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Research Article

ALARMING RATE OF GROUNDWATER DEPLETION IN PUNJAB AND DIRE NEED TO CHECK OVERDRAFTING IN THE REGION

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A B S T R A C T

Modeling in water resources using Gravity Recovery and Climate Experiment (GRACE) is based on a decade-long data for scientific analysis. The analysis of the groundwater change detection using remote sensing data is helpful in overcoming the data limitations on a regional scale. The present study is a modeling approach using GRACE data for the estimation of the variations in the groundwater for the state of Punjab. The GRACE data is applied first for the analysis of the groundwater change detection in the study area and validated with the ground truth data provided by the CGWB. The parameters that influence the model accuracy are rainfall, snow water equivalent, soil moisture, surface runoff, total canopy, aquifer matter and groundwater fluctuations in the wells being monitored. The effect of soil moisture model and the underlying aquifer of the monitored well were determined by the most successful GRACE modeling approach. There is a strong correlation that verifies a significant match between GRACE-based and ground-truth time series analysis. The successful approach is validated for the various regions in Punjab for the detection of groundwater changes. In the GRACE modeling, the effect of soil moisture and groundwater level fluctuations in individual wells studied.

INTRODUCTION

A large part of Earth's freshwater is stored in the form of groundwater. In India, groundwater is the major source of water for agricultural industrial, as well as domestic purposes. As per statistics [(1)], it accounts for nearly three-fifth of the total irrigation potential in the country. The rapid growth in population accompanied with agricultural activities, rapid rate of urbanization and industrial development lead to the increasing demand for water supply. As per the Central Ground Water Board (CGWB) 2008-09 report [(2)], the yearly replenishable groundwater resources account for 431 billion cubic meter and net yearly groundwater availability is 396 billion cubic meter to meet the annual groundwater draft for domestic, irrigation and industrial purposes amounting to 243 billion cubic meter and groundwater development for the country is nearly 61% [(3)]. India being an agricultural economy and with huge population is among the countries experiencing acute water stress [(4)]. For an agrarian economy with a population of more than 1.25 billion, the food security of the country is largely reliant on groundwater-based irrigation owing to unpredictable and erratic monsoon.

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The climate change, contamination of shallow groundwater resources on a large scale [(5)], and the planned diversion of surface water resources from the Northern regions to the dryer Southern regions [(6)] combined together all serve for the intensification of an already deteriorating water security situation.

The variation in the occurrence and distribution of ground water in the country is significantly dependent on rainfall, geomorphology and geology. In regions like North West India ground water resources are depleting, whereas the eastern parts of the country have plenty of ground water resources which remain unexploited. The distribution of rainfall also varies widely both in time and space. Most of rainfall (about 76%) occurs during the Monsoon months resulting into eight comparatively dry months. Similarly, the Meteorological subdivisions like North east India, coastal Karnataka and Goa receives more than 250 cm of rainfall annually while West Rajasthan gets only about 30 cm [(4)]. It is difficult to determine directly the Terrestrial Water Storage (TWS) on regional scales. Research [(7)-(12)] has shown that GRACE satellite observations play a crucial role in measuring the changes in total water storage (total canopy, ice, snow water equivalent, surface waters, soil moisture, groundwater, terrestrial water) over land surface, providing essential information for global hydrological modelers and hydrogeologists.

The regional picture ground water level scenario can be optimally observed using the regional scale space borne gravity anomalies obtained by Gravity Recovery and Climate Experiment (GRACE) mission. The GRACE satellite mission, launched by NASA and the German Aerospace Centre (DLR) in 2002, measured temporal variations in the gravity field, which can be used to estimate changes in TWS [(13)]. Although it's spatial resolution (160,000 km²) and temporal resolution (monthly) are low in comparison with other satellites, its major advantage is that it senses water stored in all forms, including groundwater. For the calculation of groundwater storage from GRACE data any ancillary information regarding the other components of TWS can be used, which may be either in situ observations or land-surface models. In addition, it renders no limitation when it comes to measuring the atmospheric and near-surface phenomenon, for instance, radiometers and radars [(14)]. For the period of August 2002 to October 2008 using terrestrial water storage change observations from GRACE and simulated soil-water variations using a data integrating hydrological modelling approach, the mean ground water depletion rate was estimated as 4 ± 1.0 cm/yr-1 equivalent height of water and 17.7 ± 4.5 km³/ yr. over the north-western Indian states of Rajasthan, Punjab and Haryana (including Delhi) [(13)].This study aims at better understanding of the variation in groundwater levels over the Punjab region for a period of a decade (2003-2012). The goal is to re-calculate and find out the trend of groundwater depletion across the Punjab region using GRACE data and validate the in situ well data with GRACE observations over the state of Punjab on regional scale.

Needless to say, unsustainable groundwater depletion trends has been observed through regional groundwater mapping of North India using GRACE satellite observations and Global Data Assimilation System Land surface modeling on regional level [(13)-(18)]. These findings have helped in estimating the worsening groundwater scenario, but the immense information contained within the GRACE-derived groundwater storage (GWS) time series needs to be exploited fully. The fluctuations in groundwater level are driven by anthropogenic (such as land-use/land cover change, socio-economic concerns, dam construction) and natural (such as vegetation, rainfall and soil type). Subsequently, there is a large variability in the annual groundwater storage with some areas experiencing flooding while others facing shortage. High risk of water supply shortages are observed in areas with high GWS variability irrespective of whether a little to no net loss of groundwater is noticed.

