Agriculture Sustainability in Punjab with Reference to Groundwater Availability

** Jaspal Singh*
*** Jaweriah Hazrana*
**** Aaisha Nazrana*

Abstract

Groundwater sources of Punjab have been principal factors for achieving food security in the country through the success of green revolution. In recent decades, previously abundant and reliable groundwater supplies have diminished alarmingly due to unsustainable and extensive exploitation. Several factors have contributed to this serious situation such as shifting of cropping pattern in favour of water intensive crops at the cost of water resilient ones and meager dependence on canals. The situation has been further aggravated by governmental policies, such as free electricity, aimed at economic improvement but facilitating excessive ground water utilization. The present paper examined the importance of four causal factors in depleting groundwater resources. Furthermore, an unobserved components series model was employed to generate out of sample forecasts till 2025 to highlight the drastic and unsustainable consequences of current usage pattern.

Keywords : **groundwater, sustainability, Punjab, forecasting**

JEL Classification : Q15, Q16, Q25

Paper Submission Date : January 13, 2016 ; Paper sent back for Revision : July 6, 2016 ; Paper Acceptance Date : September 6, 2016

The state of Punjab constitutes 1.54% (50.36 lakh ha) of the total geographical area of India and houses more than 2% of its population. With 85% of the area under agriculture it is a major contributor to food security and is commonly referred to as the food bowl of India. In the mid 1960s, Punjab was one of the three high potential regions where the green revolution (GR) was initially implemented. The GR was based on employment of high yielding varieties (HYVs), intensive input utilization, and increased investments in irrigation for two main food crops - rice and wheat. These changes led to substantial increase in output and cropping intensities largely attributable to the availability of groundwater sources.

The GR largely increased reliance on natural and mechanical inputs. The latter facilitated exploitation of natural inputs, specifically groundwater resources, leading to unsustainability and adverse consequences. The revolution also led to a swift rise in the total cultivated area under high water intensive crop (area under paddy rose from 2,27,000 ha in 1960 - 61 to 2,015,000 ha in 1990-91 and further to 2,845,000 ha in 2012-13) at the cost of less water-intensive crops like oilseeds, bajra, jowar, maize, and pulses. Around 97% of total cultivated area was under assured irrigation from surface and groundwater resources (Singh, 2006). The current gross water requirements amount to 6.15 million ha-m relative to availability of 3.66 million ha-m. Of the available water resources 1.52 million ha-m was supplied by surface water (with approximately 14,000 km of canals, distributaries, etc. from the rivers Sutlej, Beas, Ravi, and Ghaggar) and 2.14 M ha-m by groundwater resources

* *Research Associate,* ICAR-National Institute of Agricultural Economics and Policy Research, DPS Marg, PUSA, New Delhi-110012. Email : punjabimatti82@gmail.com
** *Research Scholar,* Department of Economics, Jamia Millia Islamia, New Delhi - 110 025.
*** *Student,* Department of Economics, Jamia Millia Islamia,(A Central University) New Delhi - 110 025.

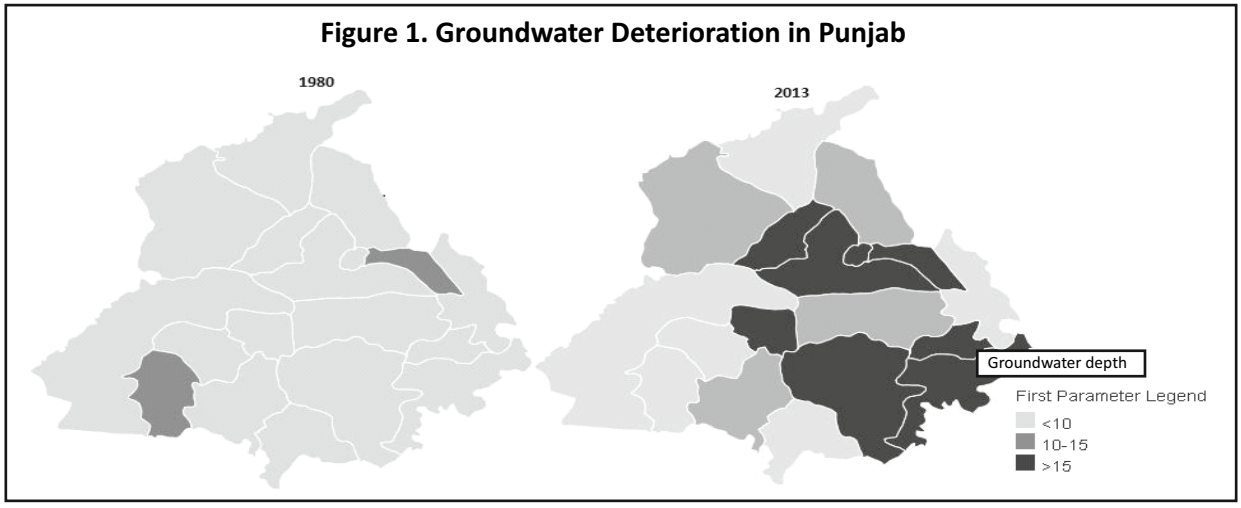
(Department of Irrigation, 2005; Water Resources Directorate, 2005). Canals cover only 29% of irrigation while the remaining 71% is supplied by wells. The discrepancy between the demand and supply of water (Statistical abstract of Punjab, 2013) is catered through over-utilization of groundwater resources leading to an excessive utilization over recharge specifically in the central region of the state which was formerly rich in water-rich alluvial aquifers (Parihar, Khepar, Singh, Grewal, & Sondhi, 1993; Singh & Sankhayan, 1991; Singh, 1992; Singh, 1995; Sondhi, 2004). The high reliance of agriculture, the chief consuming sector, on groundwater resources has transformed Punjab from a water-surplus to a water-scarce state (Central Ground Water Board, 2014).

