

# Impact of geology and geomorphology on fluoride contaminated groundwater in hard rock terrain of India using geoinformatics approach

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**Abstract** The present study demonstrates a GIS-based spatial evaluation of fluoride contamination (FC) in groundwater vis-a-vis geology and geomorphology of the area using analytical hierarchy process and weighted sum method in Palamu district of Jharkhand. The integration and analyses of the various thematic databases along with the field sampled fluoride data proved useful in delineating the FC zones. The FC index ranged between 141 and 707, and was classified into four zones, viz., low, moderate, high, and very high zones of FC. The FC index map showed that a total of 49.75% of the study area lies between high to very high FC zone. The very high FC zone is found in the moderately weathered plateau with granitic terrain, whereas the high and moderately FC zones covering 49.31 and 36.41% of the study area are dominated by plateau weathered shallow, pediment–inselberg complex, pediplain moderately weathered, pediplain shallow weathered, and inselberg which have high fluoride. The lowest FC zone covers an area of 193.27 sq. km (13.84%). The spatial analysis of geology with fluoride showed that

groundwater within granitic gneiss exhibits high FC followed by granitoid gneiss and alluvium. Geomorphologically highest FC was recorded in plateau weathered moderate (91.67%) followed by plateau weathered shallow (71.43%), flood plain (41.76%), inselberg (27.27%), and pediment (25%). The spatial analysis of groundwater yield with fluoride showed that regions having good yield exhibit maximum FC thereby accelerating the vulnerability of the population to fluorosis.

**Keywords** Fluoride · Geology · Groundwater · GIS · Hardrock

## Introduction

Groundwater composition in a region depends on natural (such as the wet and dry deposition of atmospheric salts, evapotranspiration, and soil/rock–water interactions) and that of the anthropogenic processes (Leung et al. 2005) which can alter or modify the natural system of hydrological cycle (Gaciri and Davies 1993). The type and extent of chemical contamination of the groundwater is largely dependent on the geochemistry of soil through which water flows while reaching the aquifers (Johnson 1979), and also on the dry or wet climatic zones (Dissanayake 1991). Fluoride ( $F^-$ ) is widely dispersed in nature and is estimated to be the 13th most abundant element on our planet (Mason and Moore 1982). Fluoride in drinking water is known for both beneficial and detrimental effects on health. Its concentration in the environment is highly variable and is often dependent on the presence of particular types of rocks, minerals, and water. Zhu et al. (2007) showed that soil can be expected to contain elevated dissolved fluoride concentrations with depth in an area where granite is the main

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soil-forming parent rock. The abnormal level of fluoride in water is common in fractured hard rock zone with pegmatite veins (Ramesam and Rajagopalan 1985). Fluoride ions from these minerals leach into the groundwater and contribute to high fluoride concentrations (Suttie 1969; Jubb et al. 1993; Schultheiss and Godley 1995). The concentration of fluoride in most waters is controlled by the solubility of the main fluoride-bearing mineral fluorite ( $\text{CaF}_2$ ); hence, waters that are sodium ( $\text{Na}^-$ ), potassium ( $\text{K}^-$ ), and chloride ( $\text{Cl}^-$ ) rich and calcium ( $\text{Ca}^-$ ) poor tend to contain high fluoride concentrations. In general, groundwaters contain more fluoride than surface water resources due to its maximum interaction with fluoride-bearing minerals in rock (Edmunds and Smedley 1996; Hem 1985; WHO 2000). The excess fluoride content in groundwater, its endemic ill effects on human physiology, and its source and origin in subsurface solute have attracted the attention of many scientists (Handa 1988; Subba Rao et al. 1998; Subba Rao 2003; Jain et al. 1999; Saxena and Ahmed 2001; Kundu et al. 2001). For example, endemic dental and/or skeletal fluorosis has been reported in the East African Rift Valley which is associated with volcanic rock types and thermal waters (Frencken et al. 1990). In India and Sri Lanka, fluorosis is linked to fluoride-rich alkaline groundwaters (Dissanayake 1996; Susheela 1999), and in China, problems are associated with high fluoride groundwaters and inhalation of fluoride from coal smoke (Zheng et al. 1999). The prevalence of fluorosis is mainly due to the intake of large quantities of fluoride through drinking water and is reported in many states of India (Siddiqui 1955; Jolly et al. 1973; Teotia and Teotia 1991; Susheela et al. 1993; Karthikeyan et al. 1996; Chidambaram et al. 2012; Singaraja et al. 2012, 2014). An evaluation of quality of the groundwater is an important task to be done in a scientific way which requires a simple and valuable tool for decision-making on the groundwater quality. Thus, an integrated approach of both water quality index (WQI) and geographical information system (GIS) can be used for spatial mapping of various hydrochemical parameters (Srinivas et al. 2013).

The Palamu district located in the north-western part of Jharkhand state suffers due to high concentration of fluoride in groundwater (Pandey et al. 2012). The hard rock terrain of the Palamu district, Jharkhand, India has poor groundwater zones and is a chronically drought prone region which faces acute water scarcity both for irrigation and drinking purposes (Shekhar and Pandey 2014; Tirkey et al. 2012). The recurrent drought and concomitant decline in the groundwater levels over the years in parts of the Palamu district has necessitated the need to monitor the groundwater quality of this region, so that proper management may be done to make water available even in times of water scarcity. The water scarcity resulting from

