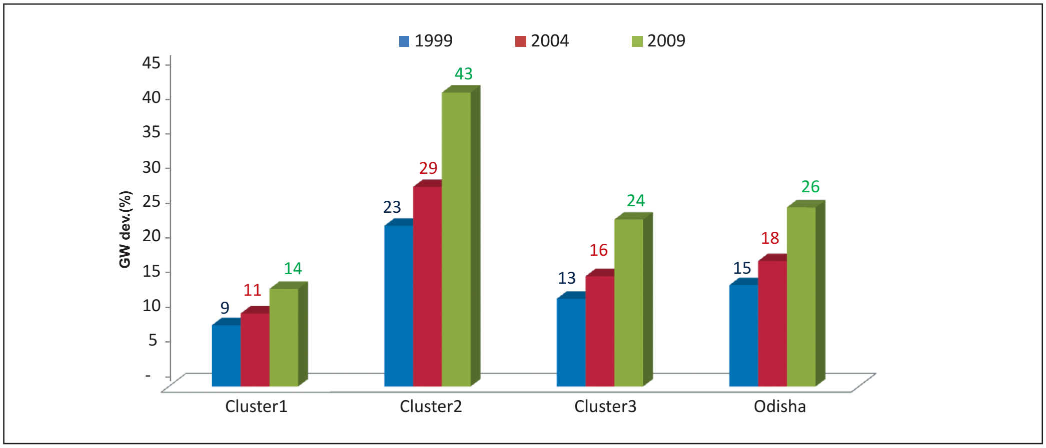

Figure 3. Trend in groundwater development (%) in each cluster

4.1.6. Inter-cluster and intra-cluster variations in groundwater table depth and aquifer properties

Data collected from the monitoring wells of Central Groundwater Board, Bhubaneswar and Directorate of Groundwater Survey & Investigation revealed that average water table depth in Odisha during pre-monsoon season is 6 meter below ground level (bgl) and varies from -1.11 meter to 28.14 meter in 2009 (Table 8). However, the average groundwater table depth in post-monsoon season increases upto 3.39 meter and varies from -0.73 to 23.87 meter. Among the clusters, water table depth in cluster2 (coastal/alluvial areas) is comparatively higher than cluster1 and cluster3 in both the seasons. Further, results of the time series regression analysis showed that average water table in cluster1 witnessed a declining trend in pre as well as post monsoon seasons during 1997 to 2009. The estimated coefficients indicated that average water table in the cluster1 declined at the rate of 8 cm and 5 cm per annum in pre and post monsoon season, respectively during the period under consideration. Contrary to it, average water table in cluster2 (coastal/alluvial areas) witnessed an increasing trend at the rate of 9 cm and 6 cm per annum during the same period. In cluster3, trend in water table was not found to be statistically significant. The fluctuation in water table between pre and post monsoon season during 1997 and 2009 was 2.4 meter varying from 1.91 meter in cluster2 to 2.61 meter in cluster3. Among the clusters, cluster2 witnessed least variability (14.92% CV) as compared to other clusters. However, the trend in water level fluctuation was not found to be statistically significant in any cluster.

Table 8. Cluster-wise trend in water table and aquifer properties in Odisha

Particulars	Cluster1	Cluster2	Cluster3	Odisha
Water level (meter) in 2009#				
Pre-monsoon	6.13	5.03	6.39	6.02
	(-1.11 to 28.14)	(-0.50 to 15.25)	(-0.95 to 18.92)	(-1.11 to 28.14)
Post-monsoon	3.63	2.73	3.57	3.39
	(0.02 to 23.87)	(-0.45 to 11.15)	(-0.73 to 15.55)	(-0.73 to 23.87)
Trend (decline/increase/no) during 1997-2009$				
Pre-monsoon	-0.089**	0.095***	0.007	0.009
	(0.034)	(0.020)	(0.020)	(0.018)
Post monsoon	-0.057*	0.068***	0.009	0.009
	(0.033)	(0.019)	(0.026)	(0.023)
Water level fluctuation between 1997-2009$				
Mean	2.36	1.91	2.61	2.40
Standard deviation	0.60	0.29	0.45	0.40
Coefficient of Variation (%)	25.62	14.92	17.22	16.71
Trend	0.032	0.057	-0.027	0.001
	(0.046)	(0.033)	(0.021)	(0.031)
Discharge (lit/sec)				
Mean	3.07	35.37	5.21	11.88
Standard deviation	3.61	20.19	6.36	17.58
Coefficient of Variation (%)	118	57	122	148
Draw-down (meter)				
Mean	21.89	10.44	20.27	18.84
Standard deviation	9.06	6.03	8.57	9.15
Coefficient of Variation (%)	41	58	42	49

#Figures within parentheses are minimum and maximum value of water table
$ figures within parentheses are standard error of the estimated regression parameter (time)
*** significant at 1% level of significance, ** significant at 5% level of significance, * significant at 10% level of significance

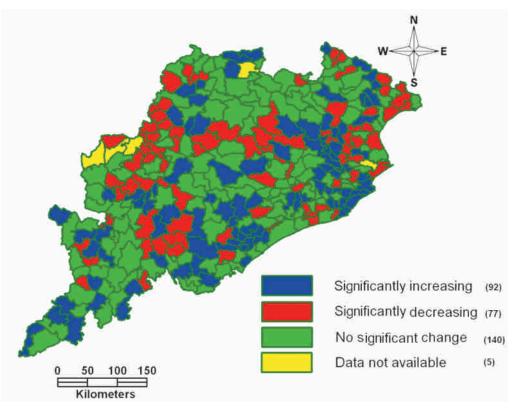

Figure 4. Block-wise trend in water table in pre-monsoon season during 1997-2009

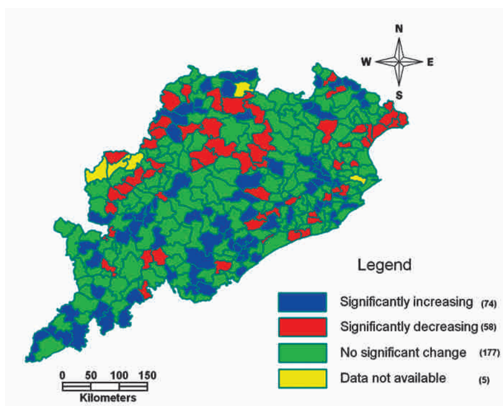

Figure 5. Block-wise trend in water table in post-monsoon season during 1997-2009

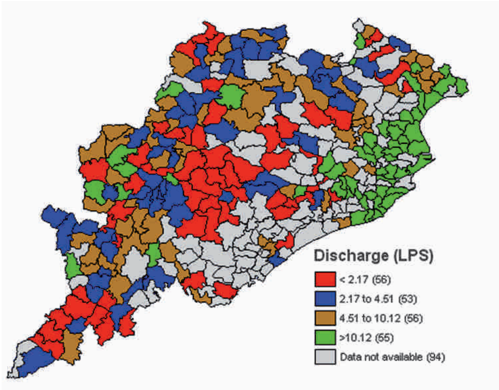

Figure 6. Block wise discharge rate (liter per second) in Odisha

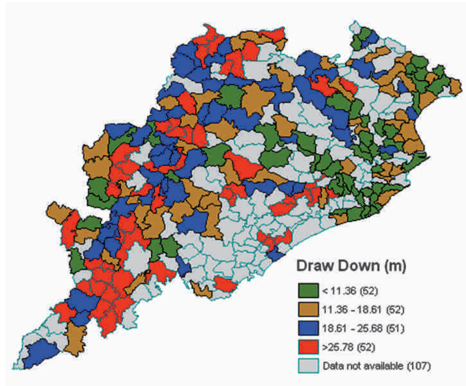

Figure 7. Block–wise draw-down (meter) in Odisha

It is to be noted that average water table depth at cluster level give macro level scenario. Therefore, trend in water table was further examined at disaggregated (block level) in both pre and post monsoon period and results are presented in figure 4 and 5. The results of time series regression analysis showed that in 140 blocks (45% of the total administrative blocks), there was no significant change in water level in pre-monsoon season during 1997 to 2009. In 92 blocks (30% of the blocks), water table was found to be increased. This indicated the scope for accelerating groundwater utilization in the blocks with no change/increase (232 blocks) in water table during the period under consideration. On the other hand, in 77 blocks (25% of total blocks), water table witnessed declining trend in pre-monsoon season during 1997-2009. This necessitates implementation of groundwater recharge activities in these 77 blocks to ensure sustainable development of groundwater in the state. The name of the blocks falling in each category (increasing trend/decreasing trend/no change) is given in Appendix.

The diagnosis of aquifer properties (discharge and draw-down) revealed that discharge (ℓ./*sec*) varies from 3 ℓ./*sec* in cluster1 to about 35 ℓ./*sec* in cluster2 with the average discharge of 11.88 ℓ./*sec* in the state. Low aquifer discharge in cluster1 necessitates adoption and popularization of micro-irrigation technology which suits well in low discharge rate scenario. Further, cluster1 and cluster3 exhibited very high variability (CV value of >100) in discharge rate as compared to cluster2 which has definite implications on groundwater development in the state. Draw-down was found to vary from 10.44 meter in cluster2 to 21.89 meter in cluster1 with the average draw-down of 18.84 meter in the state. High value draw-down in cluster1 and cluster3 are primarily due to low recuperation rate of geological formations in these areas. On the other hand, in alluvial areas (cluster2), comparatively low value of draw-down is due to high recharge rate. However, care should be taken while interpreting the value of draw-down as its value will depend largely on the type of groundwater structure (shallow tubewell/deep tubewell/dugwell) used for its extraction and hours of pumping.

