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HYDROCHEMISTRY OF PUNJAB SATLUJ FLOODPLAIN: GROUNDWATER QUALITY ASSESSMENT FROM 1970 TO 2011

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Abstract

Floodplain – a flat terrain adjacent to river that extent from the river bank to the base of the enclosed valley wall. This is water enriched natural entity. From the beginning of civilization, humans attracted to this rich water resource area. Due to inverse effects of human development activities natural system started showing quality deterioration traits. Punjab Satluj floodplain is not the exception. This area faced 56.55% land use and land cover transformation from 1970 to 2011. Surficial modifications and transformations leads to the depletion and deterioration of surface and ground water. Surface water bodies that involved river channels, drains, wetlands, ponds and lakes etc. experienced 12.5% decrease in their surface extent from 1970 to 2011, whereas groundwater fall can be measured through the increased water depth from the surface level as minimum and maximum groundwater depth for 1970 was 1m and 12.33m respectively and in 2011 this range was increased with minimum 2.75m depth and maximum 33.47m depth in study area. Groundwater quality condition can be estimated through the exceeded concentration of hydrochemical from the maximum permissible

Keywords:

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Groundwater depth;

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Land use and Land cover Change;

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consumption limit. During 1970 Calcium Bicarbonate type of water was observed in Punjab Satluj floodplain which was changed to mix type with Calcium Bicarbonate, Calcium Sulfate, Sodium Bicarbonate and Sodium Chloride type in 2011. Land use and land cover change can be enlisted as a prominent cause of this situation along with other geological and hydrological factors.

1. Introduction

Punjab Satluj floodplain covers 1042.751 SqKms area that lies between30°32’ N to 31°35’ N and 75°05’ E to 76°44’ E latitudes and longitudes respectively. This area covers Phillaur Block of Jalandhar District,Aur, Nawanshahr and Balachaur Block of ShahidBhagat Singh Nagar District, Chamkaur Sahib Block of Rupnagar District and Machhiwara, Ludhiana II and Ludhiana I Block of Ludhiana District. Due to the flat terrain, fertile alluvial soil, ample surface and sub-surface water and suitable climatic condition this area attracted to human number. Consequences of this increased human habitation resulted in lot of land use and land cover change that caused contentious situations [1] related with all the life supporting essential components that involved water, soil and air. Prominent change was noticed in agriculture and built up area as it was expanded to 93.41% and 1283.54% land respectively from 1975 to 2011. Irrigated agricultural area was increased by 172.38%, which directly made pressure on surface and sub-surface water [2]. Water as the major agent for all life forms covered 3.17% of surface area during 1970’s and reduced to 2.77% in 2011. Water depth was increased as average groundwater depth from surface level was 4.04m and 3.82m for pre and post monsoon period respectivelyin 1970 which was increased to 8.82m and8.63m for pre and post monsoon period respectively in 2011. Utilization of land not only affects the water quantity but also changed its hydrochemical composition.

Hydrochemical characteristics have been analyzed through variations in Hydrogen ion (pH), Specific Electrical Conductance (EC), Total Hardness as Calcium Carbonate (TH as $CaCO_3$), change in major cations like Calcium (Ca), Magnesium (Mg), Sodium (Na), Potassium (K) and in major anions such as Carbonate (CO_3), Bicarbonate (HCO_3), Chloride (Cl), Sulfate (SO_4), Nitrate (NO_3) in groundwater and their deviation from the World Health Organization set maximum permissible consumption limit. Change in suitability of consumption water, its health consequences and underlying causes raised questions for Government and stakeholders' regarding proper resource utilization and management.

2. Research Method

Following methodology has been applied for analyzing the hydrochemistry and groundwater quality of Punjab Satluj floodplain from 1970 to 2011 (Figure 1):

Platform: Floodplain area has been taken as a platform that faced change with time. Satluj floodplain has been demarcated through river bluff and pixel reflectance readingsanalyzed through distinctive False Color Composite's in LANDSAT MSS: 1975, IRS P-6 LISS-III: 2011 and contours generated from Cartosat I: DEM, 2008. Water samples have been taken from point locations for analyzing the hydrochemistry of study area.

