

A Spatio-Temporal Groundwater Fluoride Contamination Assessment to Infer the Hydro-geochemical Analysis of Punjab Satluj Floodplain

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Abstract

Punjab Satluj Floodplain is a Hydro-geologically, ecologically, and economically very precious resource-rich landscape. This area is fragile due to flood risk; since its inception, it has attracted lots of economic and sociocultural activities that adversely affect hydro-geochemical conditions. Spatial and statistical analysis of land use and land cover change reveals that from 1975 to 2011, this landscape experienced 56.55 % land use and land cover transformation. Maximum transformation is noticed in the agricultural and built-up areas. In 1975, agricultural and built-up areas covered 47057.11 hectares (45.13 %) and 469.5 hectares (0.45 %), respectively, of the Punjab Satluj floodplain, which was expanded and covered 91011.36 hectares (87.28 %) and 6495.7 hectares (6.24 %) respectively in 2011. Adversities of these values can be estimated from the groundwater contamination analysis that reveals the specific electrical conductance (EC), nitrate (NO₃), potassium (K), calcium (Ca), magnesium (Mg), sodium (Na), and fluoride (F) contamination in the water exceed its permissible consumption limits and effects ecological health. The present research work is the epigram of the hydrogeochemical condition of the Punjab Satluj floodplain concerning the spatial distribution of fluoride contamination and its proximate causes.

Keywords: Groundwater; Hydro-geochemical; Fluoride; Land use and land cover change; Contamination.

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1. Introduction

Fluoride contamination beyond permissible limits adversely affects an ecosystem's health. Fluorine in the soil inhibits microbial processes [1] and reduces soil fertility with time. The presence of excessive fluoride in drinking water can cause diseases among humans [2-8]. It can cause dental fluorosis, skeletal fluorosis, and deformation of bones in humans [9,10]. The possible proximate causes of fluoride occurrence in the groundwater can be categorized as natural and anthropogenic. In natural ways, fluoride concentration is associated with the presence of fluoride minerals, concentration of pH, level of calcium, and bicarbonate ions in water [11]. Among anthropogenically induced factors, land use, and land cover activities prominently adversely affect groundwater quality [12]. In

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agricultural fields, utilization of phosphate fertilizers adds fluoride [13]. The Punjab Satluj floodplain is attributed to flat terrain, fertile alluvial soil, ample surface and sub-surface water, and suitable climatic condition that attracts human population and related livelihood endeavors, further leading to the fluoride contamination in groundwater.

Punjab Satluj floodplain covers a 1042.751 sq km area that lies between 30°32' N to 31°35' N and 75°05' E to 76°44' E latitudes and longitudes, respectively. In terms of administrative coverage, it overlapped the Phillaur block of Jalandhar district, Aur, Nawanshahr, and Balachaur block of Shahid Bhagat Singh Nagar district, Chamkaur Sahib block of Rupnagar district and Machhiwara, Ludhiana II and Ludhiana I block of Ludhiana district. From 1970 to 2011, fluoride contamination in the groundwater fluctuated till 1980. The presence of fluoride in groundwater was within the acceptable permissible consumption limits, but with time, fluoride contamination was observed beyond WHO set permissible limit of 1.5 mg/l, as in 1990 and 2011, the maximum recorded fluoride value for this area was 2.38 mg/l and 2.15 mg/l respectively. Hydrogeological and anthropogenically induced land use and land cover transformations are proximate accountable causes for fluoride fluctuations in this area.

2. Methodology

The following methodology was applied for collecting, analyzing, and representing the hydrogeological and land use and land cover data set of the Punjab Satluj Floodplain:

2.1. Floodplain demarcation

Satluj floodplain was demarcated through river bluff, and pixel reflectance readings were analyzed through distinctive False Color Composite in LANDSAT MSS: 1975, IRS P-6 LISS-III: 2011 and contours generated from Cartosat I: DEM, 2008.

2.2. Hydrogeological data

Data was collected for identified fifty wells of the Punjab Satluj floodplain from the Department of Soil and Conservation, Punjab, and Central Groundwater Board, India, from 1970 to 2011. Spatial plotting of identified wells was done in the Geographic Information System, and a spline interpolation technique was applied for preparing isolines. Laboratory testing of collected samples from the field was also done to verify the results.

