Expansion of salinization in the aquifers of Punjab

EXECUTIVE SUMMARY

Punjab that once was known as the "Granary of India" or "India's bread basket" and had dominant agrarian economy, is now under the problem of looming agro-economy primarily, because of falling groundwater levels and deteriorating groundwater quality, mostly due to increasing salinity. It ranks 14th in GDP of the country with sectoral contribution of 25% from agriculture, 25% from industry and 50% from services. And, it is predominantly an agrarian state of about 85% area is cultivated with cropping intensity of more than 198%. The irrigation requirements of crops are fulfilled by groundwater and canal water but introduction of canal irrigation has led to the development of water logging and subsequent salinization rendering large chunks of fertile land converted to unproductive mainly in the south-western part of Punjab. Other factors namely, improper alignment of canals, seepage from canals & distributaries, drainage congestion, surface soil type, faulty irrigation practices, etc have also contributed to the problem of water logging, soil salinity and groundwater salinity. The problem has been compounded and expanded further by natural factors; experts describe these issues as: existence of topographic depression and impervious layer near the land surface, absence of natural drainage, erratic rains, etc. There was an apprehension that excessive withdrawal of groundwater might have caused reversal of natural groundwater flow pattern that might have caused ingression of saline water into the fresh groundwater region of central Punjab. These eventually developed concerns amongst the policy makers, water managers and environmentalists. To answer these questions and apprehension and to ascertain the quantity and impact, Punjab State Farmers' and Farm Workers' Commission have referred the task to the National Institute of Hydrology, Roorkee for a comprehensive study on these issues and suggest remedial measures to combat the situation.
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To address the apprehension related to the rise in groundwater salinity and its subsequent ingression to the fresh water zone and suggest suitable management solutions for those causes, if found impacted, the project was referred to address the following objectives by a comprehensive study:

I. Generate groundwater level scenarios based on historical data
II. Assess industrial pollutants in the entire state including industrial areas of Ludhiana
III. Assess the extent of water logged and groundwater saline zones at various aquifer depths,
IV. Investigate and identify the cause of salinity problem and its expansion in the area,
V. Identify the most vulnerable zone(s) of advancing groundwater salinity,
VI. Investigate impact of excessive groundwater pumping in central Punjab on the movement of increased groundwater salinity, and
VII. Suggest cost effective and eco-friendly management strategy for control of groundwater salinity.

To attain the above mentioned objectives and also the defined scope, a comprehensive analysis of data related to water levels, salinity, isotope and ion, meteorological, land-use and land cover (LULC), soils properties, soils map, rainfall and groundwater recharge components, study on salinity assessment and its possible ingression has been carried out and presented in this report. For analyses of the above components, some of the previous major projects' outcomes, hydrological, hydro-meteorological, hydrogeological, soil data collection from different organizations together with the extensive field investigations to address

sampling campaigns for isotope and water quality analysis of both surface and ground water are carried out.

The databases, information, field and laboratory experiment results have been analyzed using advanced tools and techniques. All related maps have been prepared as per geographical coordinate systems in the ArcGIS framework and hence, have the relevance to the actual field conditions.

Analyzed results of different components of hydrology and hydrogeology, soils, land-use and land covers, isotope characteristics and water quality parameters have been presented in 12 chapters. For example, Chapter-1 presents a detailed introduction; Chapter-2 describes the study area details; Chapter-3 highlights surface and ground water resources of Punjab state; Chapter -4 describes aquifer systems of the state; Chapter -5 illustrates details about sampling campaigns and methods; Chapter-6 gives analyzed results of water chemistry; Chapter-7 mentions about distribution of trace metals; Chapter -8 focused on problems of groundwater salinity; Chapter-9 delineates the areas of groundwater recharge zones; Chapter-10 is on MODFLOW to ascertain direction of water and Chapter-11 describes a critical appraisal of all the problems and Chapter -12 elaborates the conclusions, recommendations, and management options.

Each chapter presents a summary of results presented in the Chapter and therefore, summary of each chapter is referred for elaborative understanding. Based on the analyses of maps, databases and results, the following specific observations, conclusions and recommendations are made:

(i) The Digital Elevation Model (DEM) prepared based on the 30 m (1- arc second) SRTM data downloaded from USGS showed that Punjab has an extensive alluvial plain gently sloping from about 350 metres above mean sea-level in the northeast and the north to about 180 metres in the southwest. The south-western fringe area of the region is desertic and undulating, but has gradually been levelled with the extension of cultivation and irrigation. At the micro-regional level, human's activities have a major agent of change in moulding surface configuration. The East Punjab has more of such micro regional changes in topography than its counterpart in the West. East Punjab has favourable topography with 84% of the total land area sown and 95 per cent of the total cropped area irrigated.