4.1.7. Temporal and spatial variations in groundwater structures and ownership pattern

The number and type of the groundwater structure bears a significant impact on groundwater extraction and thus its development. The trend in number and composition (shallow tubewells/deep tubewells/dugwells) of groundwater structures has been studied across different clusters in Odisha using district level data of 2nd (1993-94), 3rd (2000-01) and 4th (2006-07) minor irrigation census. Presently, there are about 4.7 lakh groundwater structures in the state (Table 9). However, examination of the composition of groundwater structures revealed that dugwells are the predominant structure constituting 86 per cent (about 4 lakh) of the total groundwater structures in the state (Figure 8). The shallow tubewells and deep tubewells constituted 13 per cent and 1 per cent of the total groundwater structures in 2006-07, respectively. Temporally, the groundwater structures have increased by 37 per cent between 1993-94 and 2006-07. However, the rate of increase was not uniform across different type of groundwater structures and clusters (Figure 9). Among the groundwater structures, shallow tubewells witnessed maximum increase of 237 per cent followed by deep tubewells (107%) and dugwells (25%). Consequently, the share of dugwells in total groundwater structure declined from 94 per cent in 1993-94 to 86 per cent in 2006-07 (Figure 9). On the other hand, the share of shallow tubewells has increased from 5 per cent to 13 per cent during the period under consideration. Among the clusters, the rate of increase in groundwater structures was highest (102%) in cluster2 followed by cluster3 (29%) and cluster1 (25%).

Composition of groundwater structures was not found to be uniform across different clusters due to varying hydro-geological conditions and other socio-economic constraints. In cluster1 and cluster3, dugwell was the predominant structure constituting 98 per cent and 91 per cent of the total groundwater structures in 2006-07. Cluster1 and cluster3 falls in hard rock areas and dugwells are the most feasible structures in these areas. As hard rock occupies largest geographical area (>80%) of the state, this may be an important reason for the dominance of dugwells. On the other hand, in cluster2, shallow tubewells were the predominant structures constituting 64 per cent of total groundwater structures followed by dugwells (31%) and deep tubewells (5%) in 2006-07. Temporally, a structural shift in the composition of groundwater structures was observed in cluster2 between 1993-04 and 2006-07. During 1993-94, dugwells were the predominating structures constituting 51 per cent of the total groundwater structures followed by shallow tubewells (42%) and deep tubewells (7%). However, between 1993-94 and 2006-07, shallow tubewells in the cluster2 increased by 213% while dugwells could increase only by 25% during 1993-94 and 2006-07. Consequently, the share of shallow tubewells increased from 42 per cent to 64 per cent and the share of dugwells decreased from 51 per cent to 31 per cent during the period under consideration making shallow tubewells a pre-dominant structure in cluster2.

Table 9. Number of groundwater structures in different clusters over the years

Cluster	Year	Shallow Tube wells	Deep Tube wells	Dugwells	Total
Cluster1	1993-94	322	6	35252	35580
	2000-01	398	28	40002	40428
	2006-07	710	114	43753	44577
	% increase over 1993-94	120	1800	24	25
Cluster2	1993-94	15568	2616	18632	36816
	2000-01	35972	3612	23190	62774
	2006-07	48779	4048	23684	76511
	% increase over 1993-94	213	55	27	108
Cluster3	1993-94	2231	293	269906	272430
	2000-01	7511	952	315187	323650
	2006-07	11489	1873	338132	351494
	% increase over 1993-94	415	539	25	29
Odisha	1993-94	18121	2915	323790	344826
	2000-01	43881	4592	378379	426852
	2006-07	60978	6035	405569	472582
	% increase over 1993-94	237	107	25	37

The examination of ownership pattern of groundwater structures revealed that about 98 per cent of the dugwells and shallow tubewells are owned by individual farmers in Odisha (Table 10). Deep tubewells, which are big structures and involve huge investment, are primarily owned by the Government agencies (75%). However, there exists inter-cluster variation in ownership pattern of groundwater structures. In cluster2, shallow tubewells and dugwells are primarily owned by individual farmers while deep tubewells are primarily owned by Government agencies. But, in cluster1 and cluster3, about 80 per cent and 63 per cent of the deep tubewells are owned by individuals, respectively. These tubewells might be primarily used for the domestic purpose as discharge rate in cluster1 and cluster3 is low to provide irrigation using deep tubewells on community basis. Thus, groundwater extraction in Odisha is primarily done using dugwells by the individual farmers with inter-cluster variations.

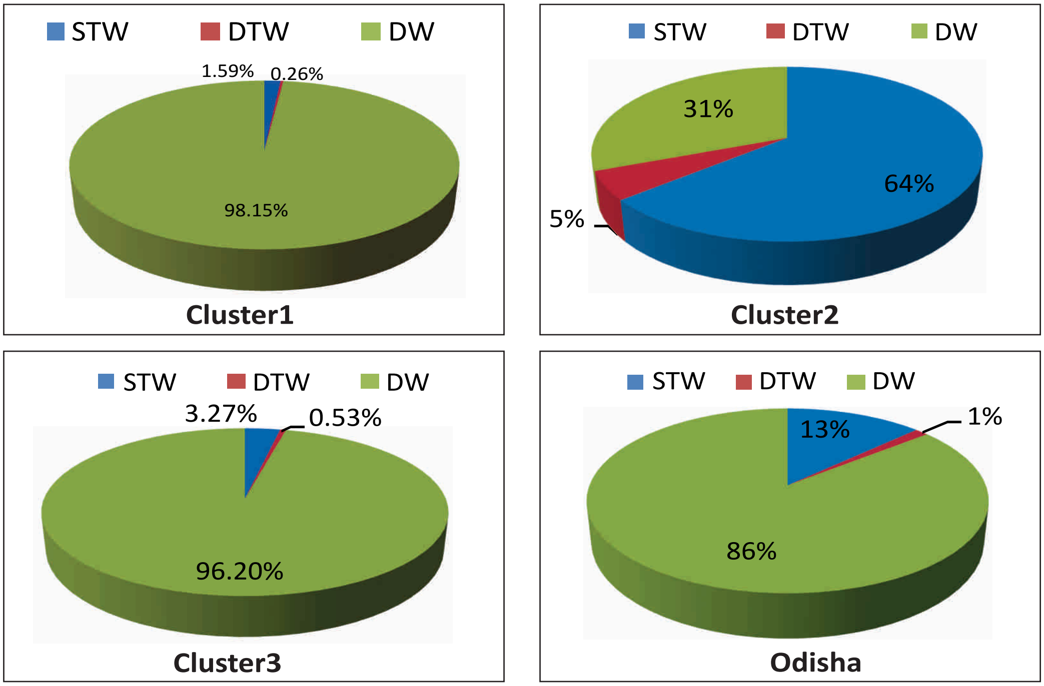

Figure 8. Composition of groundwater structures in different clusters in Odisha in 2006-07 (4th MI census)

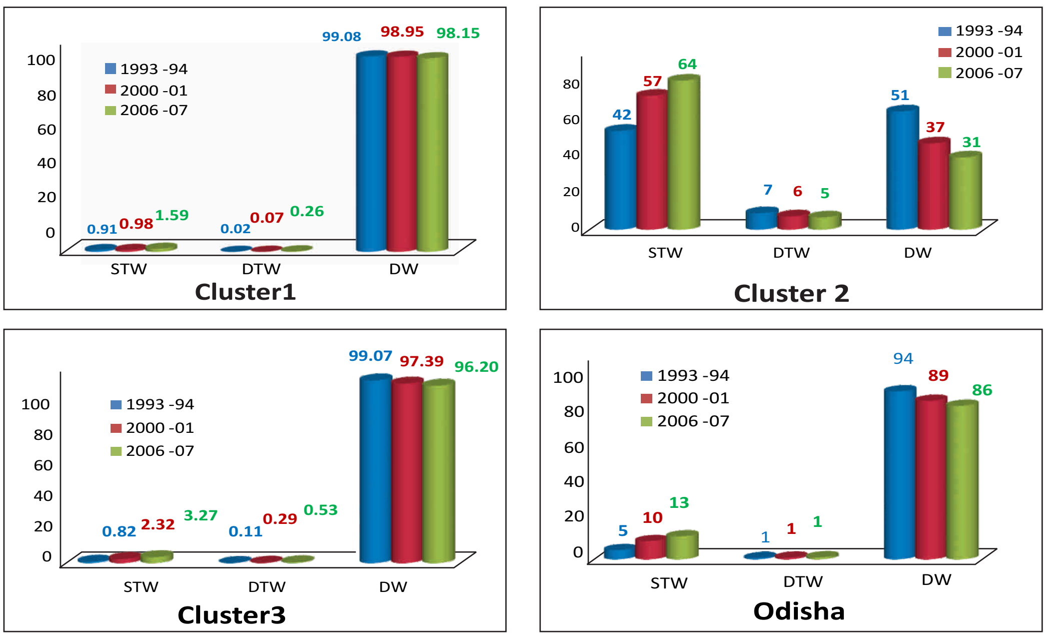

Figure 9. Changing share (%) of groundwater structures over the years

Note: STW: Shallow tubewells, DTW: Deep tubewells, DW: Dugwells

Table10. Ownership pattern of groundwater structures in Odisha in 2006-07

(% of total)

Cluster	GW structure	Government	Farmers' group	Individual farmer	Others	Total (000 no.)
Cluster1	STW	38.59	2.11	58.17	1.13	1
	DTW	12.28	7.02	**79.82**	0.88	0.11
	DW	1.18	0.05	98.55	0.23	44
	Total	1.80	0.10	97.86	0.24	45
Cluster2	STW	0.36	0.20	99.39	0.05	49
	DTW	**95.41**	0.57	3.48	0.54	4
	DW	0.20	0.07	99.66	0.07	24
	Total	5.34	0.18	94.40	0.08	77
Cluster3	STW	4.80	0.29	94.61	0.30	11
	DTW	35.02	1.39	**62.73**	0.85	2
	DW	0.27	0.44	98.36	0.13	341
	Total	0.60	0.44	98.05	0.14	354
Odisha	STW	1.64	0.24	98.02	0.11	61
	DTW	75.10	0.94	23.31	0.65	6
	DW	0.37	0.37	98.46	0.14	408
	Total	1.48	0.36	97.45	0.14	475

STW: shallow tubewells, DTW: Deep tubewells, DW: Dugwells

4.1.8. Inter-cluster variations in groundwater irrigation potential created (IPC) and its utilization (IPU)

Odisha's agricultural economy is primarily rainfed with only 35 per cent (31.77 lakh ha) of the gross cropped area irrigated through different sources (Govt. of Odisha, 2010). Groundwater resources constitute only 6.14 per cent (1.97 lakh ha) of gross irrigated area (4th MI Census). Although the irrigation potential created through groundwater in the state is 5.5 lakh ha (Table 11), its utilization (IPU) is only 35.22 per cent (1.97 lakh ha) in 2006-07 raising several efficiency issues in its utilization. The pace at which IPC through groundwater increased between 2000-01 (3rd MI census) and 2006-07 (4th MI census), due to massive Government support and incentives, could not continue for IPU resulting into decline in the per cent utilization from 51.53 per cent to 35.68 per cent during the same period. Among different sources of groundwater irrigation, dugwells predominated contributing 39.24 per cent and 43.08 per cent of the total IPC and total IPU, respectively in 2006-07. However, in utilization of created potential, shallow tubewells outpaced dugwells with the per cent utilization of 45.62. The per cent utilization of created potential declined for all the sources with deep tubewells witnessing highest decline in 2000-2006. Poor utilization of the irrigation potential through groundwater might be due to several factors such as unfavourable hydro-geological conditions, frequent failure of wells, poor maintenance, lack of assured electricity supply, saline water intrusion, etc.

