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DILEEP K. PANDA, A. MISHRA, B. K. JAMES,
S.K. JENA, R.B. SINGANDHUPE

WATER TECHNOLOGY CENTRE FOR EASTERN REGION
(Indian Council of Agricultural Research)
Chandrasekharpur, Bhubaneswar, Orissa - 751 023

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Dileep K. Panda, Scientist (Agri. statistics), WTCER
A. Mishra, Principal Scientist (SWCE), WTCER
B. K. James, Director (Acting), WTCER
S.K. Jena, Senior Scientist (SWCE), WTCER
R. B. Singandhupe, Senior Scientist (Agronomy), WTCER

Water Technology Centre for Eastern Region
(Indian Council of Agricultural Research)
Chandrasekharpur, Bhubaneswar-751023, Orissa, India
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Fax: 91-674-2301615
Email: wtcer@stpbh.soft.net
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Authors

Preface

The trend detection and study of ground water level fluctuation are essential for understanding the potential future changes given the occurrence of repeated droughts along with ever increasing anthropogenic thrust. Ground water being the safest source of drinking water, which supplies over 90 per cent of the drinking water need and the only option for the 70 per cent population of the rural India, its sustainability must be ensured through technological interventions. Again, it serves 40 per cent of the water requirement of agriculture. But, this precious natural resource is in danger due to anthropogenic factor like unscrupulous boring for agriculture so also due to natural calamity. For example, the drought 2002 created havoc in the sense that the ground water level depleted so deep that it will take years to recharge and recover in many parts of the country. In the present work, the ground water level trend over years has been studied using non-parametric statistical methods for the state Orissa that is reeling through natural calamities of one kind or the other for last few years. Detection and quantification of trends will indicate the type and amount of anthropogenic thrust on the water resources. This study is essentially a part of separating the signal that result from the impact of climate change from the noise that is an intrinsic part of hydrology. The vulnerable zones where ground water level dropped significantly over last 10 years have been identified at different level of significance so that preventive measures can be taken up.

We extend our sincere thanks to Mr. P. K. Mohapatra, Scientist-D, Central Ground Water Board (CGWB), Bhubaneswar for preparing the maps on GIS platform for the bulletin. Acknowledge and appreciate the needful help extended to us from the scientific colleagues and other staff members of WTCER, Bhubaneswar.

Hope and look forward that this bulletin will be of immense use to the developmental agencies and policy makers of the state as well as the central government to intervene and take appropriate steps to safeguard the precious ground water resource.

Authors

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Executive Summary

The Intergovernmental Panel on Climate Change has reported that one of the anticipated effects of climate change is the possible increase in both frequency and intensity of extreme weather events. Because, the global mean surface temperature of the planet earth has increased by 0.3-0.6 ^{0}C in the 20th century and it is expected that there is a possible increase in cyclone intensity of 10-20 percent against a rise in sea surface temperature of 2 to 4^{0}C. The developing country, India, which has more than 70% of its population relying on agriculture and allied activities directly or indirectly; having 7500 km. long densely populated low lying coastline; the impact of extreme events could weaken the ecological and socio-economic structure of the country. For example, the drought 2002 created havoc in the sense, the ground water levels depleted so deep that it will take years to recharge and recover in many parts of the country. The detection of potential impacts of climate change has received wide attention now a days from scientific community and of course the most debatable topic for every nation. Studying the effects of climate change on ground water resources bear high importance in ensuring proper management in terms of assessing the availability and sustainability of this precious natural resource. In the present work, the ground water level trend over years has been studied using non-parametric statistical methods for the state Orissa that is reeling through natural calamities of one kind or other for last few years.

The southwest monsoon from Bay of Bengal is responsible for kharif rain in the state Orissa, which arrives by 10th June and gets withdrawn by 10th October. Out of the normal annual rainfall of 1482 mm, the state receives around 1300 mm from monsoon rain during June to September. Even though monsoon arrived timely in 2002, the state received 167.8 mm rain in June, 140.14 mm in July, 336.1 mm in August and 195.2 mm in September, which are –21.28 %, -60.14 %, 0.15 % and –17.46 % deviated from the normal rainfall received over years. The effect of drought 2002 on the ground water levels on different geological formation of Orissa indicates that considerable number of wells falling in the range of 0 to 3 mbgl (meter below ground level) shifted in the ground water table range of 3 to < 7.5 mbgl categories. Subsequently, effect of drought has been well felt in all water level zones below 10 meters. The ground water table occurs at 3.51 mbgl over years and in drought year it depleted down to 3.96 mbgl in the consolidated region of the state Orissa that covers 80% geographical area. This significant drop is solely due to scanty rainfall in the monsoon seasons of 2002.

In pre monsoon dry season, 414 (57%) stations were identified to have water table depleted in last ten years from the total 726 monitoring stations in consolidated region of the state. Out of these positive trends, 83 (20%) stations experienced significant water table depletion at 5% level of significance; 107 (26%) stations were significant at 10% level; and 169 (41%) stations were significant at 20% level of significance. Again, out of 256 (35%)

stations where water table improved in dry season in terms of negative trends over last decade, 47 (18%) stations had significant improvement at 5% level; 60 (23%) and 96 (37%) stations were found significant at 10 and 20% level of significance respectively. The summer temperature is increasing year after year which means that the water table should deplete gradually. But the contrast result necessitates further research to see whether summer rainfall has also increased over years or this traditional flood proof area has become prone to it. In post monsoon, 393 (54%) stations of the total 726 stations were having ground water levels depleted in terms of positive trends with 44 (11%), 66 (17%) and 104 (26%) stations where ground water depleted significantly at 5, 10 and 20 % level of significance respectively. And, 230 (32%) sites indicated an improvement of water table from which 20 (9%), 29 (12%) and 46 (20%) monitoring sites were identified to have significant negative trends at 5, 10 and 20 % level of significance.

In unconsolidated region which covers the coastal tract of Orissa, 130 (60%) monitoring sites were identified showing water table depleted with 20 (15%), 31 (24%) and 47 (36%) sites were found to have significant depletion at 5, 10 and 20% level of significance respectively in summer season. Out of 72 (33 %) sites having ground water rise only in 14 (19%), 19 (26%) and 29 (40%) sites were significant at 5, 10 and 20% level of significance. In post monsoon season, out of 86 (40%) depletion trends 15 (17%), 21 (24%) and 29 (34%) sites were identified to have water table significantly depleted at 5,10 and 20% level of significance. On the contrary, 101 (47%) sites were observed to have water table rising over years with only 5 (5%) and 11 (10%) significant sites at 5 and 20% level of significance respectively. This indicates that even though the ground water tables have improved marginally in the post monsoon season, the improvements were tested not to be significant enough to draw the conclusion that overall ground water level has improved. May be temporary flooding in the coastal belt has made the water table to improve.

While delineating the geographical and seasonal heterogeneity of water table drop, it could be observed that the overall trend of ground water level has depleted over last 10 years *i.e.* 1994-2003 in the consolidated region of Orissa. There were evidence of trend heterogeneity between seasons in the sense that the spatial average of ground water levels deplete significantly in the pre-monsoon summer season in the semi consolidated and un consolidated regions. In post monsoon, the trend does not deplete significantly for both the formations. The reason may be the porous nature of soil in these deltaic regions where major rivers pass through and get flooded by monsoon rain. Water logging is also a major problem in the unconsolidated coastal regions due urbanization and other anthropogenic factors

Finally, the monitoring stations showing ground water level depletion trends are considerably more in number than the stations showing neutral or rising trends for all geologic formations. This could be interpreted that the fluctuation is not a part of noise or randomness rather the depletion is very much systematic. Again, significant cases of water table depletions are almost double the stations where water table improved significantly. This is another indication that the effect of climate change has affected the ground water resources adversely.

1. Introduction

Effect of change of climate on ground water resources possesses paramount importance in ensuring its proper management in terms of assessing the availability and sustainability of this precious natural resource. Global warming and occurrence of extreme events are the perceptible indicators of climate change. Rapid growth of world human population, which started in 1950's, and increased by two and half times to reach the present mark of above six billion, exhorts pressure on the existing natural resources. The cultivable area is shrinking day by day. Further, rapid urbanization, industrialization and deforestation have introduced variability in natural climatic process and the whole hydrological cycle shows erratic behaviors in term of extreme events.

Definition says that the extreme events such as drought, flood, cyclone, hurricane and earthquake etc. are random, rare and conventionally stationary processes. But, recently these events have become very common, continuous and re-current as if a poison process steadily gets modified to a normal distribution raising the global concern of a possible climate change has already taken place. Such events are to continue at an increasing pace well into the next century as expected by scientists globally.

In 1988, the World Meteorological Organization (WMO) and the United Nations Environment Programme (UNEP) established an international network of hundreds of scientists to assess the scientific aspects of climate change and formulate mitigation options named as the Intergovernmental Panel on Climate Change (IPCC). It is reported that one of the anticipated effects of climate change is the possible increase in both frequency and intensity of extreme weather events. Because, the global mean surface temperature of the planet earth has increased by 0.3-0.6 ^{0}C in the 20th century. As a result it is expected that there is a possible increase of cyclone intensity by 10-20 percent against a rise in sea surface temperature of 2 to 4^{0}C (IPCC, 1996 & 2001). The IPCC in it's third assessment report, released in 2001, mentioned that "there is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities". Assessing the current science on global warming, IPCC has determined the following anticipated broad impacts as:

- More hot days and higher heat indices,
- Fewer cold/frost days,
- Increase in precipitation over north hemisphere, and possible decrease in other regions (parts of Africa and the Mediterranean),
- Heavier precipitation events and more severe droughts,
- Retreat of non polar glaciers,

- Decreases in snow cover,
- Thawed, warmed and degraded permafrost in parts of the polar, sub polar and mountainous regions,
- Lengthened growing seasons,
- More frequent El Nino weather events,
- Earlier plant flowering, bird arrival, dates of animal breeding and emergence of insects,
- More coral reefs bleaching, especially during El Nino events.

The detection of potential impacts of climate change has received wide attention now a days from scientific community and it is of course the most debatable topic for every nation (Burn, 1994; Douglas *et al.*, 2000; Gan, 1998; Milly *et al.*, 2002; Palmer and Raisanen, 2002; Westmacott and Burn, 1997; Xu, *et al.*, 2003; Yang *et al.*, 2004; and Zhang *et al.*, 2001).

Relationship between climate and ground water exist at temporal scales, ranging from short-term responses to spectacular changes. Ground water dynamics is rather a stable system and respond slowly to climatic variability than the surface hydrology. Due to the enduring hydro-geologic interaction to climatic aberrations, long-term *i.e.* decadal change should be studied. Drought and flood are the most important climatic haphazard having both short term and long terms impacts on the ground water perspectives. The short-term effect of drought on ground water is much more alarming in highly populous country like India where more than 70 percent of the population rely upon ground water for drinking purpose. Simultaneously the agri-driven economics like ours, destabilize following droughts and floods. Again, an extended period of flooding elevates the ground water table and cause water logging. This waterlogged condition destroys physical and nutritional status of the soil and creates congenial environment for pathogenic parasites.

If ground water storage is large, droughts will have a small effect on long term water storage in an aquifer system. Where ground water storage has been substantially reduced by long-term withdrawals from wells, it may be limiting factor to cope up with droughts. Human induced climate change in the coming decades may further affect ground water resources in several ways, such as changes in ground water recharge resulting from the erratic behavior of the annual and seasonal distribution of precipitation and temperature, more severe and longer lasting droughts, changes on evapo-transpiration resulting from changes on vegetation and possible increased demands for ground water as a backup source of water supply (Alley, 2001). Besides, studying the availability and sustainability aspects, the link between ground water and climate can be exploited in many other ways in the sense such study can be used for drought monitoring and assessment, water quality changes, recharge estimation etc.

If changes in ground water level are detected, it may either due to climate change or due to inherent variability and randomness, which is difficult to separate. The inherent or natural variability is called noise, which is difficult to model due to its random nature. But, when the noise component follows a particular pattern or direction then it gradually turns out to be a systematic component of the process and called signal. Hence, this study is essentially a part of separating the signal that results from the impact of climate change from the noise, which is an intrinsic part of the hydrology with the following objectives:

(1) **To identify and quantify the ground water level trends for knowing the type and amount of thrust due to climate change.**

(2) **To delineate homogeneous regions having similar ground water level trends over years in the same and different seasons.**

Trend analysis helps in testing the hypothesis that there is no trend in the ground water levels and whatever dynamics taking place are intrinsic part of natural variability. Detection and quantification of trend will indicate type and amount of anthropogenic thrust on the ground water resources. Only after finding the overall trend, the subsequent queries to be answered are (1) where are the trends and (2) when do trends detected? This site, season and site-season interactions of trends will help in separating the homogenous spatial domains to formulate policy implementations to mitigate human induced changes in the ground water resources.

2. Study area

The state, Orissa, on the eastern coast of India has been the regular host to natural disasters of varying degree. This may be due to its geographical location and physical features. It is quite natural and logically acceptable to the fact that adjoining regions to seashores are more vulnerable to low pressure, cyclone and floods than the inlands. As cyclone originates in Bay of Bengal normally between 5 to 21 north latitude, Orissa's geographical location between17^{0} 47′-22^{0} 33′ N latitude and 81^{0} 31′ – 87^{0} 30′ E longitude has been the perfect ground for inviting the thrust of natural irregularities. Tracing back to the history, The Hatigumpha inscription of Orissa ascribed to the 1st century AD notes that cyclone from the sea normally comes during April and May and once in every three years in October and November. Besides, vast network of rivers in the state has been the added worries in terms of recurrent flash floods due to low-pressure triggered heavy rain in and around the lower or upper catchments. Orissa has been ravaged by natural calamities with four floods, five droughts and a super cyclone in last ten years. And, now a days the natural calamities are rather fierce and cause extensive damages. Even though annual rainfalls are quite impressive for last couple of years, it's skewed distribution causing the twin apathy of flood and drought. Table 1 shows how the quantum of annual rainfall is not the yardstick for drawing conclusion about the success of a crop in a calendar.

