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# Assessing spatio-temporal variations in groundwater table depth and salinity using geostatistics and its relation with groundwater balance in a salt affected soil

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**ABSTRACT**

In order to study spatio-temporal variation in groundwater table depth and salinity in shallow groundwater table area, a field study was carried out at Nain experimental farm of ICAR-Central Soil Salinity Research Institute (ICAR-CSSRI) situated in Nain village of Panipat, Haryana. Total 27 observation wells had been installed in such a way that few among them were near to working tubewell for observing groundwater fluctuation due to pumping. 8 observation wells were near to pond and remaining observation wells were distributed in the area confined between the pond and surface drains to observe effect of natural recharge taking place from water bodies on groundwater table fluctuation. Besides continuous groundwater table monitoring, periodic assessment of groundwater salinity ($EC_w$) was also done. Spatio-temporal behavior of groundwater table and groundwater salinity was studied using Ordinary Kriging (OK) procedure in Arc GIS 9.3 software. The variograms and krigged spatial maps were generated for pre and post monsoon seasons of 2013 and 2015. Different inflow and outflow components of groundwater were characterized using groundwater balance method. Spatial variability maps of groundwater table in pre monsoon season indicate an increase in 36% area of shallow groundwater table (<2 m below ground level-bgl) during 2013 to 2015. Whereas, area under low saline groundwater (0-4 dS $m^{-1}$) was increased and reduction in higher saline groundwater (8-16 dS $m^{-1}$) area was recorded during 2013 to 2015. Analysis of groundwater balance of the experimental farm revealed that this reduction in groundwater salinity and rise in groundwater level might be attributed to intrusion of fresh water from outside cultivated land and seepage from nearby water harvesting structures and drain. Based on the results, it can be concluded that geo statistical analysis provides an understanding of groundwater flow behavior and dynamics of groundwater salinity, which can be used to prioritize the area for implementing the groundwater management plan in salt affected areas.

***Key words:***
CSSRI,
Groundwater,
Krigging,
Saline groundwater

## 1. INTRODUCTION

Studies on water table fluctuation and change in groundwater salinity by classical statistical method is not adequate as it does not take into account the possible influence of neighbouring sampling points. To overcome this, geostatistical spatial model was developed to take care of influence of neighboring sample location to a great extent (Karatas *et al.*, 2013). Geostatistics which introduced as a management and decision tool by many researchers has been applied to reveal the spatial and temporal variation in groundwater table fluctuation (Kumar *et al.,* 1998; Kumar and Ahmed, 2003; Kumar and Remadevi, 2006; Ahmadi and Sedghamiz, 2007; Machiwal *et al.*, 2012; Mini *et al.*, 2014 and Adhikary and Dash, 2014), and groundwater quality (Misra and Mishra, 2006; Adhikary *et al.,* 2010, 2012 and Arslan, 2012). In addition to geostatistics, geographic information system (GIS) has the potential to characterize and quantify spatial data and used for decision making in groundwater resource studies (Kumar *et al.,* 2011; Demir *et al.,* 2009 and Machiwal *et al.,* 2012). Therefore, integration of these two approaches actually helps in taking management decision on groundwater resources.

Estimation of groundwater recharge is crucial for efficient and sustainable groundwater management in waterlogged saline soil in arid and semiarid regions of India (Panigrahi *et al.,* 1995 and Singh, 2011). In this region lack of drainage facility, inappropriate irrigation practices, cultivation of more water requirement crops and seepage from canal networks has resulted in rise in groundwater table. This groundwater table rise ultimately leads to twin problems of water logging and salinity. Therefore, monitoring of water table fluctuations and water quality, both spatially and temporarily is important to evaluate the impact of water logging and salinity on crop production over large areas.

Keeping these facts in mind, the present study was planned to determine the spatio-temporal variability in shallow groundwater table and groundwater salinity and its relationship with seasonal groundwater balance. The outcome of the investigation would help in planning sustainable groundwater development and management strategies for the study area.

## 2. MATERIALS AND METHODS

### Experimental Site

Experiments were conducted in the salt affected soils of experimental farm of ICAR-CSSRI at village Nain (Dist: Panipat, Haryana, India). The farm area is characterized by topographic depression, having shallow and saline groundwater conditions. The farm has a total area of 11 ha and geographically it extends from 29°19'7.09” to 29°19'10”N latitude and 76°47'30.0” to 76°48'0.0” E longitude and at an elevation of 230-235 m above mean sea level (msl). The area falls under semi-arid climate and hyperthermic soil temperature regimes with average annual rainfall of about 500-600 mm and about 1500 mm annual evaporation (Ustic soil moisture regimes) (Mandal *et al*., 2013). A thick layer of $CaCO_3$ is present at 1 m depth below the surface. Surface drain is passing about 3-4 m away from the farm boundary.