Table 11. Irrigation potential created (PC) and irrigation potential utilized (IPU)

GW structure	Cluster1		Cluster2		Cluster3		Odisha	
	2000-01	2006-07	2000-01	2006-07	2000-01	2006-07	2000-01	2006-07
Irrigation Potential Created (000 ha)*								
STW	3	5	90	155	29	43	122	204
	(26.93)	(21.28)	(71.48)	**(54.04)**	(17.67)	(17.82)	(40.61)	(36.80)
DTW	0.17	0.73	26	114	6	18	32	133
	(1.35)	(3.23)	(20.39)	**(39.68)**	(3.87)	(7.32)	(10.69)	(23.99)
DW	9	17	10	18	127	182	146	217
	(71.72)	**(75.50)**	(8.13)	(6.28)	(78.46)	**(74.86)**	(48.70)	(39.21)
Total	13	22	126	288	161	243	300	553
Irrigation Potential Utilized (000 ha) #								
STW	3	2	47	70	16	20	66	93
	(87.71)	(51.30)	(52.63)	**(44.98)**	(56.08)	(47.33)	(54.43)	(45.63)
DTW	0.11	0.27	7	12	4	7	11	20
	(61.27)	(37.24)	(29.17)	(10.91)	(58.32)	(41.32)	(35.03)	(15.13)
DW	6	7	5	5	66	72	77	84
	(70.10)	(44.14)	(46.50)	(28.70)	(51.97)	(39.42)	(52.73)	(38.90)
Total	9.60	10.21	60	88	85	100	**155**	**197**
	(74.73)	(45.44)	(47.34)	(30.44)	(52.94)	(40.97)	(51.53)	(35.68)

*figures within parentheses are share of IPC created through respective GW structure in total IPC
figures within parentheses are the per cent utilization of created irrigation potential
STW: Shallow tubewell, DTW: Deep tubewells, DW: Dugwells

Cluster-wise diagnosis of IPC revealed the creation of irrigation potential is largely affected by the type of groundwater structures. With only 13 per cent of the total geographical area, 19 per cent of agricultural land, 24 per cent of groundwater resources and 16 per cent of groundwater structures of the state, cluster2 constituted about 52 per cent (2.88 thousand ha) of the total IPC of Odisha in 2006-07. This is primarily because of dominance of shallow and deep tubewells in this region which has larger irrigation command area as compared to dugwells. Shallow and deep tubewells created 54 per cent (155 thousand ha) and 40 per cent (114 thousand ha) of the total irrigation potential created in cluster2, respectively. Cluster1 and cluster3 constituted about 4 per cent and 44 per cent of the total IPC of Odisha in 2006-07, respectively. In these clusters, dugwells were the predominating structures which constituted about 75 per cent of the total IPC in the respective cluster.

Although cluster2 constituted highest share in total IPC of the state, it exhibited least (30.44%) utilization of already created potential as compared to other clusters in 2006-07 (Table11). The poor utilization of already created potential in cluster2 was primarily because of deep tubewells which could utilize only 11 per cent of the IPC created through it. Similarly, utilization of IPC through dugwells was only 29 per cent in 2006-07 in cluster2. In cluster1 and cluster3, utilization of IPC was 45 per cent and 41 per cent in 2006-07, respectively with the declining trend over the years. The poor utilization of the already created irrigation potential leads to loss of financial resources in one hand and loss of opportunity to improve agricultural productivity and income through advantages of assured irrigation on the other. Thus, the groundwater sector in Odisha is suffering from the dual problem of under-development of groundwater resources as well as under-utilization of the already created irrigation potential. Thus, identification of factors responsible of poor utilization of already created irrigation potential will go a long way to improve the irrigation infrastructure in the state.

4.1.9. Constraints in groundwater irrigation in Odisha

Under-development and inefficient utilization of groundwater resources in Odisha might be because of several hydro-geological, agro-climatic and socio-economic constraints. However, non-functioning of the wells was found to be an important reason of poor utilization of created irrigation potential. A perusal of table 12 reveals that about a quarter of total groundwater structures in Odisha are not-in-use due to temporary or permanent reasons. 63 per cent structures are not-in-use temporarily and 37 per cent permanently. Non-functioning of groundwater structure resulted into loss of 136 thousand hectare (24.56 per cent of IPC) irrigation potential annually in Odisha. About 60 per cent (80.09 thousand ha) loss in the IPC is due to non-functioning of deep tubewells alone which irrigate highest command area as compared to other sources. Dugwells and shallow tubewells contributed 25 per cent and 17 per cent loss in IPC in 2006-07.

Among the clusters, loss in the irrigation potential due to non-functioning of wells was highest (72 thousand ha) in cluster2. This was primarily because of mass scale non-functioning of deep-tubewells as about 75 per cent of the total deep-tubewells in cluster2 were found to be defunct. As majority of these structures are owned and maintained by Government agencies, mass scale non-functioning raises several inefficiency issues in operation and maintenance of deep tubewells. Further, as deep tubewells cover largest command area as compared to other wells, theses non-functional wells can be targeted and revived which would involve much less expenditure than to create new irrigation potential. Mass scale non-functionality of this Government owned tubewells also sets a strong platform for transferring their ownership to the farmers. Operation and management transfer to *pani-panchayat*/ water users' association (WUA) is steadily being recognized in India and can be successfully adopted for the revival of deep tubewells in Odisha.

Table 12. Proportion of GW structures not in use and loss in the irrigation potential in 2006-07

(per cent)

Cluster	GW structure	In-use	Not-in-use	Temporary not- in use*	Permanently not- in use*	IPC lost (000 ha)
Cluster 1	STW	79.72	20.28	59.03	40.97	0.97 (20.28)
	DTW	79.82	20.18	69.57	30.43	0.15 (20.18)
	DW	70.66	29.34	50.86	49.14	5 (29.34)
	Total	70.83	29.17	50.99	49.01	7 (29.17)
Cluster 2	STW	81.94	18.06	65.17	34.83	28 (18.06)
	DTW	24.59	75.41	38.05	61.95	86 (75.41)
	DW	69.04	30.96	52.84	47.16	6 (30.96)
	Total	74.85	25.15	56.09	43.91	72 (25.15)
Cluster 3	STW	86.18	13.82	55.39	44.61	6 (13.82)
	DTW	69.62	30.38	47.63	52.37	5 (30.38)
	DW	75.86	24.14	66.83	33.17	44 (24.14)
	Total	76.16	23.84	66.49	33.51	58 (23.84)
Odisha	STW	82.71	17.29	63.61	36.39	35 (17.29)
	DTW	39.61	60.39	39.74	60.26	80 (60.39)
	DW	74.90	25.10	63.81	36.19	54 (25.10)
	Total	75.44	24.56	63.03	36.97	136 (24.56)

Figures within parentheses are share of IPC lost in IPC created through respective GW structure
STW: shallow tubewells, DTW: Deep tubewells, DW: Dugwells

Different sources of groundwater exhibited different reasons of non-functioning (temporary or permanent) in Odisha (Table 13). Less discharge was the prime reason for temporary non-functionality of dugwells as 33.49 per cent of total temporarily non-functional dugwells were due to it. It is to be noted that dugwells are the most feasible source of groundwater in hard rock regions which comprises of more than 80 per cent of state's geographical area and characterized by less discharge, high draw-down and uncertain water bearing zones. Artificial recharge structures can be installed in these regions to improve the discharge rate of the wells. In case of shallow and deep tubewells, mechanical breakdown was the prime reason for their temporary non-functionality. These wells can be targeted and incentives can be provided to make these wells functional. Among the permanent reasons, destruction of wells was the single most important factor of non-functionality of all type of structures. Repairing and reinstallation of these structures will go a long way to improve the groundwater utilization and bring additional land under groundwater irrigation. Drying-up of the wells was the second important reason for permanent non-functioning which can be removed through artificial recharge structures.