Table 1 : Rainfall and natural calamities in Orissa

Year	Rainfall (mm)	Natural Calamity
1990	1865.8	Flood
1991	1465.7	*
1992	1344.1	Flood & Drought
1993	1421.6	*
1994	1700.2	Flood
1995	1739.3	Flood
1996	1042.4	Drought
1997	1493.0	Drought
1998	1277.5	Severe Drought
1999	1433.8	Super Cyclone & Flood
2000	1022.9	Drought
2001	1616.1	Severe Flood
2002	1096.7	Drought
2003	1580.5	Severe Flood

* indicate the normal year

Out of total 1,55,707 km^2 geographical area of the state, around 1,18,800 km^2 area is suitable for groundwater exploration. The total annual replenishable groundwater resource is 21,01,128 ha m. Out of this utilizable resource, 19,88,856 ha m is for irrigation. Annual draft for irrigation use is estimated as 2,36,044 ha m and the balance resources of 17,52,812 ha m. can be used for irrigation.

Based on the geological set up, occurrence and distribution of aquifers and their yield potentials the state has been divided into three major hydro-geological formations (CGWB, 2000): (1) Consolidated formation which is the predominant hydro-geological class covering 80% of geological area of the state, includes hard crystalline and compact sedimentary formation of pre-cambian age; (2) Semi-consolidated formation which covers 2% of gross area of the state, includes Gondwana sand stones, shales, coal and loosely cemented tertiary sand stones; (3) Un-consolidated formation which is the alluvial deposit of coastal tract, forms narrow patches in the inland river basins and roughly covers 18% of the gross area of State (Table 2).

Table 2: Geological settings with different characteristics

Characteristics	Consolidated	Semi consolidated	Unconsolidated
Area (000 ha)	12,579	924	2,056
Ground water resource assessed (ha m)	13,48,420	1,76,856	5,75,852
Utilizable resource (ha m)	12,75,491	1,64,379	5,49,039
Annual draft for irrigation (ha m)	1,18,841	13,793	1,03,410
Water yielding capacity (liter per second)	3-10	<15	15-40

Source: CGWB (2000), Ground water year book, Orissa.

The overall groundwater development in the state is only 14.79%. The highest level of development is in Balasore district *i.e.* 41.85% and other districts have very low level of ground water exploitation.

3. Material and methods

The link between ground water and climate can be used in many other ways. Such study can be used for drought monitoring, and assessment of water quality changes, recharge estimation etc. Study of effects of climate on ground water resources requires the monitoring network, which is a surveillance system of the storage and water quality status of the ground water reservoirs, generally executed by Central Ground Water Boards (CGWB) in India through a network of observation wells called "National hydrograph network stations". In order to get unbiased readings, monitoring wells should be ideally located away from the effects of pumping and irrigation. More than 1000 monitoring wells have been excavated for this purpose depending on the aquifer characteristics and were supposed to capture the diversity of ground water system for studying the defined objective of the network precisely. Normally, ground water level monitoring is conducted four times in a year such as pre-monsoon (April), monsoon (August), post-monsoon (November) and irrigation (January) periods. But, the monsoon and irrigation time are prone to unpredictable rains and pumpages during recording of observation. Hence, for getting the unbiased picture of the ground water status, pre and post monsoon monitoring occasions have been considered. For the given purpose, ground water table depth data of observation wells of all the 30 districts of Orissa for the years, 1994 to 2003 were collected from the CGWB, Bhubaneswar. Various parametric and non-parametric statistical methods for trend analysis are presented below.

3.1 Non-parametric test for trend detection

The Mann-Kendall (MK) test given by Mann (1945) and Kendall (1975), a rank-based non-parametric statistical procedure, has been extensively used to assess the significance of monotone trends in hydro-meteorological time series such as precipitation, temperature and stream flow etc (Burn and Elnur, 2002; Gan, 1998; Xu *et al.*, 2003; and Yang *et al.*, 2004). The assumptions of classical parametric methods such as normality, linearity, and independence of data are seldom met in hydrology because of occurrences of extreme events and other human interventions. On the contrary, the non-parametric statistical tests are flexible and can handle the idiosyncrasies of data like presence of missing values, censored data, seasonality and highly skewed data as encountered in hydrological time series what the corresponding parametric tests fail to do.

Consider a time series data generated from the monitoring network for s seasons in each of the 'n' years and at 't' stations. And, each observation may be denoted by X_{igk}, which represents the water tables in meter below ground level (mbgl) collected in i^{th} ($i=1\ldots n$) year, g^{th} ($g=1\ldots s$) season and from k^{th} ($k= 1\ldots t$) station. The data can be displayed in the following manner.

		Station 1				. . .	Station t			
Seasons		1	2	. . .	s		1	2	. . .	s
	1	X_{111}	X_{121}	. . .	X_{1s1}	. . .	X_{11t}	X_{12t}	. . .	X_{1st}
	2	X_{211}	X_{221}	. . .	X_{2s1}		X_{21t}	X_{22t}	. . .	X_{2st}
	.	.			.		.			.
Years	.	.			.		.			.
	.	.			.		.			.
	n	X_{n11}	X_{n21}	. . .	X_{ns1}	. . .	X_{n1t}	X_{n2t}	. . .	X_{nst}

For the season 'g' at station 'k', the series may be expressed as $\{X_{1gk}, X_{2gk}, X_{3gk}, \ldots X_{ngk}\}$, where 'g' and 'k' are already explained. The MK test statistic for g^{th} season and k^{th} station, S_{gk}, is the sum of all signs of consecutive observation differences defined as

$$S_{gk} = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \text{sgn}(X_{jgk} - X_{jgk}) \forall 1 \le i < j \le n \qquad (1)$$

$$\text{Here, sgn}(q) = \begin{matrix} 1 & \text{if } q>0 \\ 0 & \text{if } q=0 \\ -1 & \text{if } q<0 \end{matrix}$$

Under the null hypothesis of no trend, S_g is asymptotically normally distributed with mean and variance given as

$E[S_{gk}] = 0$, and variance

$$(\sigma_{gg})_k \frac{\left[n(n-1)(2n+5) - \sum d(d-1)(2d+5)\right]}{18},$$

where d is the extent of any tie (*i.e.* length of tie) and the summation is over all the ties. Series having no repeat observations, the t becomes zero. For a time series of more than equal to 10 years i.e. $n \ge 10$, the MK test statistics is very nearly normally distributed.

Applying continuity correction, the test statistics becomes $S_{gk}' = S_{gk} - \text{sgn}(S_{gk})$ which follows normal distribution. For testing the null hypothesis, the Z value associated with the test statistic can be calculated as

$$Z_{gk} = \frac{S_{gk}}{(\sigma_{gg})_k^{1/2}} \qquad (2)$$

The null hypothesis is accepted if $-z_{(1-\alpha/2)} \le z_{gk} \le z_{(1-\alpha/2)}$, where $\pm z_{(1-\alpha/2)}$ are the (1-α/2) quantiles of the standard normal distribution at a level of significance.

The unified trend test over seasons can be derived using Hirsch-Slack test (Hirsch and Slack, 1984 and Stalnacke *et al.*, 2003) as the sum of the MK statistics for all seasons.

$$S_k = \sum_g S_{gk}, \quad g=1,\ldots s. \qquad (3)$$

which is asymptotically normally distributed with mean zero and variance

$$\text{Var}[S_k] = \sum_g (\sigma_{gg})_k + \sum_{\substack{g,h \\ g \ne h}} (\sigma_{gh})_k, \qquad g,h=1,2,\ldots s.$$

where σ_{gh} denotes the covariance between the MK test statistics for seasons g and h. In case of independent assumption of seasons, σ_{gh} becomes zero.

But, the unified trend test by summing the MK statistics for all the seasons is misleading when the seasons are highly heterogeneous. Sometimes, the overall trend gives zero value even though there is presence of distinct trends *i.e.* in case of absolutely negatively correlated seasonal observations, (Belle and Hughes, 1984). Then, it is required to have a preliminary test for homogeneity of trend.

Another very useful index to quantify the monotone trend is Kendall slope (β) given by Hirsch *et al.* (1982), extended from that proposed by Sen (1968), defined as

$$\beta_{gk} = \text{Median}\left[\frac{X_{igk} - X_{jgk}}{i-j}\right], \forall 1 \leq i < j \leq n \tag{4}$$

Here, the estimator β is the median over all combination of record pairs for the whole data set and resistant to extreme observations. A positive value of β indicates an upward trend and vice versa with time.

3.1.1 Trend homogeneity test

Homogeneity test is based on partitioning the sum of square that uses the χ^2(chi-square) test to determine the trend homogeneity between seasons, stations and season-station interactions as given in (Belle and Hughes, 1984). Here, the normalized MK trend statistics associated with g^{th} ($g=1\ldots s$) season and k^{th} ($k=1\ldots t$) station, Z_{gk}, can be presented in a two-way format as follow.

		Sites				
		1	2	....	t	$Z_{g\cdot}$
	1	Z_{11}	Z_{12}	....	Z_{1t}	$Z_{1\cdot}$
Seasons	2	Z_{21}	Z_{22}	....	Z_{2t}	$Z_{2\cdot}$
	.					
	.					
	.					
	s	Z_{s1}	Z_{s2}	....	Z_{st}	$Z_{s\cdot}$
	$Z_{\cdot k}$	$Z_{\cdot 1}$	$Z_{\cdot 2}$	....	$Z_{\cdot t}$	$Z_{\cdot\cdot}$

Hear, $Z_{g.} = t^{-1}\sum_{k=1}^{t} Z_{gk}$, the average Z value over 't' sites for the season 'g'.

$Z_{.k} = s^{-1}\sum_{g=1}^{s} Z_{gk}$, the average Z value over 's' seasons for the site 'k' and

$Z_{..} = (st)^{-1}\sum_{g=1}^{s}\sum_{k=1}^{t} Z_{gk}$, the overall average Z value.

Without loss of generality let us define the hypotheses of interest in terms of τ_{gk} from the two-way table of MK test statistics.

I. $H_0: \tau_{1.} = \tau_{2.} = \cdots = \tau_{s.}$ *i.e.* is there trend homogeneity among seasons?
II. $H_0: \tau_{.1} = \tau_{.2} = \cdots = \tau_{.t}$ *i.e.* is there trend homogeneity among sites?
III. $H_0: (\tau_{gk} - \tau_{g.} - \tau_{.k} - \tau_{..}) =$ Constant *i.e.* is there presence of site-season interaction?
IV. $H_0: \tau_{..} = 0$ *i.e.* is there presence of overall trend given the above conditions?

Under the null hypothesis that there is no trend for a particular season in a given station i.e. H_0: $\tau_{gk}=0$; then $\sum_g\sum_k Z_{gk}^2$ has χ^2(total) distribution with (st) degree of freedom. Subsequently, the total χ^2 can be partitioned into respective sources of variations as:

I. $\chi^2_{\text{total, st}} = \sum_{g=1}^{s}\sum_{k=1}^{t} Z_{gk}^2$, *i.e.* total χ^2 with st degrees of freedom(d.f.)

II. $\chi^2_{\text{homogeneity, st-1}} = \sum_{g=1}^{s}\sum_{k=1}^{t} Z_{gk}^2$, *i.e.* homoteneity χ^2 with (st-1) d.f.

III. $\chi^2_{\text{season, s-1}} = t\sum_{g=1}^{s}(Z_{g.} - Z_{..})^2$ *i.e.* χ^2 due to season with (s-1) d.f.

IV. $\chi^2_{\text{site, t-1}} = s\sum_{g=1}^{s}(Z_{.k} - Z_{..})^2$ *i.e.* χ^2 due to site with (t-1) d.f.

V. $\chi^2_{\text{site-season, (t-1)(s-1)}} = \sum_{g=1}^{s}\sum_{k=1}^{t}(Z_{gk} - Z_{.k} - Z_{g.} - Z_{..})^2$ *i.e.* χ^2 due to site-season interaction with (t-1)(s-1) d.f.

VI. $\chi^2_{\text{trend, 1}} = st\,Z_{..}^2$ *i.e.* χ^2 due to trend with 1 d.f.

The following steps help in drawing conclusions:

(1) Under the null hypotheses, the χ^2 statistics presented above are used for testing site homogeneity (χ^2_{site}), season homogeneity (χ^2_{season}), and site-season homogeneity ($\chi^2_{site-season}$).

(2) If site, season and sit-season homogeneity are not found to be significant, then test for overall trend using χ^2_{trend} is carried out.

(3) If sites are heterogeneous but not seasons then trend test for individual sites can be obtained from $sZ_{.k}^2$ (k=1, 2,…,t) which is distributed as c^2 variate under the null hypothesis $H_0 : t_{.k} = 0$.

(4) If seasons are heterogeneous but not sites then trend test for individual seasons can be obtained from $tZ_{g.}^2$ (g=1, 2,…,s) which is distributed as c^2 variate under the null hypothesis $H_0 : t_{g.} = 0$.

(5) If both sites and seasons are heterogeneous or there is significant site-season interaction then the individual entries in the site-season two way table *i.e.* Z_{gk} (g=1, 2,…,s; k=1, 2,…t) are tested for significance of trends. The null hypothesis of no trend *i.e.*($H_0 : Z_{gk} = 0$) is accepted if $-Z_{\alpha/2} < Z_{gk} < Z_{\alpha/2}$ where $\pm Z_{\alpha/2}$ is the standard normal deviate whose values are 1.68 and 1.96 at $\alpha = 0.1$ and 0.05 level of significance respectively. Otherwise, alternate hypothesis of presence of trend is accepted.