Background

According to Central Groundwater Board (Central Ground Water Board, 2012) at present Punjab's groundwater situation is extremely critical with 80% of the monitored wells suffering from over exploitation. Out of a total of 137 blocks, 25 are above exploitation, 103 are over exploited, 5 are critical and 4 are semi-critical. The problem is specifically acute in the central region of the state and the cities of Amritsar, Fategarh Sahib, Jalandhar, Kapurthala, Mansa, Ludhiana, Moga, Nawanshahr, Patiala. Sangrur districts are suffering from an extremely high level of withdrawal. Figure 1 highlights progressive deterioration between different regions.

Groundwater replenishment capacity stands at 22.53 billion cubic meter (BCM) with sources other than rainfall being major contributors (68%). The usable amount stands at 20.32 BCM while the remaining 34 BCM is for natural recharge. Moreover, over the last three decades groundwater level has plummeted at an alarming rate. Figure 1 shows the groundwater sanitation of Punjab in 1980s and 2013s. In 1980s only two districts were above 10 m of depth. However, in 2013 most of the districts were classified as being in a critical situation specifically, the central zone of the state.

Figure 1. Groundwater Deterioration in Punjab



Against this background the present study has mainly focused on two aspects. First, to determine which factors play a significant role in groundwater deterioration of the state. Second, to test the policy distortion on groundwater deterioration and generate forecast for groundwater level in 2025.

Data and Methodology

To fulfill the objectives of the study well data was collected from Central Ground water Board from the period

1980 to 2014. The data for explanatory variables (rainfall, area under paddy and wheat, and percentage area irrigated by canals) were collected from statistical abstract of Punjab (various issues), for the same period i.e. 1980 to 2014. A dummy term was included in the model to capture the impact of free electricity policy introduced in 1997.

Identification of the causal factors that are exacerbating depletion of groundwater in Punjab is a prerequisite to structural changes in utilization pattern. In this context a theoretical review of the groundwater situation led to the selection of four causal factors. A Cobb Douglas production function was specified and a regression equation is specified as follows:

$$LnY_t = \alpha + \beta_1 LnRAINFALL\_ANNUAL_t + \beta_2 LnRWAREASHARE_t + \beta_3 LnCANALSHARE_t + \beta_4 LnDUMMYELETREND_t + e$$

where,

Y_t = is groundwater depth meters in t^{th} year,

$LnRAINFALL\_ANNUAL_t$ = is annual rainfall in t^{th} year,
$LnRWARESHAR_t$ = is rice and wheat area share in GCA in t^{th} year,
$LnCANALSHARE_t$ = is canal irrigation share in t^{th} year,
$LnDUMMYELETREND_t$ = dummy for electricity with trend.
e = Error term

Forecasting Based on Unobserved Components Model : For forecasting of groundwater depth and determine the policy impact on depletion of water table, the unobserved component model (UCM) was used with the help of SAS 9.1.3 software. The UCM was composed of four terms trend, seasonal, cycle and error (Harvey, 1989). It is specified as follows:

$$y_t = \mu_t + \gamma_t + \psi_t + \varepsilon_t$$

Where, μ_t, ψ_t and γ_t denotes the stochastic trend, cycle, and seasonal terms. ε_t is the irregular component. The data utilized in the present study is in annual terms based on which the following model is specified :

$$y_t = \mu_t + \varepsilon_t$$

The trend term can be specified as a random walk model (RWM) or local level trend (LLT) model. The RWM is specified as follows :

$$\mu_t = \mu_{t-1} + \eta_t \text{ where } \eta_t \rightarrow NIID(0, \sigma_\eta^2) \qquad (2)$$