Table 13. Reason-wise distribution of non-functional groundwater structure in Odisha in 2006-07

(per cent)

Struc-ture	Temporary reasons			Permanent reasons				
	Inadequate power	Mechanical breakdown	Less discharge	Salinity	Destroyed	Dried up	Sea-water intrusion	Industrial effluents
				Cluster 1				
STW	2.35	36.47	12.94	-	83.05	8.47	-	-
DTW	6.25	37.50	18.75	-	42.86	14.29	-	-
DW	0.15	2.31	43.93	0.05	58.43	13.51	0.84	0.10
Total	0.20	2.84	43.47	0.05	58.64	13.46	0.83	0.09
				Cluster 2				
STW	4.62	30.73	15.13	3.60	59.51	16.61	2.25	0.36
DTW	8.09	39.50	11.36	2.22	71.35	8.72	1.37	0.21
DW	0.41	5.45	51.55	0.84	63.50	17.06	3.09	0.17
Total	3.48	22.53	27.90	2.15	63.83	15.02	2.40	0.25
				Cluster 3				
STW	8.78	25.20	19.50	1.00	60.43	19.00	1.57	0.29
DTW	8.12	37.64	17.34	1.34	70.13	13.76	0.67	-
DW	0.23	3.69	0.95	0.12	61.25	19.37	1.94	0.13
Total	0.40	4.20	30.71	0.15	61.32	19.30	1.92	0.14
				Odisha				
STW	5.14	30.07	15.68	3.06	60.05	16.93	2.09	0.34
DTW	8.07	39.13	2.56	2.09	71.10	9.42	1.27	0.18
DW	0.23	3.66	3.49	0.17	60.98	18.15	1.86	0.13
Total	0.83	6.76	1.46	0.53	61.41	17.59	1.85	0.15

STW: shallow tubewells, DTW: Deep tubewells, DW: Dugwells

4.1.10. Energy use aspects of groundwater irrigation in Odisha

Out of the several direct and indirect demand-side management and supply-side augmentation approaches (Jeet I., 2005; Rosegrant M., 1997; Briscoe J. and Malik R.P.S., 2006; Kumar D., 2003), regulation of energy supply and pricing have often been suggested as an effective indirect approach for sustainable groundwater development (Malik R.P.S., 2008). For the state of Odisha, regulation of energy will play a crucial role to accelerate groundwater utilization and its sustainable development. Different aspects of energy use for groundwater irrigation are presented in the following section;

4.1.10.1. Major sources of energy for groundwater irrigation in Odisha

Energy source-wise distribution of groundwater structures in Odisha using recent (4^{th}) minor irrigation census revealed that 'man/animal' is the predominant source of energy in the state (Table 14). About 69 per cent of total working wells in Odisha were operated using 'man/animal' power in 2006-07. This is primarily because of dominance of dugwells in the state, 80 per cent of which are operated using 'man/animal' power. Further, the proportion of dugwells using 'man/animal' was comparatively higher in cluster1 (89%) and cluster3 (80%) as compared to cluster2 (70%). This might be because of the fact that slow groundwater withdrawal using 'man/animal' power will lead to less draw-down and thus ensure sustainable irrigation water than using pump with electric/diesel energy in hard rock areas (cluster1 and cluster3). In case of shallow tubewell, electricity was the major source of energy in cluster1 and cluster3 as about 60 per cent of the total shallow tubewells in these clusters were found to be operated using electrical power. In cluster2, 'diesel' was the predominant source of energy (48 per cent of the total functional groundwater structures were operated using diesel) primarily due to predominance of shallow tubewells in the region, 59 per cent of which operated with 'diesel' energy. About 39 per cent of the functional shallow tubewells used 'electric' operated pumps in the areas having access to electric supply. Inspite of technological superiority and cheap operational and maintenance of electric pumps over diesel pumps, farmers are forced to use diesel operated pumps due to poor power infrastructure and unreliable electricity supply for irrigation purpose (Malik R.P.S., 2008). Deep-tubewells, the large structures and primarily owned by the Government, are electric power operated (90%) in the areas where electric supply is accessible, though majority of these tubewells were found defunct.

In Odisha, only 1.3 per cent of total electricity consumption was consumed for irrigation and agriculture purpose in 2008-09 compared to national average of 20.97 per cent. Moreover, electricity consumption in agriculture sector showed a declining trend both in terms of absolute units as well as its share in total electricity consumption between 1992-93 and 2008-09 (Figure 10). The share of electricity consumption in agriculture sector declined from 5.6 per cent in 1992-93 to 1.3 per cent in 2008-09. The electricity consumption in absolute terms (units) have declined from 305 million in 1992-93 to 155 million in 2008-09. The decline in electricity consumption for agriculture purpose is inspite of the fact that about 60 per cent of the villages are already electrified as on 31.06.2010. This indicates the inefficiency in transmission and distribution of electricity for agriculture purpose.

Table 14. Energy source wise distribution of groundwater structures in Odisha in 2006-07

(per cent)

Cluster	Structure	Electricity	Diesel	Man/animal	Others	Total functional wells (00)
Cluster1	STW	61.66	32.69	4.06	1.59	6
	DTW	74.73	13.19	10.99	1.10	1
	DW	1.20	8.97	89.03	0.80	309
	Total	2.16	9.07	87.96	0.81	316
Cluster2	STW	38.86	58.94	1.17	1.04	394
	DTW	92.47	6.33	1.20	-	10
	DW	5.01	24.48	70.14	0.37	164
	Total	30.05	48.09	21.03	0.83	568
Cluster3	STW	60.75	29.58	8.88	0.79	98
	DTW	90.18	4.45	5.14	0.23	13
	DW	5.78	11.66	79.78	2.78	2,565
	Total	8.20	12.28	76.83	2.69	2,676
Odisha	STW	43.20	52.65	3.15	1.00	498
	DTW	90.55	5.56	3.72	0.17	24
	DW	5.27	12.08	80.20	2.44	3,038
	Total	11.15	17.71	68.91	2.23	3,559

STW: shallow tubewells, DTW: Deep tubewells, DW: Dugwells

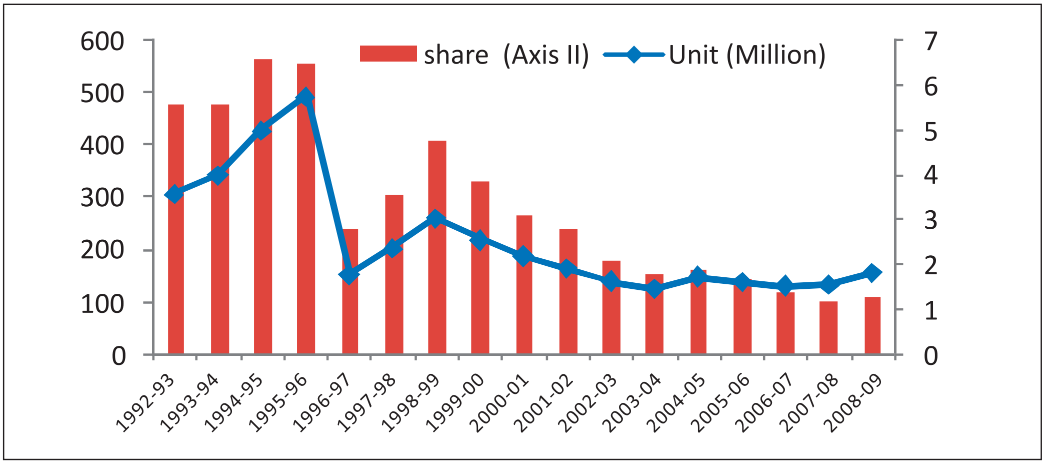

Figure 10. Electricity consumption for agriculture purpose and its share in total consumption over the years

4.1.10.2. Estimation of energy consumed in groundwater irrigation in Odisha

The energy consumption for groundwater irrigation depends on many factors such as groundwater table depth, aquifer properties, type of well, horse power of the pump (hp), pumping duration, etc. The energy consumption was estimated for different type of well in each cluster separately. The weighted average of the horse power (hp) was estimated as 3, 5, 0.5 and 0.38 for pumps with shallow wells, deep wells, dugwells and man/animal energy, respectively in cluster1 (Table 15). In cluster2, comparatively higher hp pump was used as compared to other clusters. But, due to comparatively higher water table and favourable aquifer properties, estimated discharge (lit/sec) in cluster2 was higher than other clusters.

Consequently, energy used to extract per cubic meter groundwater (KWh/m^3) was comparatively less in cluster2 (alluvial/coastal belt) than other clusters (hard rock). Among different types of wells, energy consumption (KWH/m^3) was highest in deep tubewells followed by shallow tubewells, dugwells (pump) and dugwells (man/animal) in all the clusters. The total energy consumption to extract groundwater annually (M Joule/annum) was estimated as 7.37 10^8 M Joule/annum in Odisha, 55 per cent (4.08 10^8 M Joule/annum) of which was consumed in cluster2. Cluster1 and cluster3 consumed 4 per cent and 41 per cent of the total energy consumed, respectively. Among the groundwater structures, shallow tubewells constituted highest share (63%) in the total energy consumed followed by dugwells (man/animal) in Odisha. However, this pattern varied across different clusters. In cluster1 and cluster3, dugwells (man/animal) constituted predominant share in total energy consumption, while in cluster2 shallow wells were the major consumer of energy (90%).

At farm level, energy consumption will depend on the type of the crops grown and their irrigation requirement. During *kharif* season, water requirement of many crops are mainly fulfilled by rainfall. However, supplemental irrigation is needed during long dry spell in few areas only. But during *rabi* and summer season, irrigation requirement are mainly fulfilled through groundwater. In the present study, energy requirement under different groundwater conditions for major crops grown in Odisha has been estimated and presented in the Table16. The irrigation requirement during *rabi* season (Nov-Jan) has been estimated based on potential evapo-transpiration (PET) and crop coefficient values. PET for alluvial areas (Jagatsinghpur) and hard rock area (khurda) has been calculated by FAO-56 method. The estimated energy requirement by deep tubewells (120 m) was found to be about 24 times higher than shallow wells (5 m) but, deep tubewell can irrigate higher command area.