3.2 Parametric method of trend detection

Time series data of ground water levels in meter below ground level (mbgl) have been collected for the period from 1994 to 2003 from the monitoring wells representing the consolidated, semi-consolidated and un-consolidated regions of the state. If it is assumed that the observations are independent both temporally and spatially, then the time series for a given well which is supposed to be explained by time, may be given in a model form as

$$X_i = \beta_0 + \beta_1 Y_i + e_i \, .$$

Here, X_i is the i th (i= 1, …, n) observation of ground water level; Y_i is the i th year; β_0 and β_1 are intercept and slope of the linear model; e_i is the error term which is normally distributed with mean zero and constant variance. The parameters β_1 and β_0 are estimated as

$$b_1 = \frac{\sum_{i=1}^{n}(X_i - \overline{X})(Y_i - \overline{Y})}{\sum_{i=1}^{n}(Y_i - \overline{Y})^2} \qquad (5)$$

and $b_0 = \overline{X} - \beta_1 \overline{Y}$ with Var $(b_1) = \left[\sum_{i=1}^{n}(Y_i - \overline{Y})^2\right]^{-1} \sigma^2$.

The unbiased estimate of σ^2 is given by $s^2 = \frac{\sum_{i=1}^{n}(X_i - b_0 - b_1 Y_i)^2}{(n-2)}$. Our interest is to estimate β_1 to test the null hypothesis that there is no trend detected over years i.e. $\beta_1=0$. If the t statistic,

$$t = \frac{b_1}{\sqrt{s^2 / \sum (Y_i - \overline{Y})^2}} \qquad (6)$$

is more than the table t value at $\alpha(=0.05, 0.1)$ percent level of significance with (n-2) degrees of freedom (d.f.), then the null hypothesis of no trend is rejected.

4. Results and discussions

4.1 Study of drought 2002 on ground water resources of Orissa

Drought is one of the extreme events whose severity depends on the degree of vulnerability of the natural resources and human society. As far as the quantification of this natural calamity is concerned, drought is a relative term varies from place to place. Literally, drought may be defined as a condition of deficit of sufficient magnitude to have an adverse effect on vegetation, animals and people over a sizable area (WMO, Geneva, Technical note No. 201).

Drought has been classified as meteorological, hydrological, agricultural and socio-economic to delineate its consequences. Meteorological drought can be defined as percentage departures from long-term average rainfall in a given region. Definitions of meteorological drought are considered as design specific since the atmospheric conditions that result in deficiencies of precipitation are highly variable from region to region. The south west monsoon from Bay of Bengal is responsible for *kharif* rain in the state Orissa, which arrives by 10th June and gets withdrawn by 10th October. Out of the normal annual rainfall of 1482 mm, the state receives around 1300 mm from monsoon rain during June to September. Even though monsoon arrived timely in 2002, the state received 167.8 mm rain in June, 140.14 mm in July, 336.1 mm in August and 195.2 mm in September, which are –21.28%, -60.14%, 0.15% and –17.46% deviation from the normal rainfall received over years. Fig.1 presents the district wise percentage deviated rainfall for the monsoon months, 2002.

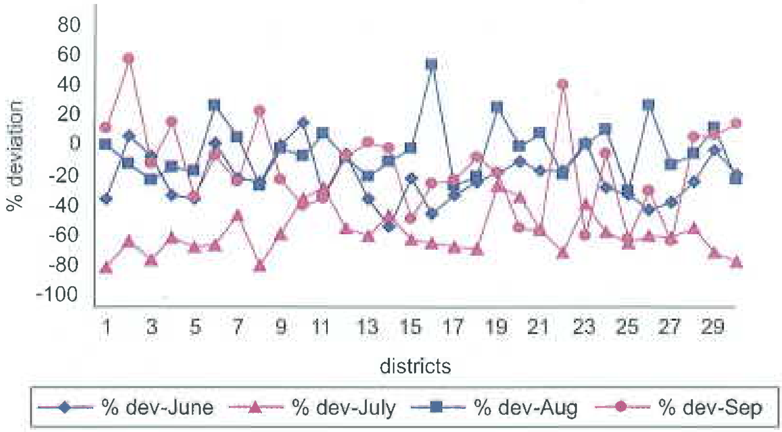

Fig.1: Percentage deviation of rainfall during monsoon months of 2002.

Table 3 given below presents the intensity of drought in accordance to percentage deviation of rainfall. This has been used to delineate the drought prone districts and severity of it.

Table 3: Classification of droughts

Classification	Percentage departure of rainfall	Drought intensity
M_0	Zero or above	No drought
M_1	0 to -25%	Mild drought
M_2	-25% to -50%	Moderate drought
M_3	-50%	Severe drought

Source: Tenth National Water Convention, 5-7 November 2003, Bhubaneswar, Ministry of Water Resources

Almost all the districts of Orissa fall under M_1 to M_3 drought categories in the monsoon months as evident from Fig. 1 and Table 3. Not even a single district of the state has received normal rainfall during the crucial month of July. The July rainfall that makes or breaks the success of kharif cropping failed far below the normal and to be specific, 25 out of 30 districts suffered severe drought. It is believed to be the lowest July rainfall experienced during the last 40 years. With high levels of day temperature, the initial weeks of the monsoon season appeared like an extended summer. Along with the rain fed minor irrigation projects, the medium and major irrigation projects also suffered the impact of weak monsoon and inadequate rainfall. As a result, agricultural operations during kharif 2002 received a serious set back. As the crucial July rain failed, 7.73 lakh hectares of paddy land remained fallow. With germination failure affecting 86,000 hectares, the agricultural operations were hampered and around 68 % of crop loss was estimated in the same drought year.

Meteorological drought if prolonged and its intensity is higher then it leads to hydrological drought with a significant impact on the broad aspect of hydrological cycle. Consequently the big reservoirs dry up, stream and rivers dwindle and the groundwater table falls. Table 4 presents the water levels of major reservoirs of Orissa during monsoon months.

Table 4: Effect of drought 2002 on surface water regime

Reservoir	Dead storage level (ft)	Reservoir water levels (ft) in different months of 2002			
		June	July	August	September
Hirakud	590.00	590.73	595.25	622.39	628.54
Rengali	109.72	111.69	110.92	117.6	123.01
Balimela	1440.00	1432.50	1433.90	1451.50	1458.00
Jalaput	2635.00	2700.10	2689.70	2703.60	2702.70
U. Kolab	844.00	846.69	846.12	849.40	850.18
Indravati	625.00	626.60	626.85	632.00	633.85

Source: Drought 2002, States Report, Dept. of Agril. & Coop., GOI, New Delhi.

It can be seen from the Table 4 that in July the water levels almost touched the dead storage level. Thus, overall effect of drought was well felt in major reservoirs of Orissa.

Here, the effect of drought 2002 on the ground water levels on different geological formation of Orissa has been studied. For studying the effect of scanty monsoon rainfall in drought year 2002 on the ground water resources, the observation wells monitored during post monsoon period (*i.e.* November) have been considered as the indicators of such climatic extreme. The frequency distribution of the monitoring wells pertaining to different water table ranges for the year 2002 and average of seven years (1994 to 2001 except 1999 which was a cyclonic year) are presented in the following Table 5. Also, the frequency distribution of monitoring wells belonging to different percentage deviation groups is presented in the said table.

Table 5(a) : Frequency distribution of monitoring wells of drought year and average year

Classification	Groundwater table (meter) below	Monitoring wells (%)	
		Drought 2002	Average (1993-2001)
A	0 to 1.5	31.17	34.42
B	1.5 to 3.0	25.45	33.12
C	3.0 to 4.5	23.12	19.74
D	4.5 to 6.0	11.56	7.27
E	6.0 to 7.5	5.45	4.03
F	<7.5	3.25	1.43

Total monitoring wells: 770

It could be observed from Table 5(a) that up to 4.5 meter below ground the percentage of monitoring wells reduced in 2002 where as the last three water level zones have more percentage of wells in comparison to the corresponding values in the average years. This indicates that considerable number of wells falling in the range of 0 to 3 m shifted in the ground water table range of 3 to < 7.5 m categories. Subsequently, effect of drought has been well felt in all water level zones below 10 meters. District wise average ground water table in different year is presented in **Appendix I**.

Table 5(b) : Frequency distribution of monitoring wells based on deviation (%) during 2002 from the average

Classification	Deviation (%)	Monitoring wells (%)
A1	-100 to -75	4.94
B1	-75 to -50	12.08
C1	-50 to -25	28.18
D1	-25 to -1	31.82
E1	0 to 25	12.99
F1	25 to 50	6.32
G1	>50	3.68

Total monitoring wells: 770

Coming to the percentage ground water table deviation of drought year over the average, 77% of monitoring wells showed –1 to –100% deviation, and only 23% of wells have their water levels improved in 2002. Pie charts of the above frequency table have been presented in **Appendix II**.

For testing the difference between the average ground water levels (mbgl) over years and the drought year 2002, the commonly used statistical test is two-sample t-test. The null hypothesis for a two sample comparison of means is a statement of no difference *i.e.* H_0: $\mu_1=\mu_2$ as against the alternate hypothesis H_1: $\mu_1 \neq \mu_2$. The test statistic is (Montgomery and Loftis, 1987).

$$t=\frac{(\overline{X}_1-\overline{X}_2)}{s_p[n_1^{-1}+n_2^{-1}]^{1/2}}, \text{ where}$$

$\overline{X}_1$: Average ground water level in drought year collected from n_1 monitoring wells,
$\overline{X}_2$: Average ground water level over years collected from n_2 monitoring wells.

If $t_{cal} > t_{tab,\alpha}$ at (n_1+n_2-2) d.f., then the null hypothesis of no difference between ground water level in average year and drought year is rejected. Here, the significance difference between post-monsoon ground water level in 2002 is tested against the corresponding average year's (1994 to 2001) water level and presented in Table 6.

Table 6: Testing difference of ground water levels

Formation	No. of wells	Year	Mean level (meter)	S.D.	t-cal	p-value
Consolidated	557	Drought	3.96	2.11	3.8	0.0001
		Average	3.51	1.80		
Semi consolidated	57	Drought	4.12	2.21	2.18	0.0311
		Average	3.33	1.60		
Unconsolidated	156	Drought	2.26	1.49	1.34	0.1807
		Average	2.05	1.26		

Table 6 presents the result of significance difference testing between the ground water levels in drought year and the average water levels over years for different geological settings. It is apparent from the table that in consolidated region the ground water table occurs at 3.51m over years and in drought year it depleted down to 3.96m and they are significantly different at 1% level of significance. Hence, it may be interpreted that the consolidated region which covers 80% of the total geographical area, the ground water level depleted significantly in the drought year, 2002. The monitoring wells showing absolute ground water level deviation greater than equal to 100% in drought year over the average year figure have not been considered for the analysis to avoid bias due to erroneously recorded data or data recorded on rainy days.

In semi-consolidated region, the temporal and spatial average ground water level exist at 3.33m below ground level and in drought year the spatial average water table dropped to 4.12m which are significantly different at 5% level of significance.

But, in un-consolidated region, which covers the coastal districts of the state, the effect of drought on ground water resources is not significant as the spatio-temporal average ground water level of 2.05m dropped to 2.26m in the year 2002 and they are not significantly different. The reason may be the vast network of rivers flowing through the region to the sea; seawater ingression in certain belt of the coastal region; and soil consists of alluvium deposits to facilitate capillary rise of water table.

To sum up, the effect of drought in the consolidated and semi-consolidated regions that cover over 82% of the geographical area of the state has significant effect on the ground water resources. But, the state has experienced five severe droughts in last 10 years. Hence, it is essential to study the ground water level trends over years to get an insight about the overall scenario given the recurrence of extreme weather events. In the following sections, the trend results have been presented.

4.2 Non parametric test results

The application of MK-test statistics using eq. (1) and (2) for trend detection has resulted in identification of positive and negative trends of the ground water levels in three predominant geological formations of Orissa. Because the ground water levels are recorded in mbgl *i.e.* meter below ground levels, the high observational values indicate the drop of water table and low values indicate the rise in water table. Hence, the positive trend values here indicate the depletion of ground water levels and negative trend values indicate the rise of water levels towards the surface over years. Areas having positive trend values indicating ground water depletion could be due to anthropogenic factor like high-density population, water extraction for agricultural purposes and regular climatic extreme events like prolonged droughts. But, areas showing negative trends indicating water table improvements are due to natural recharge over years or due to waterlogged areas being created by frequent floods for which further study may be carried out.

As location of each monitoring well is based on the scientific study of the geology and represented as the indicator of the ground water dynamics of the area, each trend value gives an idea about the water table fluctuation of that area over years. Stations showing positive and negative trends have been identified for pre monsoon (dry season) and post monsoon seasons and presented in Table 7.

Table 7: Trend directions in different geological settings

Formation	April			November		
	positive	negative	neutral	positive	negative	neutral
Consolidated	414	256	56	393	230	103
Semi consolidated	45	14	1	32	22	6
Unconsolidated	130	72	14	86	101	29

Again, stations having significant trends at 5, 10 and 20% level of significance have been detected and presented in Table 8. Generally, significance testing is carried out at 5% levels. Here, stations significant at 10 and 20% levels have also been identified as these stations are expected to be significant at 5% level in coming years until and unless technological interventions are made. Because, the unabated population growth will exhort pressure on the ground water resource directly or indirectly accompanied by more and more natural calamities will have repercussions for the decades to come. Hence, it is sensible to identify the areas having significant fluctuation at high level of significance so that steps can be taken early to avoid future risks. Region wise trend results have been interpreted below.