Finally, the GRACE-derived GWS solution is validated with in situ well observations being provided by the Central Groundwater Board (CGWB), the chief authority engaged in surveying and monitoring of groundwater in India. Inverse Distance Weighted (IDW) was used to interpolate CGWB-derived Groundwater Storage values and downscaling.

Study Area

The study includes the state of Punjab, which is the food basket of the country. My interest in choosing this area was solely dependent on my desire to know what are the groundwater level changes taking place in this agriculture-dominant state.

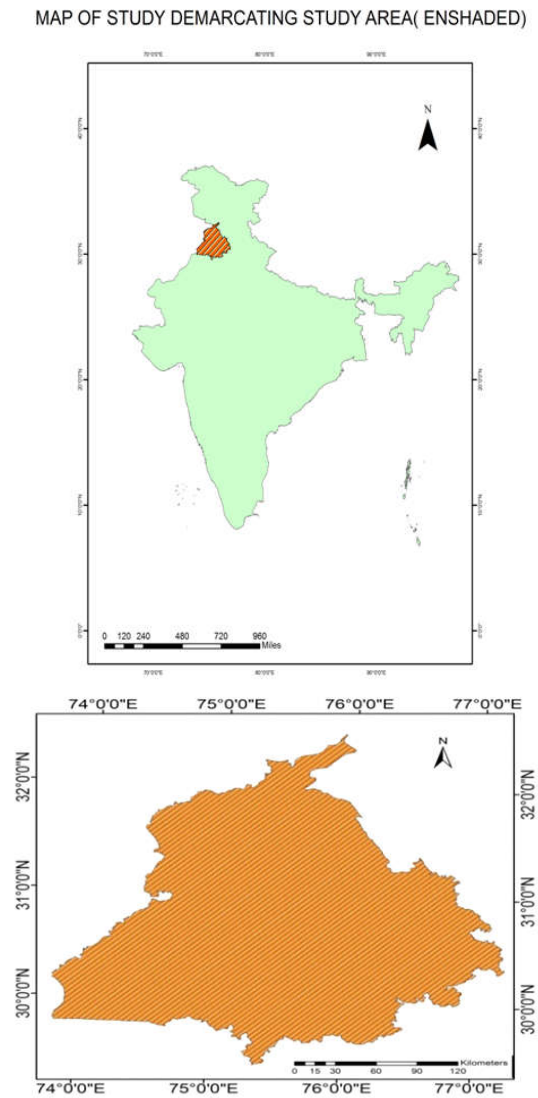


Figure I Study Area Map

Physiography: Geographical Area: 50,362 sq. km; Location: Northwest part of India; Latitude: 29"30'N - 32"32'N, Longitude: 73"55'E - 76"50'E.

Subdivisions: Punjab can be further categorized into several categories and regions like: The land on the south of Sutlej is called Malwa. The region of Malwa is long and extensive and houses a total of 11 districts. Several major cities including Patiala, Ludhiana, Sangrur, Bhatinda, Barnala, Firozpur, Moga and Barnala all are found in Malwa which is extremely rich in cotton crop. A part of the historical Punjab including the land of Amritsar, Tarn Taran and Gurdaspur forms the Majha. This region finds place between the Beas, Ravi and Sutlej. This is the place that forms as the centre of Punjab and is credited for being the place where Sikhism originated. Between Sutlej and Beas lie as a region called the Doaba. The word literally translates to a piece of land that has rivers on two sides. This prosperous and fertile land is the place where the green revolution started in India. This region majorly excels in the produce of wheat. The famous places and cities in the region of Doaba include Hoshiarpur, Jalandhar, Kapurthala and Nawanshahr.

Administrative Subdivisions: Punjab has a total of 22 districts that are further sub divided into Tehsil, Block and etc. Major districts include Amritsar, Barnala, Bathinda, Firozpur, Fazilka, Fatehgarh Sahib (Sirhind-Fategarh), Faridkot, Gurdaspur, Hoshiarpur, Jalandhar, Kapurthala, Pathankot, Ludhiana, Mansa, Moga, Ajitgarh, Muktsar, Patiala, Rupnagar, Sangrur, Shaheed Bhagat Singh Nagar (Nawanshahr), Tarn Taran. With Chandigarh as its serving Capital, the state of Punjab has a total of 157 town and 22 districts. Some of the major cities in the state of Punjab are Moga, Ludhiana, Jalandhar, Amritsar, Nawanshahr, Patiala, Bathinda and Ajitgarh.

Climate: The climatic conditions of Punjab are identified as an extreme of both the summers and the winters. The state experiences extreme temperature variation ranging from as low as -4 degrees to as high as 50 degrees, which vividly explains the extremeness of its climate. The places that are close to the Himalayan ranges are often penetrated by heavy rainfall, while the southern parts of the state are high on temperature and considerably low on rainfall.

Punjab has Three Seasons. Summers start in April and continue till late June where the scorching heat takes the temperature beyond 40 C. This is not the high time for tourism in Amritsar. July brings in rain that stays till October and brings down the heat by a considerable degree. November brings in the chill and when it reaches its peak in Late December and Early January, The Temperature drops down to even -4.

