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Development of web enabled water resource information system using open source software for Patiala and SAS Nagar districts of Punjab, India

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ABSTRACT

Over the globe, efforts are being made to collect data and develop an adequate water resource information system for optimising its use. India is the largest consumer of water, with an estimated usage of around 300 cubic kilometers per year. Punjab, a north-western state of India, is an example of severe crises aquifer depletion due to unconstrained consumption of groundwater, leading to degradation of its quantity as well as quality. Thus it is of great importance to compile up-to-date information about the water requirement for its appropriate and sustainable use. Remote sensing and geographic information system (GIS) are the technologies that can provide efficient and effective information system to tackle the water quality & water supply planning parameters. Thus, under the present study, a web-enabled water resource information system has been developed in the GIS environment for the SAS (Sahibzada Ajit Singh) Nagar and Patiala districts of Punjab by using the open source software MS4W and pmapper. This system provides digital information of natural, such as drainage, and man-made features like roads, canals, and tube wells with their location and so on, and also provide information related to water level, water quality of wells, and well depth for the study area. Such an information system can be very helpful for the administrators and can serve as a decision support system for planners and policy makers so that the areas where problems related to water quality can be identified and focused upon. The system can provide an effective and meaningful direction for the planning and development of both districts.

Key words: GIS, water resource, web enabled

HIGHLIGHTS

- Open source web-enabled water resource information system.
- This system will help to monitor the water quality.

INTRODUCTION

The natural resources, mainly fresh water, on our earth are facing pressure with rapid population growth and rising expectation for a better life, and India is no exception. Surface water and groundwater resources are being polluted, due in part to untreated sewage, and climate change is threatening to alter the timing of water supply, which could lead to increased floods and droughts. As water is a vital component for nearly every aspect of our society, including agriculture, industry, drinking, and energy production, its management is of paramount importance. In particular, the management of water resources has a profound impact on society with regard to quality of life. Water management decisions can have environmental, physical, social and economic impacts that are widespread and pervasive. The water resources of India are being examined in the context of the growing population and the national ambition to become and be seen as a developed nation (Gupta & Deshpande 2004). The vast population and ever-increasing industrial activities in India make its water resources more vulnerable to water quality deterioration (Singh 2009) and water scarcity problems. The agriculture sector is the single largest consumer of water in India, and estimates by the Ministry of Water Resources indicate that by the year 2050 irrigation needs will rise by 56 per cent. At the same time, India's drinking water demand will double and India will also have to increase water supplies to industries fivefold and supply 16 times more water for energy. While demand for water is expected to increase, supplies may be falling. Per capita surface water availability has already slumped from 2,309 m^3 in 1991 to 1,902 m^3 in 2001 and is projected to fall to 1,401 m^3 in 2025 and 1,191 m^3 by 2050 (Sharma & Bharat 2009). Additionally, there is unprecedented urbanization which is greatly energy and water intensive. The country is the biggest consumer of groundwater in the world, with an estimated usage of around 230 cubic kilometers per year, more than a quarter of the global total (World Bank 2010) and more than 60 per cent of irrigated agriculture and 85 per cent of drinking water supplies dependent on it (Clifton *et al.* 2010). As per the latest estimation of the Central Ground Water Board (CGWB), the annual groundwater extraction in Punjab state is 35.78 BCM (billion cubic metres); of this, 34.56 BCM is for agriculture and the rest is used for other purposes (CGWB report, 2017). In view of the emerging water issues, an accurate quantitative and qualitative assessment of water resource is extremely important. The quantitative assessment considers all aspects of inflows and outflows of a catchment. It often becomes a challenging task in poorly gauged mountainous catchments because of the difficulties in understanding the distribution of water quantity in space and time (Littlewood *et al.* 2003). Characterizing the heterogeneity and temporal change of water quality across surface waters is difficult through conventional sampling methodologies (Tyler *et al.* 2006). *In situ* measurements and collection of water samples for subsequent laboratory analyses provide accurate measurements for a point in time and space, but do not give either the spatial or temporal view of water quality needed for accurate assessment or management of water bodies (Schmugge *et al.* 2002). Water resource assessment and management are inherently geographical activities requiring the handling of multiple forms of spatial data, and life is literally dependent on our ability to match the supply and demand of water of appropriate quality to specific communities and users at specific times or rates.