Table 8: Significant MK test trend result for different geological formations

Formations		Consolidated			Semi consolidated			Unconsolidated		
Seasons	Sig.Level(α)	0.05	0.1	0.2	0.05	0.1	0.2	0.05	0.1	0.2
Pre mon. (April)	Positive	83	107	169	5	8	18	20	31	47
	Negative	47	60	96	2	2	3	14	19	29
Post mon. (November)	Positive	44	66	104	0	0	5	15	21	29
	Negative	20	29	46	0	0	2	5	5	11

4.2.1 Trend results of consolidated region

It could be observed from Table 7 and 8 that in pre monsoon (dry season), 414 (57%) stations were identified to have positive trends in last ten years from the total 726 monitoring stations. Out of these positive trends, 83 (20%) stations experienced significant water table depletion at 5% level of significance; 107 (26%) stations were significant at 10% level; and 169 (41%) stations were significant at 20% level of significance. Again, out of 256 (35%) stations where water table improved in dry season in terms of negative trends over last decade, 47 (18%) stations had significant improvement at 5% level; 60 (23%) and 96 (37%) stations were found significant at 10 and 20% level of significance respectively. The summer temperature is increasing year after year which means that the water table should deplete gradually. But the contrast result necessitates further research to see whether summer rainfall has also increased over years or this traditional flood proof area has become prone to it.

In post monsoon, 393 (54%) stations of the total 726 stations were having ground water levels depleted in terms of positive trends with 44 (11%), 66 (17%) and 104 (26%) stations where ground water depleted significantly at 5, 10 and 20% level of significance respectively. And, 230 (32%) sites indicated an improvement of water table from which 20 (9%), 29 (12%) and 46 (20%) monitoring sites were identified to have significant negative trends at 5, 10 and 20% level of significance.

4.2.2 Trend results semi consolidated region

In the pre monsoon season, positive trends were seen in 45 (75%) of the total 60 monitoring sites with 5 (11%), 8 (18%) and 18 (40%) sites where significant depletion took place at 5, 10 and 20% level of significance respectively. As far as negative trend is concerned, out of 14 (23%) sites identified, 2 (14%) and 3 (21%) sites were found to have significant water table improvement at 5 and 20% level of significance.

In post monsoon season, water table fluctuation reflected a downward trend at 32 (53%) sites of which only 5 (15%) sites were significant at 20% level of significance. Also, 22 (36%) sites were identified having improved water table in last 10 years from which only 2 (9%) site were significant at 20% level of significance.

4.2.3 Trend results unconsolidated region

In pre-monsoon season, 130 (60%) monitoring sites were identified showing water table depleted in terms of positive MK trend statistics with 20 (15%), 31 (24%) and 47

(36%) sites found to have significant depletion at 5, 10 and 20% level of significance respectively. Out of 72 (33 %) sites having negative trends, significant ground water rise could be observed only in 14 (19%), 19 (26%) and 29 (40%) sites at 5, 10 and 20% level of significance.

In post monsoon season, out of 86 (40%) positive trends 15 (17%), 21 (24%) and 29 (34%) sites were identified to have water table significantly depleted at 5,10 and 20% level of significance. On the contrary, 101 (47%) sites were observed to have water table rising over years with only 5 (5%) and 11 (10%) significant sites at 5 and 20% level of significance respectively. This indicates that even though the ground water tables have improved marginally in the post monsoon season, the improvements were tested not to be significant enough to draw the conclusion that overall ground water level has improved. The Mann-Kendal trend summary statistics presented in Table 9 gives the idea about the overall trend direction with variability for different geologic formations.

Table 9: Mann-Kendal trend summary statistics

Formation	Seasons	Mean	S.D.	Min	Max
Consolidated	April	0.282	1.302	-3.400	3.220
	November	0.267	1.033	-3.400	3.400
Semi consolidated	April	0.571	1.057	-2.236	2.862
	November	0.125	0.749	-1.609	1.609
Unconsolidated	April	0.317	1.280	-3.398	2.683
	November	0.076	1.015	-2.862	2.683

It could be observed from Table 9 that for all the three geological formations the average trends turn out to be positive for both the pre and post monsoon seasons indicating that there is an overall drop in ground water levels irrespective of seasons. But, the variability in terms of standard deviation is very high for all the spatial and temporal domains under study. Further, except consolidated region, the seasonal difference seems to be there for the other two geologic formations. Stations showing significant trends at 5% level are presented through tables and maps in **Appendix III** with 'MKZ' and 'MKS' representing Mann Kendall test statistics and slope respectively. And, 'b_1' and 't' represents corresponding parametric slope and t test statistics.

4.2.4 Trend homogeneity results

In fact, the pre and post monsoon seasons are so contrasting towards the ground water level characterization that seasonal trend test of Hirsch *et al.* (1982) can't be carried out by just adding the trend statistics over seasons to get unified trend for a region as in eq.(3). Further, the spatial variability of trend results needs the study for testing the homogeneity aspects of it. Following the procedure mentioned earlier, the trend homogeneity between seasons, stations and season-station interactions have been worked out based on partitioning the sum of square that uses the χ^2 to test the homogeneity. Accordingly, the χ^2_{total} *i.e.* $\sum_g \sum_k Z_{gk}^2$ has been partitioned into two major sources of variations such as $\chi^2_{homogeneity}$ and χ^2_{trend} with (st-1) and 1 degrees of freedoms. Again, the $\chi^2_{homogeneity}$ has been partitioned into assignable sources such as $\chi^2_{(site,\, t-1)}$, $\chi^2_{(season,\, s-1)}$ and $\chi^2_{(site\text{-}season,\, (t-1)(s-1))}$. For testing homogeneity, two seasons(s=2) for each of the formations and 726, 60 and 216 sites (t) have been studied for the consolidated, semi and un-consolidated formations respectively and given in Table 10.

Table 10: Test of trend homogeneity for different formations

Sources	Consolidated			Semi consolidated			Unconsolidated		
	χ^2-value	D.F.	Sig.	χ^2-value	D.F.	Sig.	χ^2-value	D.F.	Sig.
Total	2113.848	1452	-	119.560	120	-	597.088	432	-
Homogeneity	2004.105	1451	-	105.021	119	-	580.375	431	-
Site	1325.293	725	N.S	63.369	59	N.S	316.935	215	N.S
Season	0.078	1	N.S	5.960	1	S	6.273	1	S
Site-Season	678.734	725	N.S	35.692	59	N.S	257.167	215	N.S
Trend	109.743	1	S	14.539	1	Not used	16.713	1	Not used
Avg. (Z..)	0.275			0.348			0.196		

N.S: not significant; S: significant; D.F.: degrees of freedom; Sig: significance

In consolidated regions, neither the sites nor the seasons were found significant for heterogeneity as $\chi^2_{site,\,725} < \chi^2_{0.975,\,725}$ and $\chi^2_{season,\,1} < \chi^2_{0.975,\,1}$ respectively. So, the overall trend was tested by using χ^2_{trend} which under null hypothesis, H_0: $\tau_{..} = 0$, distributed as χ^2 with 1 degrees of freedom. Here, as χ^2_{trend} was found to be significant, the average of MK-test statistics Z_{gk} over seasons (g=1,2) and sites (k=1,2...726) *i.e.* $Z_{..}$ was used to draw conclusions. Hence, it could be interpreted that the overall trend of ground water level has depleted over last 10 years *i.e.* 1994-2003 in the consolidated region of Orissa.

For semi consolidated and un consolidated regions, there were evidence of trend heterogeneity between seasons as $\chi^2_{season,\,1} > \chi^2_{0.975,\,1}$ for both the cases. But sites were found to be homogeneous for both the geologic formations as the computed χ^2_{site} were less than the corresponding table values with associated degrees of freedoms. Hence, the test of significance of overall ground water level trend for each season have been carried out using the average MK-test statistics for each season ($Z_{g.}$). Under the null hypothesis, H_0: $t_{g.}=0$, $tZ_{g.}^2$ (g=1,2) is distributed as χ^2 variate with one d.f. Here, $tZ_{g.}^2$ have been obtained to test the overall seasonal trends and if $tZ_{g.}^2 > \chi^2_{0.975,\,1}$ (=5.02) then the season g has significant trend at α=0.025 level.

Table 11: Seasonal trend test

Formation	Season	$Z_{g.}$	$t(Z_{g.})^2$	Sig.
Semi consolidated	April	0.571	19.56	S
	Nov	0.125	0.98	N.S
Unconsolidated	April	0.317	21.70	S
	Nov	0.078	1.25	N.S

From Table 11 it is clear that the spatial average of ground water levels deplete significantly in the pre-monsoon summer season in the semi consolidated and un consolidated regions of Orissa state. In post monsoon, the trend does not deplete significantly for both the formations. The reason may be the porous nature of soil in these deltaic regions where major rivers pass through and get flooded by monsoon rain. Water logging is also a major problem in the un consolidated coastal regions due urbanization and other anthropogenic factors.

4.3 Parametric test results

Even though non-parametric method of trend analysis has many advantages and most suitable for this situation where record length is short *i.e.* 10 years, parametric trend analysis has been carried out for completeness and to cross check the non-parametric trend results. Using eq. (5), the parametric slopes have been computed for all the monitoring wells and formation wise positive and negative slopes are presented in Table 12.

Table 12: Parametric trend directions in different geological settings

Formation	Pre monsoon		Post monsoon	
	positive	negative	positive	negative
Consolidated	432	294	422	304
Semi consolidated	42	18	31	29
Unconsolidated	141	75	109	107

It can be seen from Table 12 that the positive trends, which means depletion of ground water table, are more than the negative trends in all geological formations and in both the seasons. Many of these positive and negative trends have very low values indicating almost no trend. Hence, it is important to find out the significant trends. Using eq. (6) the t-statistics have been computed and significant trends are presented in Table 13.

Table 13: Significant parametric trend result for different geological settings

Formations		Consolidated		Semi consolidated		Unconsolidated	
Seasons	Sig. Level (α)	0.05	0.1	0.05	0.1	0.05	0.1
April	Positive	132	186	12	17	34	50
	Negative	77	101	3	4	23	30
Nov	Positive	74	112	1	8	20	32
	Negative	35	59	1	4	10	18

Again, it can be seen from the above table that the significant positive trends are more than the negative trends for all formations irrespective of seasons. And, the parametric trend results follow in line with the non-parametric trend result, which is explained in detail earlier.

5. Trend quantification results

The monotone trend has been quantified using Kendall slope in eq.(4) for all the geological formations in both pre and post monsoon seasons. The box plots of trend magnitude in Fig. 2 presented below reveals that in pre monsoon summer season, the ground water levels have been depleted in all the geologic formations as the mean slopes are above zero with maximum negative outliers in consolidated regions.

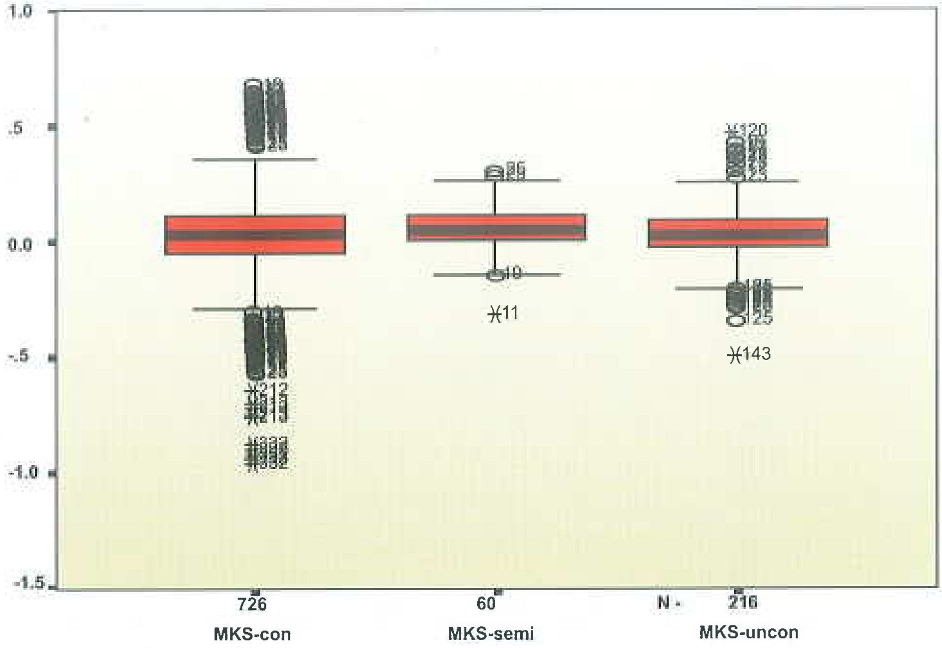

Fig. 2: Kendal slopes for the pre monsoon season in different formations

Specifically, the ground water level depleted by an average of 0.018, 0.053 and 0.028m (10 yrs)$^{-1}$ in consolidated, semi and unconsolidated regions of Orissa in summer season as presented in Table 14.

Table 14: Kendal Slope summery statistics

Formation	Seasons	Mean	S.D.	Min	Max
Consolidated	April	0.018	0.196	-0.938	0.680
	November	0.028	0.140	-0.802	1.185
Semi consolidated	April	0.053	0.115	-0.316	0.333
	November	0.020	0.132	-0.487	0.343
Unconsolidated	April	0.028	0.128	-0.495	0.482
	November	-0.0002	0.085	-0.453	0.330

In post monsoon season, the box plots in Fig. 3. and Table 11 reveal that the ground water tables have been depleted in consolidated and semi consolidated regions where as there is evidence of improvement in unconsolidated regions.