### Groundwater Table Depth Monitoring and Water Sampling

For regular monitoring water table fluctuation, total 27 observation wells had been installed in such a way that few among them were near to working tube well to observe influence of groundwater pumping, 8 observation wells were installed around the pond and remaining observation wells were installed in the area confined between pond and drain to observe the impact of water bodies on fluctuation of groundwater table. A handmade water recording and sample collecting device was used for measuring water table depth and collecting water samples for salinity analysis. Groundwater table depth was measured as distance between the soil surface to the water surface. Contour survey of the farm was carried out using dumpy level for measuring natural slope. Initially 18 observation wells were installed, but later on another 9 observation wells were established for covering the whole farm. Groundwater salinity ($EC_w$) was measured using an electrical conductivity meter. The water table depth at each observation well was monitored fortnightly from 2013 to 2015. However, for comparing spatio-temporal changes in water table depth and salinity, pre (June-July) and post monsoon (Oct-Nov) month's of the year 2013 and 2015 was taken.

### Hydrologic Budget for Groundwater Balance

The groundwater balance of the study area, which accounts of water gains and losses, for a defined time period, can be written as:

$$\Delta G = \left(D_p + P_s - G_p\right) + \left(Q_{in} - Q_{out}\right) \qquad ...(1)$$

Where, $D_p$ is the deep drainage below root zone; $P_s$ is the pond seepage; $Q_{in}$ and $Q_{out}$ are lateral water fluxes into and out of the farm area along a boundary; $G_p$ is groundwater withdrawal through pumping; and $\Delta G$ is change in saturated groundwater storage. The units of all components of water balance equation are in depth (cm) per time period.

The deep drainage below root zone can be expressed through:

$$D_p = I + R - E - R_O - \Delta S \qquad ...(2)$$

Where, $I$ and $R$ represents irrigation and rainfall, respectively, $E$ and $R_0$ represents evaporation and runoff from the area, respectively and $\Delta S$ represents change in soil moisture over a given time period. As the study area was enclosed by bunds along the farm boundary, the surface runoff is almost negligible.

Fluctuation of groundwater table in the observation wells in the farm area was used to estimate the change in groundwater storage (Healy and Cook, 2002).

$$\Delta G = \Delta O_w \; X \; S_p \qquad ...(3)$$

Where, $\Delta O_w$ is the average change of the measured groundwater levels in the observation wells per time period and $S_p$ is the specific yield of the aquifer. As the study area situated in unconfined alluvial sandy zone, average specific yield of 15% (Central Ground Water Board, CGWB, 2009), was taken for estimating change in groundwater storage.

### Statistical Analysis

Descriptive statistical analysis of the groundwater table depth and salinity was performed using data analysis module of Microsoft Excel 2013. Kolmogorov-Smirnov (K-S) test was performed to assess the normality of groundwater table depth and salinity data (Narany *et al.*, 2014).

### Geo-statistical Analysis of Spatial Variability for Ground water Salinity and Depth

Geo-statistical approaches are often used to characterize the variance structure, determination of spatial distribution, and trend changes of groundwater table depth and quality. Ordinary kriging (OK) was used for determining spatial dependence of groundwater table depth and quality (Adhikary *et al.*, 2012). The OK method which uses a semi-variogram was used to quantify the spatial dependence between neighbouring observations:

$$\gamma(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} [Z(x_i + (h) - Z(x_i)] \qquad ...(4)$$

Where, $\gamma$ ($h$): The estimated or "experimental" semi-variance value for all pairs at a lag distance $h$; $z$ ($x_i$): Ground water table depth or groundwater salinity at point $I$; $z$ ($x_{i+h}$): Groundwater table depth or groundwater salinity at other points separated from $x_i$ by a discrete distance $h$; $x_i$: The geo-referenced positions where $z$ ($x_i$) values were measured; $n$: The number of pairs of observations separated by the distance $h$.

Four types of semi-variogram models (Circular, Spherical, Exponential, and Gaussian) were tested using geo-statistical module in Arc-GIS 9.3. For the selection of the best model, predictive performance of the fitted models were checked on the basis of cross validation tests. The values of mean standardized error (MSE), root mean square error (RMSE), average standard error (ASE) and root mean square standardized error (RMSSE) were estimated to ascertain the performance of the fitting models (Mahmoodifard *et al.*, 2014). MSE should be close to zero if the prediction standard errors are valid. If the RMSE is close to the ASE, the prediction errors were correctly assessed. If the RMSE is smaller than the ASE, then the variability of the predictions is overestimated; conversely, if the RMSE is greater than the ASE, then the variability of the predictions is underestimated. The same could be deduced from the RMSSE statistic. It should be close to one. If the RMSSE is greater than one, the variability of the predictions is underestimated; likewise if it is less than one, the variability is overestimated.

The parameters of the geostatistical model *i.e.* nugget, sill and nugget to sill ratio were analyzed for their spatial dependence. According to Liu *et al.* (2008), a variable is considered to have strong spatial dependence if the nugget-to-sill ratio is less than 0.25, and has a moderate spatial dependence if the ratio is between 0.25 and 0.75; otherwise the variable has a weak spatial dependence. The surface maps of pre and post monsoon groundwater depths and salinity were produced from best-fit geostatistical models and quantitative analysis was done using Arc-GIS 9.3.