After laboratory testing, Eq. (1) was applied to acquire the actual value of the stated substance:

$$\text{Fluoride (F): } \frac{1.449-x}{0.184} - 0.744 = x \text{ mg/l} \quad (1)$$

The geological condition of the Punjab Satluj Floodplain was sourced from a Map produced by the Geological Survey of India 2004.

2.3. Land use and land cover change

Land use and land cover maps generated from the 1975 LANDSAT 2 MSS and 2011 IRS P6 LISS III satellite imageries, while employing unsupervised classification techniques and further generated Figs, were combined in the matrix form for comparative analysis. This matrix helped in the interpretation of the category-wise transformation through *to and from* the procedure.

3. Discussion and Analysis

3.1. Spatial patterns of fluoride contamination

In the Punjab Satluj floodplain, field fertilization played a predominant role in groundwater contamination with fluoride. According to the World Health Organisation, the maximum acceptable limit of fluoride content in consumable water is 1.5 mg/L [14]. For 1970 and 1980, fluoride concentration in the groundwater of the study area was under the permissible limit (Figs. 1(a) and 1(b)). During 1970, it ranged between 0.2 to 1.46 mg/L; in 1980, it was 0.16 to 1.02 mg/L (Table 1). During 1990, fluoride contamination was increased, and the upper limit reached 2.38 mg/L. Highly contaminated groundwater ranging between 2 to 2.38 mg/L was observed in the northwestern and northeastern parts of Balachaur and Nawanshahr block of Shahid Bhagat Singh Nagar district, respectively. This range was also found in the Aur block of Shahid Bhagat Singh Nagar district and the eastern part of the Phillaur block of Jalandhar district (Fig. 1(c)). For 2000, the maximum value of fluoride was under the admissible limit, i.e., 1.2 mg/L (Fig. 1(d)). But for 2011, it again increased, and noted that the maximum limit was 2.15 mg/L. A circular patch with more than 2 mg/L fluoride contamination was found in the center of the study area consisting of the southern part of Aur block of Shahid Bhagat Singh Nagar district and the northern part of Ludhiana II block of Ludhiana district (Fig. 1(e)). The application of phosphate fertilizers in the irrigated fields increased the fluoride values. It is also added from the combustion of coal in industries and brick kilns, which acts as a potential source of fluoride that falls with rain and becomes part of groundwater through runoff and infiltration [13].

Table 1. Fluoride concentration in Punjab Satluj Floodplain: variability analysis from 1970 to 2011.

Parameters	Maximum Permissible					
	Limit for Consumption (WHO, 2011)	1970	1980	1990	2000	2011
Fluoride (mg/l) (Range Variability)	1.5	0.2-1.46	0.16-1.02	0.21-2.38	0-1.2	0.12-2.15
Mean		0.78	0.44	0.61	0.43	0.47
Standard Deviation		0.37	0.29	0.52	0.32	0.47