India is exploring and developing new ways to manage and sustain water resources to meet the demand for diverse uses. In the knowledge-driven society, information tools can help bring in sustenance through the availability of updated information on the quantity and quality of this resource. The water resource information system will act as a single-window solution for all water resources and can provide a clear understanding of the status and trends of the water resources and related data (ISRO 2009). However, it requires handling of multiple forms of spatial and temporal data. The geospatial technology has emerged strongly with diverse applications, as it provides unbiased, reliable, repetitive and synoptic data as well as tools for integration of information for analysis (Sharma & Jaglan 2012). The GIS technologies provide the spatial database for regular monitoring of the various parameters, for generation of thematic maps as well as analysis of temporal changes in them. Even in poorly gauged catchments, use of geographical information system and remotely sensed data analysis tools has been found to be effective for investigating practical problems and for detecting important features of water resources (Shrestha *et al.* 2004). Open Source Web GIS software systems have been increasingly put to use because the open source tools provide the functionality equivalent to that of proprietary web GIS products. There are many technologies and open source software to create a web GIS application such as Geo-server, Geomoose, Map Server, Map Builder, Open Layers, and so on. There is a growing need for web-based geographic information systems for easy and fast dissemination, sharing, displaying and processing of spatial information. The development of a geospatial web portal was proposed to be the best solution to Hydrological Information and Data Management (Nagraj & Gosain 2013). The use of free and open source GIS (geographic information systems) tools is increasing day by day. The technical features provided by the open source software are comparable to their proprietary peers.

In the context of Punjab State, the major concern in respect to groundwater is the overall decline in the water level as well as degradation of water quality. It is apprehended that the declining groundwater trend will further aggravate with installation of more tube wells. The information system can be used as a baseline for retrieval of quick information and can be useful for developing measures to regulate the construction of all groundwater abstraction structures in critical and semi-critical blocks as well as determine the water quality. The study was therefore undertaken to develop a web GIS-based information system with special reference to drinking water quality for two districts of the State.

STUDY AREA

Two districts, SAS Nagar and Patiala, were selected for the development of application due to availability of spatial and non-spatial data (Figure 1). The SAS Nagar and Patiala districts lie in south-east of the Punjab state. The SAS Nagar district is bounded by Patiala and Fatehgarh Sahib District in the south-west, Rupnagar in the north-west, Chandigarh and Panchkula in the east and Ambala district of Haryana in the south. Administratively, SAS Nagar is divided into three tehsils; that is, Derabassi, Kharar and Mohali, comprised of three development blocks. The Patiala district is divided into five sub-divisions (tehsils) namely Patiala, Samana,

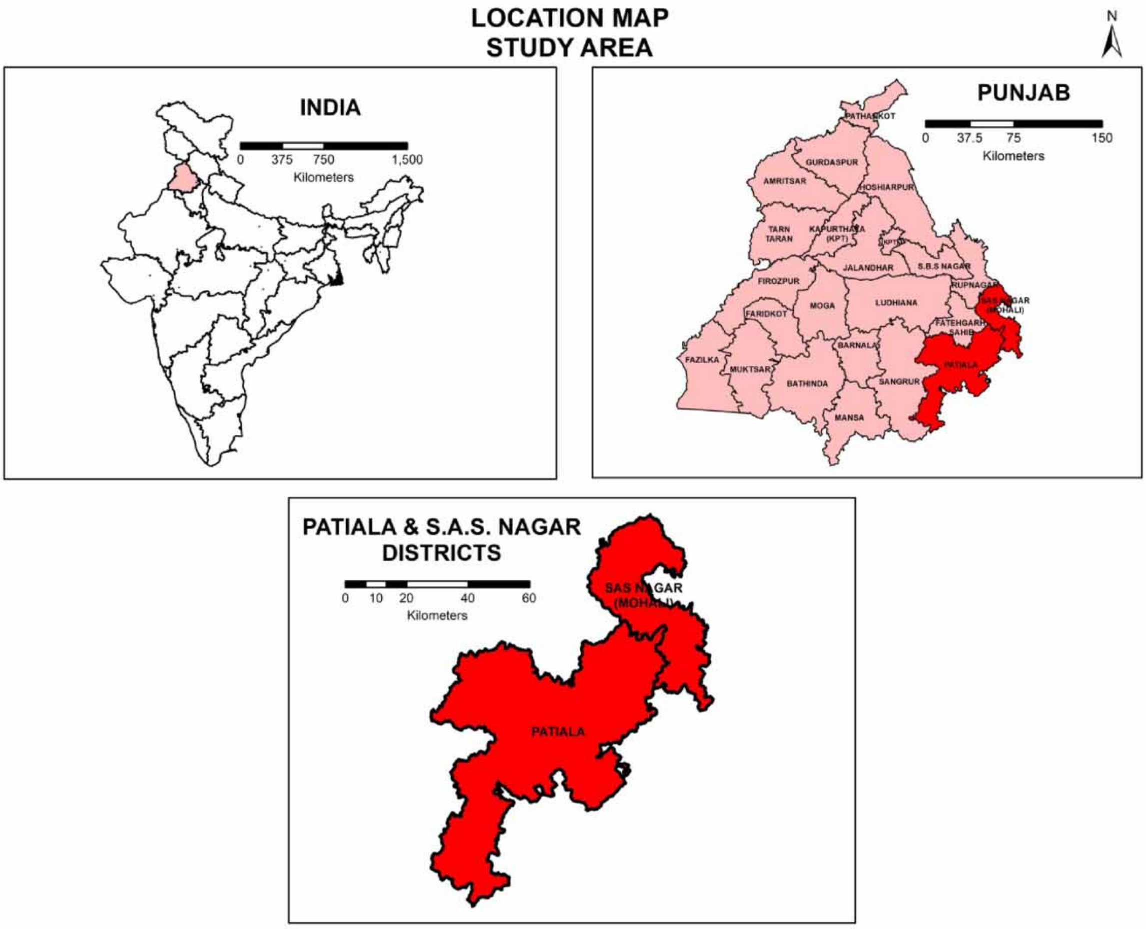

Figure 1 | Location of the study area.