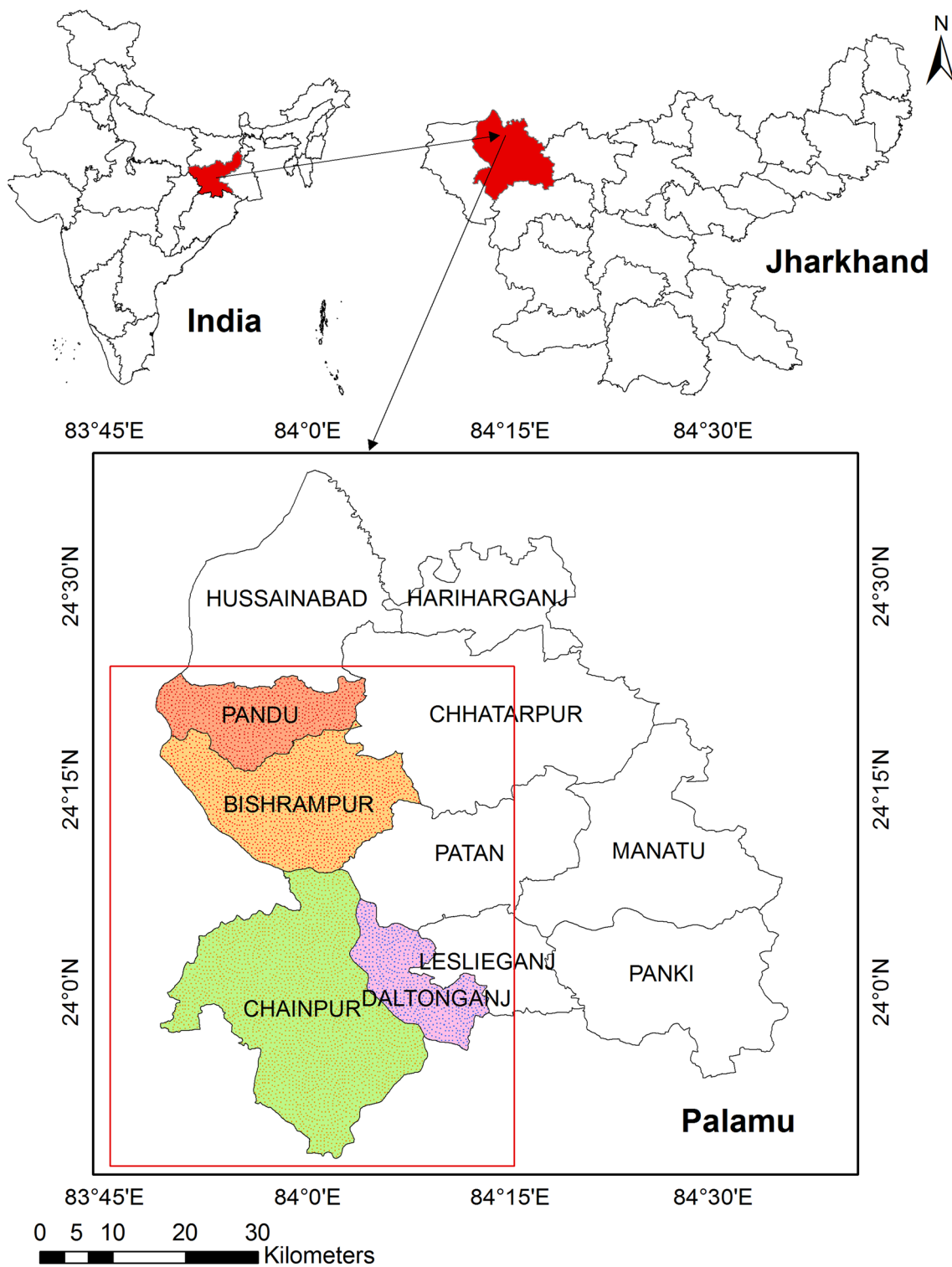
increasing demand for water over the years in different parts of the world has been aggravated by the problems of water pollution or contamination (Utom et al. 2013).

The present study delineates the high fluoride contamination zones in the groundwaters of the four blocks of Palamu district, viz., Daltonganj, Bishrampur, Chainpur, and Pandu, using analytical hierarchy process (AHP) and GIS. Thus, this study will help in decision-making process for groundwater management in the region and identify zones which need proper attention. GIS proves to be a very efficient tool for analyzing, interpreting, manipulating, and incorporating the geological, hydrogeological, and geomorphological data (Anbazhagan and Nair 2004; Jha and Peiffer 2006; Jha et al. 2007; Shekhar et al. 2014). The multi-criteria decision-making (MCDM) provides an effective tool for water management by adding structure, auditability, transparency, and rigor to decisions (Shekhar et al. 2014; Dunning et al. 2000; Flug et al. 2000; Joubert et al. 2003). The pattern of long-term variation of groundwater level depends on the variations in precipitation and it can be inferred that groundwater gets recharged during rainfall, as it shows a rise in the water level during the subsequent months after rainfall but, however, declines substantially during pre monsoon periods (January–May) which results in deep average depth to water level in Palamu district (Tirkey et al. 2012). The water level is deeper towards the northern region of the Palamu district and lies between 9 and 12 m, whereas the maximum region exhibiting 6–9 m water level depth covers the entire portion of the central region of the Palamu (Shekhar et al. 2014).

## Study area

The area under investigation comprises of Daltonganj, Bishrampur, Chainpur, and Pandu blocks of Palamu district of Jharkhand state covering an area of 1397 sq. km, and is located between  $23^{\circ}47'N$  to  $24^{\circ}23'N$  latitude and  $83^{\circ}48'E$  to  $84^{\circ}13'E$  longitude. Agriculture in the district is limited owing to semi-arid climatic conditions. The average elevation in the area ranges from 300 to 600 m above the mean sea level. The hills in the districts are widely scattered. The streams flow from south to north forming tributaries of major rivers like Koel and Sone. Climatically, the district comes under monsoonal sub-tropical zone characterized by mean annual precipitation of 1000 mm and a mean annual temperature of  $25.1^{\circ}C$ . The location map of the study area is shown in Fig. 1.

In Palamu district, groundwater mainly occurs in the unconfined aquifer formed by weathered residuum. Semi-confined and confined conditions exist in deeper fractures and joints. The yield of the exploratory wells is from 14.4 to  $288\text{ m}^3/\text{year}$ , and highly variable and the hydraulic



**Fig. 1** Location map of the study area

conductivity of the aquifer in Palamu varies from 0.002 to 3 m/day (Shekhar et al. 2014). The geological formation of the Palamu district comprises mainly rocks of Archaean, Vindhyan, and Gondwana ages. The Archaean rocks include both schists of Dharwar age and gneisses and

granites. The schists, mainly horn-blende and biotite, are the oldest rocks of the area and occur as parallel and lenticular bands in the gneisses (CGWB 2009). Recent alluvium overlying granite gneiss is of quaternary age group; sandstone and shale are of Gondwana age group, while

chotanagpur granite gneiss and basic rocks are of Achaean age group (Table 1).

## Materials and methods

The geology and geomorphology map of the four blocks of Palamu district was digitized and prepared using the geology and geomorphology map of Palamu district published by the Geological Survey of India (GSI) and updated with the remote sensing satellite data like AWiFS and LISS III. The groundwater yield map was prepared using the yield data from Rajiv Gandhi National Drinking Water Mission atlas (Rajiv Gandhi National Drinking Water Mission Atlas 2005), whereas the soil map of the study area was digitized and prepared taking reference of Bihar soil map published by National Bureau of Soil Survey and Landuse Planning (NBSS and LUP Bihar 1998). The groundwater sample for fluoride analysis for the four blocks of Palamu district was collected during premonsoon (2012) using global positioning system (GPS). The groundwater sample data were spatially analysed in geographic information system (GIS) platform to find out the relationship of fluoride contamination with reference to geology, geomorphology, groundwater yield, and soil of the study area. The non-permissible (NP) fluoride samples (in percentage) were obtained after overlaying the surveyed ground sampled points in all the different classes of each theme which were then given weightage according to weighted sum method (WSM), in the range 1–10, according to their percentage of fluoride contamination. The weightage 1 was assigned to the class having lowest percent of fluoride content (1–10), whereas weightage 10 was assigned to the class where the percentage of NP fluoride content was in the range 90–100 in each of the four themes. The thematic maps, viz., geology, geomorphology, groundwater yield, and soil, were assigned weights using Saaty's analytical hierarchy process (AHP). The normalization process reduces the subjectivity associated with the assigned weights of the thematic maps. The normalized weights of the thematic layers were examined for consistency as recommended by Saaty (1980). The following

steps were followed to compute consistency ratio (CR) for each theme:

Step 1: Principal eigenvalue ( $\lambda$ ) was computed by eigenvector technique.