Geology: Located in the fertile great North Indian Plain, the state of Punjab has a combined area of 50,362 sq. km. The state shares its borders with Pakistan on the west, on its northern frontier by the Jammu and Kashmir, Himachal Pradesh on the east while the south is bordered by Rajasthan and Haryana. The major area of Punjab falls in the belt of the great north Indian fertile land with an abundance of Alluvial Soil which is irrigated by a wonderful system of rivers and manmade canals. To add to this, a string of mountains strengthen the land. On an average, the height of these is almost 300 meters above sea level. On the southern part, the state and its soil become semi-arid, which gives way to the Thar. The Shivaliks also run along the state and form as the foothills of the great Himalayas.

The land of Punjab is categorized under the seismic zones II, III, and IV. The Geological Survey of India has classified the state into Newer Alluvium, Older Alluvium and Shiwalkis. Loose grey sand, undifferentiated Aeolian flat / sand sheet and newer ones, blue grey to light micaceous sand with inter-bands of purple red clay, undifferentiated semi-consolidated and stabilized older dunes with kankar and some carbonaceous material from the part of the Newer Alluvium. The Older Alluvium comprises of sand and loam with kankar, sticky clay, grey medium to coarse micaceous sand with kankar surrounded to sub angular unsorted pebbles, gravel and cobble in adjoining foothills. The Upper Shivalik Group comprises of friable, grey micaceous sandstone brown, red and purple clay and conglomerate.

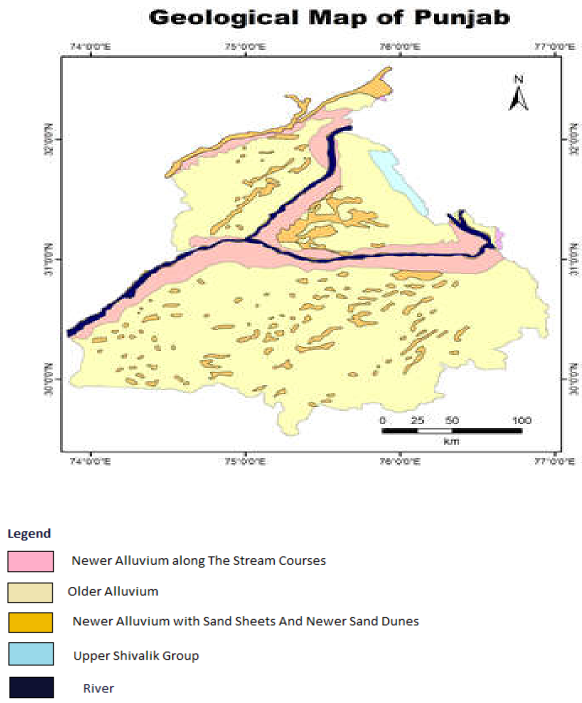


Figure II Geological Map of Punjab. (Source: GSI)

Geomorphology: Geomorphologically [Figure 4 the region is divided into six major pgysiographic units namely Siwalik Hills, piedmont plain, alluvial plain, sand dunes, flood plains and paleochannels. The Shiwalik Hills, covering nearly 2.6% of the total area of the state (Gurdaspur, Rupnagar, S.B.S Nagar, S.A.S Nagar and Hoshiarpur districts and marked by dense scrub forest), are steeply sloping in the north-east and a large number of choes are said to be originating in this zone through which there is drainage of excess storm water. The transitional zone between the alluvial plains and Shiwalik Hills is the piedmont plain which spreads over 10-15 km in Gurdaspur, Hoshiarpur, S.B.S Nagar, S.A.S. Nagar and Rupnagar districts at an elevation of 300-375m above Mean Sea Level. It is characterized by gentle slopes with undulations and seasonal rivulets transport storm water along with the sediments, which are deposited within the piedmont area (finer ones) and alluvial fans (coarser ones). The alluvial plain spreading over Tarn Taran, Amritsar, Gurdaspur, Doaba and Malwa plain occupies nearly 77% of the total geographical area of the state. Sand dunes are commonly found as low ridges along the courses of the old rivers and choes. The flood plains covering approximately 10% of the total area of the state are primarily of the five major rivers in the state- Ravi, Beas, Satluj and Ghaggar along with seasonal rivulets or choes that are active during the monsoon season and they are characterized by continuous erosion and deposition (sediments are young and stratified without any significant alteration of sediments) owing to which there is no consolidation of sediments into pedogenic horizons. The paleochannels occupy a low-lying topographic position on the landscape and are the remnants of old active channels. These are the resultant of the continual changes in the courses of the major rivers (Ravi, Satluj, Beas and Ghaggar) and their tributaries, which are rendered defunct and silted over a period of time.

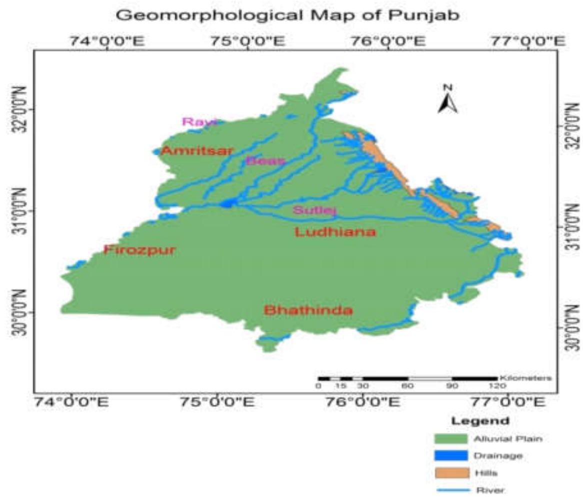


Figure III Geomorphological Map of Punjab. (*Source*: Bhuvan)

***Land Utilization**:* Land use/land cover information is vital input for rational land use planning and conservation of the environment. The map also shows that the maximum area is under agriculture which means water is basic requirement for irrigation purposes. This too leads to the curiosity of knowing the groundwater fluctuations that are taking place in the region. The region also has a wide network of man-made and natural drainage comprising of rivers and interconnected network of canals.