Time period: Comparative analysis has been done while taking 1970 as base year and 2011 as current year.

Data Sources: Secondary and primary data sets have been used. Secondary data has been collected from Department of Soil and Conservation, Punjab and Central Groundwater Board, India. Laboratory testing of collected samples from field has also been done for verifying the results. For assessing groundwater quality thirteen parameters have been selected that include Hydrogen ion (pH), Specific Electrical Conductance (EC), Total Hardness as Calcium Carbonate (TH as CaCO3), Bicarbonate (HCO3), Chloride (Cl), Sulfate (SO4), Nitrate (NO3), Potassium (K), Calcium (Ca), Magnesium (Mg), Sodium (Na), Fluoride (F) and Sodium Adsorption Ratio (SAR).

Data Analysis and Presentation: Data tabulation, statistical methods and graphs have been prepared in AqQa Spreadsheet, Statistical Package for the Social Sciences and Microsoft Excel.

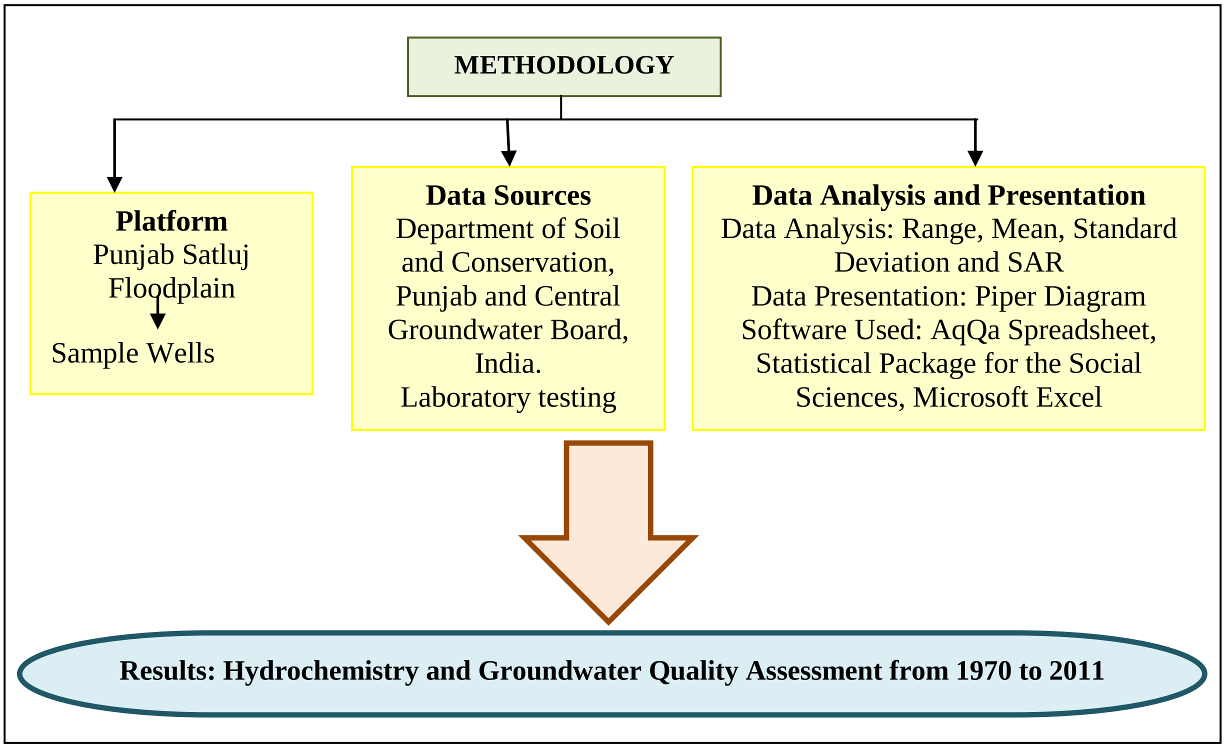


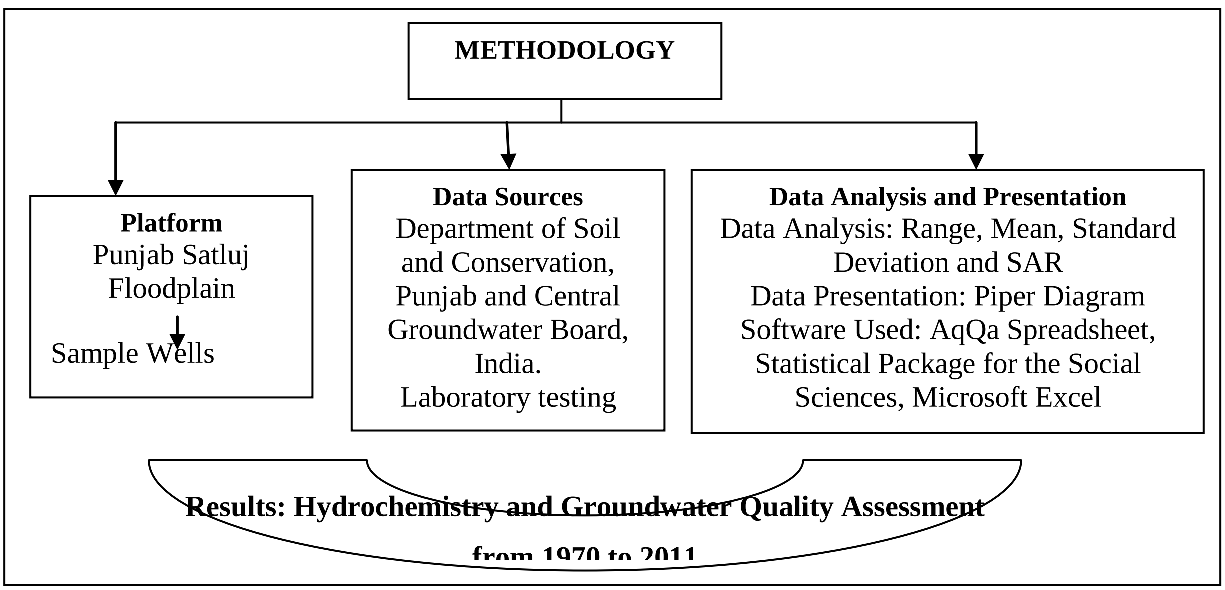
Figure 1: Methodology Adopted for Analyzing the Hydrochemistry and Groundwater Quality of Punjab Satluj Floodplain

3. Results and Analysis

With effect of precipitation rate, weathering processes, soil erosion, groundwater mobility, rate of infiltration, anthropogenic adulteration to the surface and sub-surface soil and water, groundwater hydrochemistry has been changed [3], [4], [5]. This area is characterized with the new alluvium of Holocene epoch. Blue grey to light grey micaceous sand with interbands of purple red clay has been found in large part of study area whereas loose grey micaceous sand has been observed along the stream courses. Flat terrain, fertile soil, ample water resources and suitable climatic conditions favor this land for habitation and related activities. This can be easily related with the 93.41% agricultural and 1283.54% built up area expansion within four decades i.e. 1970 to 2011. This increase in agricultural land can also be linked with the successful execution of Green Revolution in Punjab. Green Revolution was introduced in Punjab during 1966-67. Implementation of this revolution leads to the utilization of High Yielding Variety of seeds, pesticides, fertilizers, mechanization, irrigation and other related input advancements in agricultural sector.