Nabha, Rajpura and Ghanaur comprised of eight community development blocks; that is, Patiala, Sanaur, Nabha, Bhunerheri, Rajpura, Ghanaur, Samana and Patran, for the purpose of administration. Most of the region consists of plains in the form of agricultural land, some part of it having industries, which depend on groundwater. A subtropical continental monsoon climate is characterized by seasonal rhythm: hot summers, cold winters, erratic rainfall and high temperature fluctuations have been observed in the study area.

DATA USED

Survey of India (SOI) Toposheets

Survey of India (SOI) Toposheets covering the study area of SAS Nagar are 53B/09, 53B/10, 53B/13, 53B/14 and 53B/15 at 1:50,000 scale and Survey of India (SOI), whereas the toposheets covering the study area of Patiala are 53B/02, 53B/03, 53B/04, 53B/06, 53B/07, 53B/08, 53B/10, 53B/11, 53B/12 and 53C/01 at 1:50,000 scale. These maps were used for mapping the transport network and annotation of cities, towns and village settlements.

Satellite data

The satellite imagery of IRS LISS-III (Linear Imaging Self-scanning Sensor) digital satellite (Table 1), were collected from Punjab Remote Sensing Centre, for the study area of districts SAS Nagar and Patiala.

MATERIALS AND METHODS

The following flowchart describes the methodology used for the development of the village information system for SAS Nagar and Patiala districts (Figure 2).

Table 1 | Satellite data of SAS Nagar and Patiala districts

Satellite	Sensor	Spatial resolution	Swath	Format	Temporal resolution	No. of spectral bands	Month/year of data
Resource sat	LISS-III	23.5 m	141 km	Tiff/Imagine	24 days	4	2007-08