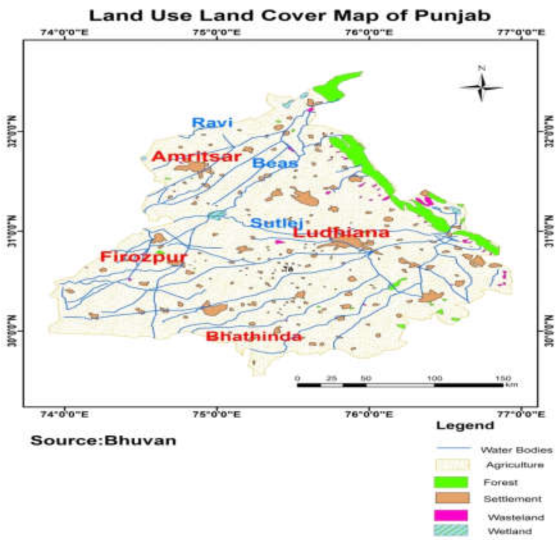


Figure IV Land Use/ Land Cover Map of Punjab. (Source: Bhuvan)

MATERIALS AND METHODS

Table 1 Primary and Secondary Data Sets

dataset	Un its	Type	Spatial resolution	Temporal Resolution	Observation Period	Source
JPL Level 3 TWS	EWT-cm	GRACE Observation	1º	Monthly	Jan 2003-Jan 2012	GRACE Tellus
NOAH/MOSAIC /VIC/CLM Soil Moisture	Kg/m²(cm)	GLDAS Land Surface Model Parameter	1º	Monthly	Jan 2003-Jan 2012	GIOVANNI-GLADAS
NOAH/MOSAIC /VIC/CLM Snow Water Equivalent	Kg/m²(cm)	GLDAS Land Surface Parameter	1º	Monthly	Jan 2003- Jan 2012	GIOVANNI-GLDAS
NOAH/MOSAIC /VIC/CLM Canopy Storage	Kg/m²(cm)	GLDAS Land Surface Model parameter	1º	Monthly	Jan 2003-Jan2012	GIOVANNI-GLDAS
In situ Well Data	Depth to well(m)	CGWB Observation	Point	Variable (Mostly Quarterly)	Variable Range from Jan 2003-Jan 2012	From CGWB
CGWB-derived GWS over Punjab	EWT-cm	Processed CGWB GWS	Point	Quarterly	Jan 2003-Jan 2013	

***Primary and Secondary Datasets**:* The ground water depletion scenario in Punjab was studied at a regional scale for 2003-12, using coarse resolution JPL RL05 product of GRACE mission i.e., monthly 1^0x1^0 grid TWS data (equivalent water column thickness in cm) and soil moisture and precipitation data from GLDAS-2.0 NOAH Model 1^0x1^0. For the estimation of the groundwater storage, the data at the same resolution was used followed by the plotting and comparison with the rate of precipitation over the same time period. . The groundwater storage changes pre-post monsoon was mapped. The results obtained were validated by the CGWB data for the Punjab region.

The final monthly GWS Anomaly was derived as the average of the land surface model outputs from NOAH, MOSAIC, VIC, CLM; and the monthly error was estimated to be the standard deviation of the TWS anomalies generated from the four land surface models.

In Situ Well Data: Well depth data for 157 wells distributed unevenly across the states of Punjab was collected from the Central Ground water Board in the form of excel sheets. The data had varied anomalies in terms of temporal gaps, number of observations taken and missing data of each well. This lead to the dire need for pre-processing of the data and appropriate set of wells were selected to carry out the groundwater storage time series. Moreover, metadata lacked information with regard to specific yield information, aquifer type (confined, semi-confined or unconfined), and impact of anthropogenic activities on the local water table for individual wells. The area under study being quite large intelligent validation required to infer relevant and meaning results. For this, well selection for validation was done carefully.

***Control Mechanism**:* High-quality well sites were selected based on the following parameters:
* Discarding missing or invalid data.
* Selection of wells containing at least four observations in a year during the study period with minimum reading in May and November in a particular year.

METHODOLOGY

Terrestrial water storage (TWS) is defined as vertically integrated water of all forms above and below the Earth's surface. (e.g., surface water, soil moisture, groundwater, and snow. and ice). The TWS Anomaly is extracted from GRACE-GLADAS that provides information about the total water thickness (Equivalent Water Thickness) in and above the Earth's crust 10 [(19)-21)]. It includes surface water storage, soil moisture, groundwater storage, snow water equibvalent, rainfall and total canopy. In order to extract the groundwater anomalies from the GRACE-derived anomalies, we are required to reduce the other quantities from the TWS. In the present study, level 3 GRACE TWS anomalies that are expressed as thickness of water column in centimetres has been used. The spatial resolution of the data is 1º x 1º. The data is checked for leakage and measurement errors. Since the area does not experience snowfall and due to lack of precise surface run off, the relevance of these two quantities has been overlooked. The soil moisture has been taken from Global Land Assimilation System (GLDAS) with the same spatial resolution as of GRACE TWS. The TWS is the sum of soil moisture, accumulated snow and plant canopy, surface water.