## 3. RESULTS AND DISCUSSION

### Contour Survey

Contour survey of the farm revealed that farm has fairly leveled topography. The elevation of the farm ranges between 212.99 to 213.67 m above (msl). High elevation was observed in south east corner of the farm where farm pond was excavated and excavated soil had stacked over the land. Lowest elevation was found in the middle of the farm from south east side.

### Descriptive Data Analysis

Descriptive statistical analysis was carried out to provide a preliminary inference on groundwater table depth and salinity in pre and post monsoon seasons of 2013 and 2015. Table 1 provide summary of groundwater table depth and salinity statistics for 2013 and 2015 for pre and post monsoon

**Table: 1**
**Summary statistics of the groundwater table depth (m) and salinity (dS m$^{-1}$) at Nain farm, Panipat**

| Groundwater parameter | Observation | Mean | Standard deviation (SD) | Standard Error (SE) | Maximum | Minimum |
|---|---|---|---|---|---|---|
| Groundwater table depth (m) | Pre monsoon (2013) | 2.3 | 0.6 | 0.1 | 3.4 | 0.4 |
| | Post monsoon (2013) | 1.4 | 0.3 | 0.1 | 2 | 1 |
| | Pre monsoon (2015) | 2.1 | 0.6 | 0.1 | 3.8 | 1.5 |
| | Post monsoon (2015) | 1.3 | 0.3 | 0.1 | 1.8 | 0.7 |
| Groundwater salinity (dS m$^{-1}$) | Pre monsoon (2013) | 9.5 | 6.6 | 1.5 | 22.8 | 1.6 |
| | Post monsoon (2013) | 9.0 | 5.9 | 1.4 | 22.9 | 1.1 |
| | Pre monsoon (2015) | 7.2 | 5.4 | 1.1 | 16.8 | 0.5 |
| | Post monsoon (2015) | 7.1 | 5.6 | 1.1 | 16 | 0.4 |

seasons. During pre monsoon season of 2013, the mean value of groundwater table depth was 2.3 m, while in post monsoon season groundwater table rose upto 1.4 m, which shows that considerable amount of recharge took place during this period. But when we compared mean values of groundwater table between the years, it was observed that there was no significant rise or decline in water table depth. In 2015, mean groundwater table was 2.1 and 1.3 m in pre and post monsoon season, respectively. Standard deviation (SD) of groundwater depth was 0.6 and 0.3 in pre and post monsoon season in both the years inferred that overall no significant rise or decline in water table depth was occurred in the study area. Mean groundwater salinity in pre and post monsoon season was 9.5 and 9 dS $m^{-1}$ in 2013. While in 2015, mean groundwater salinity in pre and post monsoon season reduced by 2.3 and 1.9 dS $m^{-1}$, respectively, compared to 2013. This improvement in groundwater salinity was probably due to recharged from rain and fresh groundwater sources.

**Distribution of Spatial Data**

The Kolmogorov-Smirnov (K-S) test measures the difference between observed and expected distributions (Narany *et al*., 2014). K-S test revealed that both groundwater table depth and groundwater salinity data were not normally distributed (Table 2). To adjust data values to the normal distribution, Box cox transformation with 0.5 power was carried out.

The fitted Semi-variogram models of groundwater table depth and groundwater salinity for pre and post monsoon season of 2013 and 2015 are presented in Fig. 1a-1d and Fig. 2a -2d and their cross validation parameter presented in Table 2. For groundwater table depth, spherical and gaussian were the best fitted semi variogram model in pre and post monsoon season of 2013 whereas, gaussian and exponential were the best fitted semi variogram model in pre and post monsoon season of 2015. Positive nugget values were observed for both groundwater table depth and groundwater salinity (Table 2), which could be attributed to the short range, random and inherent variability in topography and parent material observed in most salt affected lands. High nugget value in groundwater salinity indicates that there was existence of short range variability in the farm. In pre monsoon season higher sill values observed for both groundwater table depth (0.3 and 0.15) and salinity (5.68 and 5.15) suggesting that there was increase in spatial variance of the groundwater table and salinity (Table 2). This was mainly due to recharging of considerable amount of groundwater with fresh water present in water bodies and inflow of groundwater from low laying southeast side of the study area (Fig. 3a-3d). The nugget ($C_0$) to Sill ($C_0$+C) ratio was used to characterize short distance auto correlation and spatial dependence of the variables, utilizing these indices, it was found that groundwater table depth had moderate spatial dependency and groundwater salinity had moderate to near weak spatial dependence in the study area.

Higher spatial dependence of groundwater table depth might be attributed to spatial homogeneity of structural factor such as nearly leveled topography exists in the farm. Lower spatial dependency of groundwater salinity might be due to the fact that seepage from water bodies recharge the ground water and fresh water floats over the saline ground water. This good quality fresh water over saline groundwater leads to spatial heterogeneity in groundwater salinity. The accuracy of the geostatistical models in ground water table and salinity prediction was checked by RMSE, RMSSE, ASE and MSE. The cross validation results showed acceptable accuracy with MSE close to zero, ASE closer to RMSE and RMSSE close to one (Table 2).