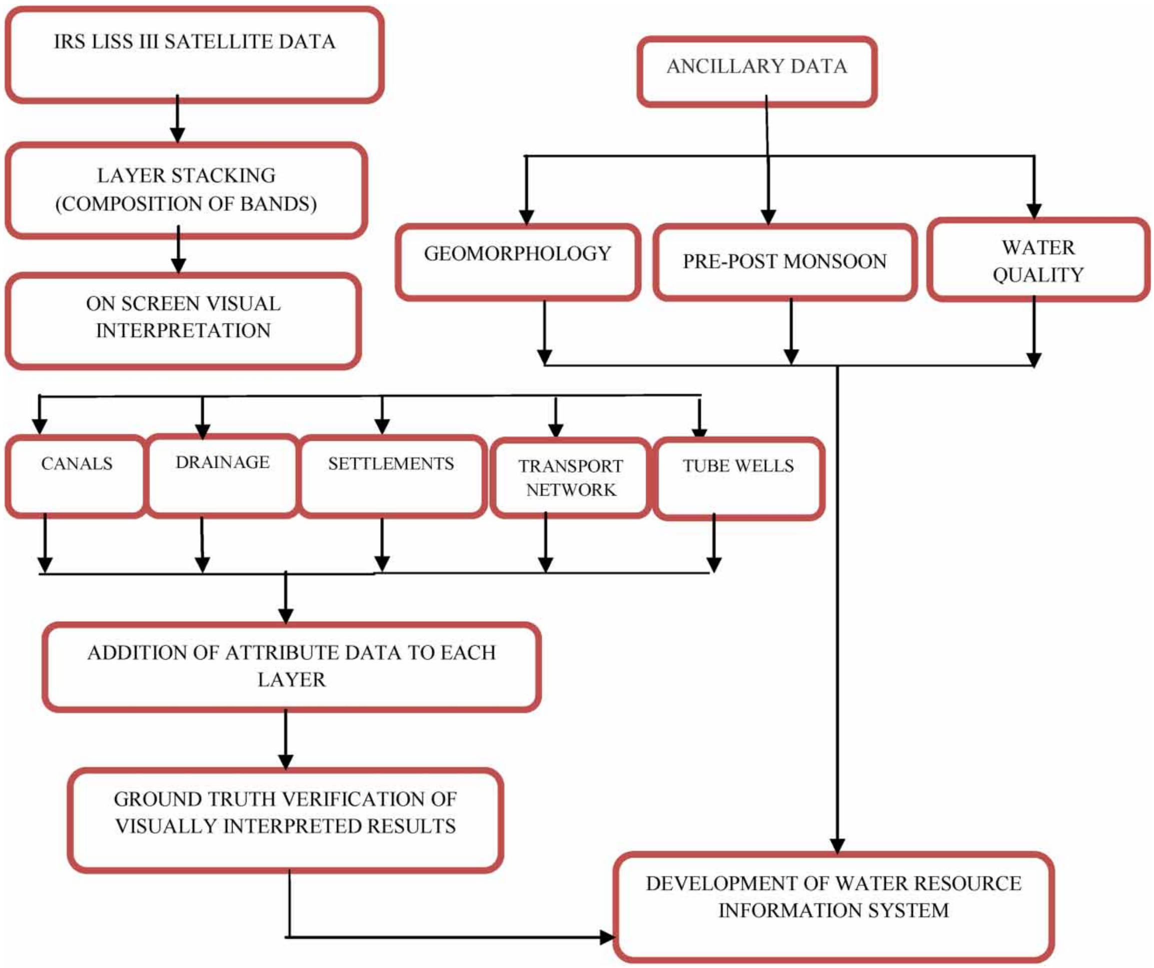

Figure 2 | Flowchart of methodology.

Generation of maps from the geospatial data

LISS-III digital satellite data comprises four spectral bands: MIR (Mid Infrared), NIR (Near Infrared), R (Red) and G (Green). A stack of four bands was prepared to generate a single composite band image for the scene, covering the districts of SAS Nagar and Patiala (Figure 3). The composition of bands was done by using the raster processing tools of the software ArcGIS 10.

The generated composite band image was used to extract the geospatial data of SAS Nagar and Patiala districts, by 'on screen visual interpretation'. The different visual interpretation elements (color, tone, texture, shape, size, association and location) were used to identify various features from the satellite imagery. The settlements, canal network, drainage, and transport network were digitized and saved in a geo-database. Canal network, drainage and transport network layers were digitized as 'line' feature classes and settlements were digitized as a 'polygon' layer. Road network contains the whole road network of the district. Roads were further classified as National Highway, State Highway, District road and other road (Figure 4(a)). Canals are further classified into Main canal, Branch canal, Distributaries canal and other minor canals (Figure 4(b)). Drainage feature class contains

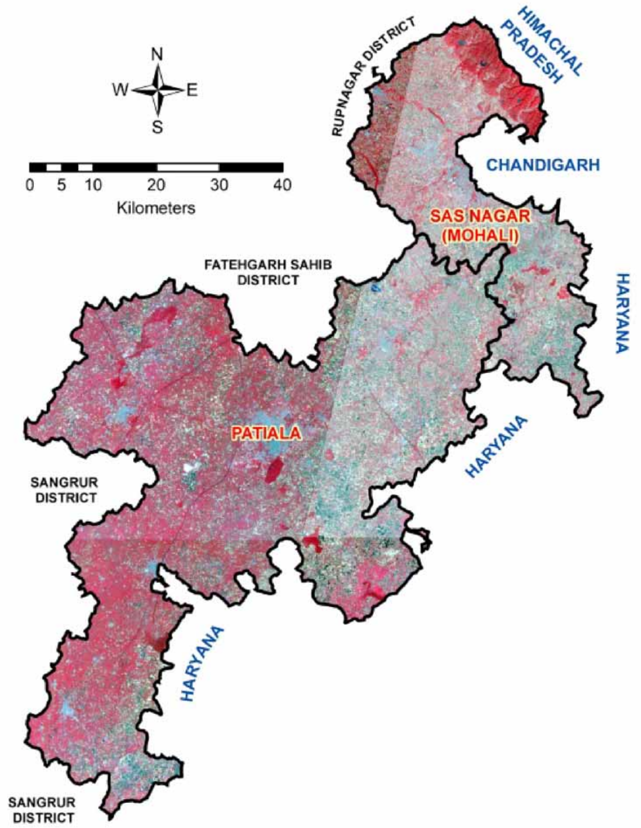

Figure 3 | LISS III image of the SAS Nagar and Patiala districts.

all the river and drains of both districts (Figure 5(a)). The information regarding the tube wells/observation wells was obtained from CGWB and Department of Agriculture, Punjab. The location of the tube wells for both the districts was categorised based on depths of the wells (Figure 5(b)) in the ArcGIS domain. The water samples were collected in 287 villages in SAS Nagar and 486 villages in Patiala district. Due to the increasing population, agriculture, and industry, the pressure on the wells' water has been increased in the study area.

This was followed by editing, and post-digitization operations like correction of topological errors were done to finalize the digitized five layers. In this, the topology for all five layers was generated to check for any errors, such as dangling lines in the case of line layers and overlapping polygons in the case of polygon layers. The topological errors reported by the error inspector were corrected. Finally, attribute data (about the name and category of a particular feature) related to all the five layers was added into the attribute table of the corresponding layer.