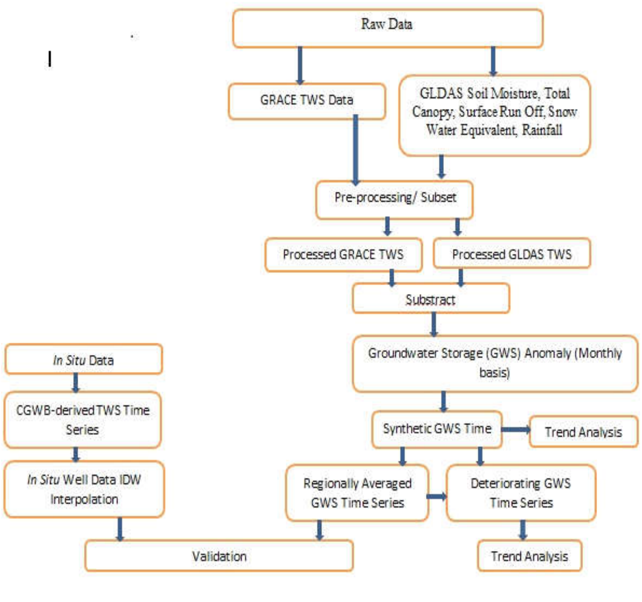
$\Delta GWS = \Delta TWS - (\Delta TC + \Delta SM + \Delta SWE + \Delta SR + \Delta\ RF)$

Where,

ΔGWS = Groundwater Storage Anomaly
ΔTWS = Total Water Storage Anomaly
ΔTC = Total Canopy Anomaly
ΔSM = Soil Moisture Anomaly
ΔSWE = Snow Water Equivalent Anomaly
ΔSR = Surface Runoff Anomaly
Δ RF = Rainfall Anomaly

For the final monthly GWS Anomaly, the average of the land surface model outputs from MOSAIC, VIC, NOAH and CLM were taken, and the standard deviation of the TWS anomalies generated from these four land surface models was used to calculate the monthly error (Kato *et al*., 2007). The well depth data of unevenly distributed 157 wells across the state of Punjab was provided by the CGWB with the time series data for the well depths varying radically from well to well in terms of missing data, temporal gaps and the number of observations taken.

The Methodology comprises processing the data in two steps i.e. processing of the raw data and the in situ well data being provided by the CGWB. The raw data is the GRACE and GLDAS data which is processed to obtain the TWS GRACE and the TWS GLDAS (by the addition of rainfall and soil moisture). The GWS is then calculated by subtracting the TWS GLDAS from TWS GRACE. The GWS time series is then plotted followed by trend analysis. The in situ well data is IDW interpolated and downscaling is done at 1º x 1º spatial resolution so as to bridge the mismatch of spatial scale to get the resolution needed for impacts assessment.



Flow Chart 1 Methodology adopted

RESULTS AND DISCUSSION

The in situ well data IDW interpolation and downscaling helped in the validation of the GRACE-GLDAS-derived results for the Punjab region. The maps obtained after IDW interpolation of the values obtained by subtracting the pre-monsoon values from the post-monsoon (Figure V- XIV) show the regions in the state which have experienced groundwater depletions. The maps provide the information on yearly basis. During the years 2003, 2006, 2010 and 2011, there has been a stark depletion in the groundwater when considering the overall scenario in the state.