(ii) Geomorphologic map shows that Punjab exhibits gradational landforms, mainly fluvial, formed by the deposition of sediments and also a low lying flat topography in most of the area. The Shiwalik hill range in the North eastern part of the State has Piedmont form of landforms. Alluvial wetlands are found in some parts of Patiala and Amristar districts. Sand dunes are mainly spread in the south western districts of Punjab like Fazilka, Muktsar, Bathinda and Mansa.

(iii) The lithologic map reveals that Punjab has mixed lithological sequences mostly dominated by : (a) silt-clay with Kankar and micaceous sand in the plain areas. (b) Occurrence of coarse sand, boulders, conglomerate and clay is common in the Shiwalik range. (c) sorted boulders, cobble, pebble in sandy matrix, sand, silt, clay and conglomerate are dominant along the river courses. (d)Variegated clay stone mixed with sandstone and siltstones are dominant lithological formations in major part of the plain areas, while sequences of oxidixed silt, clay with kankar are present in the South-western part of the State.

(iv) Flood plains along the rivers are made of new alluvium deposited by the rivers, while the upland plains consist of old alluvium. The interfluves are given names compounded from those of their confining streams: Bist Doab (area between Sutlej and Beas Rivers), Bari Doab (area between Beas and Ravi Rivers). The region is a great mass of alluvium brought down by the Indus and the five rivers, uniting in the southwest at Panjnad (five streams). In between the Yamuna and Sutlej Rivers in the east, the Ghaggar River and its tributaries contributed to the same process of alluviation in what is now called the Malwa Tract.

(v) The whole Punjab region has four landform types; (i) the Shiwalik Hills (ii) the dissected foot-hill zone (iii) the upland plains and the Malwa tract, and (iv) the flood plains along all the rivers.

(vi) The soil map of the Punjab State shows that major soils are loamy (Ustochrepts of Ustic), kandi soils, podzolic & forest soils, sierozems, flood plain (bet soils or ustifluvent) soils, sodic & saline soils, sandy and desert soils (calciorthids), loamy, kandi and sierozem soils cover nearly 70% area of the State with distribution of 25%, 23% and 22%, respectively. Loamy soils are fertile and productive soil group. Kandi soils have been formed by deposits of river torrents of Shiwalik hills and are eroded in nature and less productive, but suitable for dry farming. Podzolic and forest soils have been developed mainly in steep slopes and rugged topography. They are stony, gravelly and sandy soils. The topography of these soils is prone to water erosion.

(vii) Four main categories of soil-related problems identified in the state as: Salt-affected soils, Water erosion in Silwalik hills, piedmont and flood plain soils; Wind erosion in sandy soils; Flooding and water-logging in flood plain soils.

(viii) The landuse map of Punjab prepared using the Landsat 8-OLI MSI DATA of 2018 Rabi season (December- March) and Kharif season showed agricultural land (Rabi=55%; Kharif = 73%), fallow land (Rabi=22%; Kharif=7%), settlement (Rabi=17%; Kharif=16%); water bodies (Rabi=6%; Kharif=3%) and habitat settlement of 1% area. Cotton and paddy are the main kharif crops, while wheat and barley are the main rabi crops grown in the State. Cropping intensity of the state is 198%. In addition to this some summer crops are also grown in summers Zaid crops.

(ix) Mean monthly rainfall of 119 years (1901-2019) showed that June to September are the monsoon months with July as the peak rainfall month followed by August. The annual average rainfall based on 35 years data showed that it has decreased from 739.1 mm in 1980 to 546.9 mm in 2015.

(x) Out of five rivers, namely, Beas, Chenab, Jhelum, Ravi, and Sutlej; three rivers Sutlej, Beas, and Ravi are perennial rivers and have the source of water from the melting of the Himalayan snows and ice. In addition, the Ghaggar is almost a seasonal river that flows through the south-western part of Punjab.