A field survey was carried out to verify the visual interpretation results. A number of sites were visited, corresponding to different categories of settlements. The location of these sites was recorded with the help of Global Positioning System (GPS) and the field photographs were taken.

Water quality mapping

Water availability depends on its quantity and quality, its improper use deteriorates water quality. The water samples were collected from the tube wells of SAS Nagar (287 villages) and Patiala district (486 villages) (Figure 5(a) and 5(b)). These samples were analysed for various water quality parameters like pH, TDS (Total Dissolved Solids), total hardness, total alkalinity, chloride, sulphate, nitrate, calcium, magnesium, fluoride, and iron using standard methods prescribed by American Public Health Association (APHA 2005). This analysis was done for gathering the information of water quality for irrigation and drinking purposes of the study area. The geo-database was prepared based on each individual parameter attached with the district boundary.

Development of web enabled water resource information system

Open source tools viz. MS4 W version 3.1.0' (Map Server 4 Windows) package containing default installations of: Apache 2.2.24 HTTP Server, PHP 5.4.14, Map Server CGI 6.2.1 etc. 'Pmapper version 4.3.2 was

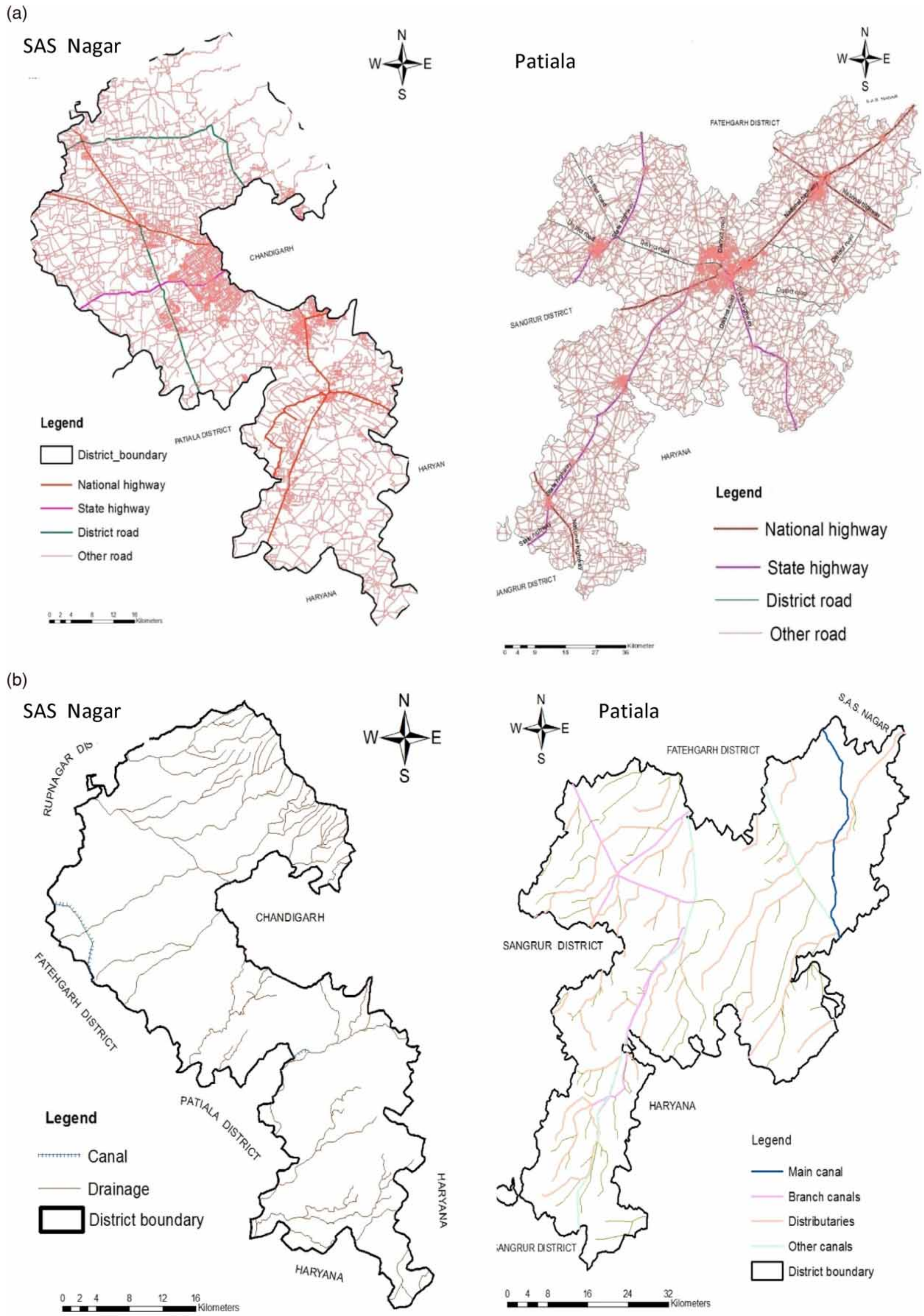

Figure 4 | (a) Transportation and (b) canal network of SAS Nagar and Patiala district.

installed in the windows platform computer. Apache 2.2.24 HTTP Server is open source software which acts as a web server for the Windows computer. Pmapper was used to define the Graphical User Interface (GUI) of the application.