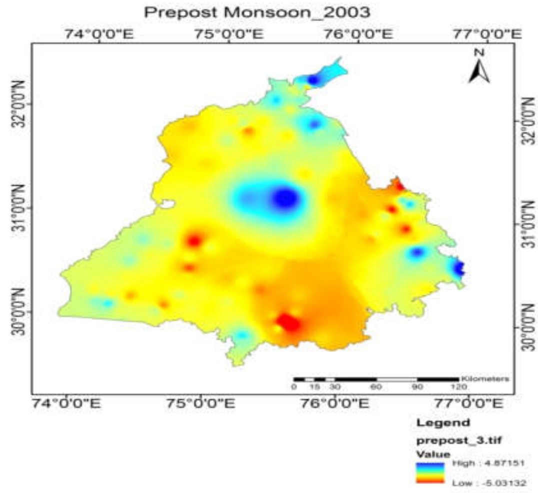


Figure V *In Situ* Well Data after IDW Interpolation for 2003

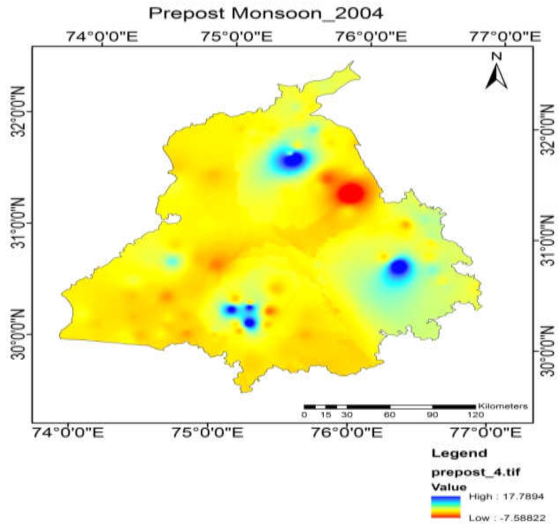


Figure VI In Situ Well Data after IDW Interpolation for 2004

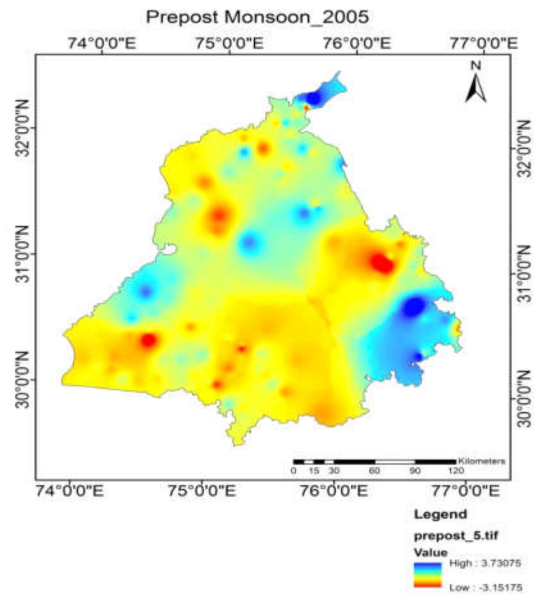


Figure VII In Situ Well Data after IDW Interpolation for 2005

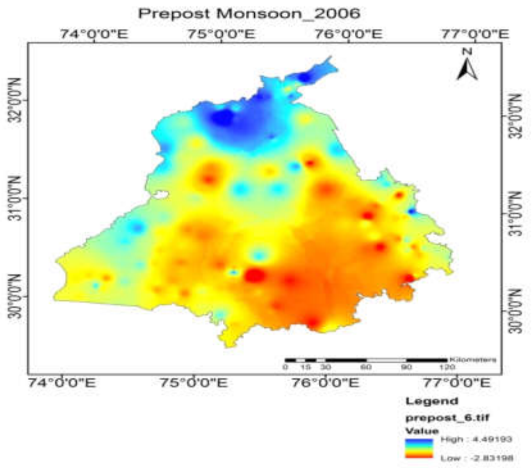


Figure VIII In Situ Well Data after IDW Interpolation for 2006

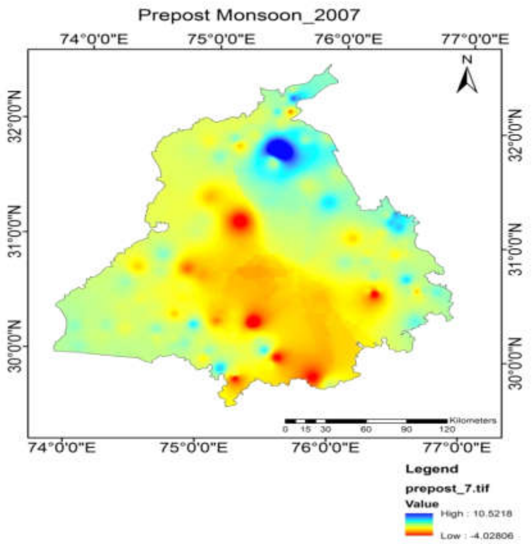


Figure IX In Situ Well Data after IDW Interpolation for 2007

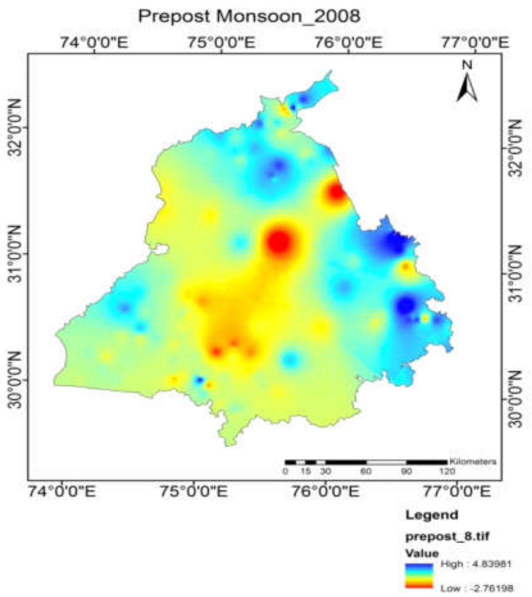


Figure X In Situ Well Data after IDW Interpolation for 2008

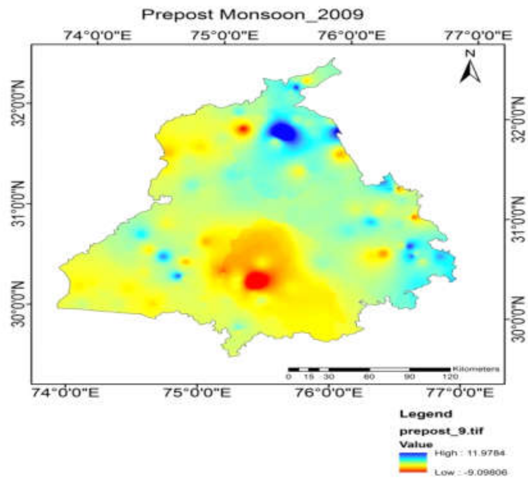


Figure XI In Situ Well Data after IDW Interpolation for 2009

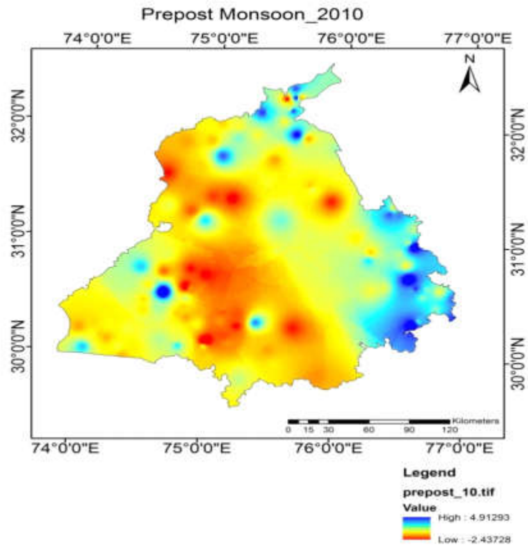


Figure XII In Situ Well Data after IDW Interpolation for 2010