The spatial distribution of groundwater table depth and

**Table: 2**
**Geostatistical parameters of different models selected for ordinary kriging analysis and cross validation results of groundwater table depth and groundwater salinity at Nain farm**

| Groundwater parameter | Observation | Best fitted model | K-S test result and Transformation | Nugget ($C_0$) | Sill ($C_0$+C) | Nugget: Sill (%) | MSE | ASE | RMSE | RMSSE |
|---|---|---|---|---|---|---|---|---|---|---|
| Water table depth (WTD) (m) | Pre monsoon (2013) | Spherical | K-S test: No normal distribution Box Cox (Power-0.5) | 0.15 | 0.30 | 50 | -0.03 | 0.70 | 0.67 | 0.93 |
| | Post monsoon (2013) | Gaussian | | 0.04 | 0.07 | 57.14 | -0.03 | 0.26 | 0.28 | 1.09 |
| | Pre monsoon (2015) | Gaussian | | 0.07 | 0.15 | 46.66 | -0.03 | 0.49 | 0.52 | 1.05 |
| | Post monsoon (2015) | Exponential | | 0.02 | 0.07 | 28.57 | -0.009 | 0.24 | 0.24 | 0.97 |
| $Ec_w$ (dS $m^{-1}$) | Pre monsoon (2013) | Circular | K-S test: No normal distribution Box Cox (Power-0.5) | 4.2 | 5.68 | 73.94 | 0.08 | 6.49 | 6.89 | 1.08 |
| | Post monsoon (2013) | Circular | | 1.79 | 4.66 | 38.41 | 0.02 | 5.46 | 5.20 | 0.98 |
| | Pre monsoon (2015) | Gaussian | | 3.33 | 5.15 | 64.66 | -0.04 | 5.21 | 4.96 | 1 |
| | Post monsoon (2015) | Circular | | 3.81 | 5.33 | 71.48 | -0.08 | 5.43 | 5.30 | 1.04 |

MSE- Mean Standardized Error, RMSE -Root Mean Square Error, ASE -Average Standard Error,RMSSE -Root Mean Square Standardized Error