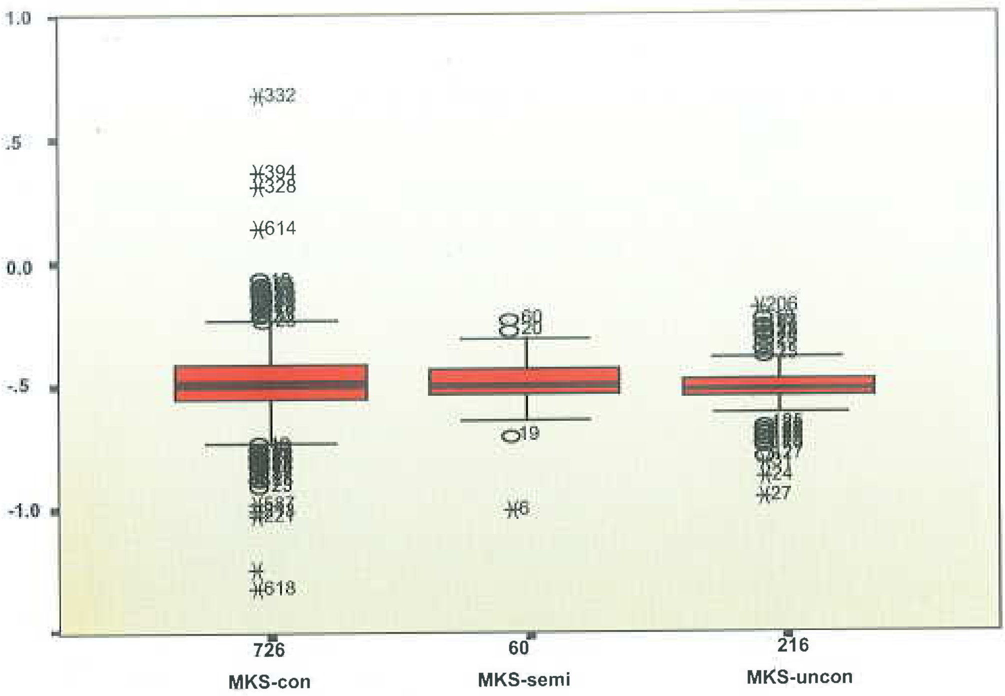

Fig. 3: Kendal slopes for the post monsoon season in different formations

The magnitudes of depletions are 0.028 and 0.02m (10 yrs)$^{-1}$ for consolidated and semi consolidated regions and an improvement of - 0.0002m (10 yrs)$^{-1}$ for unconsolidated region. Unexpectedly, the presence of more positive outliers in consolidated region has resulted in an over depletion in post monsoon than pre monsoon season.

It could be observed that there is presence of both positive and negative slope outliers in all formations irrespective of seasons, which is reflected in terms of high standard deviations over averages. Hence, the trend magnitude at a particular site is more informative than the average value of a region.

Further, the pre monsoon summer season experienced a ground water depletion of 0.23 meter in 10 years *i.e.* 0.23 m (10 years)$^{-1}$ for the monitoring stations identified to have significant depletions for the state as a whole. Most of the cultivable area remains fallow during pre-monsoon months in the state. Such an amount of water table depletion may be ascribed to the significant rising trends of temperature over the years. In post monsoon seasons, the ground water depleted at the rate of 0.17 meter in 10 years. The water table improvements at 0.30 and 0.19 m. (10 years)$^{-1}$ for pre and post monsoons in few stations may be due to flooding effect or recharge need to be investigated.

6. Conclusions

The detection and attribution of ground water level trends is essential for understanding the potential future changes given the occurrence of repeated droughts along with ever increasing anthropogenic thrust. As ground water is the safest source of drinking water and can be exploited for agriculture in crisis, its sustainability must be ensured through technological interventions. Here, the water table trends over years have been identified and quantified with the following salient findings.

- ✓ The ground water level dropped significantly due to drought 2002 in the consolidated region of the state Orissa that covers 80% geographical area.

- ✓ The monitoring stations showing ground water level depletion in terms of positive trends are considerably more in number than the stations showing negative trends which indicate an improvement of water table for all geologic formations. This could be interpreted that the fluctuation is not a part of noise rather the signal is being identified.

- ✓ Again, significant cases of water table depletions are almost double the stations where water table improved significantly. This is another indication of the adverse effect of climate change on ground water resources.

- ✓ As far as homogeneity of site, season and site-season in relation to ground water level trends are concerned, the consolidated region of the state has experienced an overall significant depletion of ground water level in last 10 years irrespective of seasons. But, semi and un-consolidated regions have suffered significant water table depletion in pre monsoon summer season only.

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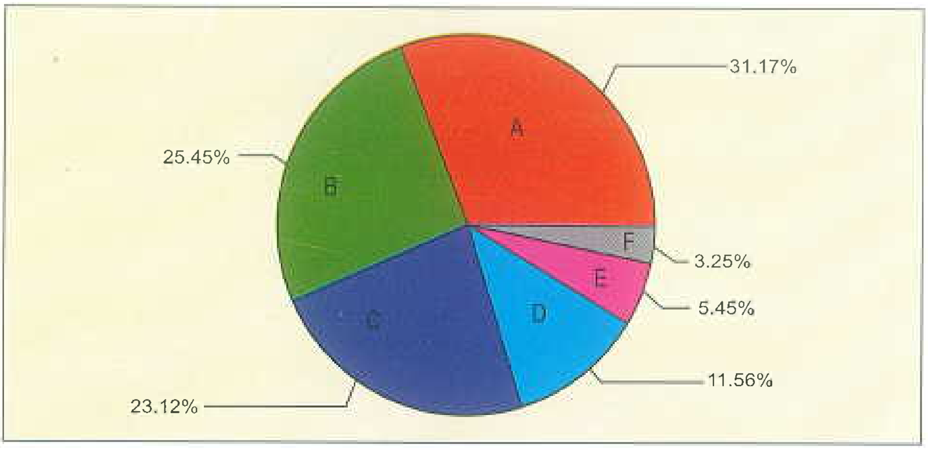
Appendix - I

Average groundwater depths (mbgl) in different hydro-geological formations of Orissa

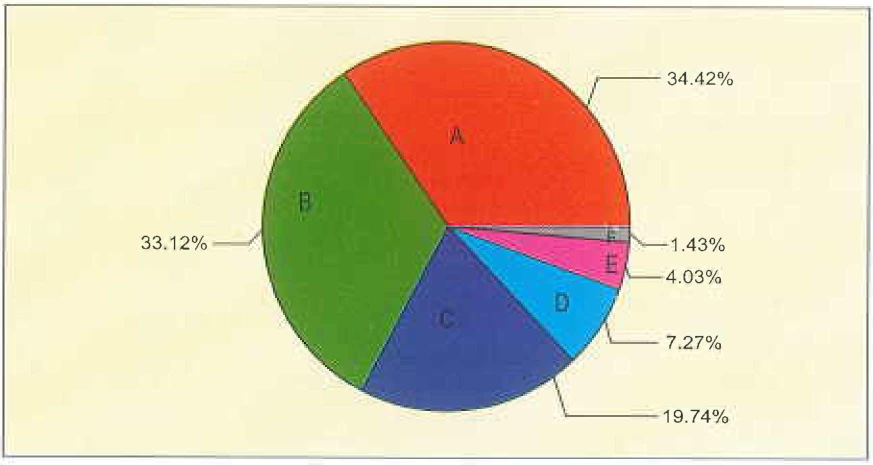
Consolidated districts	2001	2002	2003	Average (1994-2000)	Deviation (%) in 2002 over average
Bargarh	2.879	3.191	1.985	2.567	-10.140
Bolangir	3.421	4.166	2.288	3.498	-46.796
Boudh	2.750	3.482	2.043	2.983	-18.575
Deogarh	2.617	3.290	2.280	2.397	-18.810
Dhenkanal	3.397	4.189	2.308	3.670	-14.211
Gajapati	3.873	3.912	2.404	3.830	-16.727
Ganjam	2.197	2.777	1.345	2.406	-19.109
Jharsuguda	4.682	4.817	2.547	3.845	-26.951
Kalahandi	3.433	4.498	3.157	3.524	-24.295
Keonjhar	3.567	3.599	2.693	3.409	-25.884
Koraput	3.990	4.465	3.035	3.766	-27.625
Malkanagiri	2.999	2.854	2.035	2.591	-8.228
Mayurbhanj	3.613	4.236	2.749	3.914	-14.146
Nowrangpur	3.205	4.938	3.408	3.364	15.270
Nayagarh	2.848	3.772	2.778	3.262	-6.579
Nuapada	2.927	3.906	2.893	3.103	-25.286
Phulbani	5.976	6.915	4.744	6.055	-37.233
Rayagada	4.255	4.959	3.492	4.174	-5.570
Sambalpur	3.146	3.468	2.295	3.254	-15.613
Sonepur	2.830	3.062	1.712	2.412	-15.423
Sundargarh	4.343	3.680	2.767	4.343	-2.141
Semi-consolidated					
Angul	3.080	4.175	2.157	3.264	-27.906
Khurda	3.546	4.043	2.283	3.422	-18.167
Unconsolidated (Coastal/alluvium area)					
Balasore	2.078	2.439	1.654	2.430	-0.359
Bhadrak	2.047	2.323	1.611	2.056	-13.004
Cuttack	1.808	2.289	1.374	1.945	-14.320
Jatsinghpur	1.163	1.385	1.245	1.391	-16.830
Jajpur	1.830	2.704	2.117	2.314	0.406
Kendrapada	1.958	2.392	1.791	2.092	-17.708
Puri	2.016	2.055	1.287	2.000	-2.750

Appendix - II



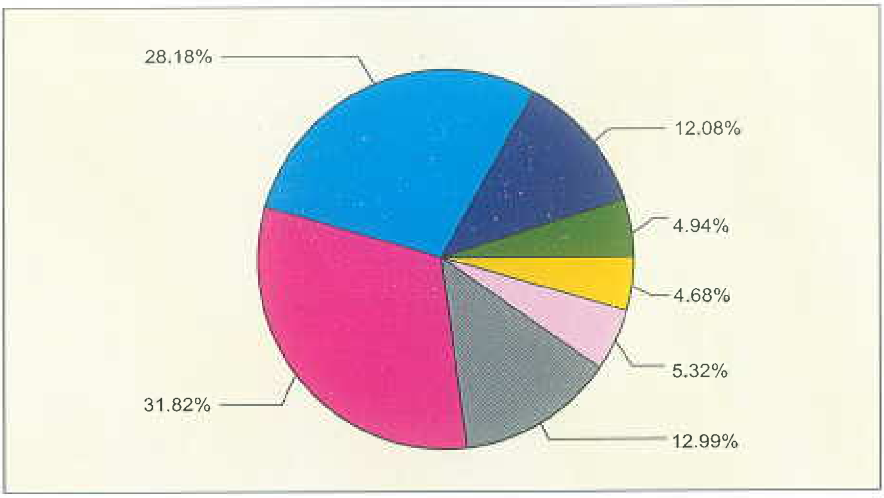
A : 0 to 1.5 (240) **B: 1.5 to 3.0 (190)** **C : 3.0 to 4.5 (178)**
D: 4.5 to 6.0 (89) **E: 6.0 to 7.5 (42)** **F : <7.5 (25)**

Fig. 1: Frequency distribution of groundwater level (mbgl) in drought year (2002)



A: 0 to 1.5 (265) **B: 1.5 to 3.0 (255)** **C: 3.0 to 4.5 (152)**
D: 4.5 to 6.0 (56) **E: 6.0 to 7.5 (31)** **F: <7.5 (11)**

Fig. 2: Frequency distribution of average (8 years) groundwater level (mbgl)



A1: -100 to -75(38) **B1: -75 to -50(93)** **C1:-50 to -25 (217)**
D1: -25 to -1.0(245) **E1: 0 to 25(100)** **F1: 25 to 50 (41)** **G1: >50(36)**

Fig. 3: Frequency distribution of wells showing % deviation in 2002 from the average

Appendix III

Table 1. Significantly depleted groundwater level stations in pre-monsoon (April) season