Table 15. Cluster and well-wise energy consumption for groundwater irrigation in Odisha

Cluster	Well type	Estimated hp	Corrected hp	Energy (KW)	Total head (m)	GW draft (ℓ./sec)	Energy (KWh/cum)	Annual GW extraction (Cum/well)	Working wells (00)	Total energy (MJoule/annum) (10^6)	Share (%)
Cluster1	STW	3.54	3	2.24	12.24	7.35	0.085	25880	6	4.5	15.90
	DTW	5.78	5	3.73	30.71	4.88	0.212	17866	1	1.2	4.43
	DW_pump	0.75	0.5	0.37	8.94	1.68	0.062	4141	38	3.5	12.48
	DW_manual	0.38	0.38	0.28	7.02	1.63	0.048	3923	275	18.8	67.19
	Total	-	-	-	-	-	-	-	**320**	**28**	-
Cluster2	STW	2.70	3	2.24	11.03	8.16	0.076	33814	394	365.8	89.63
	DTW	9.41	10	7.46	17.63	17.02	0.122	56429	10	24.6	6.04
	DW_pump	1.14	1	0.75	6.63	4.52	0.046	11858	49	9.5	2.34
	DW_manual	0.38	0.38	0.28	5.81	1.97	0.040	4910	115	8.1	1.99
	Total	-	-	-	-	-	-	-	**568**	408.1	-
Cluster3	STW	2.63	3	2.24	12.53	7.18	0.087	29865	98	91.0	30.23
	DTW	6.24	5	3.73	29.45	5.09	0.203	19607	13	18.7	6.22
	DW_pump	0.94	0.5	0.37	9.23	1.63	0.064	4091	519	48.7	16.17
	DW_manual	0.38	0.38	0.28	7.30	1.57	0.050	3837	2046	142.6	47.37
	Total	-	-	-	-	-	-	-	**2676**	**301.0**	-
Odisha	STW	-	-	-	-	-	-	30740	498	461.3	62.57
	DTW	-	-	-	-	-	-	38833	24	44.6	6.05
	DW_pump	-	-	-	-	-	-	8562	605	61.7	8.37
	DW_manual	-	-	-	-	-	-	4063	2436	169.6	23.00
	Total	-	-	-	-	-	-	-	**3564**	737.2	-

STW: shallow tubewell, DTW: Deep tubewell, DW: Dugwell, GW: groundwater
For estimating annual groundwater extraction number of pumping days in monsoon and non-monsoon season were taken as 50 and 120, respectively. Further, pumping hours per day were calculated using 4th MI census.

Further, energy requirement to lift groundwater was more in hard rock areas due to relatively lower water level and high draw down than the alluvial areas. Thus, the decision to invest in shallow or deep tubewells rests on area to be irrigated, availability of cheap energy source (diesel VS electricity) and relative cost economics.

Table 16. Energy requirements under different groundwater Conditions

Crops	WR (m)	Wells and Tube wells Depth (m) and corresponding Energy Requirements (KWh/ha)									
		1	2	5	10	15	20	30	50	100	120
Jagatsinghpur (Alluvial area)											
Potato	0.43	44	88	220	439	659	879	1318	2197	4394	5273
Onion	0.29	30	59	148	296	445	593	889	1482	2963	3556
Brinjal	0.32	33	65	164	327	491	654	981	1635	3270	3924
Garlic	0.38	39	78	194	388	582	777	1165	1941	3883	4659
Groundnut	0.39	40	80	199	399	598	797	1196	1993	3985	4782
Chilli	0.39	40	80	199	399	598	797	1196	1993	3985	4782
Bitter gourd	0.28	29	57	143	286	429	572	858	1431	2861	3433
Sunflower	0.45	46	92	230	460	690	920	1379	2299	4598	5518
Khurda (hard rock area)											
Potato	0.43	53	105	264	527	791	1055	1582	2636	5273	6327
Onion	0.29	37	74	184	368	552	736	1104	1839	3679	4414
Brinjal	0.32	39	79	196	392	589	785	1177	1962	3924	4708
Garlic	0.38	48	96	239	478	717	956	1435	2391	4782	5738
Groundnut	0.39	49	98	245	491	736	981	1471	2452	4905	5886
Chilli	0.39	49	98	245	491	736	981	1471	2452	4905	5886
Bitter gourd	0.28	36	71	178	356	533	711	1067	1778	3556	4267
Sunflower	0.45	55	110	276	552	828	1104	1655	2759	5518	6621

WR: water requirement (meter)

4.1.11. Economic aspects of groundwater irrigation

The groundwater irrigation in India is primarily in private domain and involves high investment cost. Cost of groundwater irrigation varies widely across different types of the groundwater structures and source of the energy used. Therefore, the cost of groundwater extraction was estimated for different types of groundwater structures in each cluster under alternative sources of energy (electric/diesel). The estimated cost of groundwater extraction (Rs/m^3) was significantly higher in cluster1 and cluster3 (hard rock areas) as compared to cluster2 (alluvial/coastal belt) due to comparatively higher digging cost, higher head and less discharge in these areas (Table 17). In cluster1 (hard rock), estimated groundwater extraction cost was 131 per cent, 233 per cent and 330 per cent higher than cluster2 (alluvial) in diesel operated shallow wells, deep tubewells and dugwells, respectively. Similarly, in electric operated shallow wells, deep tubewells and dugwells, estimated groundwater extraction cost in cluster1 was 207 per cent, 435 per cent and 657 per cent higher than cluster2 (alluvial), respectively. Similar pattern was found between cluster3 and cluster2.

Table 17. Economics of groundwater irrigation

Particulars	Energy source	Cluster1			Cluster2			Cluster3		
		STW	DTW	DW	STW	DTW	DW	STW	DTW	DW
Horse power of the pump (hp)	E, D	3	5	0.5	3	10	1	3	5	0.5
Energy (KW)[1]	E,D	2.24	3.73	0.37	2.24	7.46	0.75	2.24	3.73	0.37
Total head (meter)	E,D	12.24	30.71	8.94	11.03	17.63	6.63	12.53	29.45	9.23
GW draft (ℓ./sec)	E,D	7.35	4.88	1.68	8.16	17.02	4.52	7.18	5.09	1.63
Diesel (ℓ./ m^3)[2]/electricity (KWh/ m^3) consumption	Electricity	0.085	0.212	0.062	0.076	0.122	0.046	0.087	0.203	0.064
	Diesel	0.028	0.071	0.021	0.026	0.041	0.015	0.029	0.068	0.021
Cost of energy (Rs/ m^3)[3]	Electricity	0.09	0.23	0.07	0.08	0.13	0.05	0.10	0.22	0.07
	Diesel	1.28	3.20	0.93	1.15	1.84	0.69	1.31	3.07	0.96
Digging Cost (000, Rs)	E,D	100	300	90	50	150	30	100	300	90
Pump Cost (000, Rs)	E,D	15	30	8	15	55	10	15	30	8
Annual Maintenance cost (Rs)	Electricity	150	300	80	150	550	100	150	300	80
	Diesel	750	1500	400	750	2750	500	750	1500	400
Annual water extraction (m^3/well)[4]	E,D	25880	17866	4141	33814	56429	11858	29865	19607	4091
Total annual amortized cost (Rs/m^3)	Electricity	0.48	1.97	2.52	0.19	0.37	0.34	0.42	1.80	2.55
	Diesel	0.51	2.04	2.60	0.21	0.41	0.38	0.44	1.86	2.63
Total irrigation cost (Rs/m^3)	Electricity	0.58	2.21	2.59	0.28	0.51	0.39	0.51	2.02	2.62
	Diesel	1.78	5.24	3.53	1.36	2.25	1.07	1.74	4.93	3.59
Share of energy in total irrigation cost (%)	Electricity	16.17	10.57	2.63	30.21	26.37	12.79	18.55	11.07	2.68
	Diesel	71.61	61.05	26.40	84.47	81.64	64.68	74.87	62.26	26.78
Total electricity (KWh/well)/diesel (ℓ./well) consumption	Electricity	2189	3790	256	2577	6870	543	2585	3989	261
	Diesel	733	1270	86	864	2302	182	866	1337	87
Per well subsidy (Rs/well)	Electricity	6522	11295	762	7679	20474	1619	7702	11887	777
	Diesel	8024	13896	938	9448	25188	1992	9476	14625	956

E: Electric pump, D: Diesel pump

1. 1 hp=0.746 KW
2. 1Hp pump consumes about 250 ml diesel per hour
3. Diesel cost @ Rs.45/litre, Electric cost @ Rs 1.1/unit (KWh)
4. For estimating annual groundwater extraction number of pumping days in monsoon and non-monsoon season were taken as 50 and 120, respectively. Further, pumping hours per day were calculated using 4^{th} MI census.
5. Amortization was done at 6% rate of interest and average age of wells was assumed as 15 years for hard rock areas and 20 years for alluvial region. Average age of pump was assumed as 10 years
6. Subsidy was estimated @Rs. 10.94/liter diesel and Rs. 2.98/unit (KWh) of electricity

Further, the groundwater extraction cost (Rs/m^3) was significantly higher in diesel operated pumps as compared to electric operated pumps. In cluster1, estimated groundwater extraction cost in diesel operated shallow wells, deep tubewells and dugwells was 309 per cent, 237 per cent and 136 per cent higher than electric operated pumps, respectively. In cluster2, estimated groundwater extraction cost in diesel operated shallow wells, deep tubewells and dugwells was 490 per cent, 443 per cent and 271 per cent higher than electric operated pumps, respectively. Similarly, in cluster3, estimated groundwater extraction cost in diesel operated shallow wells, deep tubewells and dugwells was 490 per cent, 443 per cent and 271 per cent higher than electric operated pumps, respectively. Significantly higher cost of groundwater extraction in diesel operated pumps (than electric pump) was due to higher share of diesel in total irrigation cost than electricity (Table 17). The share of diesel in total irrigation cost was 72 per cent, 61 per cent and 26 per cent in cluster1, 84 per cent, 82 per cent and 65 per cent in cluster2 and 75 per cent, 62 per cent and 27 per cent in cluster3 in shallow wells, deep tubewells and dugwells, respectively. On the other hand, the share of electricity in total irrigation cost was 16 per cent, 11 per cent and 3 per cent in cluster1, 30 per cent, 26 per cent and 13 per cent in cluster2 and 19 per cent, 12 per cent and 3 per cent in cluster3 in shallow wells, deep tubewells and dugwells, respectively. Therefore, the impact of a unit increase in energy cost, a common phenomenon now a days, on total irrigation cost will be much less in electric operated wells than diesel pumps. However, in a situation which is plagued by poorly developed power infrastructure, deficit and unreliable power supply, shifting from diesel to electric energy is the most challenging task.