Source: Central Groundwater Board, India

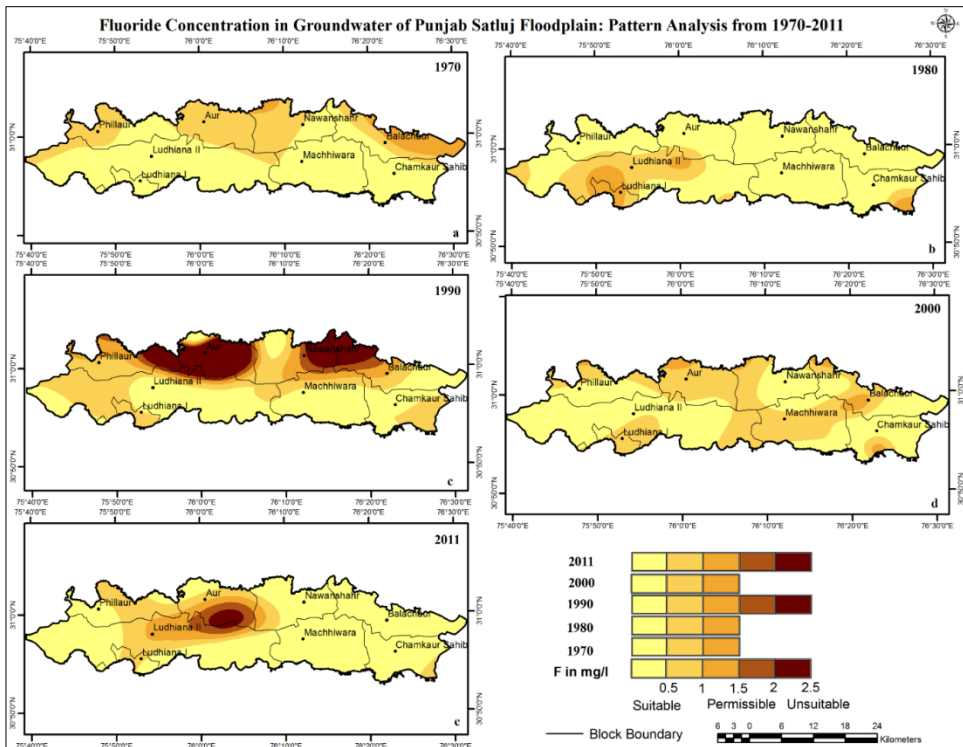


Fig. 1. Fluoride Concentration in Groundwater of Punjab Satluj Floodplain: pattern analysis from 1970-2011. Source: Interpreted from data provided by Central Groundwater Board, India.

3.2. Proximate causes

Both natural and anthropogenic factors are proximately accountable for fluoride fluctuations.

3.2.1. Hydrogeological condition

- (i) Geologically, Punjab Satluj Floodplain is attributed with loose grey micaceous sand along the Satluj River course and blue-grey to light grey micaceous sand with interbands of purple-red clay in the floodplain area. Micaceous sand is observed to be a source of fluorine [15].
- (ii) A Piper diagram prepared from the observed samples revealed the hydrochemical condition of groundwater that prevailed in the Punjab Satluj floodplain in 2011 (Fig. 2). Analysis extracted from the Piper diagram depicts that Punjab Satluj floodplain groundwater is mixed with calcium bicarbonate, calcium sulfate, sodium bicarbonate, and sodium chloride. In the Punjab Satluj Floodplain, a basic to alkaline type of water was observed from 1970 to 2011 [16,17]. Sodium bicarbonate and alkaline water are

associated with high fluoride contamination [18], as they favor the release of fluoride from minerals into groundwater [19].

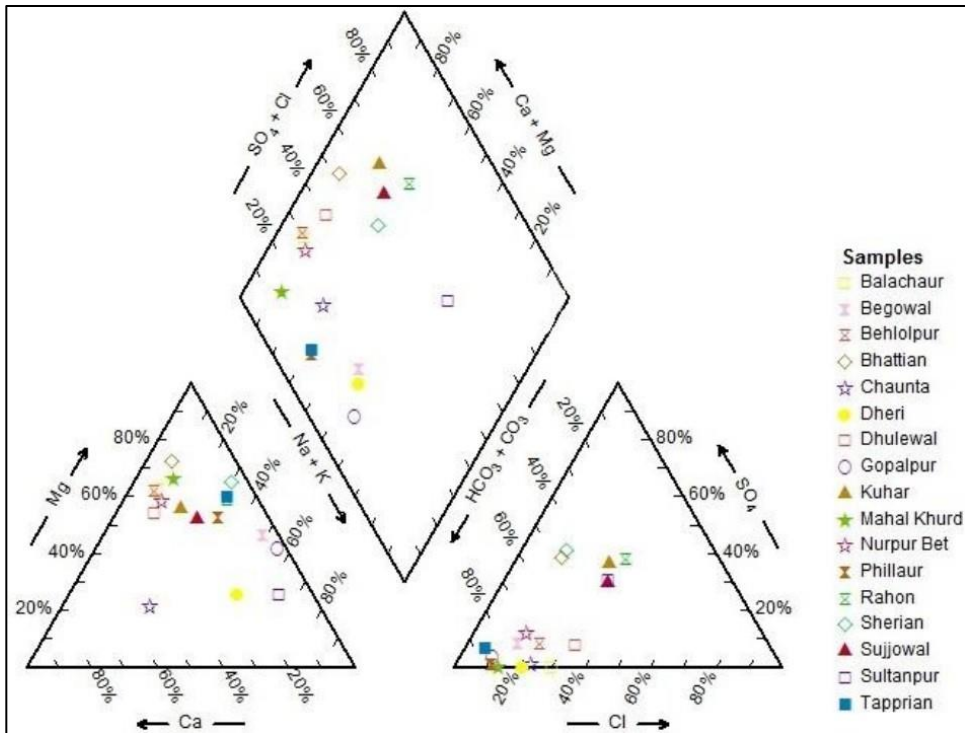


Fig. 2. Hydrochemical condition of Punjab Satluj Floodplain groundwater in 2011.