If the slope term is included in the RWM, it becomes LLT with stochastic trend and slope.

$$\mu_t = \mu_{t-1} + \beta_{t-1} + \eta_t \text{ where } \eta_t \rightarrow NIID(0, \sigma_\eta^2) \qquad (3)$$

$$\beta_t = \beta_{t-1} + \xi_t \text{ where } \xi_t \rightarrow NIID(0, \sigma_\xi^2)$$

The RWM is suitable for suitable for flat series based on which the LLT is initially selected. If $\sigma_\eta^2 = 0$, the trend is smoother and the model becomes the Smooth Trend Model (SMTM), if $\sigma_\xi^2 = 0$, it becomes the linear trend model with fixed slope (LTMFS) and if $\sigma_\eta^2 = \sigma_\xi^2 = 0$, the model becomes the deterministic linear time trend (DLTT).

Table 1. Level Break Summary Statistics

Year	Break Type	Estimate	Standard Error	Chi-Square	DF	Pr > ChiSq
1998	Level	0.935	0.3892	5.78	1	0.0162

Table 2. Estimated Parameters of Cobb-Douglous Production Function

Variable	Coefficients
Constant	3.54* (1.747)
Log Rainfall annual	-0.031* * (0.014)
Log Rice-Wheat Share	0.461** (0.204)
Log Canal Share	-0.0873 (0.094)
Dummy Electricity-Trend	0.051*** (0.007)
R^2	0.86
Durbin-Watson	2.281
F - Value	12.92***
Observations	32

Note: All variables were expressed in logarithmic form
Figures within parentheses are standard error of estimated parameters
***, **, * significant at 1%, 5%, and 10% level of significance, respectively

Results and Discussion

To exacerbate the deteriorating groundwater level situation in Punjab, some policies have played a significant role. Due to these policies, on one hand Punjab has successfully provided sufficient food grains to the country, on the other hand the state has over utilized its natural resources. Some policies, such as introduction of MSP policy and effective procurement by FCI have ensured marketing for main food grain crops. These policies together with free electricity for agriculture played a major role in shifting the cropping pattern of the state which again resulted in a high stress on groundwater utilization. The initiatives were principally aimed at raising farming profits and ascertaining public procurement but tended to disregard the impact on natural resources leading to adverse effects. A major example is subsidized agricultural power supply introduced in 1997 which had a marked impact on increasing access to groundwater resources. These factors have collectively contributed towards depleting Punjab's once rich water table at an unsustainable rate which is beyond its natural replenishment capacity.

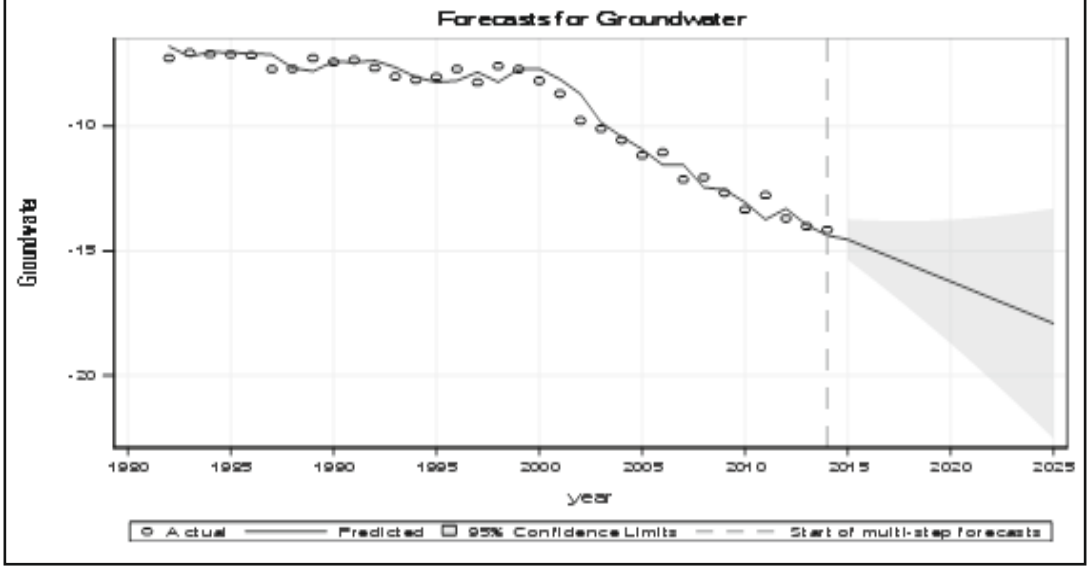
Table 1 provides the structural break results of unobserved component model. The state government started provision of free electricity to farmers in 1997, the model proved that the policy resulted in a significant level shift in the rate of groundwater depletion in 1998.