This natural entity faced loss of huge land cover for the expansion of anthropogenic activities. All these resulted in the change of Hydrochemistry of groundwater. This can be linked through the following findings:

- In this area Calcium Bicarbonate type of water was observed during 1970 which was changed to mix type with Calcium Bicarbonate, Calcium Sulfate, Sodium Bicarbonate and Sodium Chloride type of water in 2011 (figure 2 & 3). Piper diagram has been prepared for depicting the condition of groundwater, in this bottom left is a ternary plot of the cations and bottom right shows anions. The central diamond plot reflects the specific type of water. Samples in the top quadrants characterized with calcium sulfate water that is having typical of gypsum ground water and mine drainage; samples in the left quadrant shows calcium bicarbonate type of water which are typical of shallow fresh ground water; samples in right quadrant are sodium chloride type which are typical of marine and deep ancient groundwater; and samples in the bottom quadrant are sodium bicarbonate type of water which are typical of deep ground water influenced by ion exchange.



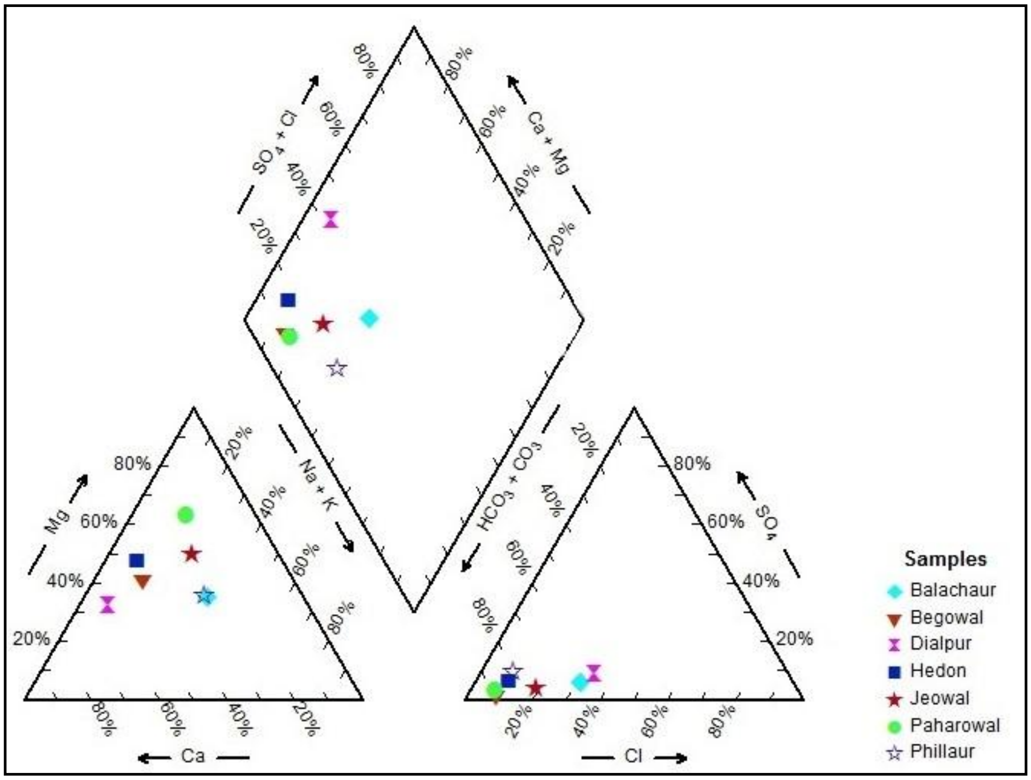


Figure 2: Hydrochemical Facies of Ground water in Punjab Satluj Floodplain during 1970