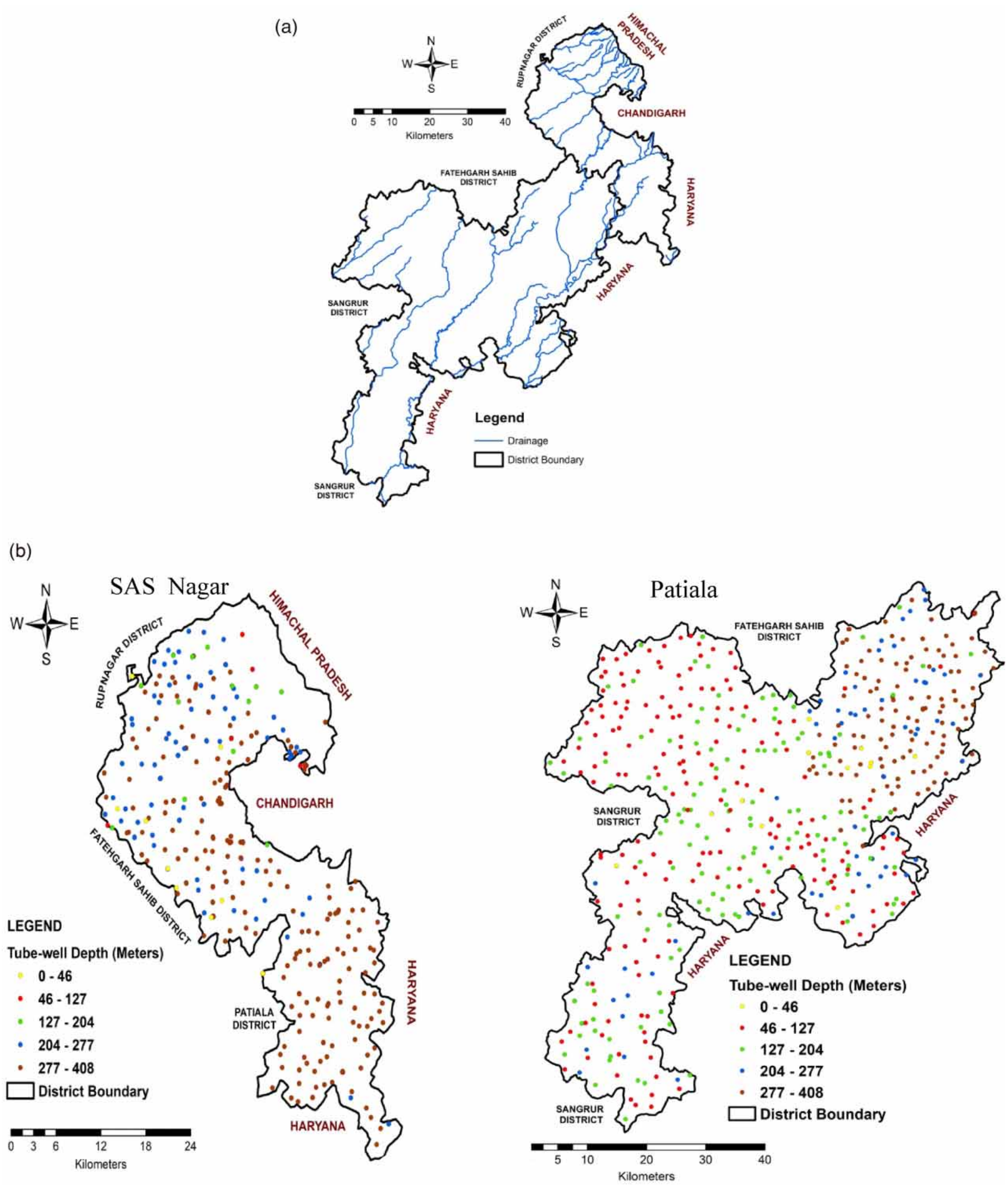

Figure 5 | (a) Drainage network and (b) observation well and piezometer location of SAS Nagar and Patiala district.

RESULTS AND DISCUSSION

Water quality mapping of SAS Nagar and Patiala district

Different water quality parameters like pH, TDS (Total Dissolved Solids), total hardness, total alkalinity, chloride, sulphate, nitrate, calcium, magnesium, fluoride and iron were tested to identify vulnerable locations. The data interpretation of water quality parameters has been done as per Indian standard code 10500-1991 (BIS specification 2010). The results of different parameters in both the districts are summarized in Table 2.