Step 2: Consistency index (CI) was calculated from the following equation (Saaty 1980):

$$CI = \frac{\lambda_{\max} - n}{n - 1}$$

where  $n$  is the number of criteria or factors.

Step 3: Finally, consistency ratio (CR) was calculated as (Saaty 1980):

$$CR = \frac{CI}{RCI}$$

where  $RCI$  random consistency index.

The value of  $RCI$  was obtained from the Saaty's 1–9 scale. The value of consistency ratio (CR) should be less than 10% (Saaty 1980) for consistent weights. The CR for the above four themes was found to be 0.05

For obtaining the fluoride contamination (FC) index, the non-permissible fluoride index (NPFI<sub>ij</sub>) for each of the four parameters (geology, geomorphology, yield, and soil) was determined using Eq. 1, and thereafter, the four vector layers were rasterized based on the assigned weightage and then spatially overlaid in the GIS keeping their projection and cell size same.

$$NPFI_{ij} = W_j \times q_{ij} \quad (1)$$

where NPFI<sub>ij</sub> is the value of non-permissible fluoride index,  $W_j$  is the relative weight (assigned according to AHP), and  $q_{ij}$  is the quality rating of unbiased value of a parameter  $j$  (where;  $j = 1 \dots 4$  indicates geology...soil) at  $i$ th pixel location and determined using reclassification technique. The final FC index map was generated using the following equation:

$$FC_i = \frac{\sum_{j=1}^n NPFI_{ij}}{\left[ \sum_{j=1}^n NPFI_{ij} \right]_{\max}} \quad (2)$$

where  $FC_i$  is the value of water quality status with respect to fluoride contamination at  $i$ th location.

**Table 1** Age of the rocks and hydrogeological properties of the region (CGWB 2009)

| Lithology                  | Age group            | Hydrogeological condition   |
|----------------------------|----------------------|---|
| Recent alluvium            | Quaternary           | Groundwater under unconfined conditions   |
| Sandstone and shale        | Gondvana super group | Groundwater restricted to weathered zone occurs under semi-consolidated conditions              |
| Basic rocks                | Vindhyan super group | Groundwater under semi-confined conditions within fractured joints and cavities                 |
| Chotanagpur granite gneiss | Archeans             | Groundwater within weathered mantle and within secondary porosity zone of the consolidated part |
| Older metamorphic rocks    | Archeans             | Groundwater restricted to weathered unconsolidated zone   |

The methodology adopted in the present study is shown in Fig. 2.

## Results and discussion

### Geology

The area under investigation is a part of the Chotanagpur Plateau of the Jharkhand state, composed mainly of archaean gneiss and granitic rocks along with sandstone, shale, and limestone of Gondwana Age, and exhibits a complex geological setting of rock formations. The igneous and metamorphic terrain of Pre-cambrian age is juxtaposed against the coal bearing Gondwana formation of sedimentary origin.

Granite, granite gneiss, and granitoid gneiss, collectively known as the chotanagpur granite gneiss, are the predominant geology of the study area with major dominance in the western part of the study area. Sandstone and shale comprising the dominant sedimentary rock of the study area are found in the middle part of the region mainly in the Bishrampur and Chainpur block. Alluvium deposits in the middle part of the area are found along koel river and characteristically developed over meta sedimentary rocks. The various geological formations present in the study area are shown in Fig. 3.

Table 2 shows that major portion of the study area comprises of granite gneiss (present towards the western portion of the study area) and granitoid gneiss (of pre-cambrian age and present towards the eastern portion of the study area) which together cover an area of 1162 sq. km