(xi) Groundwater resource estimate by the CGWB (2017) indicated that the net groundwater resources are: 21.58 BCM (Billion Cubic Meter) against the annual replenishable recharge of 23.78 BCM, whereas the net draft for all uses is 35.78 BCM and net draft for irrigation is 34.56 BCM, leading to the groundwater deficit of 14.2 BCM. The stage of ground water development was 166% and out of total 138 blocks, 109 blocks (79% of the total geographical area) are categorized as "over exploited" , 2 blocks (1%) are categorized critical, 5 blocks (4%) are semi critical, and 22 blocks (16%) are categorized as safe in development of groundwater resources.

(xii) Groundwater levels are falling in central Punjab, and a depletion of 0.13 m to 22.48 m with an average fall of 9.46 m between years 2000 to 2019. Maximum depletion of 22.48 m was found in Barnala district followed by Sangrur of 22.15 m; Patiala by 18.39m, Moga by 16.20m and Jalandharby 15.39 m . However, depletion in the groundwater level less than 1 m was found in Fazilka and Muktsar districts.

(xiii) The spatiotemporal variations of groundwater levels for the period from 2000 to 2019 for the pre monsoon season compared with the average of two series of data 2001-2010 and 2010-2019 showed that the groundwater levels varied from 3.05m to 12.68 m (bgl) in the year 2000, which fluctuated to 2.83 m to 22.64 m (bgl) in the year 2010 and changed to from 3.01 m to 24.79 m (mbgl) in the year 2019.

(xiv) Groundwater is declining at an alarming rate in fresh water regions (mainly central Punjab) while the south-western part of Punjab is facing the problems of water logging and salinization. The State can be characterized by two distinct topographical and hydro-geological settings: high yielding fresh groundwater regions in northern and central districts and the saline groundwater regions in south western districts. Two extreme scenarios, groundwater depletion and water logging, in close proximity to one another are probably a unique case of extreme ecosystem vulnerabilities that require intensive, extensive and sustained solutions.

(xv) A significant long term rise of water table from 1973 to 2017 has been observed in 4 villages Lalbai, Badal, Bireng Khera and Middu Khera in Lambi block of Muktsar district where the rise in water table was found 1946%, 2059%, 1081%, 1274%.

(xvi) Punjab has problems of deteriorating groundwater quality triggered from the rapid increase in population, urbanization, industrialization, and extensive agricultural practices. Groundwater at shallow depth has been reported largely contaminated by the surface water pollution. Analysis of trace/heavy metals of 275 samples carried out for: Arsenic (As (total)), Aluminium (Al^{3+}), Iron (Fe^{3+}), Manganese (Mn^{2+}), Zinc (Zn^{2+}), Copper (Cu^{2+}), Chromium (Cr^{3+}), Cadmium (Cd^{2+}), Nickel (Ni^{2+}), and Lead (Pb^{2+}) showed that about ~3.8% of the groundwater samples have As concentration above acceptable limit (10 ppb) and ~ 0.38% exceeded the permissible limit of 50 ppb as prescribed by the BIS (2012). Cd^{2+} has concentration less than the acceptable limit of 3 ppb. Cu^{2+} has concentration within the acceptable limit of 0.05 mg/l. The concentration of Ni^{2+} is found within the acceptable limit (20 ppb) in the groundwater and surface water except one sample from Budhanala, the concentration of Pb^{2+} in both surface and ground water is within the acceptable limit of 20 ppb, in case of Al^{3+}, about ~ 44% groundwater samples exceeded the acceptable limit (30 ppb) and ~ 1.52 % samples exceeded the permissible limit (200 ppb), about ~14.83% groundwater samples exceeded the acceptable limit of 0.3 mg/L for Fe^{3+} for drinking water for both surface and groundwater. The mean concentration of Fe^{3+} was 251 ppb for groundwater; and for canal water it was 3810 ppb. In case of Mn^{2+}, ~7.6 % of groundwater samples exceeded the acceptable limit of 100 ppb, whereas ~3% samples exceeded the permissible limit of 300 ppb. Cr^{3+} has excess concentration than the acceptable limit of 0.05 mg/L in 0.38 % of groundwater samples, the concentration of Zn^{2+} is found within the acceptable limit of 5000 ppm.

(xvii) Measurements for electrical conductivity in canal water samples collected at an interval of 20 km were made and it was found that the electrical conductivity was constant at 240 µS/cm at all places except at Azamwala (270 µS/cm) and Chakjaanisar (>300 µS/cm).