In most of the villages in Patiala district, fluoride concentration was much higher than the permissible limit. Its presence in water may be due to the various discharge sources like industrial waste, geological materials (rocks and sediments) and can be treated using distillation, reverse osmosis and so on. It can cause brownish discoloration of teeth, and bone damage in the case of humans. Iron and fluoride concentrations was higher in 9 villages of SAS Nagar. In Patiala, more than 80% of the villages had fluoride concentration more than the permissible

Table 2 | Number of villages under different water quality categorization

	Parameter limits	SAS Nagar			Patiala		
		1[a]	2[b]	3[c]	1[a]	2[b]	3[c]
pH	Acceptable = 6.5–8.5	262			446	–	37
TDS (Total Dissolved Solids)	Acceptable <500 mg/L Permissible up to 2,000 mg/L	276	11	–	219	263	1
Total hardness	Acceptable <300 mg/L Permissible up to 600 mg/L	193	94	–	297	185	1
Total alkalinity	Acceptable <200 mg/L Permissible up to 600 mg/L	4	283	–	291	263	1
Calcium	Acceptable <75 mg/L Permissible up to 200 mg/L	280	7	–	477	6	–
Magnesium	Acceptable <75 mg/L Permissible up to 200 mg/L	257	30	–	331	151	1
Sulphate	Acceptable <200 mg/L Permissible up to 400 mg/L	287	–	–	446	31	6
Nitrate	Acceptable <45 mg/L Permissible up to 100 mg/L	287	–	–	483	–	–
Fluoride	Acceptable <1.0 mg/L Permissible up to 1.5 mg/L	251	27	9	58	–	425
Iron	Acceptable <0.3 mg/L Permissible up to 1.0 mg/L	278	–	9	465	–	18
Chloride	Acceptable <250 mg/L Permissible up to 1,000 mg/L	287	–	–	329	130	24

[a]Acceptable.
[b]Permissible.
[c]Unsuitable.

limit and 18 and 24 villages showed the problem of Iron and Chloride respectively in groundwater. High fluoride concentration in groundwater of the study area is due to weathering and leaching of fluoride-bearing minerals present in the aquifer material, which is mostly sediments of geogenic origin. According to reports, fluorosis affects 62 million people in India, including 6 million children, owing to the excessive consumption of fluoride-containing water (Susheela 1999). Also a study done by UNICEF (1999) reveals that the fluoride-related health problems affect 65 percent of India's rural population. According to the World Health Organization's (WHO) recommended fluoride concentration in drinking water, 19 Indian states have a serious fluoride pollution issue in their drinking water (CGWB 2010). Fluoride levels in drinking water are several times higher than the safe limit in states such as Andhra Pradesh, Tamil Nadu, Rajasthan, Punjab, Bihar, Uttar Pradesh, Madhya Pradesh, and West Bengal (Gupta *et al.* 1999; Pillai & Stanley 2002). Several recent researches had indicated a spatio-temporal variation in fluoride concentration in Punjab groundwater; however, these findings reported a substantial high concentration of fluoride: at Bathinda district, the range was 0–14.1 mg L^{-1} (Singh *et al.* 2013), and Southern Districts of Punjab, which ranges from 0.60–5.07 mg L^{-1} (Ahada & Suthar 2019). In Punjab, the water supply sources having a higher concentration of fluoride are either abandoned or de-fluoridation plants are installed at such water sources to remove the fluoride content and ascertain availability of potable water to the population being served through that source. Similarly, other researchers have found high fluoride concentration and water quality parameters in the groundwater of southwestern Punjab, leading to deterioration of water quality (Kaur *et al.* 2017; Kumar *et al.* 2021). The Figure 6 shows the location of the vulnerable villages in SAS Nagar and Patiala district with respect to fluoride and iron.

Development of web GIS-based water resource information system

To proceed with the development of the water resource information system for SAS Nagar and Patiala districts, all the six layers, namely: road network, canal network, drainage, settlement, tube-well location and district boundary, and water quality for SAS Nagar and Patiala were exported from the feature classes into shape files, which is the most suitable format to build an MS4W web GIS application. These files were placed in 'C:\ms4w\apps\pmapper'