Table 2 shows the results of log linear regression function which aims at identifying the factors affecting groundwater deterioration. The table shows that annual rainfall is negatively and significantly associated with the groundwater table. Lack of rainfall put high stress on groundwater on the one hand and leads to less groundwater recharge on the other hand. An increase in rainfall increases the replenishment of groundwater and decreases the gap between demand and supply of groundwater. Government policies and market infrastructure have helped in increasing area under rice and wheat crops which have a higher water consumption level compared to other crops. These also have a positive and significant effect on the groundwater table (significant at 5% level). The share of percentage area irrigated by canal is negatively associated with groundwater but does not significantly impact the groundwater table. This can be attributed to the fact that the canal system in Punjab has not undergone any

Table 3. Forecasts of Groundwater Level of Punjab

Year	Forecast	Standard Error	95% Confidence Limits	
2015	-14.54	0.416	-15.36	-13.73
2016	-14.88	0.567	-15.99	-13.77
2017	-15.22	0.727	-16.64	-13.79
2018	-15.55	0.898	-17.31	-13.79
2019	-15.89	1.079	-18.00	-13.78
2020	-16.23	1.269	-18.71	-13.74
2021	-16.56	1.469	-19.44	-13.68
2022	-16.90	1.678	-20.19	-13.61
2023	-17.24	1.896	-20.95	-13.52
2024	-17.58	2.122	-21.74	-13.42
2025	-17.91	2.357	-22.53	-13.29

Figure 2. Groundwater Level with Forecasts in Punjab

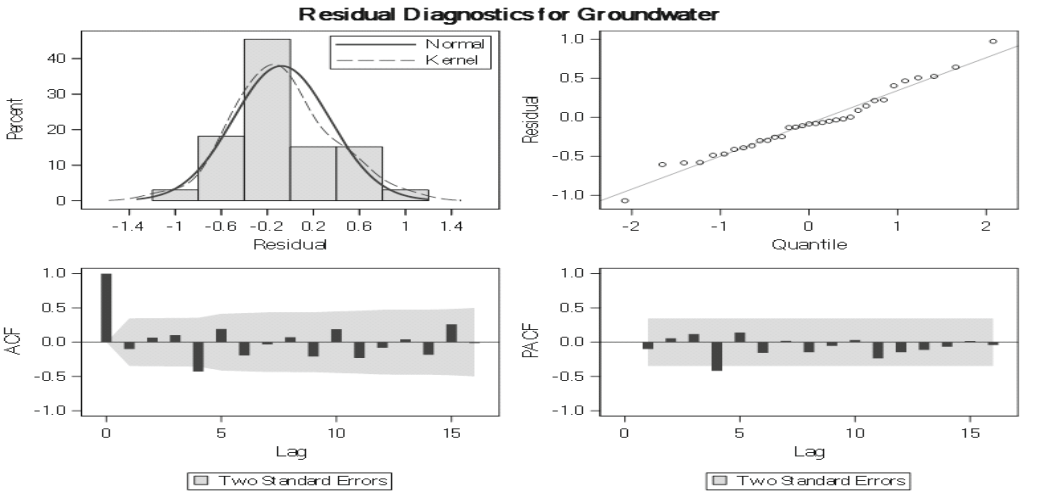


significant changes during the study period. To capture the impact of free electricity policy a dummy variable was added in the analysis. It is found that the free electricity policy has a significant impact on groundwater depletion (coefficient significant at one percent level of significance). The provision of free electricity has increased access and reliance on groundwater leading to overutilization. The table also provides the Durbin-Watson statistics, R^2 value and *'F'* statistics, all values show that the model is a good fit.

Based on visual inspection it can be seen that both the level and slope components are present based on which the LLT model is selected. Table 3 shows the forecasts values with their standard error and confidence intervals. All the forecasts values fall within the intervals providing good estimation. Figure 2 shows groundwater level graph with forecasting.

Forecasts of groundwater imply a continual decline of the availability of groundwater in Punjab. If the current pattern of groundwater utilization is not modified to integrate sustainability the state will face a more critical and severe crisis in the future.In the present scenario the level of groundwater decrease stands at approximately 1/3 meter per year in the state. However, this is predicted to reach the extreme level of -17.91 meter by 2025.