(xviii) Groundwater samples analysed for major cations, viz. Ca^{2+}, Mg^{2+}, Na^{+}, K^{+} and major anions viz. HCO_3^-, F^-, Cl^-, SO_4^{2-}, NO_3^- are found in the order: $Na^+ > Ca^{2+} > Mg^{2+} > K^+$ and anions: $HCO_3^- > SO_4^{2-} > F^- > Cl^- > NO_3^-$ to see the contributions of ions to total groundwater salinity.

(xix) Groundwater quality is under the major influence of rock water dominance except in the south-west Punjab where evaporation water dominance is found leaving few samples which showed rock dominance. The Gibbs diagram indicates that the evaporation is major controlling factor along with weathering of rocks and aquifer minerals for evolution of ionic species in groundwater of the south west Punjab

(xx) Plots of Na^+ v/s Cl^- shows that the high Na^+ ions apart from halite dissolution excess of Na^+ have contributed from other sources. Groundwater samples located below the 1:2 line, indicated that in addition to silicate weathering, there are other hydro-geochemical process, which significantly affected the Na+ ions concentration in groundwater.

(xxi) Wilcox diagram shows that the shallow groundwater samples (<200 ft) fall under the category of permissible to doubtful categories for irrigation uses while majority of samples fall under the category of good to excellent.

(xxii) TDS of groundwater samples for pre-monsoon season vary from 121 mg/L to 9514 mg/L with an average value of 1103 mg/L; for monsoon season from 174 mg/L to 8911 mg/L with an average value of 1152 mg/L and for post monsoon season from 168 mg/L to 9581 mg/L with an average value of 1136 mg/L. Ions have contributed to the TDS of groundwater collected from different depth in the order for samples collected from aquifer depth < 200 ft anions as: $SO_4^{2-} > HCO_3^- > Cl^- > NO_3^- > F^-$, cations as: $Na^+ > Ca^{2+} > Mg^{2+} > K^+$; for aquifer depths 200-500 ft and > 500 ft anions as: $HCO_3^- > SO_4^{2-} > Cl^-$ $NO_3^- > F^-$, cations as: $Na^+ > Ca^{2+} > Mg^{2+} > K^+$.

(xxiii) Data on salinity showed that major fresh water zones (TDS = <500mg/l) are located near to Shiwalik area comprising districts of Hoshiarpur, Pathankot, Gurdaspur and parts of Jalandhar, SBS Nagar and Rupnagar; moderately fresh water zones (TDS = 500 – 1000 mg/l) are located in Amritsar, Tarn Taran, Jalandhar, Kapurthala, Ludhiana, Moga, Patiala, Fatehgarh, parts of districts SBS Nagar, Rupnagar, and Sangrur; moderately saline groundwater (TDS = 1000 – 2000 mg/l) are located in parts of districts of Sangrur, Mansa, Barnala, Bhatinda, Firozepur, Fazilka and Sri Muktsar

Sahib while saline groundwater (TDS = > 2000 mg/l) is found in parts of districts Sri Muktsar Sahib, Firozepur, Faridkot and Fazilka. Area with TDS values < 500 mg/L in the pre-monsoon season decreased by 8% during the monsoon season and increased in areas of other categories of TDS values such as, 500-1000 mg/L; 1000-2000 mg/L and > 2000 mg/L.Saline groundwater with TDS values >2000 mg/l is found in parts of districts Sri Muktsar Sahib, Firozepur, Faridkot and Fazilka. Area under saline groundwater in Firozepur, Faridkot and Fazilka with TDS values > 2000 mg/l increased by 58 % in year 2019 as compared to the year 2000.

(xxiv) Isotope studies show that canal is the main source of groundwater recharge in south west Punjab and evaporation process is responsible for increasing the salinity. In central Punjab, groundwater and rain are the main sources of groundwater recharge, while rain is the main source of groundwater recharge in Kandi area. In the south west Punjab area, there has been some primary salinity formed as a result of mineral dissolution which further increased due to evaporation process.