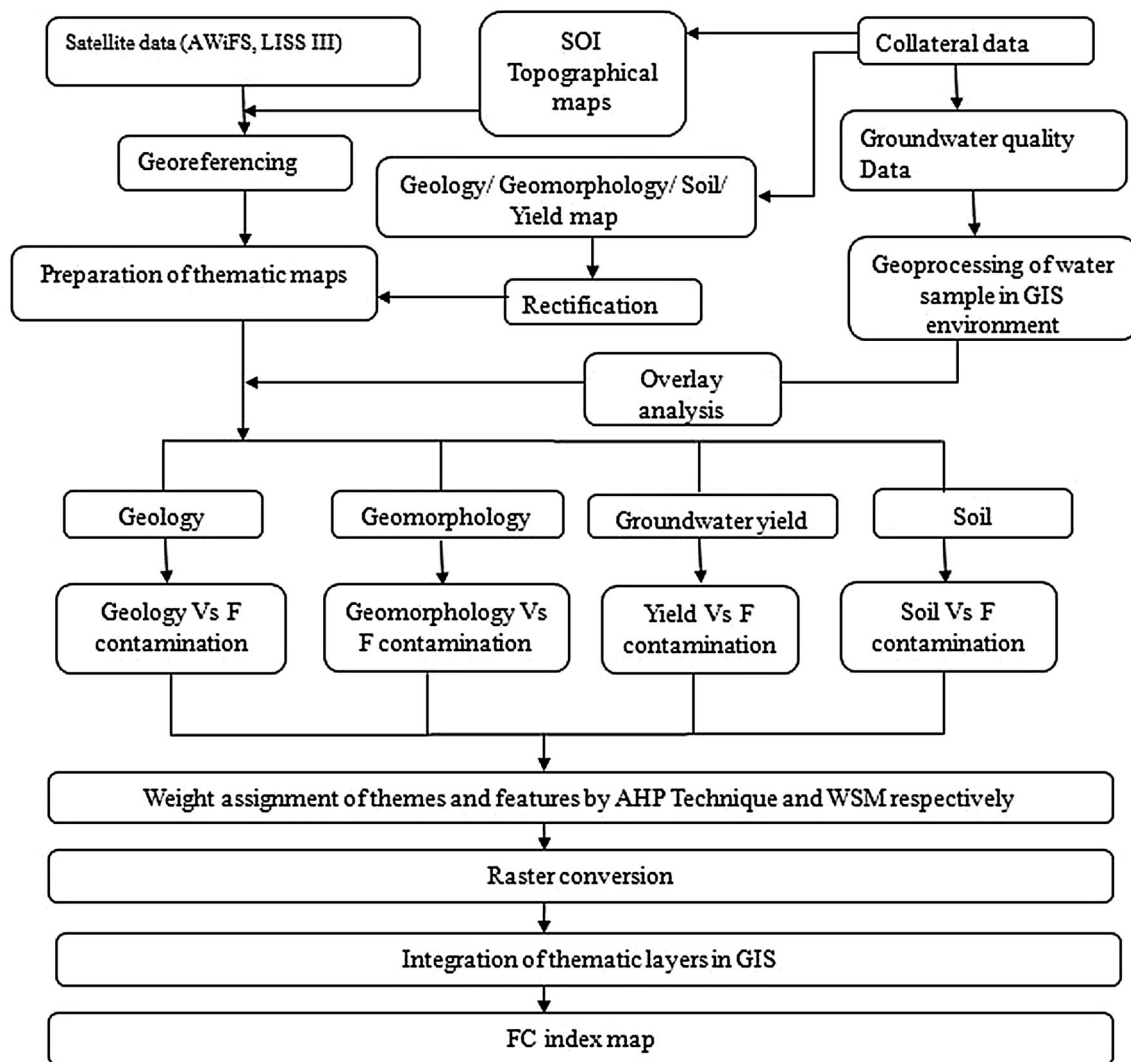
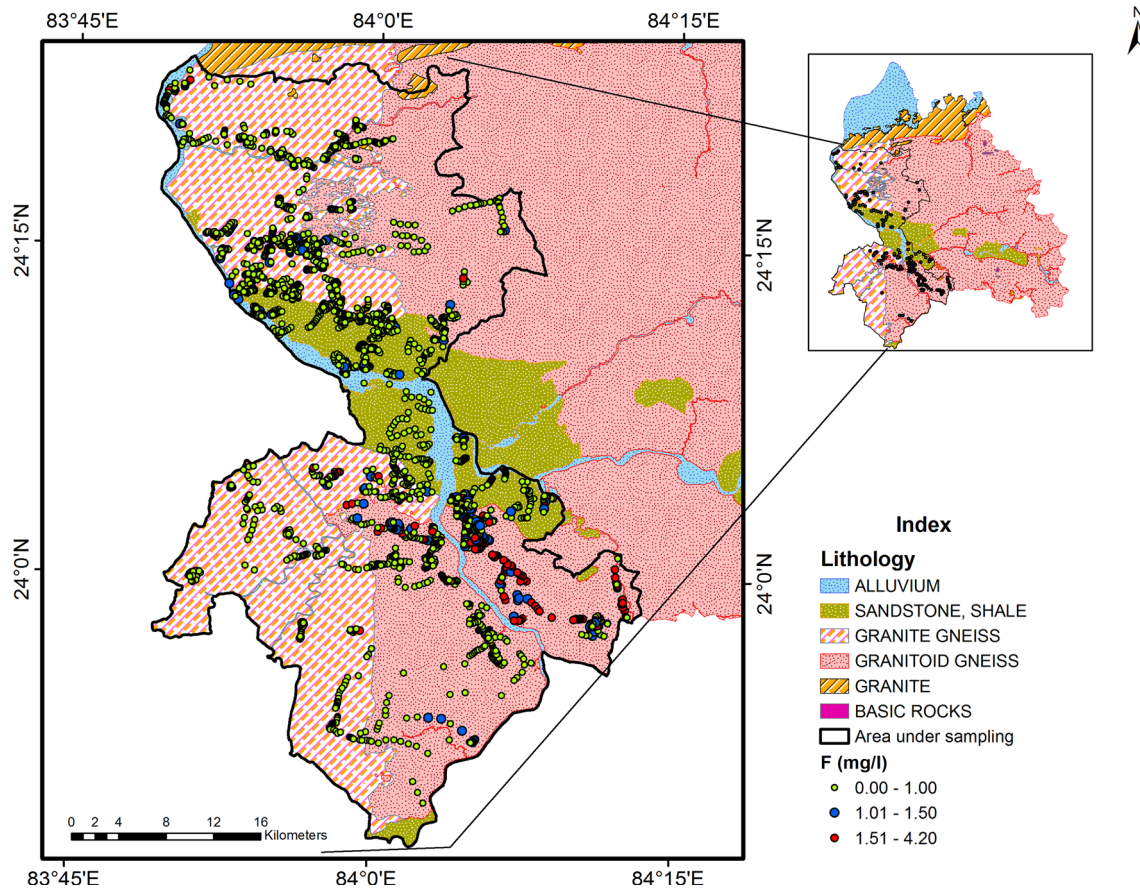


Fig. 2 Methodology flowchart



**Fig. 3** Geology v/s fluoride contamination

**Table 2** Area statistics and fluoride contamination in water samples with respect to various lithological units of the study area

| Lithological units       | Area (sq. km) | % of total study area | Total samples | P    | NP  | %NP  |
|--------------------------|---------------|-----------------------|---------------|------|-----|------|
| Granite gneiss           | 592.08        | 42.45                 | 1244          | 1032 | 713 | 68.9 |
| Granitoid gneiss         | 569.75        | 40.85                 | 922           | 650  | 272 | 41.8 |
| Sandstone, shale         | 150.31        | 10.78                 | 548           | 515  | 33  | 6.4  |
| Alluvium (clay dominant) | 75.12         | 5.38                  | 150           | 107  | 43  | 40.2 |
| Granite                  | 3.07          | 0.22                  | 0             | –    | –   | –    |
| Basic rocks              | 4.48          | 0.32                  | 0             | –    | –   | –    |

*P* permissible, *NP* non-permissible

which is 83.3% of the total study area. About 10.78% (150.3 sq. km) of the study area is covered by sandstone and shale in the central region, whereas granite is found covering an area of only 0.22% (3.07 sq. km). Alluvium (clay dominant) is located mainly in the vicinity of major rivers and covers an area of 75.12 sq. km which is 5.38% of the total study area. The highest concentration of fluoride is exhibited in granitoid gneiss (4.2 mg/l), whereas in granite gneiss, sandstone–shale, and alluvium, the maximum concentration is found to be 2.60, 1.90, and 1.76 mg/l, respectively.

### Geology v/s fluoride contamination

Based on spatial analysis of geology with fluoride contamination, it can be remarked that groundwater within granite gneiss (68.9%) exhibits high fluoride contamination followed by granitoid gneiss (41.8%) and alluvium (40.2%), whereas sandstone and shale represent lowest fluoride contamination (Table 2). Granite gneiss and granitoid gneiss together cover a major portion of the study area (83.3%). It is evident that this region is prone to harmful effects of fluoride, and hence, proper groundwater

management should be done in these regions to minimize its effect.

## Geomorphology

The geomorphology of an area has large control on land transformation in terms of setting up of industrial area and concomitant utilization of surface and subsurface water resources. The geomorphology map of the study area was prepared using LISS III satellite image through visual interpretation. Remote sensing provides an opportunity for better observation and analysis of various hydrogeomorphic features following the synoptic, multispectral repetitive coverage of the terrain (Horton 1945; Kumar and Srivastava 1991; Sharma and Jugran 1992). The various landforms delineated in the study area are classified as pediplain moderately weathered, pediplain shallow weathered, pediment–inselberg complex, flood plain, plateau weathered moderate, plateau weathered shallow, pediment, inselberg, alluvial plain, and river/waterbody/sand. Majority of the area is covered by pediplain shallow weathered (71.06%) and pediment–inselberg complex (28.98%), and pediplain moderately weathered, and together, they cover 78% of the total area (Table 3). The various geomorphological formations present in the study area are shown in Fig. 4.