Presently, for irrigation/agriculture sector, being a special category both from political and social ground, the Government is providing diesel as well as electricity at subsidized rate. However, the impact of energy subsidy on the sustainability of the water resources is a debatable issue among the researchers. On diesel, the Government is providing subsidy of ₹.10.97 per liter as on February, 2012. Similarly, the electricity tariff in Odisha is kept only at 110 paise per unit for LT connections and 100 paisa/unit for HT connections under a metered or pro-rata tariff system (OERC, 2011). However, the cost of electricity supply has been determined at 408.87 paise per unit for 2011-12 and a cross subsidy of 298.87 paise per unit (408.87 – 110 paise per unit) is paid to the farmers. Therefore, an increase in electricity tariff atleast by 217 paise per unit is required to reach the lower limit (408.78 – 20% =327.07) of the prescribed electricity tariff (±20 per cent of the supply cost) by National Electricity Policy (OERC, 2011).

The increase in electricity tariff will not only reduce the subsidy burden on Government exchequer but also bring about efficiency in use of groundwater resources due to positive marginal cost of the pumping (Kumar and Singh, 2001; Saleth, R.M., 1997). But, tariff hike may also curtail the electricity demand and thereby groundwater utilization. Due to the small share of electricity cost in total production cost (Narayanmoorthy, A. 1997), tariff hike shall produce a meager impact on groundwater withdrawal though there are divergent views on implications of tariff hike on electricity demand and groundwater use (Kumar and Singh, 2001; Saleth, R.M., 1997; De Fraiture and Perry, 2002) Kumar and Patel argued that net returns from the well irrigated commands will be more elastic to adequacy and reliability of irrigation water rather than the cost of energy. The positive impact of adequate and quality electricity supply on farm economy will trickle down to well irrigators with 'man/animal' power (especially in hard rock areas) who will switch to electric pump to cover higher command area and reduce drudgery.

The estimated groundwater extraction cost with the increased electricity tariff rate (327 paise per unit for assessment year 2011-12) was lesser (30% to 135% in cluster1, 117% to 207% in cluster2 and 30% to 149% in cluster3 depending upon type of wells) than subsidized diesel operated wells. Hence, the farmers with the diesel pump will naturally be shifting to electric pumps provided assured and quality electricity supply is guaranteed. Additionally, if conducive product disposal infrastructure (marketing, processing, cold storage, etc) is provided, the assured irrigation will also motivate the farmers to diversify towards high value crops such as vegetables, floriculture, etc which will accelerate the overall agricultural growth in the state. It is worth noting that above mentioned benefits of electricity based irrigation rest on the provision of assured and quality power supply and development of favourable marketing infrastructure in the state. The part of the investment in developing power and marketing infrastructure can be made through the increase in power tariff and the removal of estimated annual subsidy per well (Table17). Therefore, in the Odisha state, which is pioneer in electricity reforms in the country, there is ample opportunity to harness the potential of groundwater resources through suitable energy regulations for accelerated agricultural growth.

4.1.12. Inter-cluster variations in agricultural performance in Odisha

Odisha occupies 4.74 per cent of the geographical area and 3-4 per cent of the agricultural and irrigated area of the country. The predominant agriculture and allied sectors contribute about 30 per cent of the Odisha's GDP and provides livelihood to about 60 per cent of the workforce. About 36 per cent of the total geographical area of the state is put to agriculture use (Table 18) as compared to national average of 42 per cent. Further, there exists wide variation in land use pattern in different regions of the Odisha (Figure 11). In cluster1 and cluster3, 25 and 37 per cent of the total geographical area is used for agriculture purpose, respectively as compared to 52 per cent in cluster2. This is primarily because of predominance of forest area (46 % in cluster1 and 39% in cluster3) in the former regions. The topography of the agriculture land in the state is not uniform across the regions. 47, 28 and 24 per cent of the cultivated area in Odisha is categorized as high, medium and low land with wide inter-cluster variations (Figure 11). The cultivated land in cluster1 and cluster3 is predominated by high land constituting 64 and 51 per cent of the total cultivated land, respectively. On the other hand, cultivated land in cluster2 is predominated by low land constituting 43 per cent of the total cultivated land. Varying topographic characteristics along with the input use pattern and available infrastructure facilities determine cropping pattern in a particular region.

Table 18. State of Agriculture in Odisha during TE 2008

Particulars	Cluster1	Cluster2	Cluster3	Odisha
Geographical area (000, ha)	3808	2093	9697	15571
Net Sown area (000, ha)	953	1080	3616	5649
Agriculture coverage (%)	25.02	51.58	37.29	36.14
Gross Sown Area (000, ha)	1463	1897	5709	9068
Cropping Intensity (%)	154	176	158	161
Normal Rainfall (mm)	1524	1498	1407	1451
Net Irrigated Area (000, ha)	259	566	1225	2049
Gross Irrigated Area (000, ha)	412	982	1847	3240
Irrigation Coverage (%)	28.15	51.76	32.35	35.73
Groundwater Development (%)	14.23	42.90	24.37	26.14
Fertilizer Consumption (Kg/ha)	39	75	48	54
Share of Power Consumption for Agriculture Purpose (%)	-	-	-	1.30
Average paddy yield (kg/ha)	2067	2320	2336	2317
Agriculture Development Index (%)*	22.93	62.78	36.96	40.18

Agriculture development index has been estimated using agriculture coverage, cropping intensity, irrigation coverage, fertilizer consumption, groundwater development and paddy yield
Data source: Directorate of Economics and Statistics, Government of Odisha

The Odisha's agriculture is primarily rainfed (only 35.62% irrigation coverage) and dominated by paddy-fallow/pulses copping pattern. The paddy and pulses occupied 67 per cent and 50 per cent of the *kharif* and *rabi* cropped area, respectively in triennium ending (TE) 2008-09 (Figure 12). Paddy was the predominant cereal crop constituting 91 per cent of the total cereals area in the state TE 2008-09 (Table 19). In cluster1 and cluster3, cropping pattern was found to be more diversified than in cluster2. In cluster2, 91 per cent of the *kharif* and 53 per cent of the *rabi* cropped area was found to be occupied by cereals (paddy constituted 99% of total cereals area) and pulses in TE 2008-09, respectively. The low and medium land topography (83% of total cultivated area) in cluster2 might have contributed significantly for the dominance of paddy in the cropping pattern because of suitability of paddy (95 per cent of the low land and 86 per cent of the medium land was occupied with paddy) in these areas (Figure 13). Interestingly, in 43 per cent (0.97 lakh ha) of the total high land (2.25 lakh ha) in cluster2, paddy was cultivated in TE 2008-09 which can be substituted by the non-paddy crops. In cluster1, comparatively less area is cultivated under cereals (71%) than cluster2 in *kharif* season and paddy occupied 71 % of the total cereals areas. About 20 per cent of the *kharif* cropped area was occupied by pulses and oilseeds in TE 2008-09. The oilseeds and pulses must have been cultivated in high land (61% of total cultivated land) in cluster2. Further, 99, 76 and 35 per cent of the total low (1.37 lakh ha), medium (2.33 lakh ha) and high (6.72 lakh ha) land in *kharif* season was occupied with paddy, respectively. Therefore, paddy occupied high land area (35% or 2.34 lakh ha) in cluster1 can be substituted by the non-paddy crops. In the *rabi* season, 40 per cent of the total cultivated area was constituted by pulses followed by oilseeds (22%) and vegetables (19%) in TE 2008-09. It is to be noted that the share of vegetables in total *rabi* cropped area was highest in cluster1 as compared to other regions. Thus, the promotion of vegetables cultivation in cluster1 along with the micro-irrigation system (feasible technology for low discharge rate aquifers) appears the promising target. Similarly, in cluster3, vegetable cultivation can be promoted by diverting about 35 per cent (7.12 lakh ha) of the high land area which is presently been cultivated under paddy. Thus, there exists scope for diversification in paddy occupied 10.43 lakh ha (36% of the total high land) area in Odisha by developing irrigation facilities (both surface and groundwater), adequate input supply and efficient marketing infrastructure. Cluster1, cluster2 and cluster3 constitute 22.44 (2.34 lakh ha), 9.30 (0.97 lakh ha) and 68.26 (7.12 lakh ha) per cent share in this potential area (10.43 lakh ha), respectively.