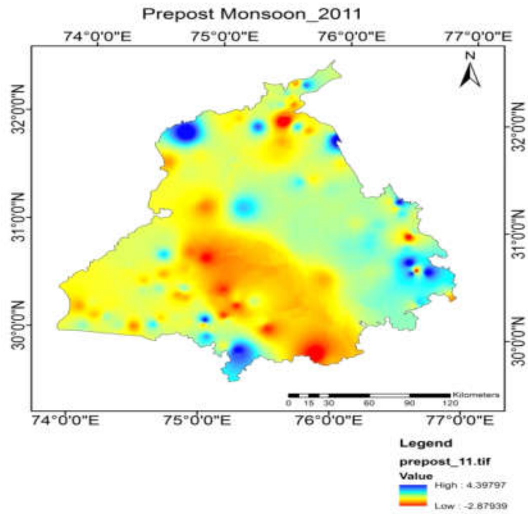


Figure XII In Situ Well Data after IDW Interpolation for 2011

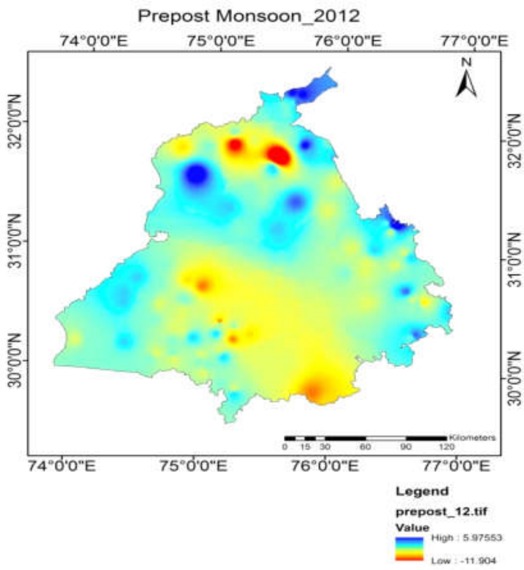


Figure XIV In Situ Well Data after IDW Interpolation for 2012

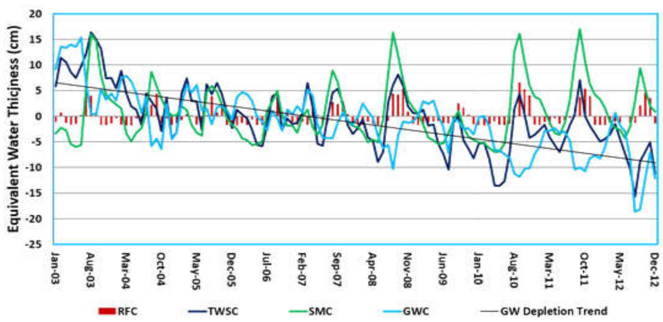


Figure XV Monthly Time Series Analysis of the GRACE-GLDAS Data

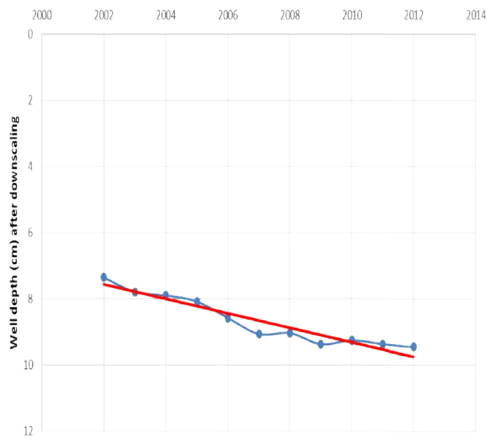


Figure XVI In Situ Water Level Fluctuations from data provided by CGWB (Trend marked by the red line)

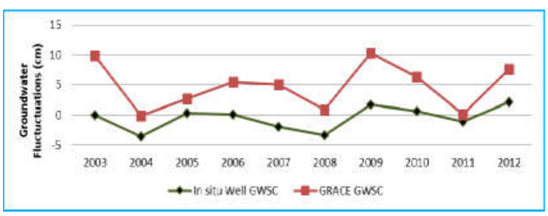


Figure XVII In Situ Well GWSC vs GRACE GWSC

- The total volume groundwater depletion over the state of Punjab from Jan 2003 to Dec 2012 has been nearly 98.3 km³.
- The rate of depletion of groundwater in the state of Punjab has been estimated to be 2.14 cm/yr. derived from GRACE.
- The rate of depletion of groundwater has been found to be 1.95 cm/yr. from CGWB data.