District	Location	Well No	MKZ	MKS	b1	t
Angul	Bantala	73H-2A2	2.147	0.126	0.155	2.713
Angul	Kukurang	73H-1A18	2.147	0.251	0.193	2.084
Angul	Paranga	73H-1A5	2.862	0.333	0.315	5.402
Angul	Talcher	73H-1A3	1.968	0.180	0.172	2.005
Balesore	Basta	73O-2A2	2.504	0.409	0.424	3.178
Bargarh	Gaisilet	64P-1B4	2.683	0.256	0.263	4.094
Bargarh	Jamurda	64O-3C10	1.968	0.532	0.437	2.245
Bargarh	Padampur	64P-1A1	2.504	0.285	0.409	2.474
Bhadrak	Bagdavinayakpur	73K-4C5	2.504	0.277	0.295	2.608
Bhadrak	Chandbali	73L-1C6	2.683	0.100	0.125	3.482
Bhadrak	Pirhat	73L-1C5	2.147	0.053	0.076	2.050
Bolangir	Bharsuja	64P-1B3	2.326	0.117	0.134	2.152
Bolangir	Bolangir-1	64P-2B1	1.968	0.240	0.231	1.959
Bolangir	Bongamunda	64L-3D4	2.326	0.120	0.121	4.037
Bolangir	Burda	64P-1C1	2.773	0.158	0.176	3.420
Bolangir	Dumerbahal	64P-2C3	1.968	0.132	0.116	2.241
Bolangir	Gudighat	64P-3A2	1.968	0.200	0.159	1.221
Bolangir	Hardatal	64P-2B5	1.968	0.180	0.282	2.240
Bolangir	Kurusur	64L-4D4	2.326	0.129	0.159	3.021
Bolangir	Lathor	64L-2D2	2.415	0.384	0.370	3.643
Bolangir	Sikachhira	64P-2B6	1.968	0.136	0.124	2.139
Bolangir	Suka	64P-1C5	2.147	0.239	0.152	1.889
Cuttack	Tangi	73H-2D4	2.236	0.073	0.073	1.412
Deogarh	Rengalbeda	73C-2C3	2.147	0.603	0.688	2.559
Dhenkanal	Deogaon	73H-2C6	1.968	0.224	0.174	2.149
Dhenkanal	Kaimati	73H-2C9	2.326	0.136	0.156	2.253
Gajapati	Gosani	74B-1A6	2.504	0.236	0.221	3.848
Gajapati	Mohana	74A-3B2	1.968	0.574	0.560	2.745
Gajapati	Narayanpur	74B-1A3	2.147	0.080	0.066	2.817
Gajapati	Raygarh	74B-1A2	2.147	0.080	0.066	2.817
Gajapati	Tumbagarh	74A-4B2	1.968	0.407	0.380	2.337
Ganjam	Baragam	74A-1C9	1.968	0.350	0.241	2.015
Ganjam	Kamappalli	74A-3D18	2.862	0.638	0.640	5.954
Jajpur	Chhatia	73L-2A8	1.968	0.480	0.343	2.129
Jharsuguda	Bhikhampali	64O-1C2	2.236	0.320	0.413	2.862
Jharsuguda	Brajrajnagar	64O-1D3	2.147	0.300	0.308	2.683
Kalahandi	Dalguma	65M-1A3	1.968	0.065	0.093	2.279
Kalahandi	Daspur	65I-1D3	2.326	0.191	0.189	3.504
Kalahandi	Golmunda	64L-4D1	2.683	0.207	0.208	4.756
Kalahandi	Jaring	65M-1A2	2.683	0.157	0.320	2.570
Kalahandi	Karlapada	64P-4A2	2.504	0.107	0.108	3.942

Kalahandi	Risida	64P-3B5	1.968	0.169	0.189	2.046
Kalahandi	Santapur	65M-1B2	1.968	0.124	0.138	2.886
Kalahandi	Tundla	64P-3B4	1.968	0.152	0.176	1.977
Kalahandi	Utkela	64P-4A4	1.968	0.118	0.186	2.137
Kendrapa	Indupur	73L-2B1	2.326	0.101	0.107	3.301
Kendrapa	Pattamundai	73L-2C2	2.415	0.114	0.129	4.377
Kendrapa	Rajnagar-R	73L-2C4	2.326	0.145	0.159	4.528
Kendrapa	Sukinda	73H-1D3	2.236	0.067	0.100	1.193
Keonjhar	Anandapur	73K-4A2A	1.968	0.076	0.080	2.950
Keonjhar	Baxibarigan	73G-3C2	2.147	0.455	0.424	2.980
Keonjhar	Ukunta	73G-1C4	2.504	0.282	0.260	3.114
Koraput	Koraput-ii	65J-1C2	1.968	0.046	0.084	1.607
Kurdha	Pichkuli	73H-4B1	2.057	0.193	0.206	3.610
Malkangiri	Govindpali	65J-2B1	2.147	0.191	0.178	3.764
Malkangiri	Raddaguda	65F-4C5	2.504	0.074	0.100	2.672
Mayurbhanj	Bahalda Road(kona)	73J-3A6	2.326	0.421	0.457	2.710
Mayurbhanj	Nalgoja	73O-1A5	2.504	0.217	0.316	2.886
Mayurbhanj	Naujara	73J-4A3	2.504	0.361	0.423	2.883
Nawarangpur	Anchalguma	65I-3C2	2.147	0.114	0.119	2.812
Nawarangpur	Dondasora	65I-2A2	2.326	0.131	0.273	2.544
Nawarangpur	Kosagumunda	65I-3A1	2.683	0.364	0.390	2.623
Nawarangpur	Papadahandi	65I-3C1	1.968	0.150	0.155	3.110
Nayagarh	Daspalla-i	73D-3D1	2.236	0.088	0.097	2.591
Nayagarh	Kandapara	73H-3A4	1.968	0.163	0.152	1.761
Nayagarh	Odagaon	73D-4D1	2.147	0.202	0.208	1.308
Nayagarh	Ranpur	73H-4B2	2.147	0.512	0.517	3.915
Nayagarh	Subalaya	73D-3D4	1.968	0.115	0.194	2.195
Nuapara	Komna	64L-2C4	2.147	0.095	0.110	2.335
Phulbani	Barkhama	64P-4D4	1.968	0.130	0.129	2.271
Phulbani	G-udaigiri	73D-4B6	2.326	0.354	0.341	2.819
Phulbani	Kurtamgarh	64P-4D2	1.968	0.183	0.185	2.794
Phulbani	Ranipathar	73D-2B6	2.326	0.313	0.365	2.864
Phulbani	Sunagaon	64P-4C3	2.862	0.180	0.194	4.838
Phulbani	Telapalli	73D-3A5	2.147	0.280	0.308	2.902
Phulbani	Tumdibandh	65M-1C2	2.862	0.397	0.367	5.231
Puri	Bedpursasan	74I-1A11	1.968	0.165	0.180	1.848
Puri	Brahmagiri	74E-1C2A	2.147	0.057	0.074	2.694
Puri	Kakatpur	73L-4A2	2.594	0.146	0.169	4.311
Puri	Kumareswar	73H-4D9	2.147	0.230	0.229	2.965
Puri	Pratapramchandr	74E-1D9	2.326	0.386	0.392	4.901
Puri	Rebana nuagaon	74E-1C4	2.236	0.114	0.118	3.242
Rayagada	Dongasoroda	65M-2C2	2.862	0.162	0.169	3.280
Rayagada	Kulnara	65M-3B2	2.415	0.164	0.140	2.990
Rayagada	Ramnaguda	65M-4C1	2.057	0.084	0.075	2.623
Rayagada	Shirikona	65M-4B4	2.504	0.152	0.112	4.131
Sambalpur	Bamra	73B-4B1	2.147	0.340	0.304	2.833

Sambalpur	Dandaipali	73C-2A3	2.326	0.646	0.717	3.408
Sambalpur	Gorupali	73C-3A2	2.504	0.231	0.301	3.808
Sambalpur	Jugipali	64O-2D5	1.968	0.168	0.172	3.319
Sambalpur	Kusumi	73C-1C2	2.862	0.317	0.301	5.274
Sambalpur	Larasara	64O-4D4	2.147	0.195	0.209	3.314
Sambalpur	Rairakhol(rampu	73C-4B1	2.326	0.172	0.143	3.404
Sonpur	Bagdiha	64O-4C16	2.862	0.190	0.162	5.012
Sonpur	Charuapali	64P-1C3	2.504	0.200	0.207	3.724
Sonpur	Khari	64P-1C4	2.147	0.230	0.246	3.208
Sonpur	Mahadevpali	64P-1D7	2.594	0.185	0.202	3.145
Sonpur	Sankara	64P-1D11	2.594	0.150	0.238	3.251
Sonpur	Singhijuba	64O-4C4	1.968	0.100	0.061	1.081
Sonpur	Telipalli	64O-4C21	2.057	0.542	0.664	3.246
Sundargarh	Deolipali	73C-1A2	2.683	0.382	0.383	4.083
Sundargarh	Kutra	73B-4B3	3.220	0.434	0.441	6.046
Sundargarh	Sabdega	73B-3A2	2.147	0.191	0.249	2.050
Sundargarh	Talsara	73B-3A1	1.968	0.680	0.687	3.083

Table 2. Significantly depleted groundwater level stations in post-monsoon (November) season

District	Location	Well No	MKZ	MKS	b1	t
Balesore	Basta	73O-2A2	0.094	2.147	1.853	0.085
Balesore	Jaleswar	73O-1A1	0.188	1.968	2.300	0.187
Balesore	Remuna	73K-2D7	0.185	2.504	3.544	0.189
Bargarh	Barpalli	64O-4C7	0.362	2.326	3.393	0.364
Bargarh	Bheden	64O-4D11	0.073	2.504	3.683	0.073
Bargarh	Deobahal	64O-3C9	0.040	1.968	3.076	0.059
Bargarh	Gaisilet	64P-1B4	0.193	1.968	2.536	0.191
Bargarh	Gorbhaga	64O-3D5	0.055	1.968	2.832	0.059
Bargarh	Tora	64O-3C6	0.135	2.236	1.906	0.244
Cuttack	Achhutpur	73L-2A12	0.032	2.147	2.503	0.056
Cuttack	Bahugram	73L-3A10	0.033	1.968	2.304	0.037
Cuttack	Cuttack town	73H-3D8A	0.209	1.968	2.536	0.208
Cuttack	Kantapara	73H-3D2	0.087	2.504	3.752	0.090
Cuttack	Kusunpur	73L-2B7	0.065	2.683	3.557	0.058
Cuttack	Niali	73L-4A8	0.043	2.326	3.243	0.045
Cuttack	Sankhmiri	73H-3B1	0.014	1.968	2.422	0.014
Dhenkanal	Babandh	73H-2B6	0.247	1.968	3.017	0.286
Ganjam	Chamakhandi	74A-1D4	0.077	2.683	2.732	0.100
Ganjam	Gayagonda	73D-4D2	0.123	1.968	2.167	0.205
Ganjam	Pudamari	74A-3B5	0.074	2.683	2.213	0.176
Jagatsing	Paradeepgarh	73L-3C5	0.214	2.326	3.055	0.309
Jajpur	Arkhapur	73L-2A5	0.250	2.504	4.097	0.277
Jharsugada	Katarbaga	64O-1C3	0.143	2.147	1.842	0.344
Kalahandi	Bawanipatna	65M-1A1	0.273	2.504	4.280	0.273

Kalahandi	Daspur	65I-1D3	0.130	2.504	3.661	0.143
Kalahandi	Golmunda	64L-4D1	0.156	2.862	5.843	0.176
Kalahandi	Gunupur	65M-2A2	0.080	3.041	5.553	0.085
Kalahandi	Jaring	65M-1A2	0.173	2.147	3.253	0.211
Kalahandi	Kegaon	64L-4D3	0.424	3.399	5.866	0.443
Kalahandi	Ladugaon	65I-2C4	0.110	2.147	2.439	0.166
Kalahandi	Langigarh	65M-2B2	0.083	2.236	2.964	0.238
Kalahandi	Madanpur	64P-3C1	0.181	1.968	2.084	0.135
Kalahandi	Risida	64P-3B5	0.086	2.326	2.512	0.201
Kalahandi	Santapur	65M-1B2	0.160	1.968	2.601	0.173
Kendrapa	Pattamundai	73L-2C1	0.041	2.147	3.678	0.045
Koraput	Boriguma	65I-4C1	1.185	2.504	5.944	1.190
Koraput	Lakshmipur	65N-1A1	0.392	2.147	3.253	0.695
Koraput	Peddagadavalasa	65N-1B1	0.833	2.326	5.333	0.889
Malkangiri	Govindpali	65J-2B1	0.111	1.968	2.747	0.158
Malkangiri	Kanyashram	65F-4C3	0.080	2.504	2.853	0.119
Malkangiri	M.v.58	65F-4C4	0.074	2.236	2.472	0.077
Mayurbhanj	Deoli	73J-4D1	0.160	2.683	3.960	0.203
Nawarangpur	Debugaon	65I-3B1	0.154	2.147	2.437	0.175
Nawarangpur	Dondasora	65I-2A2	0.173	1.968	3.132	0.313
Nawarangpur	Kundei	64H-4D1	0.228	1.968	1.718	0.210
Nawarangpur	Papadahandi	65I-3C1	0.230	3.041	4.005	0.309
Nawarangpur	Sonamasigan	65I-4B4	0.073	1.968	1.495	0.095
Nayagarh	Subalaya	73D-3D4	0.140	2.326	2.638	0.170
Nuapara	Sinapalli	64L-4C2	0.089	2.504	3.954	0.092
Puri	Chandanpur	74E-1D4	0.330	2.147	1.913	0.328
Puri	Satpada	74E-2B1	0.247	2.147	2.998	0.230
Rayagada	Dongasoroda	65M-2C2	0.097	2.504	4.322	0.099
Rayagada	Gumda	65M-4D3A	0.651	2.147	4.613	0.787
Rayagada	Kombhikot	65M-4B3	0.099	2.683	4.117	0.114
Rayagada	Kutragada	65M-2C4	0.042	1.968	2.097	0.076
Sambalpur	Bhalipali	64O-3D24	0.240	1.968	2.667	0.368
Sonpur	Sarasmal	64O-4C13	0.132	1.968	2.117	0.214
Sonpur	Singhijuba	64O-4C4	0.121	2.504	2.804	0.218
Sundargarh	Jalda	73B-4D6	0.210	2.147	2.700	0.403

Table 3. Significantly rising groundwater level stations in pre-monsoon (April) season

District	Location	Well No	MKZ	MKS	b1	r
Angul	Bhogabereni	73H-1A15	-0.316	-1.968	-2.595	-0.312
Angul	Samal	73G-4A1	-0.121	-2.236	-2.488	-0.128
Balesore	Kansa	73K-2D4	-0.116	-1.968	-2.752	-0.144
Balesore	Khontopara	73K-3D3	-0.174	-2.147	-2.894	-0.147
Balesore	Oupada	73K-3C4	-0.283	-1.968	-2.189	-0.291
Bargarh	Bhukta	64O-2B1	-0.836	-2.504	-4.163	-0.849
Bargarh	Deobahal	64O-3C9	-0.027	-2.147	-2.223	-0.032