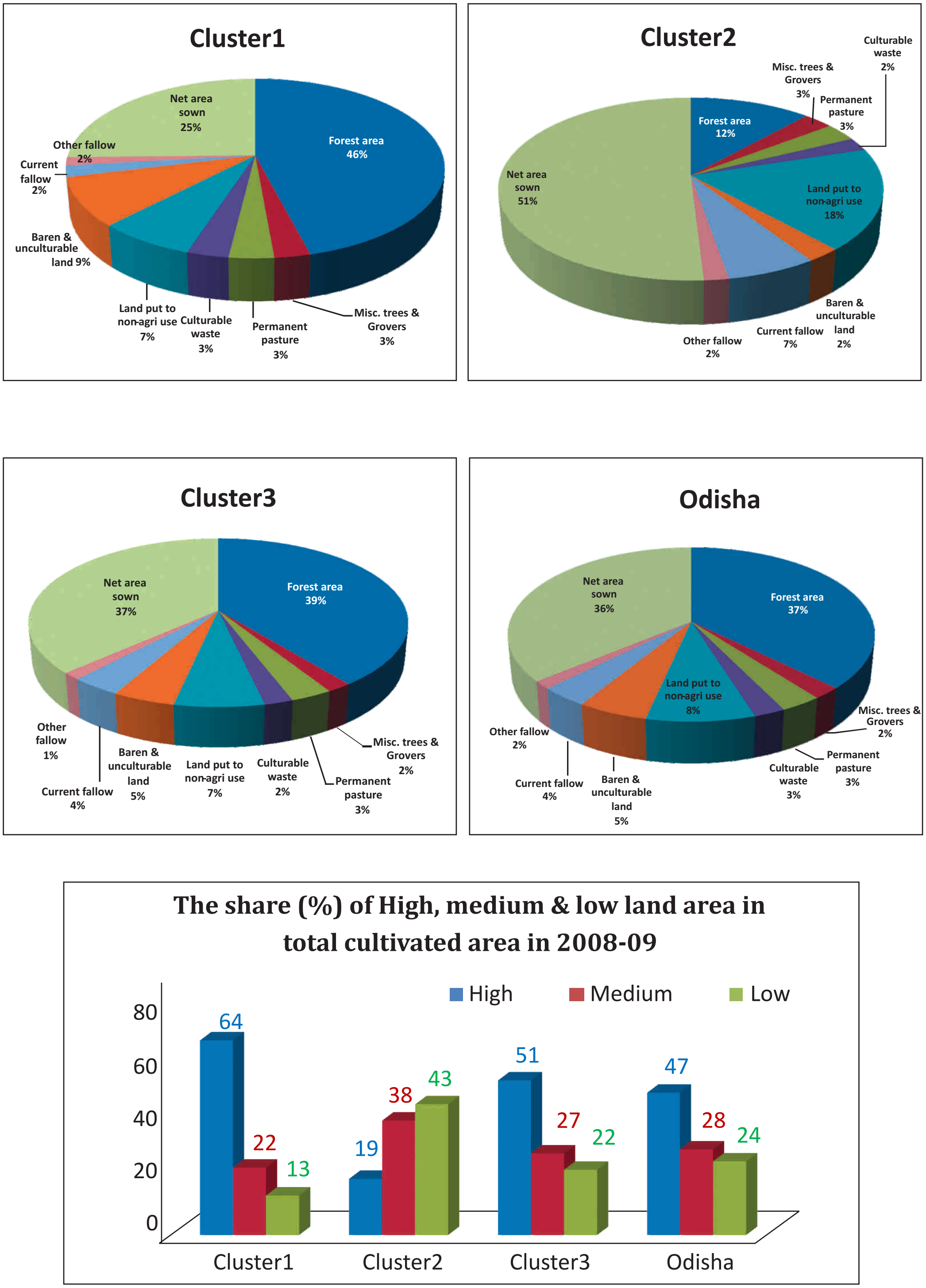

Figure 11. Cluster-wise land use pattern in Odisha in 2008-09

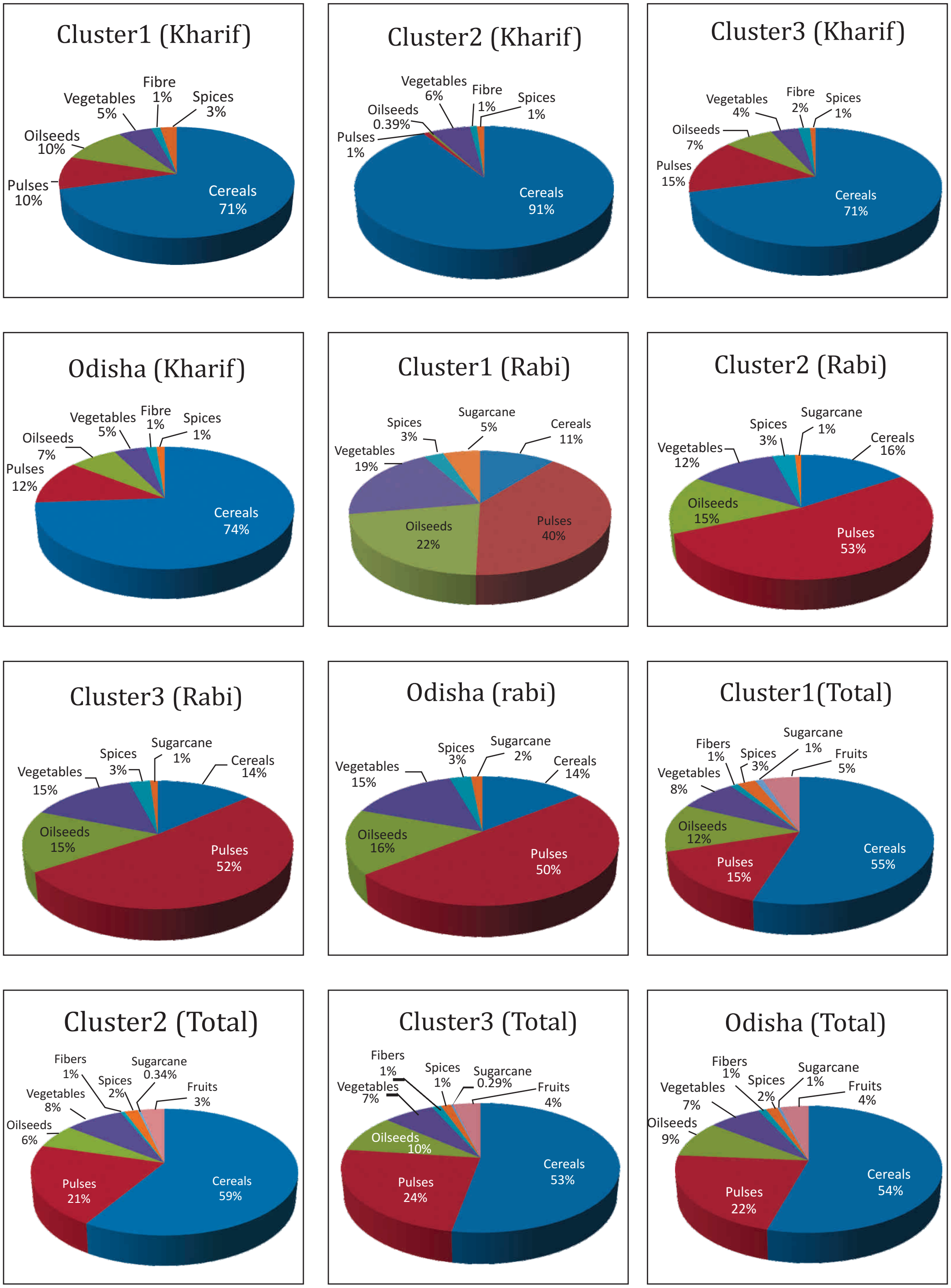

Figure 12. Cluster and season wise cropping pattern(the share of crops in gross cropped area) in Odisha in TE 2008-09

Table 19 . Cluster and season wise area under different crops in Odisha in TE 2008-09

(000, ha)

Crop	Cluster1			Cluster2			Cluster3			Odisha		
	Kharif	*Rabi*	Total	*Kharif*	*Rabi*	Total	*Kharif*	*Rabi*	Total	*Kharif*	*Rabi*	Total
Rice	546	24	571	990	112	,103	2,727	193	2,919	4,126	326	4,452
Other cereals	224	8	231	6	4	9	187	22	209	416	33	449
Total Cereals	769	32	801	996	116	1,112	2,913	215	3,129	4,542	359	4,901
Pulses	104	117	221	9	388	397	608	826	1,434	722	1,256	1,978
Foodgrains	874	149	1,022	1,005	504	1,509	3,521	1,042	4,563	5,263	1,616	6,879
Oilseeds	113	64	177	4	111	115	311	244	555	428	407	835
Vegetables	58	58	116	64	92	155	173	237	410	287	375	662
Fibers	16	-	16	11	-	11	74	-	74	98	-	98
Spices	29	8	37	12	24	36	34	46	81	73	73	147
Sugarcane	-	16	16	-	6	6	-	17	17	-	39	39
Fruits	-	-	75	-	-	64	-	-	220	-	-	353
Total Cropped area	1090	298	1463	1096	737	1897	4113	1587	5709	6299	2622	9016

Figures within parentheses are Gross cropped area (000 ha)

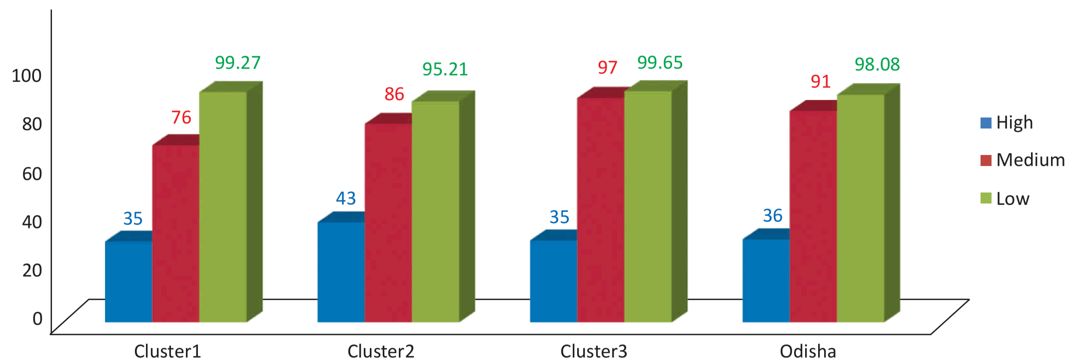

Figure 13. The share (%) of *Kharif* paddy area in total high, medium & low land

However, it is to be noted the agriculture development in cluster1 and cluster3 (which have high potential of diversification towards non-paddy crops) far behind than in cluster2. The estimated agriculture development index (consisting of agriculture coverage, cropping intensity, irrigation coverage, groundwater development, fertilizer consumption and paddy yield) in cluster1 and cluster3 was only 22.93 and 36.96 respectively as compared to 62.78 per cent in cluster2 in TE 2008-09 (Table 18). The comparatively poor agriculture performance in cluster1 and cluster3 was due to poor irrigation facilities (less groundwater development and irrigation coverage), less fertilizer consumption (kg/ha) resulting into less cropping intensity. The irrigation coverage in cluster1 and cluster3 was 28.15 per cent and 32.35 per cent, respectively as compared to 51.76 per cent in cluster2 in TE 2008-09. Similar pattern was found in groundwater development and fertilizer consumption. The groundwater development activities in cluster1 and cluster3 would not only provide assured irrigation but also encourage farmers to increase fertilizer consumption. Additionally, if conducive product disposal infrastructure (marketing, processing, cold storage, etc) is provided, the assured irrigation will motivate the farmers to diversify towards high value crops such as vegetables, floriculture, etc which will accelerate the overall agricultural growth in these regions as well as in the state.