Geomorphological unit represented by pediplain shallow weathered covers 549.07 sq. km (71.06%) and is located in the northern region of the study area with dominance of agricultural land and plantations (Fig. 4). Pediment–inselberg complex present in the northern and southern regions of the study area covers an area of 404.72 sq. km (28.98%), while pediplain moderate weathered is present in the central and parts of northern regions which constitutes an area of 300.20 sq. km (21.50% of the study area). About 0.65% of the study area is covered by alluvial plain and is located on nearly level slopes in the vicinity of river. A major river along with adjoining sand area covers

an area of 50.03 sq. km which is 3.58% of the study area. Pediment and plateau weathered moderate together covers an area of 13.06 sq. km and are present in parts of northern and southern regions of the study area, respectively. About 1.16 and 1.26% of the study area are covered by flood plain and valley fill moderate, respectively. Plateau weathered shallow located at few locations covers 0.87% (12.16 sq. km) of the study area.

## Geomorphology v/s fluoride contamination

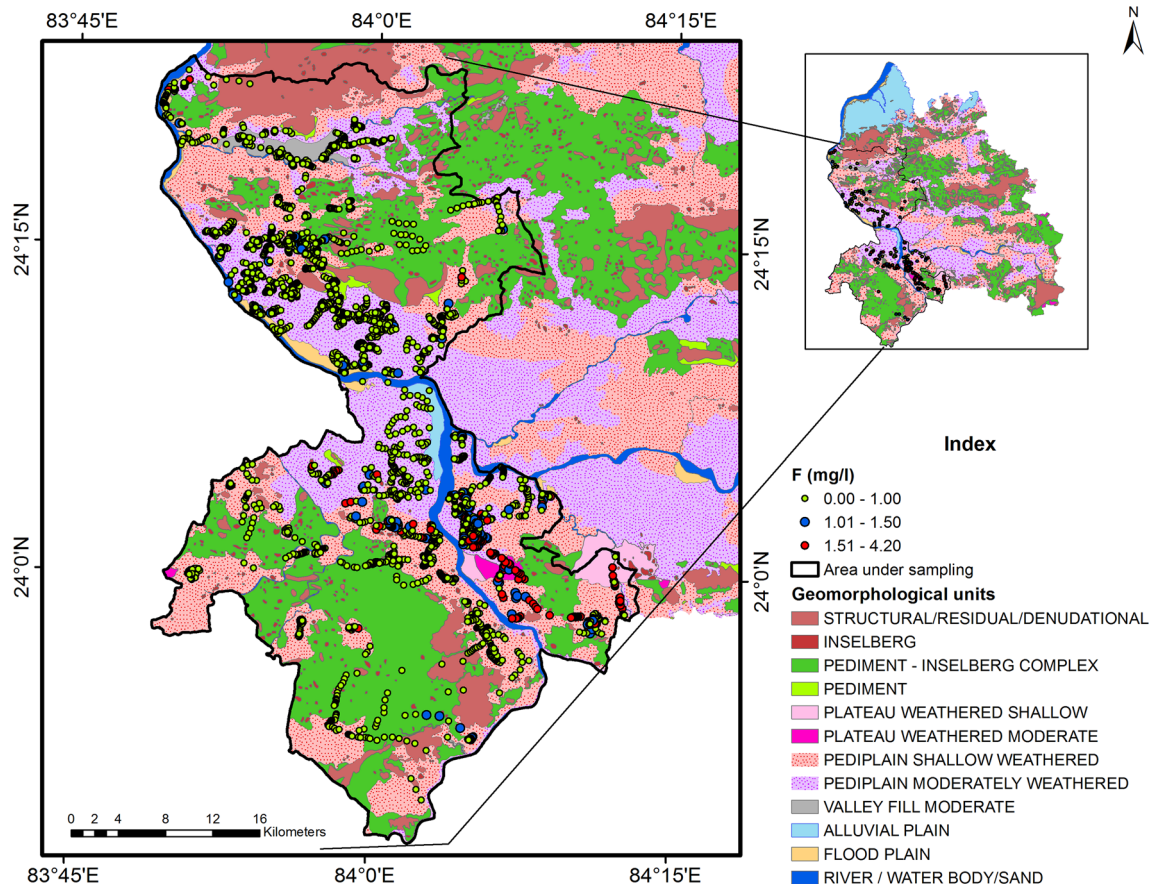
The spatial analysis of fluoride contamination in groundwater samples with reference to geomorphology is shown in Fig. 4. The ground water samples were collected from various geomorphological units, and out of 2864 samples, 988 samples are from pediplain shallow weathered, 158 from pediment–inselberg complex, 1437 from pediplain moderately weathered, 54 from river/water body/sand, 11 from inselberg, 89 from valley fill moderate, 91 from flood plain, and remaining 36 from alluvial plain, pediment, and plateau weathered moderate. The analysis revealed that highest  $F^-$  contamination was recorded in plateau weathered moderate (91.67%) in which out of the total 12 samples, 11 samples were non-permissible followed by plateau weathered shallow (71.43%), and flood Plain moderate (41.76%), while pediplain shallow weathered, pediment–inselberg complex, pediplain moderate weathered, inselberg, and pediment have 22.57, 22.15, 16.35, 27.27, and 25% of NP fluoride in groundwater, respectively. The rest of the landforms, viz., river/water body/sand and valley fill moderate, have less percentage of NP fluoride (Table 3).

## Groundwater yield

The well-yield data provide a measure of actual ground water potential that can be derived from an aquifer in terms of liter per minute (lpm) water output from a tube well.

**Table 3** Area statistics and fluoride contamination in water samples with respect to various geomorphological units of the study area

| Geomorphological units                  | Area (sq. km) | % of total study area | Total samples | P    | NP  | %NP   |
|---|---------------|-----------------------|---------------|------|-----|-------|
| Pediplain shallow weathered (<5 m)      | 549.07        | 71.06                 | 988           | 765  | 223 | 22.57 |
| Pediment–inselberg complex              | 404.72        | 28.98                 | 158           | 123  | 35  | 22.15 |
| Pediplain moderately weathered (5–20 m) | 300.20        | 21.50                 | 1437          | 1202 | 235 | 16.35 |
| River                                   | 50.03         | 3.58                  | 54            | 49   | 5   | 9.26  |
| Inselberg                               | 24.63         | 1.76                  | 11            | 8    | 3   | 27.27 |
| Valley fill moderate (5–20 m)           | 17.56         | 1.26                  | 89            | 87   | 2   | 2.25  |
| Flood plain                             | 16.15         | 1.16                  | 91            | 53   | 38  | 41.76 |
| Plateau weathered shallow (<5 m)        | 12.16         | 0.87                  | 7             | 2    | 5   | 71.43 |
| Alluvial plain                          | 9.04          | 0.65                  | 5             | 5    | 0   | 0     |
| Pediment                                | 6.90          | 0.49                  | 12            | 9    | 3   | 25.0  |
| Plateau weathered moderate (5–20 m)     | 6.16          | 0.44                  | 12            | 1    | 11  | 91.67 |



**Fig. 4** Geomorphology v/s fluoride contamination

Most of the groundwater samples were collected from the region having aquifer depth between 30 to 80 m and groundwater yield between 10 and 400 lpm (Fig. 5).