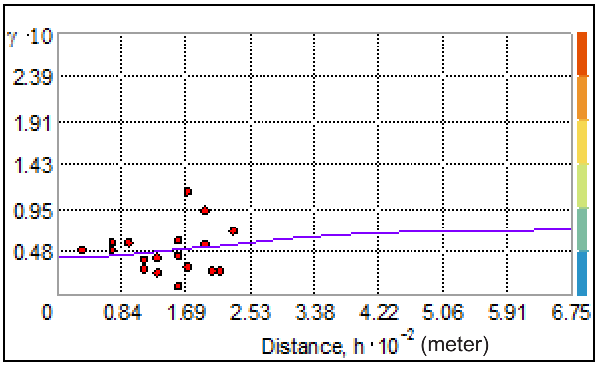


**Fig. 1a. Semi variance and fitted models for pre monsoon ground water table depth in 2013**

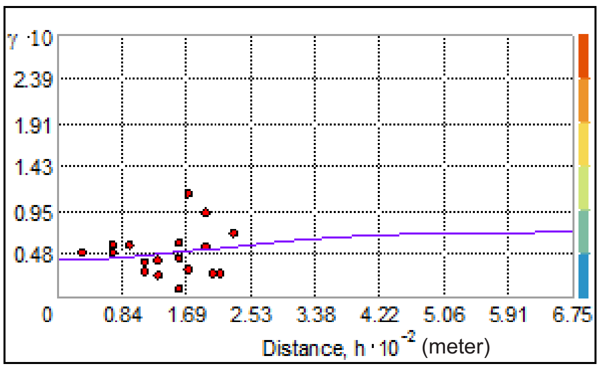


**Fig. 1b. Semi variance and fitted models for post monsoon ground water table depth in 2013**

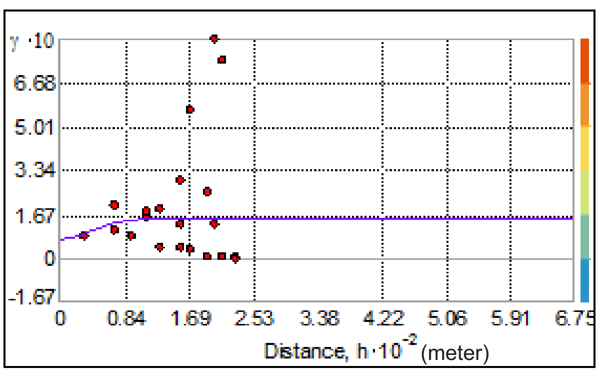


**Fig. 1c. Semi variance and fitted models for pre monsoon ground water table depth in 2015**

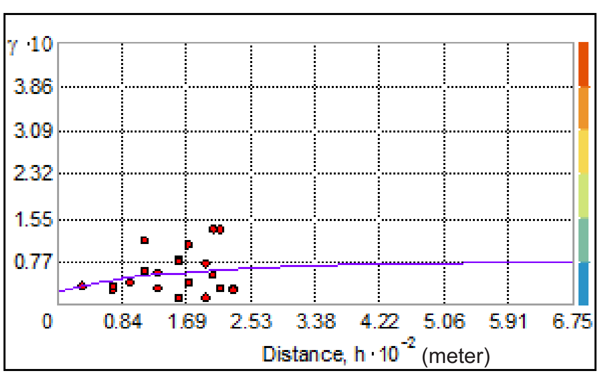


**Fig. 1d. Semi variance and fitted models for post monsoon ground water table depth in 2015**

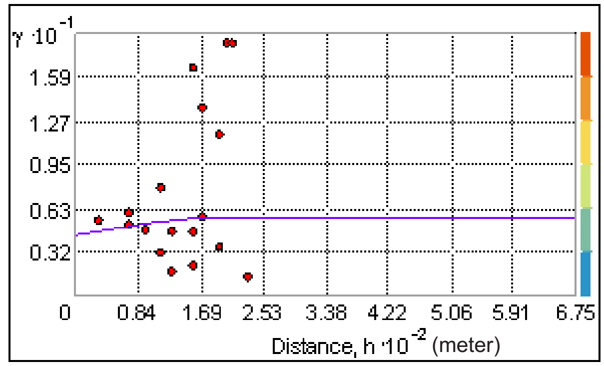


**Fig. 2a. Semi variance and fitted models for pre monsoon ground water salinity in 2013**

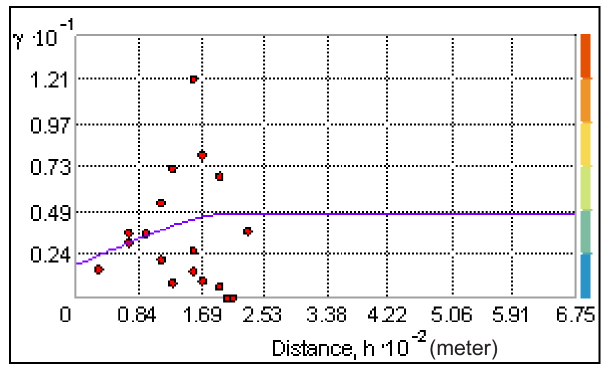


**Fig. 2b. Semi variance and fitted models for post monsoon ground water salinity in 2013**

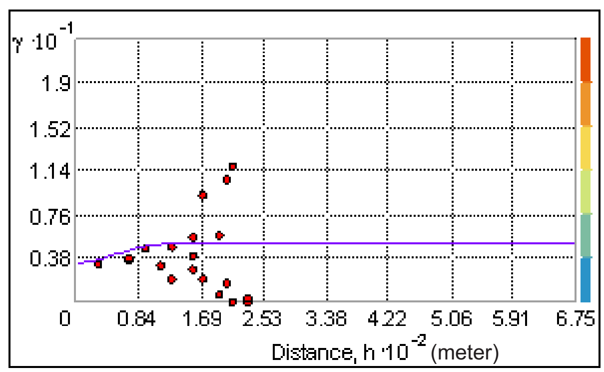


**Fig. 2c. Semi variance and fitted models for pre monsoon ground water salinity in 2015**

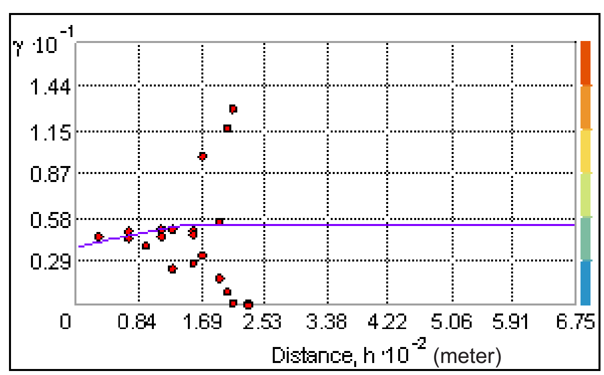


**Fig. 2d. Semi variance and fitted models for post monsoon ground water salinity in 2015**

salinity for the pre and post monsoon season in 2013 and 2015 are presented in Fig. 3a-3d and Fig. 4a-4d. The area under different water table and salinity ranges is presented in Table 3. In pre monsoon season, water table depth in most of the area ranged between 1.5-3 m below ground level (bgl), while in post monsoon season it varied between 1-1.5 m bgl, indicating a considerable rise in groundwater table after monsoon season. The spatial variability maps of water table depth for pre monsoon season of 2013 indicated that in 88% of the study area water table depth ranged between1.5-2.5 m bgl and only 12% area had below 2.5 m bgl. In post monsoon season of 2013, 91.4% area had water table depth above 1.5 m bgl and 8.6% area between 1.5-2 m bgl. Similar trend ground water recharge was observed in 2015 season also (Table 3), indicating in shallow unconfined aquifer, very little time lag for recharge from rainfall. Spatial variability maps of groundwater salinity showed that there was 32% reduction in area having salinity range between 8-16 dS $m^{-1}$ and 6% increase in area having salinity range between 0-4 dS $m^{-1}$. Observation on ground water salinity over a period of two years between