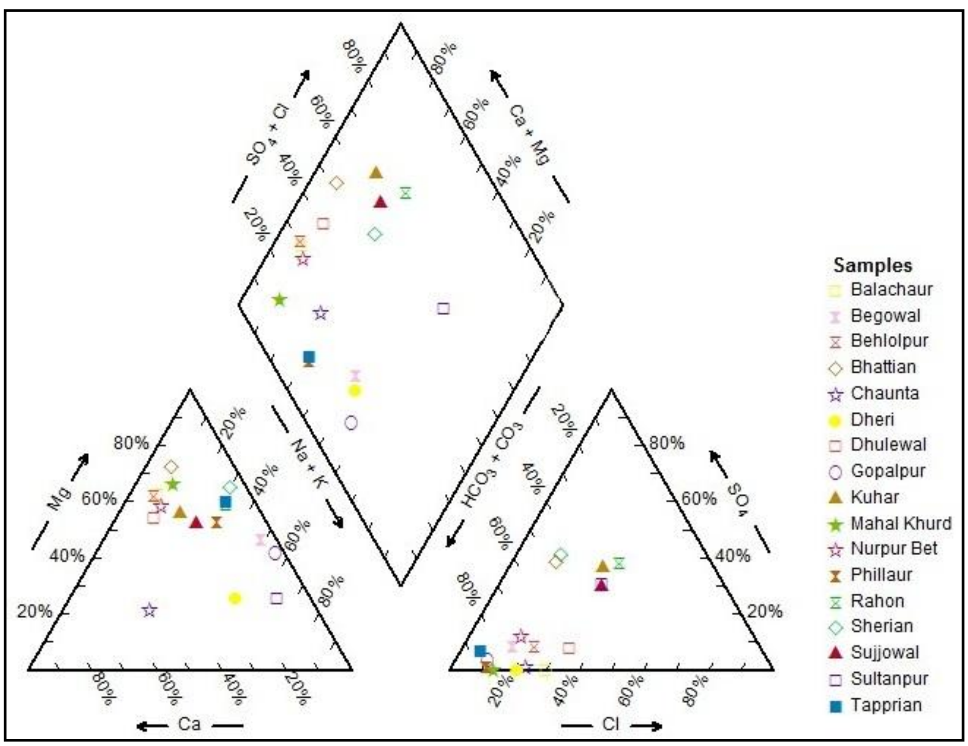


Figure 3: Hydrochemical Facies of Ground water in Punjab Satluj Floodplain during 2011

- **Fluctuations in Hydrogen Ion Concentration:** Hydrogen ion concentration depicts at pH scale. It indicates the basic and alkaline property of water. pH value less than 7 is considered acidic, value 7 at pH scale show neutral character, more than 7 means water is basic and above 8.5 depicts water is alkaline [6]. Water having above 8.5 pH value is bitter in taste [7]. Its value is altered from the addition of carbon dioxide from plant respiration process and decomposition of organic material as it releases carbon dioxide, and also through run off from land [8]. According to World Health Organization (2006) [9] permissible limit of pH value ranged 6.5 to 9.2 and values above this affect the potability of water. During 1970, pH value of groundwater of Satluj floodplain ranged between 7.35 and 7.8. For 2011, pH value ranged between 7.01 and 8.19 (table 1). Overall groundwater of Punjab Satluj floodplain is basic in nature.
- **Variation in Specific Electrical Conductance:** Electrical conductivity (EC) depicts the salinity level of that area as dissolved salts in water conduct electricity [10]. Salt concentration and EC have a direct relationship. Electrical conductivity reflects the conductance of a cubic centimeter of water at a standard temperature of 25ºC. It is measured in microSiemens/cm (µS/cm) [6]. Irrigation practices add salts to the parcel of land, which affects the EC of groundwater [10]. Temporal analysis of its variability depicts the deviation from the standard permissible consumption limit i.e. 1000 µS/cm set by World Health Organization (2011) [11] (table 1). During 1970, groundwater EC ranged 406 to 1215 µS/cm at 25ºC. But its maximum value exceeds permissible limit and reached at 1460 µS/cm in 2011. During this period prominent part was incorporated in beyond permissible limit.
- **Variation in Total Hardness as Calcium Carbonate in Groundwater:** Groundwater hardness is significantly affected by the agricultural activities, as itssolid wastes are deposited in the sanitary landfills. It produces gaseous Carbon Dioxide (CO_2), which when dissolved and reacted with the Calcium Carbonate ($CaCO_3$) rich groundwater, it produces soluble Calcium Bicarbonate. This process resulted in increased hardness of groundwater [12]. According to World Health Organization (1971) [13] stated international standards for drinking water, maximum permissible consumption level of hardness as $CaCO_3$ is 500 mg calcium carbonate per liter (table 1). Analysis of hardness for study area reveals its presence in acceptable permissible limit. During 1970, whole study area covered under suitable consumption limits as water hardness ranged between 185 and 459 mg/L. For 2011, groundwater hardness was 169 to 408 mg/L.