Bhadrak	Akhuapada	73L-1B8	-0.143	-2.504	-3.733	-0.171
Dhenkanal	Balmi	73H-2B1	-0.183	-1.968	-2.067	-0.173
Dhenkanal	Gangutia	73H-2C3	-0.150	-2.326	-2.113	-0.239
Gajapati	Gumma	74B-1A5	-0.476	-2.326	-3.003	-0.470
Ganjam	Bananai	74A-2D4	-0.217	-1.968	-2.085	-0.233
Ganjam	Belagan	74A-3D13	-0.570	-2.326	-4.326	-0.600
Ganjam	Gallery	73D-4C3	-0.134	-2.594	-3.526	-0.165
Ganjam	Govindpur	74A-3D19	-0.640	-3.220	-5.861	-0.564
Ganjam	Hinjlikatu	74A-3C1	-0.367	-2.504	-3.487	-0.395
Ganjam	Koilingi	74A-4C11	-0.884	-2.326	-3.280	-0.829
Ganjam	Kukudahandi	74A-3D3	-0.389	-3.041	-4.670	-0.481
Ganjam	Mantridi	74A-4D4	-0.543	-2.683	-2.848	-0.639
Ganjam	Mujhagarh	73D-4C4	-0.457	-3.220	-4.514	-0.470
Ganjam	Narendrapur	74A-3D5	-0.552	-3.220	-6.336	-0.563
Ganjam	Purusatampur	74A-2D1	-0.213	-2.147	-2.452	-0.264
Ganjam	Tanganapalli	74A-3D8	-0.167	-2.147	-3.572	-0.165
Ganjam	Tarasingi	73D-4C2	-0.517	-3.399	-5.241	-0.512
Jagatsing	Jagatsingpur	73L-3A2	-0.261	-3.399	-7.962	-0.300
Jagatsing	Nuagaon	73L-4A6	-0.042	-1.968	-2.048	-0.040
Jajpur	Chinguripal	73G-4D4	-0.496	-2.862	-5.865	-0.514
Jajpur	Kabatabandha	73L-1A6A	-0.200	-2.326	-2.119	-0.210
Jajpur	Panikoili-ii	73L-1A5	-0.213	-2.147	-2.154	-0.181
Jajpur	Trilochanpur	73L-1A10	-0.199	-2.862	-2.983	-0.219
Kalahandi	Bandigaon	65I-2D10	-0.295	-2.147	-4.229	-0.295
Kalahandi	Jaipatna	65I-3D1	-0.172	-2.057	-3.645	-0.161
Kalahandi	Moter	65I-2D1	-0.318	-2.683	-6.668	-0.308
Kalahandi	Mukhiguda	65I-3D2	-0.441	-2.147	-3.427	-0.469
Kalahandi	Ranmalchak	65I-2D9	-0.203	-1.968	-2.422	-0.250
Kendrapa	Chatua	73L-3B12	-0.100	-2.504	-3.386	-0.108
Kendrapa	Rajgarh	73L-3C6	-0.039	-2.057	-2.472	-0.040
Keonjhar	Banspal	73G-2B1	-0.357	-2.594	-5.154	-0.410
Koraput	Boriguma	65I-4C1	-0.939	-2.504	-4.707	-0.938
Koraput	C-kusumi-ii	65I-4B6	-0.870	-2.147	-1.945	-0.838
Koraput	Damanahandi	65I-4B11	-0.550	-2.147	-2.418	-0.581
Koraput	Kenduguda	65J-1C10	-0.089	-2.504	-1.456	-0.159
Koraput	Podagada	65J-1D1	-0.119	-2.057	-2.280	-0.119
Koraput	Sasanhandi-ii	65I-4B5	-0.490	-1.968	-2.245	-0.640
Malkangiri	Bhejangawara	65F-4D1	-0.135	-3.041	-4.235	-0.173
Malkangiri	Kalimela	65F-4D5	-0.251	-2.147	-2.945	-0.298
Malkangiri	Khairput	65J-3A3A	-0.190	-2.504	-3.531	-0.163
Malkangiri	Kodumulguma	65J-3A2	-0.265	-1.968	-2.449	-0.355
Malkangiri	M.v.19	65F-4D4	-0.101	-2.683	-3.907	-0.108
Malkangiri	M.v.7	65F-3D3	-0.148	-2.147	-3.060	-0.139
Malkangiri	Malkangiri	65F-3D1	-0.434	-1.968	-2.736	-0.441
Malkangiri	Venkatapalam	65F-4C1	-0.137	-2.326	-2.915	-0.135
Mayurbhanj	Badasahi	73K-2C4	-0.469	-2.326	-4.474	-0.550

Mayurbhanj	Rairangpur	73J-3A2	-0.119	-2.147	-3.207	-0.125
Mayurbhanj	Singdachak	73G-1D4	-0.166	-1.968	-2.992	-0.165
Nuapara	Bargan-s	64L-4C1	-0.202	-1.968	-2.365	-0.255
Nuapara	Lakhna	64L-2C2	-0.761	-2.683	-3.919	-0.763
Phulbani	Phirinjia-ii	73D-3A4	-0.307	-2.862	-4.638	-0.321
Phulbani	Raikia-i	73D-4A6	-0.092	-2.594	-1.689	-0.323
Phulbani	Raikia-ii	73D-4A2	-0.209	-1.968	-2.855	-0.215
Puri	Astarang	74I-1B1	-0.062	-1.968	-1.894	-0.271
Sambalpur	Hirakud	64O-2D4	-0.230	-2.326	-3.319	-0.285

Table 4. Significantly rising groundwater level stations in post-monsoon (November) season

District	Location	Well No	MKZ	MKS	b1	t
Balesore	Kansa	73K-2D4	-2.862	-0.370	-3.328	-0.437
Bhadrak	Bagdavinayakpur	73K-4C5	-1.968	-0.052	-2.206	-0.061
Bolangir	Ichhapur	64O-4B3	-2.683	-0.070	-4.235	-0.080
Dhenkanal	Hatwari	73H-1C7	-2.147	-0.173	-2.411	-0.159
Ganjam	Phulata	74A-3D25	-2.147	-0.505	-2.860	-0.484
Ganjam	Polasora	74A-2D2	-2.326	-0.267	-3.075	-0.257
Ganjam	Sheragada	74A-2C4A	-2.147	-0.230	-2.764	-0.226
Ganjam	Tarasingi	73D-4C2	-2.862	-0.228	-4.193	-0.205
Jagatsing	Jaipur	73L-3B5	-2.504	-0.054	-3.807	-0.055
Kalahandi	Dasigaon	65I-2D7	-2.147	-0.166	-1.870	-0.125
Kalahandi	Moter	65I-2D1	-2.683	-0.151	-4.482	-0.148
Kalahandi	Mukhiguda	65I-3D2	-2.147	-0.332	-2.966	-0.311
Keonjhar	Deogan	73K-4A4	-2.326	-0.080	-1.528	-0.114
Koraput	Ghatarala	65I-4B13	-2.683	-0.326	-6.344	-0.331
Koraput	Kenduguda	65J-1C10	-2.326	-0.070	-3.393	-0.063
Koraput	Narayanpatna	65N-1A2	-2.952	-0.305	-2.703	-0.494
Koraput	Sasanhandi-ii	65I-4B5	-1.968	-0.124	-2.916	-0.120
Koraput	Şhoshanhandi	65I-4B2	-2.147	-0.072	-1.316	-0.077
Mayurbhanj	Chitrada	73K-1D3	-2.147	-0.120	-2.514	-0.191
Puri	Puri	74E-1D2	-1.968	-0.137	-2.549	-0.166
Puri	Sakhigopal-i	74E-1D5	-2.147	-0.047	-2.281	-0.054
Sambalpur	Gunderpur	64O-3D6	-2.594	-0.105	-3.339	-0.129
Sambalpur	Sason	73C-2A2	-2.326	-0.087	-3.448	-0.098
Sundargarh	Alikera	73B-4A4	-2.147	-0.270	-2.060	-0.309
Sundargarh	Himgiri	64O-1C1	-3.399	-0.488	-7.920	-0.531