The Monthly Time Series analysis of the GRACE data and the in situ well data level fluctuations obtained after downscaling show that there has been a depletion of the groundwater over the time period of 10 years.

An interesting result in this study has been found based on the GRACE-GLDAS-derived results and it is that the highest abstraction of groundwater has taken place in the industrial zone i.e. the districts of Ludhiana, Amritsar, Abohar, Bhathinda and Mansa. Also, some areas experience water logging. This can be attributed to the rice cultivation in the state. Future work should concentrate on minimizing and deleting the impact of these processes to get better TWS and GWS calculations.

There has been a slowdown in the rate of depletion of the groundwater although the overall trend is drastic depletion. Perhaps this can be attributed to a number of factors such as awareness of the extent of water resources, comprehensive groundwater recharge programs to the accessible aquifers that have been mostly tapped out and the financial and technical / infrastructure limitations- at the moment prevent further exploitation of deeper groundwater reserves; this has turned out to be a blessing in disguise as the aquifers get time to recharge naturally.

The study finds that there has been a net loss of approximately 98.3 km³ of groundwater during the study period over the state of Punjab. Needless to say, rampant extraction of groundwater reserves at this rate only lead to threat to water and food security in the state which is primarily agriculture based and is the food basket of the country. If the rate of depletion persists at the current rate, the region would not only experience reduced agricultural productivity, but also acute drinking water shortage during the peak summers.

There is a dire need to combat the groundwater depletion with vigorous water conservation practices, but the erratically behaving groundwater system requires strong storage and distribution mechanisms. The situation can be effectively combatted with a balanced combination of resilient water storage, distribution and conservation mechanisms.

Although a time period of 10 years is a short in which to assess the shifts in the GWS behavior, the study suggests the variability of the GWS in the Punjab region is on the rise. This behavior should be closely examined as there are shifts in the variability that serve as the precursor to the change in the entire regional groundwater system. The region needs to upgrade its existing storage and distribution systems.

As far as the in situ well observations are concerned, in the absence of sufficient metadata, the conversion of the observations required undertaking a lot of assumptions. For instance, it was presumed that each selected well was connected to an unconfined aquifer and that each had the same specific yield. Although a large element of uncertainty was added to the final GWS outputs due to the presumptions combined with temporal heterogeneity and under sampling, the solutions derived from GRACE are nonetheless agreeable.

Both the GWS solutions are strongly correlated and show a stark linear one-to-one relationship and both data sets mostly lined up and showed similar behavior. Having more metadata and more frequent in situ well data observation would be immensely helpful in establishing more accurate GWS values and bring more definitive comparison between the GRACE-derived GWS datasets and in situ well observations.

The combination of a net loss of groundwater and a rise in the GWS fluctuations simply paint a desolate picture of water scarcity and also wide-ranging fluctuations in the water tables. The problem needs to be tackled by tapping the deepest reservoirs of imagination, innovation and tenacity. With the aid of these remote sensing tools and superior clairvoyance of the regional groundwater dynamics, the future of the Punjab region need not be a water-stressed one.

In India, as elsewhere, groundwater is a crucial component of the ecosystem should be used judiciously without adversely interfering with the natural hydrologic cycle. Groundwater is considered as the most crucial for the agriculture and livestock population. Punjab, the food basket of India, is witnessing drastic decline in groundwater with the increasing overdrafting owing to increased number of tubewells for agricultural as well as domestic purposes in the recent years and so the region is experiencing increased abstraction rate. In recent study conducted by CGWB for monitoring the groundwater level in the Jalandhar, Faridkot, Kapurthala, Firozepur, Ludhiana, Bhatinda, Patiala, Amritsar, Gurdaspur and Taran Taran districts Punjab.

Incessant misuse of groundwater causes many problems which can be clearly seen in the major districts of the Punjab state where crisis arise from pollution by industrial toxic wastes, water logging and overdraft in the phreatic aquifer. Infiltration basins and check impoundments are remedial artificial recharge measures in order to overcome over-exploitation in current scenario. In the areas experiencing marked decline in water levels artificial recharge methods should be greatly emphasized. It is also important to strengthen water, soil and groundwater institutions through training, capacity building and education in specific areas viz. groundwater modeling, artificial recharge, watershed management, quality monitoring and aquifer remediation on consistent basis. In order to sustain the existing food grain production to meet the ever-increasing population and maintain the socio-economic condition of the small and marginal farmers, it is need of the hour to address the issue in order to reverse the declining water table.

CONCLUSION

The present study is undertaken in Punjab keeping in mind the drastic fall in water level owing to increasing population growth and pressure for meeting water demand for domestic and agricultural purposes. The considerable water use in the state of Punjab is amounting to declining groundwater levels. Studies need to be carried out to find out the reason for the water logging in some areas of the state when the other regions are experiencing groundwater depletion. In view of the increased stress on ground water in the state, the regular evaluation of the groundwater potential on a scientific and technical basis should be done in addition to the judicious utilization of groundwater so that the recharging possibilities are not exceeded and social equity is ensured. The investigation and exploration of the aquifers for new fresh groundwater resources on sustainable basis should be done, especially in the flood basins of Sutlej, Beas and Ravi. Optimal utilization of water for diverse purposes especially for agriculture should be ensured on long-term sustainable basis. For areas suffering from acute water scarcity due to saline groundwater, installation of desalination plants, using flash distillation, electro-dialysis or reverse osmosis techniques should be done.

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