Table 1: Hydrochemistry of Punjab Satluj Floodplain: Range Variability Analysis for 1970 and 2011

Parameters	**Maximum Permissible Limit for Consumption (WHO 2011)**	**Statistical Summary**							
		1970				**2011**			
		Max	Min	Mean	SD	Max	Min	Mean	SD
pH	6.5 - 9.2	7.8	7.35	7.64	0.14	8.19	7.01	7.61	0.29
EC (µS/cm at 25°C)	1000	1215	406	906.58	273.24	1460	360	797.86	375.52
Total Hardness as $CaCO_3$ (mg/L)	500	459	185	320.25	70.32	408	169	255.05	57.021
Bicarbonate (mg/L)	1000	650	259	491.42	134.12	768	128	353.38	180.39
Chloride (mg/L)	250	96	8.9	41.34	29.37	121	13	38.81	29.81
Sulfate (mg/L)	250	57	1	25	16.48	248	0	54.75	72.25
Nitrate (mg/L)	50	47	0.5	15.82	14.77	92	0	52.43	29.11
Potassium (mg/L)	10	56	1.4	8.58	14.39	63	2	11.99	15.34
Calcium (mg/L)	75	110	33	69.42	23.93	78	8	36.33	17.63
Magnesium (mg/L)	50	47	16	35.67	8.79	77	12	39.95	14.75
Sodium (mg/L)	200	186	20	83.17	53.13	237	13	79.95	71.76
Fluoride (mg/L)	1.5	1.46	0.2	0.78	0.38	2.15	0.12	0.47	0.48
SAR (Meq/L)	< 10	4.72	0.48	2.02	1.34	6.87	0.39	2.46	2.24

Source: Central Groundwater Board, India

- **Variation in Bicarbonate:** It is the primary anion in groundwater [14]. Its increased value enhances the alkalinity level. Its excessive amount has been added to the groundwater from the crop fields as it produces carbon dioxide [8]. World Health Organization (1971) [13] stated permissible maximum limit is 1000 mg/L. During 1970, bicarbonate concentration ranged between 259 and 650 mg/L. In 2011, maximum bicarbonate limit reached at 768 mg/L (table 1).

- **Variation in Chloride:** Excessive addition of chloride ions took place through the application of potash fertilizers into the agricultural field [15] and from the road salts [16]. According to World Health Organization (2006) [9], maximum permissible consumption limit of chloride in water is 250 mg/L, beyond this affects the taste and corrodes the metals. With time due to the increased consumption pattern of fertilizers, variation in the upper limit of chloride content was observed (table 1). That was ranged between 8.9 and 96 mg/L for 1970, which was under the suitable consumption limit. During 2011, chloride concentration ranged between 13 and 121 mg/L.
- **Variation in Sulfate ion Concentration:** According to World Health Organization (2011) [11], maximum acceptable limit of sulfate ions in consumable water is 250 mg/L. This permissible limit gets altered from the run off taking place through the fertilized agricultural fields [17]. During 1970, sulfate ion concentration in groundwater was below the permissible limit and ranged between 1 and 57 mg/L. In 2011, its maximum value was increased and ranged between 0 and 248 mg/L. That was very close to the maximum permissible consumption limit.
- **Variation in Nitrate Concentration:** Presence of nitrate in groundwater is affected by the utilization of nitrogenous fertilizers and manures. It also added through the exposure of wastewater disposal, which includes the human and animal excreta [11]. Maximum allowable limit of nitrate in consumable form is 50 mg/L [11]. During 1970, groundwater nitrate contamination was under the permissible limit and ranged between 0.5 and 47 mg/L in Satluj floodplain area and during 2011, nitrate concentration in groundwater ranged between 0 and 92 mg/L.
- **Spatial-temporal Variation in Potassium Concentration:** Potassium is added to the groundwater through weathering of potash silicate minerals and from the application of potash fertilizers to the field and utilization of surface water for irrigation [18]. According to European Economic Community [9] maximum permissible consumption limit is 10mg/L. Throughout the analysis period, potassium content was found beyond its acceptable limit of consumption. During 1970 its concentration ranged between 1.4 and 56 mg/L. For 2011, groundwater potassium content was ranged between 2 and 63 mg/L.