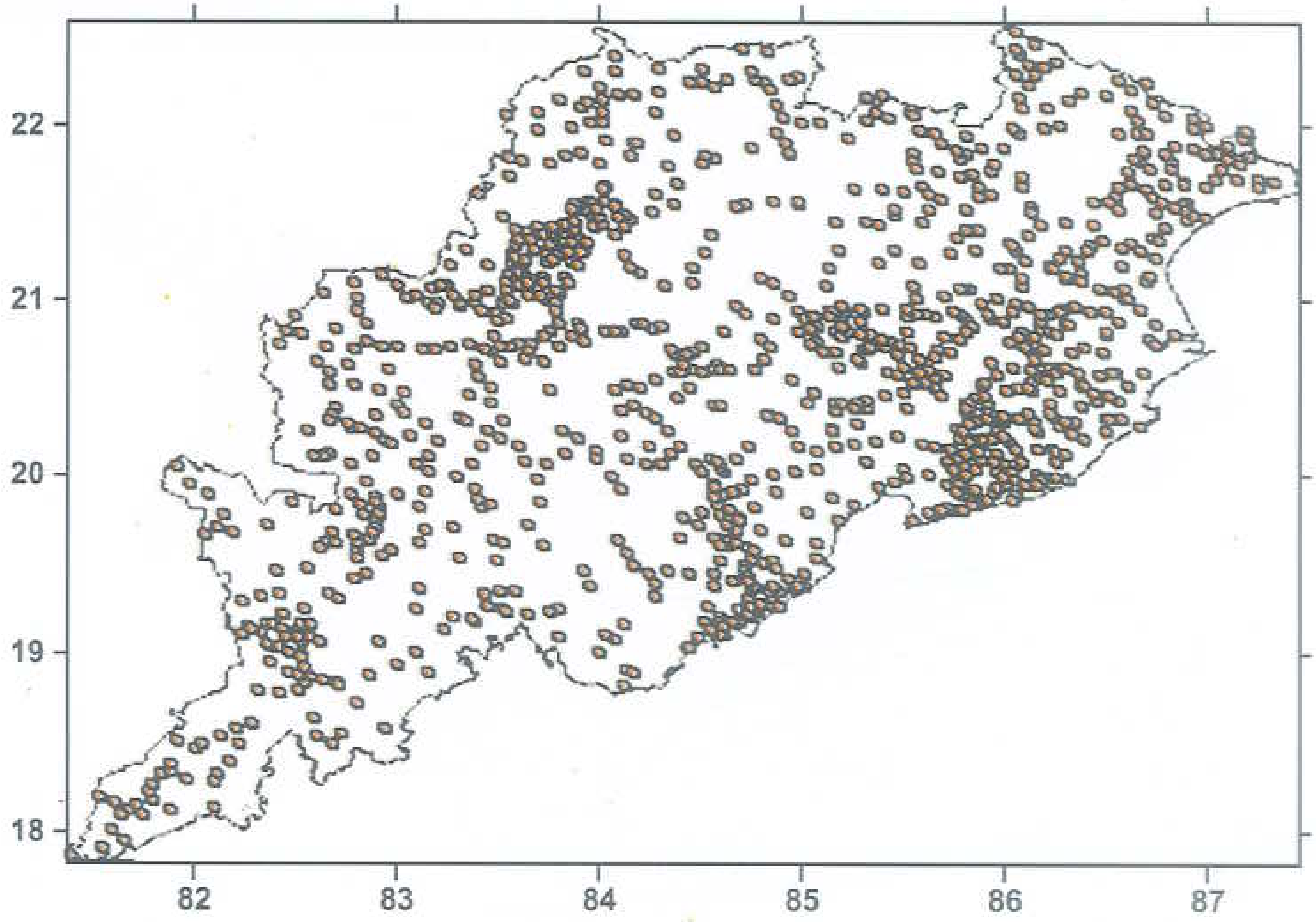


Fig. 0: National hydrograph monitoring stations of Orissa

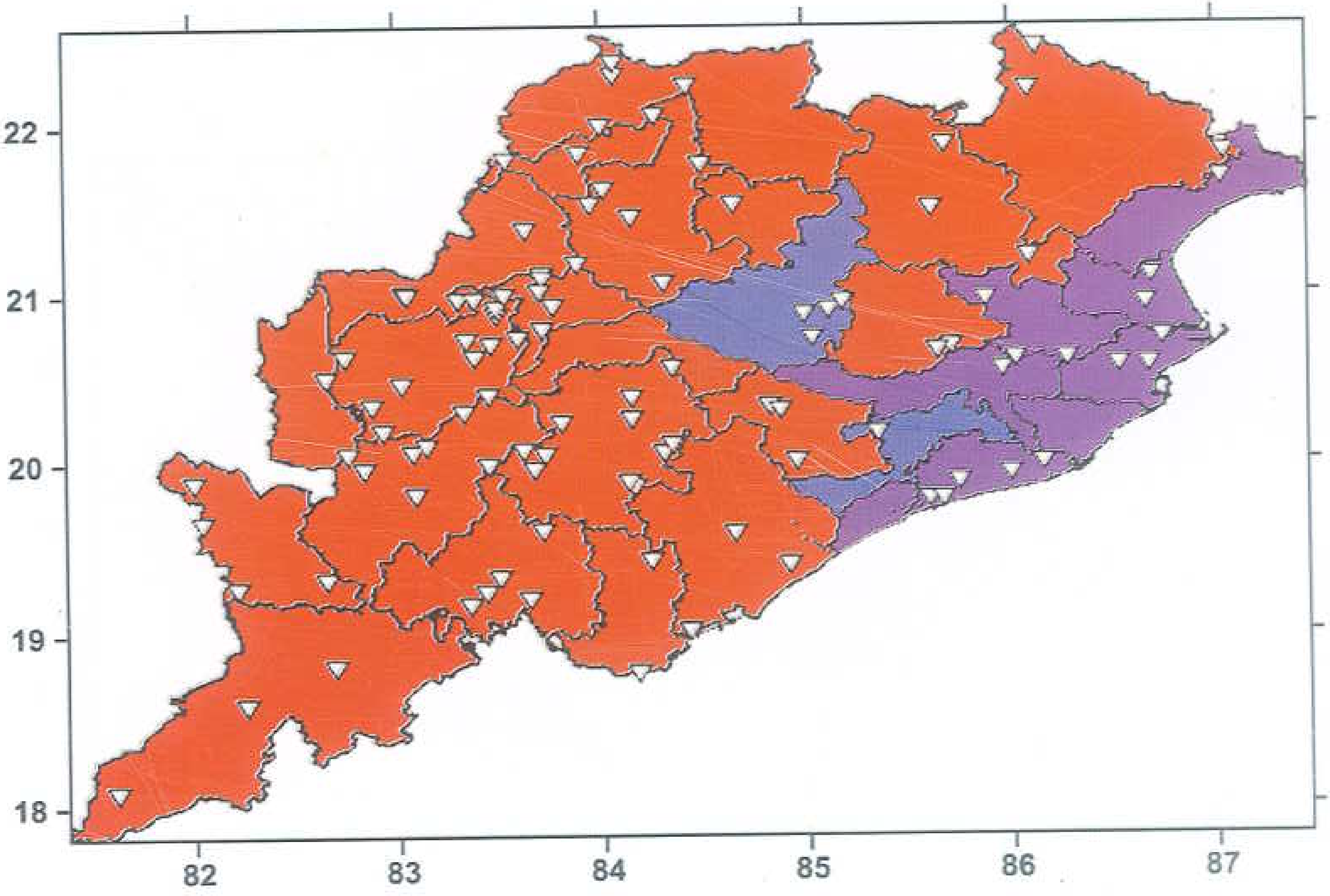


Fig. 1: Significantly depleted groundwater level stations in pre-monsoon (April) season

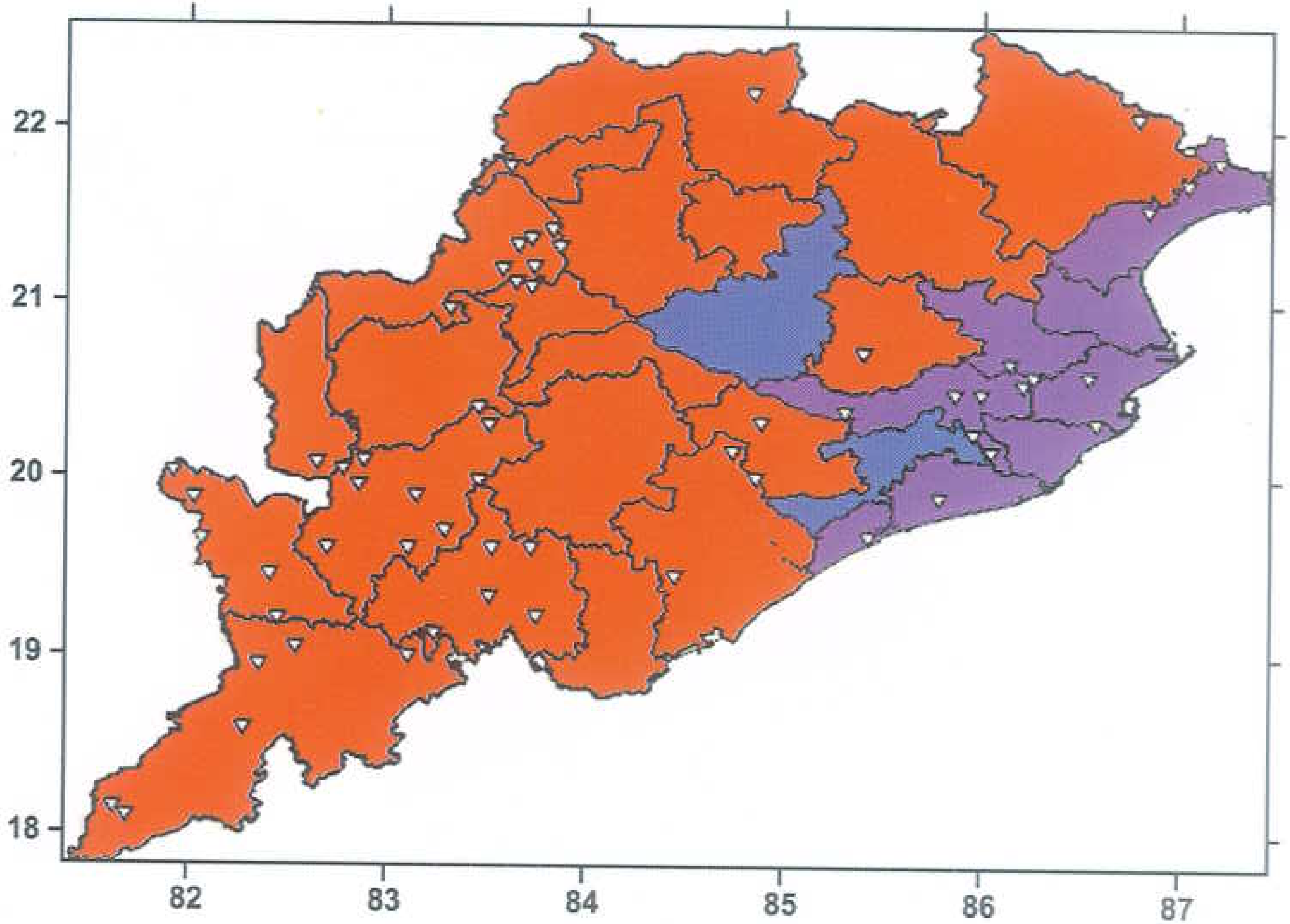


Fig. 2: Significantly depleted groundwater level stations in post-monsoon (November) season

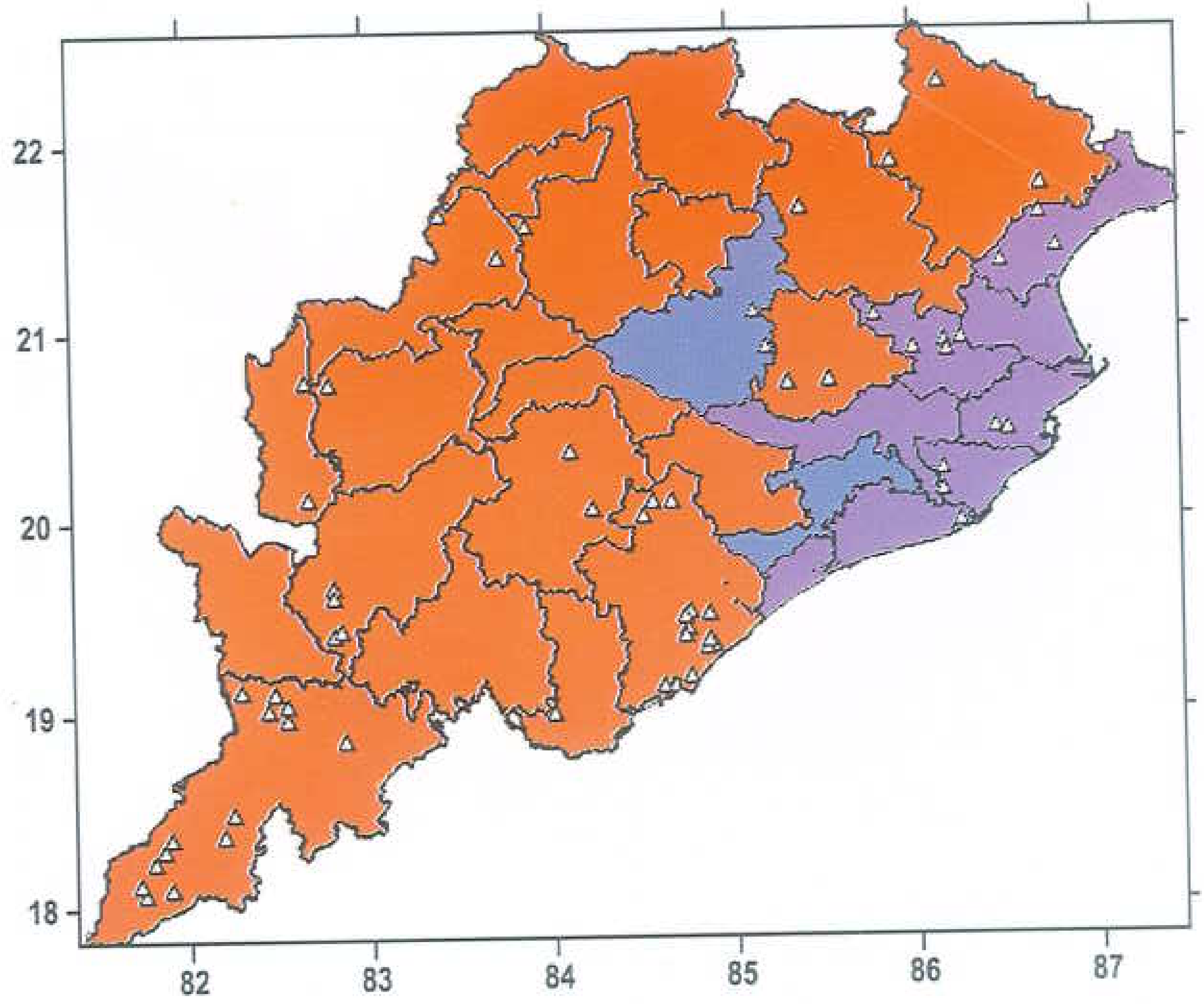


Fig. 3: Significantly rising groundwater level stations in pre-monsoon (April) season

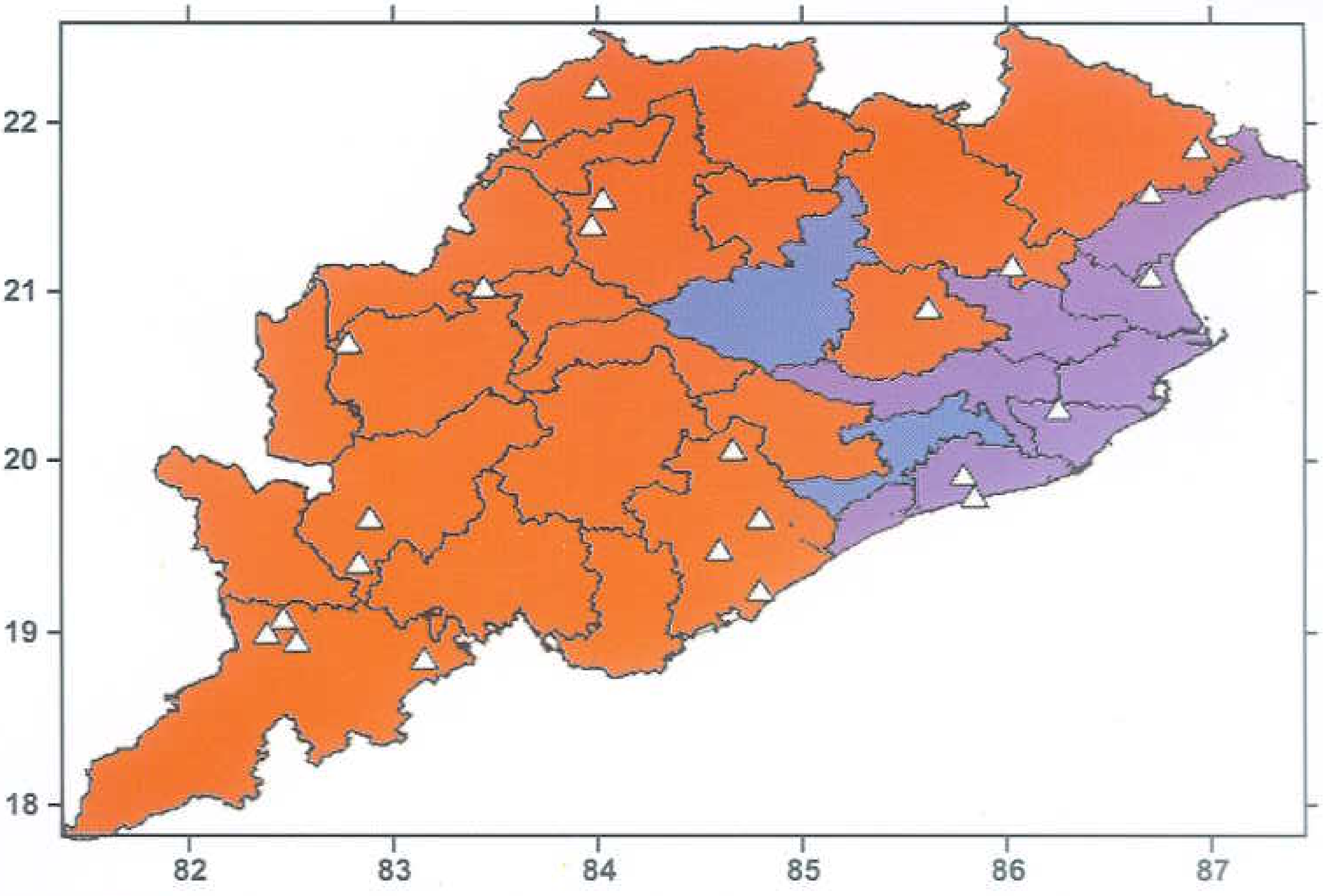


Fig. 4: Significantly rising groundwater level stations in post-monsoon (November) season