Figure 3. Residuals Diagnostics for Groundwater



Moreover, to check the fit and adequacy of the LTT model, different diagnostic plots based on model residuals are provided in Figure 3. The residual histogram and Q-Q plot show conformation to normality. The ACF and PACF plots also do not show the presence of autocorrelation.

Conclusion and Policy Implications

The above analysis establishes that the groundwater situation in Punjab is not only very critical but is deteriorating at a rapid rate. The present study identified three causal factors which are significant contributors towards groundwater depletion. These are annual rainfall, share of wheat and rice in gross cropping area, and the introduction and provision of free electricity since the year 1997. The study clearly shows that free electricity policy played a significant role in groundwater depletion. To instill sustainability in resource utilization there is a requirement to reduce reliance on groundwater resources and restore their balance. This indicates an urgent requirement to introduce structural changes such as integrating improvement in utilization of groundwater through diversification to other less water-reliant crops and a reduction in access to groundwater (due to free electricity).

Strong focus on gradual shift in cropping pattern through innovative farming and irrigation methods/technology, and measures such as crop diversification from high water consuming crops like paddy and sugarcane to less water consuming crops are very necessary for state policy makers. Notably, despite the implementation of a diversification plan, alternative crops (such as paddy-wheat combination) are not produced. Promotion of other crops like maize, cotton, rapeseed, mustered etc. is mainly dependent on well-established market infrastructure, attractive price policy, and crop insurance. Co-operative groundwater tube wells are another way to reduce the stress on groundwater as well as on electricity consumption for consuming groundwater.

Limitations of Study and Scope for Further Research

The present study focused only on the state of Punjab as a whole and utilized data from 1980 to 2014 to establish the impact of several variables in contributing towards groundwater depletion.

From the analysis of this study several future research areas emerge. First, the state of Punjab demonstrates groundwater variation over separate regions. Employment of a more disaggregated data set in a regression model

will highlight the disparity within the state. It will also aid in establishing the role of different variables in aggravating the groundwater situation. Second, a comparative analysis of Punjab with other water scarce states will contribute towards highlighting the national picture. Such an analysis will lead to policy implications which will be highly beneficial for formulating effective policies.

References

Central Ground Water Board, Ministry of Water Resources. (2012). *Ground water year book.* New Delhi : Government of India.

Central Ground Water Board, Ministry of Water Resources. (2010). *State profile : Groundwater scenario of Punjab.* Retrieved from http://cgwb.gov.in/gw_profiles/St_Punjab.htm

Central Ground Water Board, Ministry of Water Resources. (2014). *Dynamic groundwater resources of India (as on 31st March, 2011)*. Faridabad : Ministry of Water Resources, River Development and Ganga Rejuvenation, Government of India.

Department of Irrigation, Govt. of Punjab. (2005). *Utilization of Sutlej and Ravi-Beas waters by Punjab canal networks*. Punjab : Government of Punjab.

Directorate of Economics and Statistics, Government of Punjab (2005). *Statistical abstract of Punjab*. Chandigarh : Government of Punjab

Parihar, S. S., Khepar, S. D., Singh, R., Grewal, S. S., & Sondhi, S.K. (1993). *Water resources of Punjab - A critical concern for the future of its agriculture (2nd ed.)*. Research Bulletin. Ludhiana, Punjab : Punjab Agricultural University.

Singh, B. (1992). Groundwater resources and agricultural development strategy: Punjab experience. *Indian Journal of Agricultural Economics, 47*(1), 105-113.

Singh, C. B., Chhibba, I. M., & Brar, J. S. (2006). *Technologies for efficient management of soil, water and nutrients in Punjab. Technical Bulletin 1*. Ludhiana, Punjab : Department of Soils, Punjab Agricultural University.

Singh, G. (1995). Groundwater behaviour during the last two decades and future trends in Punjab. *Water Management, Proceedings of Symposium held on Water Resources Day*. Punjab Agricultural University, pp. 50-55.

Singh, I. P., & Sankhayan, P. L. (1991). Sustainability of water resources during the post-green revolution period in Punjab. *Indian Journal of Agricultural Economics, 46* (3), 433-439.

Singh, K. (2006). *Fall in water table in central Punjab : How serious?* The Punjab State Farmers Commission (PFSC), Government of Punjab.

Sondhi, S. K. (2004). Strategies for management of groundwater resource in central Punjab. *Proceedings of the Workshop on Sustaining Agriculture: Problems & Prospects*, 11 November, pp. 31- 39.

Water Resources Directorate. (2005). *District-wise abstract of groundwater estimates.* Chandigarh, Punjab.