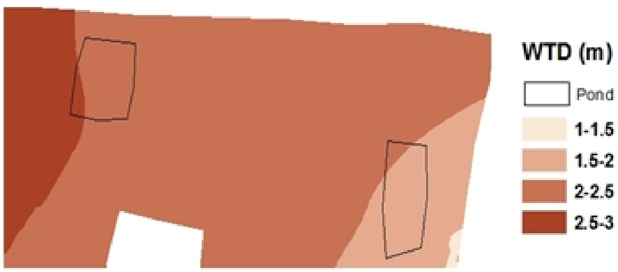


**Fig. 3a. Spatial map of water table depth in pre monsoon season in 2013 at Nain farm**

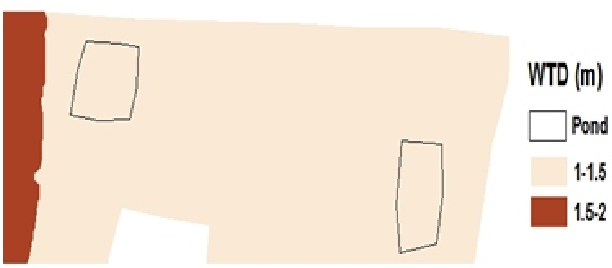


**Fig. 3b. Spatial map of water table depth in post monsoon season in 2013 at Nain farm**

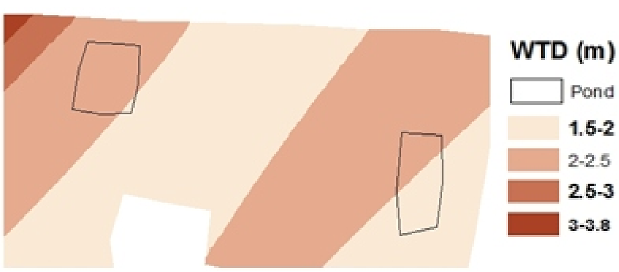


**Fig. 3c. Spatial map of water table depth in pre monsoon season in 2015 at Nain farm**

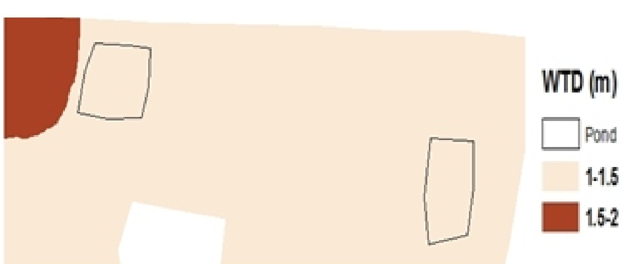


**Fig. 3d. Spatial map of water table depth in post monsoon season in 2015 at Nain farm**

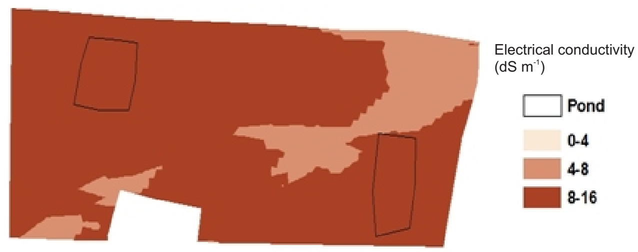


**Fig. 4a. Spatial map of groundwater salinity in pre monsoon season in 2013 at Nain farm**

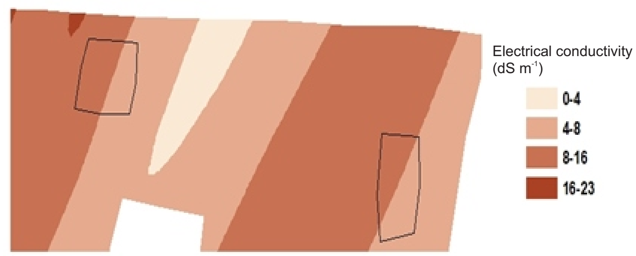


**Fig. 4b. Spatial map of groundwater salinity in post monsoon season in 2013 at Nain farm**

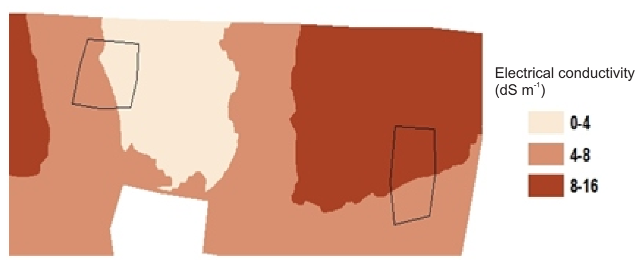


**Fig. 4c. Spatial map of groundwater salinity in pre monsoon season in 2015 at Nain farm**

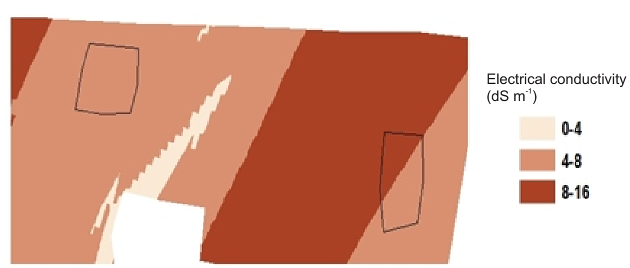


**Fig. 4d. Spatial map of groundwater salinity in post monsoon season in 2015 at Nain farm**

(2013 to 2015) revealed that area under low groundwater salinity (0-4 dS $m^{-1}$) increased from 0% to 17%, conversely, area under high groundwater salinity (8-16 dS $m^{-1}$) reduced to 34% from 82.8%. Analysis of variability maps of ground water table in pre monsoon season inferred that, in the year 2015, considerable increase in area (36%) of shallow ground water table (<2 m bgl) as compared to year 2013.