Majority (53.5%) of the study area exhibits groundwater yield between 50 and 200 lpm within the depth range of 30–80 m having NP fluoride content of 39.1% which are present in the central region of the study area in the vicinity of river. Thus, the central region should be given more attention for groundwater management as more people will be affected with fluorosis as major population reside in that region. The major town in this region is Daltonganj which is a highly populated urban area, and hence, water treatment and other steps should be taken in this direction. Low yield (10–50 lpm) occurring at depth greater than 80 m with NP fluoride content of 31.47% also covers large area in the northern and southern regions.

#### Groundwater yield v/s fluoride contamination

The spatial analysis of groundwater yield with fluoride contamination (Fig. 5; Table 4) revealed that highest proportion of fluoride (39.6%) persist at shallow depth within very high yield aquifer (200–400 lpm), whereas at deeper aquifer (>80 m) giving yield of 10–50 lpm, high

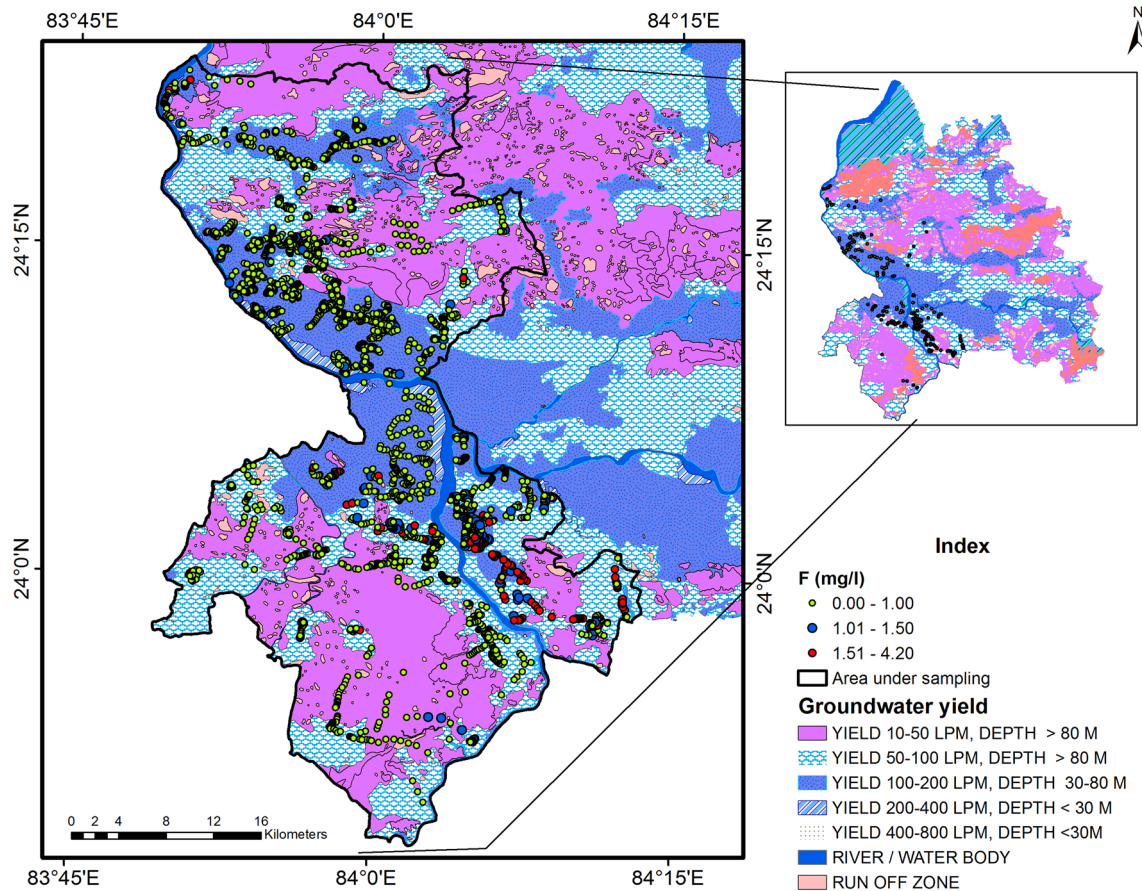
percentage of fluoride (31.47%) persist. The overall high fluoride percentage could be attributed to yield of aquifer with high mobility in shallow aquifer mostly found over soft weathered sediments. The percent of NP fluorides within various groundwater yield units are shown in Table 4.

#### Soil

In plateau region as in the present geomorphic setting, soil gets developed primarily due to in situ weathering of rock present in the area. Therefore, the characteristic of soil, mainly their chemical composition is influenced by the geochemistry of their parent rock type.

The distribution of different soils and their association in terms of their taxonomy along with their composite statistics are shown in Fig. 6 and Table 5, respectively. The map shows that fine typic paleustalfs and loamy lithic haplustalfs comprise majority of the study area covering an area of 664.47 sq. km (47.57%) and 410.01 sq. km (29.36%), respectively. The fine typic paleustalfs and fine-loamy soil is present in the northern, southern, and central regions of the study area, respectively, whereas the coarse loamy and loamy soil covering an area of 129.35 and





**Fig. 5** Groundwater yield v/s fluoride contamination

**Table 4** Area statistics and fluoride contamination in water samples with respect to various groundwater yield units of the study area

| Groundwater yield                | Area (sq. km) | % of total study area | Total samples | P    | NP  | %NP   |
|----------------------------------|---------------|-----------------------|---------------|------|-----|-------|
| Yield 200–400 lpm, depth <30 m   | 25.19         | 1.80                  | 96            | 58   | 38  | 39.6  |
| Yield 100–200 lpm, depth 30–80 m | 322.71        | 23.11                 | 1519          | 1272 | 247 | 16.3  |
| Yield 50–100 lpm, depth 30–80 m  | 424.70        | 30.41                 | 975           | 753  | 222 | 22.8  |
| Yield 10–50 lpm, depth >80 m     | 520.82        | 37.29                 | 197           | 135  | 62  | 31.47 |
| Run-off zone                     | 53.15         | 3.81                  | 23            | 16   | 7   | 30.4  |
| River                            | 50.02         | 3.58                  | 54            | 49   | 5   | 9.3   |

410.01 sq. km, respectively, are present in the northern and southern regions of the study area (Table 5).