- **Variation in Calcium Concentration:** Maximum permissible limit of calcium ion concentration is 75 mg/L [9]. This value is affected by the pH, carbon dioxide and carbonate minerals [19], [20]. In study area, range of calcium concentration in groundwater varied with time. For 1970, it ranged between 33 and 110 mg/L. During 2011, it exceeds its maximum acceptable limit and ranged between 8 and 78 mg/L.
- **Variation in Magnesium Concentration:** According to WHO (2006) [9], maximum acceptable consumption limit of magnesium ion in water is 50 mg/L. This value is elevated by the application of fertilizers in the fields, which when infiltrated add magnesium in groundwater [20]. For 1970, it was observed under the permissible limit and ranged between 16 and 47 mg/L for study area. For 2011, it ranged between 12 and 77 mg/L.
- **Variation in Sodium Concentration:** Maximum sodium ion concentration for consumable water is 200 mg/L [11]. Groundwater contamination with excessivesodium content took place through its addition from the road deicing chemicals, water treatment processes, domestic water softeners and sewage effluents [21]. During 1970, sodium content in groundwater was under the admissible limit of consumption i.e. 20 to 186 mg/L. In 2011, sodium contamination in groundwater was increased and ranged between 13 and 237 mg/L.
- **Variation in Fluoride Concentration:** According to WHO (2011) [11], maximum acceptable limit of fluoride content in consumable water is 1.5 mg/L. Application of phosphate fertilizers in the irrigated fields increased the fluoride values. For 1970, fluoride concentration in the groundwater of study area was under the permissible limit, it ranged between 0.2 and 1.46 mg/L. During 2011 it was increased and ranged between 0.12 and 2.15 mg/L.
- **Variation in Sodium Adsorption Ratio:** Sodium Adsorption Ratio (SAR) helped in the evaluation of sodium hazard in water. Water used for irrigation with high SAR level tend to increase the high sodium level in soil that adversely affect soil infiltration rate and also leads to soil crusting [22]. In Punjab Satluj floodplain maximum SAR value was 4.72 meq/L in 1970 that increased to 6.87 meq/L in 2011. This acceptable value reflects the suitability of water for irrigation. It can also be linked with the high Electrical conductivity its maximum value was 1215 µS/cm in 1970 and 1460 µS/cm in 2011. Increasing EC level have tendency to mitigate the negative sodium effects on one side but accentuates the crop stress with increased salinization.

Changing value of hydrochemicals in groundwater of Punjab Satluj floodplain reflects that in coming years their values in groundwater exceeds maximum permissible limit and affects the health of living beings.

4. Conclusion

Groundwater of Punjab Satluj floodplain is basic in nature. Earlier in 1970, it was Calcium Bicarbonate type which transformed to mix type with Calcium Bicarbonate, Calcium Sulfate, Sodium Bicarbonate and Sodium Chloride type water. Analysis of water quality against selected parameters revealed that between 1970 to 2011, Specific Electrical Conductance (EC), Nitrate (NO3), Potassium (K), Calcium (Ca), Magnesium (Mg), Sodium (Na) and Fluoride (F) contamination in water exceeded its permissible consumption limits. Although presence of other hydrochemicals that include Bicarbonate (HCO3), Chloride (Cl), Sulfate (SO4), Sodium Adsorption Ratio (SAR) also increased but ranged between permissible limit which tends to exceedits permissible limit in coming years. This analysis set forth the base for policy makers to take some relevant and supportive measures for conservation of this life savior element.

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