Increase in area of shallow groundwater table (< 2 m bgl) and low salinity (0-4 dS $m^{-1}$) in 2015 compared to 2013 indicates that during the period of 2013-2015, considerable amount of groundwater recharge took place from fresh groundwater sources. This might be due to the fact that fresh runoff water from nearby drain stored into the ponds, percolated and recharged the groundwater and diluted its salinity over time. Apart from the nearby pond area, significant reduction in area of higher salinity (8-16 dS $m^{-1}$) was also occurred in south west side of the farm (Fig. 4a-4d).

**Groundwater Balance Analysis**

The analysis of different groundwater balance components (Table 4) shows that during winter season and summer season of 2015 net groundwater recharge was negative due to higher groundwater withdrawals to meet out crop water requirements, higher atmospheric evaporative demand and outflow of groundwater from the area. Heavy rainfall (11.2 cm) and inflow of water from adjoining drain (3.77 cm) during the month of March, 2015 resulted in an average groundwater table rise of 17 cm. During monsoon season 2015, ground water recharge was positive. Groundwater inflow from outside farm area and nearby drain was the major contributor to groundwater rise up during the monsoon season of 2015. The study area received a mean net recharge of 34.7 cm during the monsoon season of 2015, which resulted into an average groundwater table rise of 2.31 m during this period.

There was continuous intrusion of groundwater from outside farm area and resulted into rise in water table depth. Inflow and out flow of the groundwater played a vital role in groundwater table depth and salinity. Whenever groundwater inflow from the outside farm area occurred, water table rose up and groundwater salinity declined was noticed. Opposite trend was noticed when outflow of the groundwater occurred from the farm area. Groundwater salinity moderately correlated ($R^2$ = 0.48) with the groundwater table depth (Fig. 5c). This reduction in groundwater salinity and slight rise in groundwater table depth was probably due to intrusion of water from outside farm area and seepage from nearby water harvesting structure and drain. In monsoon season, deep

**Table: 3**
**Classification and distribution of area (%) of water table depth and groundwater salinity at Nain farm**

| Year | Season | % area of Water table depth (WTD) (m) | | | | | % area of Groundwater Salinity (dS $m^{-1}$) | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 1-1.5 | 1.5-2 | 2-2.5 | 2.5-3 | 3-4 | 0-4 | 4-8 | 8-16 | 16-24 |
| 2013 | Pre monsoon | 0.3 | 11.6 | 75.2 | 12.8 | - | - | 17.2 | 82.8 | - |
| | Post monsoon | 91.4 | 8.6 | - | - | - | 5.87 | 42.89 | 50.94 | 0.30 |
| 2015 | Pre monsoon | - | 48.0 | 49.5 | 2.2 | 0.4 | 17.1 | 49.0 | 33.9 | - |
| | Post monsoon | 93.5 | 6.5 | - | - | - | 3.6 | 56.8 | 39.6 | - |

**Table: 4**
**Groundwater balance of Nain farm, Panipat**

| Season | Period (2015) | Irrigation (cm) | Rainfall (cm) | Evaporation (cm) | Pumping (cm) | Soil Storage (cm) | Pond Seepage (cm) | Deep Drainage (cm) | Water table depth fluctuation (cm) | Water inflow (cm) |
|---|---|---|---|---|---|---|---|---|---|---|
| Summer | ($8^{th}$ Jan-$25^{th}$ Feb) | 2.09 | 0.77 | 5.17 | 2.3 | -1.15 | 0.77 | -1.16 | 1.8 | -4.49 |
| | ($25^{th}$ Feb-$1^{st}$ April) | 0.93 | 11.92 | 10.25 | 0.8 | 1.22 | 0.67 | 1.37 | -2.6 | 3.77 |
| | ($1^{st}$ April-$15^{th}$ April) | 0 | 3.7 | 5.4 | 0 | -0.88 | 0.22 | -0.82 | 4.0 | -4.63 |
| | ($16^{th}$ April-$3^{th}$ May) | 0.99 | 1.3 | 22.45 | 2.3 | -3.04 | 0.21 | -17.11 | 6.9 | -26.12 |
| | ($13^{th}$ May-$3^{rd}$ June) | 1.41 | 1.9 | 21.08 | 2.2 | -1.15 | 0.04 | -16.63 | 4.4 | -23.16 |
| | Total Summer | 5.42 | 19.59 | 64.35 | 7.65 | -4.99 | 1.91 | -34.35 | 14.6 | -54.63 |
| Monsoon | ($3^{rd}$ June-$16^{th}$ July) | 1.44 | 43 | 30.01 | 2.8 | 5.82 | 0.67 | 8.61 | -6.3 | 12.76 |
| | ($16^{th}$ July-$5^{th}$ August) | 1.03 | 1.8 | 8.84 | 0.9 | -3.93 | 0.52 | -2.08 | -15.2 | 12.66 |
| | ($5^{th}$ August-$3^{rd}$ Sept) | 1.37 | 29.13 | 8.93 | 0.5 | 8.86 | 0.81 | 12.71 | -12.6 | 25.61 |
| | ($3^{rd}$ Sep-$7^{th}$ Oct) | 0.82 | 6.8 | 11.32 | 0.5 | -2.67 | 0.92 | -1.03 | -0.6 | -0.03 |
| | Total Monsoon | 4.66 | 80.73 | 59.1 | 4.77 | 8.08 | 2.91 | 18.21 | -34.7 | 51.01 |