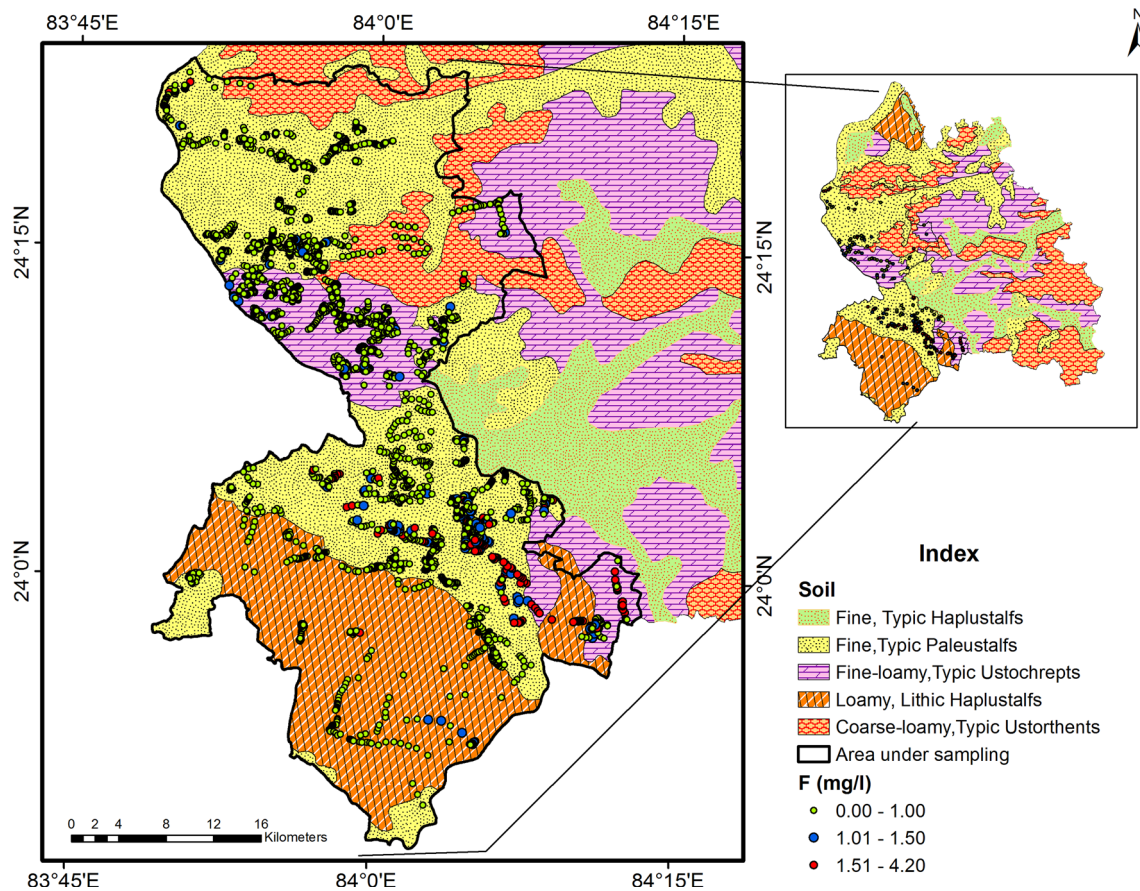
**Soil v/s fluoride contamination**

The fluoride contamination analysis carried on soil reveals that the area dominated by fine typic paleustalfs and loamy lithic haplustalfs has less percent of NP fluoride in groundwater (19.7 and 10.9% NP fluoride) and can be utilized for industrial purpose. Although the coarse loamy and fine-loamy soil covers lesser portion of the study area,

but they are found to be highly contaminated having 44.9 and 36.7% NP fluoride content in groundwater.

*Delineation of fluoride contamination (FC) zones*

The fluoride contamination index map obtained after spatial overlay of the themes showed that the minimum and maximum values lie in the range 141–707 which was divided into four classes of low, moderate, high, and very high, as shown in Fig. 7. The FC index map shows that about 49.31 and 0.44% of the study area lie between high



**Fig. 6** Soil v/s fluoride contamination

**Table 5** Area statistics and fluoride contamination in water samples with respect to various soil units of the study area

| Soil Taxonomy                   | Area (sq. km) | % of total study area | Total samples | P    | NP  | %NP  |
|---------------------------------|---------------|-----------------------|---------------|------|-----|------|
| Coarse loamy, typic ustorthents | 129.35        | 9.26                  | 49            | 27   | 22  | 44.9 |
| Fine, typic paleustalfs         | 664.47        | 47.57                 | 1853          | 1488 | 365 | 19.7 |
| Fine-loamy, typic ustochrepts   | 192.76        | 13.80                 | 265           | 600  | 97  | 36.7 |
| Loamy, lithic haplustalfs       | 410.01        | 29.36                 | 697           | 189  | 76  | 10.9 |

risk to very high risk of groundwater fluoride contamination, and the remaining 13.84 and 36.41% area is occupied by low-to-moderate level of groundwater fluoride contamination (Table 6).

The very high fluoride contamination zones are present in parts of south-eastern and south-western regions of the study area covering an area of 6.15 sq. km. The very high contamination may be due to the underlying granitic rocks which have high fluoride content; thus, the leaching of granitic rocks rich in fluoride results in elevated fluoride in groundwater (Brindha and Elango 2013). The presence of geomorphological feature plateau weathered moderate may be responsible for this region to have high FC index where high fluoride was recorded (91.67% of NP fluoride content).

The naturally occurring fluorides in groundwater are a result of the dissolution of fluoride containing rock minerals by water, while artificially high soil fluoride levels can occur through contamination by application of phosphate fertilizers, sewage sludge, or pesticides (EPA 1997). The longer residence time of water in the aquifer zone, caused by a high rate of evapotranspiration and a weathered zone of low hydraulic conductivity, are the supplementary factors that activate the dissolution of fluorine-bearing minerals to further increase  $F^-$  content in the groundwater (Shaji et al. 2007). Moreover, the very high contamination zone falls in the region where groundwater yield has high fluoride content, viz., yield 100–200 lpm with 16.3% NP fluoride and covers 322.27 sq. km which is