4.1.13. Policy options for sustainable development of groundwater resources in Odisha

- Positive impact of groundwater development on agricultural income in Odisha proofs groundwater an important tool for accelerating agricultural growth in the state. The sincere efforts should be extended to develop groundwater resources on sustainable basis.
- Varying hydro-geological conditions and therefore groundwater utilization in different parts of the state necessitate location specific intervention for sustainable management of groundwater resources. The adoption and popularization of water saving options like micro-irrigation technology in cluster1, where draw-down is very high and discharge is low, is appropriate. This shall be accompanied by implementation of suitable location specific groundwater recharge activities using scientific tools and investigations in these areas which would improve the well yield and subsequently groundwater draft for irrigation.
- On the other hand, groundwater exploitation in comparatively better developed alluvial/coastal areas (cluster2) needs precautions with respect to sea water intrusion. The regulation of pumping depth, horse power (hp) and

pumping hours within the safe limit and its strict monitoring at local governance level in coastal areas is essential to avoid negative externalities of groundwater development.

- The groundwater resources in Odisha are suffering from dual problem of its under-development as well under-utilization of already created irrigation potential. The administrative blocks witnessing no change/increasing in water table depth over the years shall be targeted to accelerate the groundwater utilization for irrigation. On the other hand, in the blocks witnessing declining trend in water tables needs groundwater extraction in conjunction with the use of surface water. Recharge activities shall also be implemented in hydrologically bound areas i.e. either on watershed basis or river basin areas.

- The under-utilization of already created irrigation potential not only lead to loss of financial resources but also opportunity to improve agricultural productivity through advantages of assured irrigation. The under-utilization of already created irrigation potential is primarily because of non-functioning of a large number of wells. Action should be initiated towards repair, reinstallation and maintenance of these defunct wells to improve irrigation infrastructure which would involve much less investment than creating new structures in the state.
- Mass-scale non-functionality of deep wells (primarily owned by Government) sets an urgent need of transferring their ownership towards better performing '*Pani-Panchayat/*water users' association.
- It is prudent to invest in providing quality electricity for pumping at higher prices than subsidizing electricity for agriculture as removing electricity subsidy would increase the irrigation cost only by 3-16 per cent in cluste1, 13-30 per cent in cluster2 and 3-19 per cent in cluster3 depending upon the type of wells used. This increase will be much lower than the irrigation cost using even subsidized diesel. Consequently, if assured and quality electricity is guaranteed, irrigators with diesel pump will switch to electrical energy to maximize the net profit. The part of the investment needed for creating such infrastructure can be met by removal of energy (electricity/diesel) subsidy.

- There exists scope for diversification in paddy occupied 10.43 lakh ha (36% of the total high land) area in Odisha. The scope for diversification is more in the regions (cluster1 and cluster3) witnessing poor agricultural performance. Sustainable groundwater development activities along with adequate input supply and efficient marketing infrastructure would go a long way to improve the agricultural performance in the state.

4.2. Summary and conclusion

Odisha's agriculture sector is characterized as low input-low productive with high risk and regional inequality. The groundwater development bears a positive relationship with the agricultural income and as most of the ultimate irrigation potential (UIP) from groundwater in Odisha remains unutilized due to under-development of groundwater resources, its sustainable development will accelerate the agriculture growth in the state. However, the groundwater resources in Odisha are suffering from dual problem of its under-development as well under-utilization of already created irrigation potential. The under-development of groundwater in the state is primarily due to predominance of hard-rock geology which restricts its development due to its aquifer properties. Implementation of suitable recharge activities using scientific tools and investigations in these areas would improve the well yield and subsequently groundwater draft for irrigation. On the other hand, groundwater exploitation in comparatively better developed alluvial/coastal areas needs precautions with respect to sea water intrusion. The regulation of pumping depth, horse power (hp) and pumping hours within the safe limit and its strict monitoring at local governance level in coastal areas is essential to avoid negative externalities of groundwater development. The under-utilization of already created irrigation potential not only lead to loss of financial resources but also opportunity to improve agricultural productivity through advantages of assured irrigation. Non-functioning of wells was one of the important factors of poor utilization of created potential. These defunct wells can be repaired, reinstalled and maintained to improve irrigation infrastructure which would involve much less investment than creating new structures in the state. Mass-scale non-functionality of deep wells (primarily owned by Government) sets an urgent need of transferring their ownership towards better performing *Pani-Panchayat/*water users' association.

The energy use pattern, which bears a direct relationship with groundwater development, exhibited regional variations in the state. In the hard rock region, 'man/animal' power was the dominant energy source (because of predominance of dugwells), while diesel emerged as a major energy source in the alluvial/coastal areas. Inspite of technological superiority and cheap operational and maintenance of electric pumps over diesel pumps, farmers are forced to use diesel operated pumps due to poor power infrastructure and unreliable electricity supply for irrigation purpose. The cost of groundwater extraction using diesel is much higher than electricity and the increased groundwater extraction cost at higher electricity tariff (if electricity subsidy is removed) will be lesser than using diesel even at subsidized rate. Consequently, if assured and quality electricity is guaranteed, irrigators with diesel pump will switch to electrical energy to maximize the net profit. The positive impact of assured and reliable electricity will also trickle down to irrigators using 'man/animal' power to switch to electric pump in the hope of higher irrigation coverage and reduced drudgery. Additionally, if conducive product disposal infrastructure (marketing, processing, cold storage, etc) is provided, the assured irrigation will motivate the farmers to diversify towards high value crops such as vegetables, floriculture, etc which will accelerate the overall agricultural growth in the state. The scope of diversification is more in hard rock regions of the state. However, realization of the above mentioned benefits rests on the condition of assured and quality electric supply for irrigation and conducive market infrastructure in the state. The part of the investment needed for creating such infrastructure can be met by removal of electric as well diesel subsidy. Therefore, in the Odisha state, which is pioneer in electricity reforms in the country, there is ample opportunity to harness the potential of groundwater resources through suitable technological interventions and energy regulations for accelerated agricultural growth.

References:

A. Narayana Moorthy (2008), "Losers and gainers of groundwater irrigation development: an empirical study from peninsular India", Annual Report, 2008, IWMI water policy research prgramme , Phase II: 2006-2010.

Ballabh Vishwa, K Chowdhary, Sushil Pandey and Sudhakar Mishra (2002). 'Groundwater Development and Agricultural Production: A Comparative Study of Eastern Uttar Pradesh, Bihar and West Bengal'. IWMI-Tata Water Policy Research Program, Anand

Briscoe, J. and Malik, R.P.S. India's Water Economy: Bracing for a Turbulent Future. The World Bank, Oxford University Press, New Delhi, 2006.

CGWB, Groundwater Scenario of India, Ministry of Water Resources, Government of India, 2010.

De Fraiture, C., Perry, C. Why is the irrigation water demand curve inelastic at low price ranges? Paper presented at International conference on: Irrigation water Policies: Micro and macro considerations. Jointly organized by Worldbank and Government of Morocco. Agadir, Morocco, June 15-17, 2002.

Dhawan, B.D. (1982). 'Development of Tubewell Irrigation in India'. Agricole Publishing Academy, New Delhi.

Government of Odisha, Economic Survey, 2009-10, Planning and Coordination Department, Directorate of Economics and Statistics, 2010.

Jeet, I., Groundwater Resources of India: Occurrence, Utilization and Management, New Delhi, Mittal Publications, 2005.

Kumar, Dinesh, Demand Management in the Face of Growing Water Scarcity and Conflicts in India: Institutional and Policy Alternatives for Future. In Chopra, Kanchan, Rao, Hanumantha, C.H. and Sengupta, Ramprasad (Eds.) *Water Resources and Sustainable Livelihoods and Eco-System Services*, Concept Publishing Company, New Delhi, 2003, 97-131.

Kumar, M.D. and Singh, O.P., market instruments for demand management in the face of growing scarcity and overuse of water in India. Water Policy **5**(3), 86-102, 2001

Kumar, M.D., Patel, P.J., Depleting buffer and farmers response: study of villages in Kheralu, Mehsana, Gujarat. In: Moench, M. (Ed.), Electricity prices: A tool for Groundwater management in Inda? VIKSAT- Natural Heritage Institute, Ahmedabad.

Malik, R.P.S., Energy regulations as a demand management Option: potentials, problems, and prospects, In Saleth, R.M. (Ed), Strategic analyses of the National River Linking Project (NRLP) of India, Series 3. Promoting Irrigation Demand management in India: Potentials, Problems and Prospects. International Water Management Institute, Colombo, Sri Lanka, 2008, 71-92.

OERC, Annual Report, 2010-11, Orissa Electricity Regulatory Commission, Government of Odisha, 2011.

Rodell, M, Isabella Velicogna and James S Famiglietti (2009): "Satellite-based Estimates of Groundwater Depletion in India", *Nature,* Vol 460, 20 August.

Rosegrant M., Water resources in 21st Century: Challenges and implications for action. Food, agriculture and environment Discussion paper 20. IFPRI, Washington DC., 1997.

Saleth, R. M., Power tariff policy for groundwater regulation: Efficiency, Equity and sustainability. Artha Vijnana 39 (3), 312-322, 1997.

Sethi, L. N., Sudhindra N. Panda and Manoj K. Nayak (2006), " Optimal crop planning and water resources allocation in a coastal groundwater basin, Orissa, India", Agricultural Water Management, 83, pp. 209-220.

Shankar, P.S.V, H. Kulkarni, S.R. Krishna (2011), India's groundwater Challenge and the way forward, *Economic & Political Weekly,* January 8, Vol xlvi 38 no 2.

Sharma, K.D. (2009), "Groundwater management for food security" , current Science, Vol. 96, No. 11, 10 June, 2009, pp. 1444-1447.

Singh, O.P. (2008), "Impact of energy pricing and supply regulation on irrigated agriculture: A comparative analysis from water rich and water scarce regions of India", Annual Report, 2008, IWMI water policy research programme , Phase II: 2006-2010.

Srivastava, N.S.L. Animate Energy in Agriculture. Publication on Invited Papers International Conference on Managing Natural Resources for Sustainable Agricultural. Production in the 21st Century, held at New Delhi during February 14-18, 2000, 466-477, 2002.

Swain, M., Mrutyunjay, Swain and D.K. Das, (2009), " regional disparity in agricultural development in Orissa in the pre and post reform period", Social Change, vol. 39 no.2 , pp. 195-215.