3.2.2. Agricultural implications

Since 1975, the Punjab Satluj floodplain has experienced 56.55 % land use and land cover transformation in 36 years. Major changes were noticed in the agricultural land use area, which covered 47057.11 hectares in 1975 and increased to 91011.36 hectares in 2011. In the Punjab Satluj Floodplain, agricultural land was expanded to 93.41 % from 1975 to 2011, and irrigated agricultural area was increased by 172.38 %. As the green revolution phase depicted the audacity of increased use of fertilizers, from 1960-61, fertilizer consumption of nitrogenous, phosphatic, and potassic (NPK) nutrients in Punjab State was 5 thousand tonnes, which was increased to 1918 thousand tonnes in 2011-12 (Table 2 and Fig. 3). Although, fertilizer intake increased the fertility level of soil and amplified the plant growth, but, along with that subsequent increase in phosphate-containing fertilizers to the agricultural fields were added the fluoride content in the soil and groundwater [20,21]. Phosphatic fertilizers contain a remarkable amount of fluoride [22].

Table 2. Nutrient consumption in Punjab.

Year	Nitrogenous	Phosphatic	Potassic	Total (NPK)
1960-61	05	-	-	5
1970-71	175	31	7	213
1980-81	526	207	29	762
1990-91	877	328	15	1220
2000-01	1008	282	23	1313
2011-12	1416	448	54	1918

(Values in Thousand Tonnes)

Source: Statistical Abstract of Punjab, 2001 and 2012.

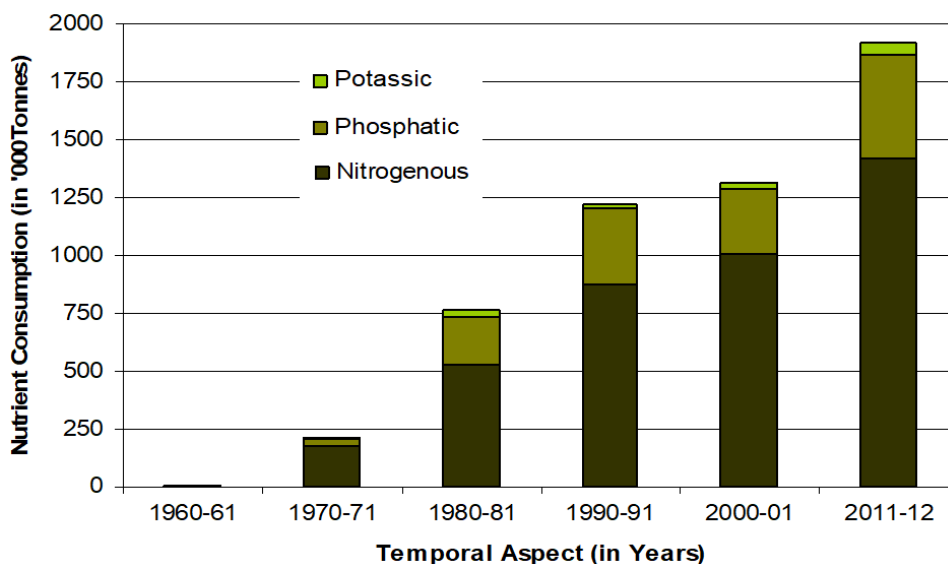


Fig. 3. Nutrient consumption in Punjab. Source: Statistical Abstract of Punjab, 2001 and 2012.

4. Conclusion

The hydrochemical composition of groundwater in the Punjab Satluj floodplain is affected by hydrogeological characteristics, and further alterations are accentuated with human interventions. The presence of micaceous sand and sodium bicarbonate with alkaline water type excessive use of phosphatic fertilizers are the proximate causes of fluoride contamination in the groundwater of the Punjab Satluj floodplain. It is recommended to observe the periodical testing of water and soil so that the requisite amount of fertilizers and irrigation procedures can be implemented to hamper the rise of fluoride content in the groundwater of the Punjab Satluj floodplain.

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