percolated fresh water from the nearby paddy field recharged groundwater. This fresh water dilutes saline water and reduces its salinity over a period of time.

## 4. CONCLUSIONS

Spatio-temporal variability of groundwater table depth and salinity and its relationship with seasonal groundwater balance was studied in a shallow saline groundwater zones. Groundwater table depth and groundwater salinity measured through observation wells and subjected to spatio-temporal variability analysis. Spatial variability maps of groundwater table in pre monsoon season indicated that area under shallow groundwater (<2 m bgl) was increased by 36% during 2013 to 2015. However, during this period (2013-2015), area under low groundwater salinity (0-4 dS $m^{-1}$) increased by 17%, while higher salinity (8-16 dS $m^{-1}$) area reduced by 49%. Groundwater table in shallow aquifer was increased and groundwater salinity was reduced after rainy season. Analysis of groundwater balance revealed that this reduction in groundwater salinity with groundwater table rise up mainly due to intrusion of percolated fresh water from outside farm area and seepage water from nearby water harvesting structure and drain. Hence, study shows that geo statistical analysis provides an understanding of groundwater flow behavior and dynamics of groundwater salinity, which can be used to prioritize the area for implementing groundwater management plan in a salt affected shallow water table areas.

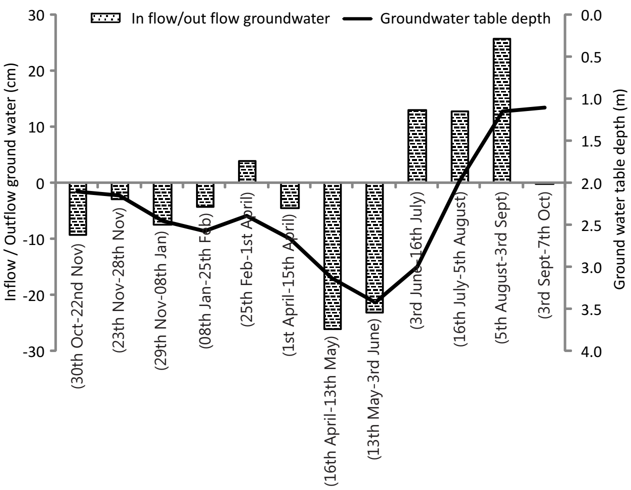


**Fig. 5a. Temporal dynamics of inflow and outflow of groundwater with groundwater table depth**

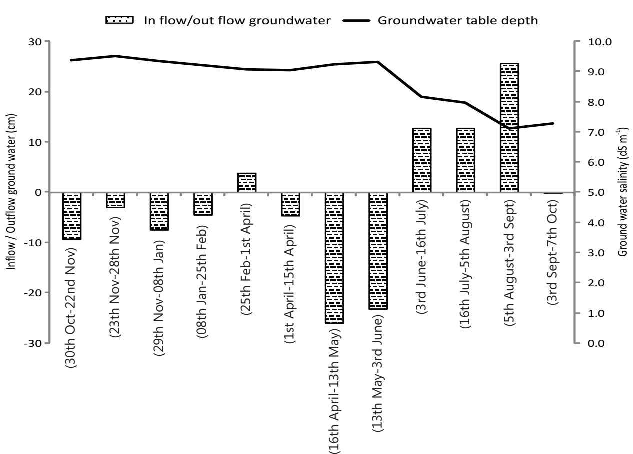


**Fig. 5b. Temporal dynamics of inflow and outflow of groundwater with groundwater salinity**

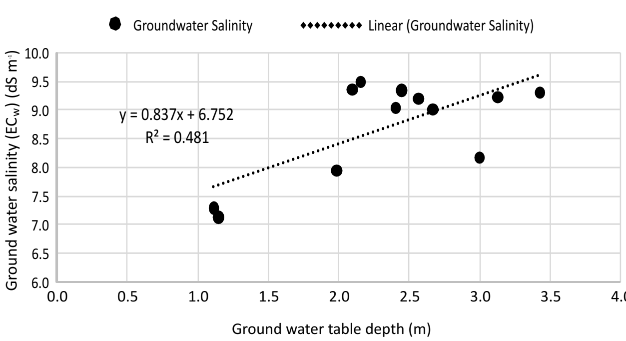


**Fig. 5c. Relationship between groundwater table depth with groundwater salinity at Nain farm, Panipat**

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