(xxv) The plots of $\delta^{18}O$ and EC for different aquifer depths of < 200 ft ,and > 200 ft revealed the effectiveness of evaporation process. These plots show three main types of trends : (i) an enrichment in the isotopic composition that increases linearly with the salinity (<200 ft: δ18O=-6 to -8‰; EC rising from 1000 to 14000 µS/cm); (ii) > 200ft $\delta^{18}O$= ~ -6‰ and EC rising from 1000 to 5000 µS/cm) , and (iii) the isotopic composition that exponentially saturated with increase in salinity in groundwater samples for aquifer depth < 200 ft to limits at $\delta^{18}O$=-7 ‰ (Groundwater + rain recharge), -9‰ (canal + groundwater recharge), -11 ‰ (canal recharge).

(xxvi) At the observed depleted values of $\delta^{18}O$=-7, -9, - 11‰ in different areas, the salinity in groundwater increases to the tune of 5000, 8000 and 11000 µS/cm respectively with the enrichment of $\delta^{18}O$ due to evaporative enrichment. Beyond the above limits, salt content is expected to have occurred due to dissolution of host salts.

(xxvii) On the basis of tritium dating, groundwater is categorized as recent water (>10TU; <20 yr; EC <400µS/cm); modern groundwater water (>5TU; <50 yr; EC = 400-500 µS/cm; sub-modern groundwater, (>1 TU; <100 yr; EC = 500 µS/cm to 1000 µS/cm); old groundwater (< 1TU; >100 yr or more commonly older than 1000 yr; EC = > 1000 µS/cm); recent to sub modern water with higher TU and higher salinity.

(xxviii) In areas where evaporation rates are high and the infiltration rates are low, the ground surface develops saline soils. In the subsequent wetting season, these salts are dissolved with the infiltrating water and add salinity to the groundwater on its recharge. Thus, as the time progresses the salt concentration in groundwater increases. In the areas where the water table is shallow, the excess drying due to capillary action can also causes salt mineralization.

(xxix) A certain level of salinity (EC = 7000-8000 µS/cm) is being developed in the area due to evaporative enrichment while the higher than this salinity is caused by the dissolution of host salts due to higher residence time of groundwater. It also appears from the tritium data that higher salinity due to dissolution of host salt is now at very limited places as most of it has been diluted. But salinity due to evaporative enrichment is in its dominating phase and if the similar trend is continued, it may rise higher than what we have observed presently. $\delta^{18}O$ data also corroborates the same.

(xxx) There is remote possibility of spread of salinity to the deeper aquifers. This is concluded from tritium dating as the old groundwater with low TU values appears to be isolated in deep aquifers. To validate this, MODFLOW model was developed, validated and used as a prediction model for any scenario analysis of the modeling area of southwest Punjab. The overall groundwater flow direction was found towards the SW direction

Recommendations

Following recommendations are offered as way forward:

(i) Regulation and limiting groundwater usage by enforcing groundwater legislation for future expansion of construction of wells farther inland, educating the farmers to reduce their present withdrawal to achieve groundwater balance and adopting water saving practices viz. reduction of non-beneficial evaporative and leakage losses, increase of irrigation efficiency, a change to less water demanding production processes and land uses and to find alternative sources of water other than groundwater (surface water or re-use of waste water) in central Punjab where the groundwater is declining at an alarming rate,

(ii) Priority areas for groundwater recharge are Barnala, Fatehgarh Sahib, Hoshiarpur, Jalandhar, Kapurthala, Moga, Patiala, Sangrur, SAS Nagar.

(iii) Installation of sub-surface drainage system or gravity drain for low lying area may be an option in South west Punjab mainly the Muktsar district where water levels are rising,

(iv) Crop adaptation or change in cropping pattern to manage salinity in soils and water, through introducing crops with lower water requirements; introducing salt tolerant and semi salt tolerant crops may be one of the options in southwest Punjab. In Muktsar and Firozpur areas where salinity is increasing due to evaporative enrichment, change in cropping pattern such as replacing rice with maize in Kharif season and replacing wheat with mustard in Rabi season is recommended.

(v) Conjunctive use (or blending) in terms of water quality could be practiced to meet demand for non-drinking purpose. This could be achieved by blending poor quality water (brackish groundwater) with better quality water from canals to dilute the salinity. Blended water could be used for horticulture, gardening and cleaning purpose. This option can be tried in south west Punjab area where groundwater with EC < 4000 μS/cm is available. The saline water that will be pumped out will be replaced in due course of time by the freshwater through precipitation recharge or subsurface flow. This can be achieved by a careful planning and execution.