Fig. 7 FC index map

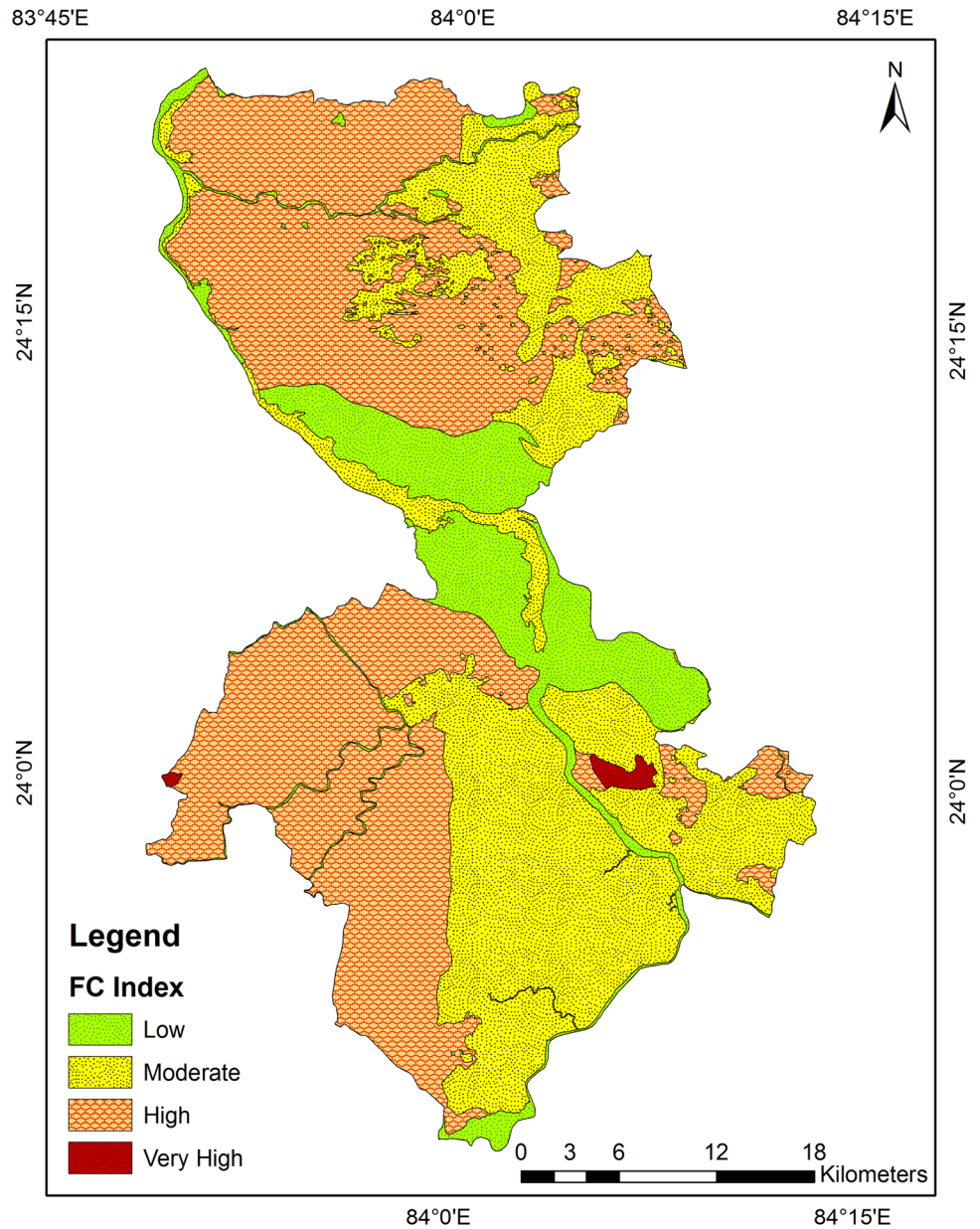


Table 6 Area statistics of the various ranges of FC index

| FC index range        | Area (sq. km) | % area |
|-----------------------|---------------|--------|
| 141–282.5 (low)       | 193.27        | 13.84  |
| 282.6–424 (moderate)  | 508.47        | 36.41  |
| 424.1–565.5 (high)    | 688.68        | 49.31  |
| 565.6–707 (very high) | 6.15          | 0.44   |

23.11% of the study area. As the highly contaminated region has good groundwater yield, it means that greater population is vulnerable to fluorosis (WHO 2004).

The high fluoride contamination zone covers the maximum portion of the study area with an area of 688.68 sq. km which is 49.31% of the entire study area and is present

predominantly in the northern, south-western, and parts of south-eastern and north-eastern regions. The FC index lies in the range 424.1–565.5. This is also a granitic terrain having high fluoride content and is dominated by the geomorphological landforms plateau weathered shallow, pediment—inselberg complex, pediplain moderately weathered, pediplain shallow weathered, inselberg, and valley fill moderate which have high fluoride content, viz., 71.43, 22.15, and 16.35 and 22.57, 27.27, and 2.25% of NP fluoride, respectively. The soil type falling under the high fluoride contamination zone is coarse loamy which is highly permeable and hence helps in easy infiltration of fluoride to the deeper aquifers which easily contaminates the groundwater.

Fluoride is a mobile ion and its retention in the soil depends on the amount and rate of water percolating into the soil zone which depends on the permeability of the soil. High permeability leads to high water content infiltration, thus causing the ion to move deeper into the water table where it is retained (Abugri and Pelig-Ba 2011). The groundwater yield of the region within this zone lies between 10 and 50, 50–100, and 100–200 lpm with NP fluoride content of 22.4, 22.8, and 16.3% of NP fluoride, respectively. The moderately fluoride contaminated zones are present in the south-eastern and north-eastern regions covering an area of 508.47 sq. km which is 36.41% of the study area. This zone comprises mainly of landforms pediment–inselberg complex and pediplain shallow weathered having 22.15 and 22.57% NP fluoride content. The flood plains, pediplain moderate weathered, and inselberg are also present in some parts of the moderate contaminated zone in the northern and southern regions which also contributes to the groundwater contamination as they exhibit 41.76, 16.35, and 27.27% NP fluoride, respectively. The fine and loamy type of soil mostly dominates this zone, whereas the NP fluoride zones with groundwater yield of 10–50, 50–100, and 100–200 lpm also fall under this region having high fluoride. The runoff zone covering an area of 53.08 sq. km with 30.4% of NP fluoride content is also present within this zone. The low fluoride contamination zone is present in the central region of the study area covering an area of 193.27 sq. km which is 13.84% of the study area. Sandstone and shale are the main geology of this zone with pediplain moderate weathered comprising the major landform of this zone.

The study showed that Daltonganj and a portion of the Chainpur block were found to be contaminated with very high percentage of fluoride. Hence, Daltonganj being a major and highly populated urban city of the Palamu district should be given more attention to elucidate the harmful effects of fluoride. Thus, the present study indicates the regular monitoring of groundwater to avoid human health risks and to assess its quality for various ecological purposes; in addition, the proper management practices are required for sustainable use of groundwater in the agriculture-dominated region of Daltonganj.

## Conclusion

The present study helped in delineating the regions having excessive fluoride contamination in the four blocks of Palamu district, viz., Daltonganj, Bishrampur, Chainpur, and Pandu, using AHP and WSM in GIS platform. The fluoride contamination index map was obtained to determine the zones having high fluoride underlain by hard granitic terrain.

The results revealed that groundwater in the study area in larger part is under moderate-to-high fluoride contamination. The fluoride contamination zones were classified into four types, viz., low, moderate, high, and very high. The study showed that geology and geomorphology have large impact on the fluoride contamination of the region and the high contamination may be due to the underlying granitic rocks which have high fluoride content, and hence, the leaching of granitic rocks rich in fluoride results in elevated fluoride in groundwater.

The southern portion of the Daltonganj block has high fluoride content, and as this region has good groundwater yield (100–200 lpm), it means that greater population are vulnerable to fluorosis. This is a major cause of concern as the Daltonganj region is prone to drought and high fluoride contamination will highly affect the availability of fresh drinking water. The study produced a valuable map for town planners and groundwater management personnel, because it gives a very comprehensive indication of regions having high fluoride contamination.

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