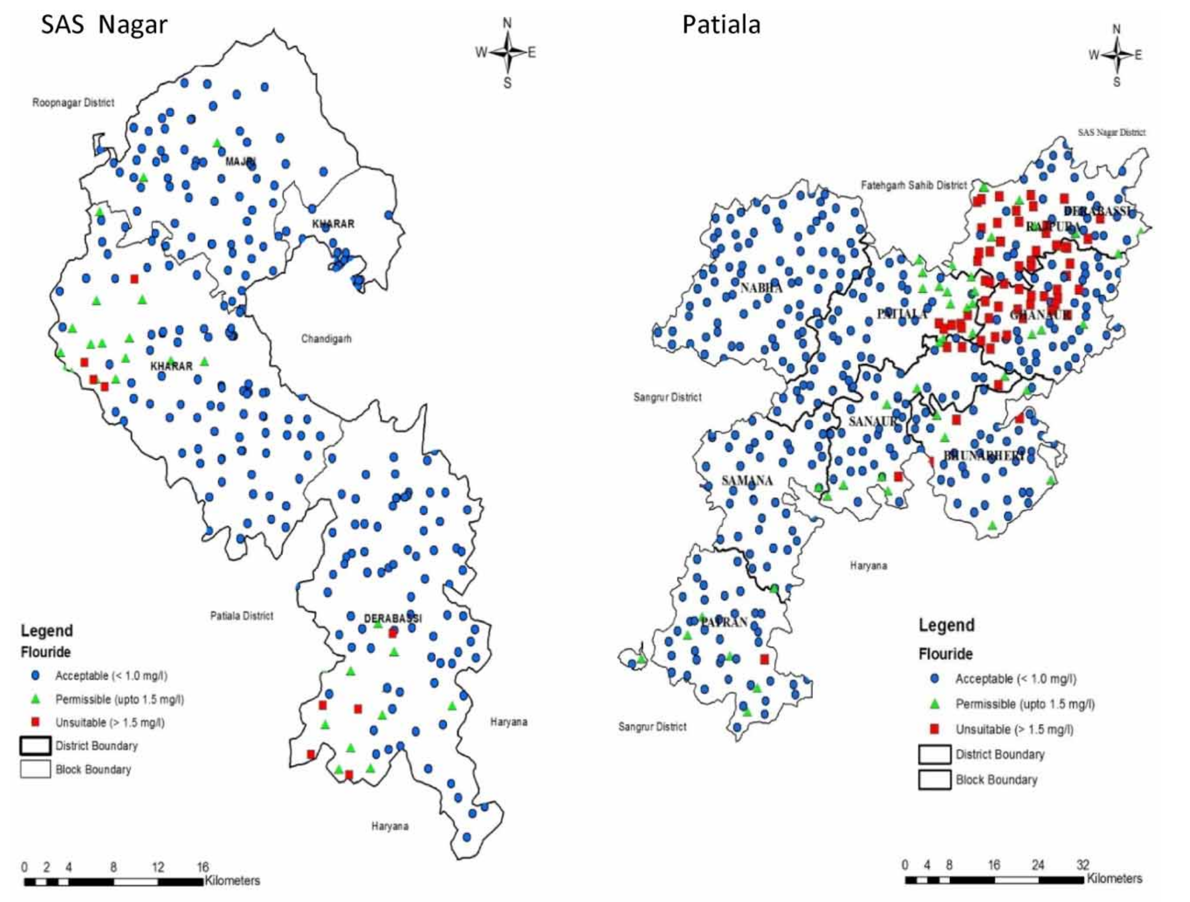

Figure 6 | Fluoride in groundwater of SAS Nagar and Patiala districts.

in 'pmapper_demodata' folder. The Map file was created for the application. It defines the map layers, including their data source, projections and symbology. The customization to make the different categories of each layer appear in a different color was also coded in the Map file. At last, the 'config' file for the application was created. The location of the Map file is included in the 'config file'. 'Config' is the main configuration file of the application, which is used to fetch the desired layers from the Map file, to show them in the application. The 'Config' file was modified to add various customizable functionalities, such as 'search functionality' in the application.

The Apache web server was restarted to launch the developed water resource information system on the 'http://localhost/' of the computer in the web browser. The whole 'Water Resource Information System' was run in the web browser to test that it is functioning properly. A number of requests were made to fetch different data. All the tools and search queries were tested for any errors. The application has a simple Graphical User Interface (GUI), as shown in Figure 7. The collected and analysed water quality information has been added into the system by following the procedure discussed above. Once the information on water quality is updated in the system, the system generates a spatio-temporal map using an interpolation technique accordingly displayed in the form of a map view. Each layer is provided with two options: visible and invisible. Whichever layer the user wish to make visible/invisible, this can be done by clicking on the checkbox of that particular layer. All the layers can also be viewed collectively at the same time. On the bottom right of the screen appears a reference map, which shows the extent of both the districts (inside the red box); this is visible on the main screen. At the top left of the screen, a search box has been provided. The search can be performed on the basis of districts, settlements, and water supply source and admin block. Towards the right of the screen, a vertical toolbox appears, which contains the various tools; that is, pan, zoom in, zoom out, identify, select, home, back, next, measure, transparency, refresh and tool tip. The functionality of each tool is explained in the following text. The 'home' button is used to go to the home screen of the application. It automatically makes all eleven layers visible on the screen. The tool 'refresh' is used to refresh the application. In addition, it also provides many other important tools such as measure distance/area, and the identity of features based on the information supplied. However, the spatio-temporal data of

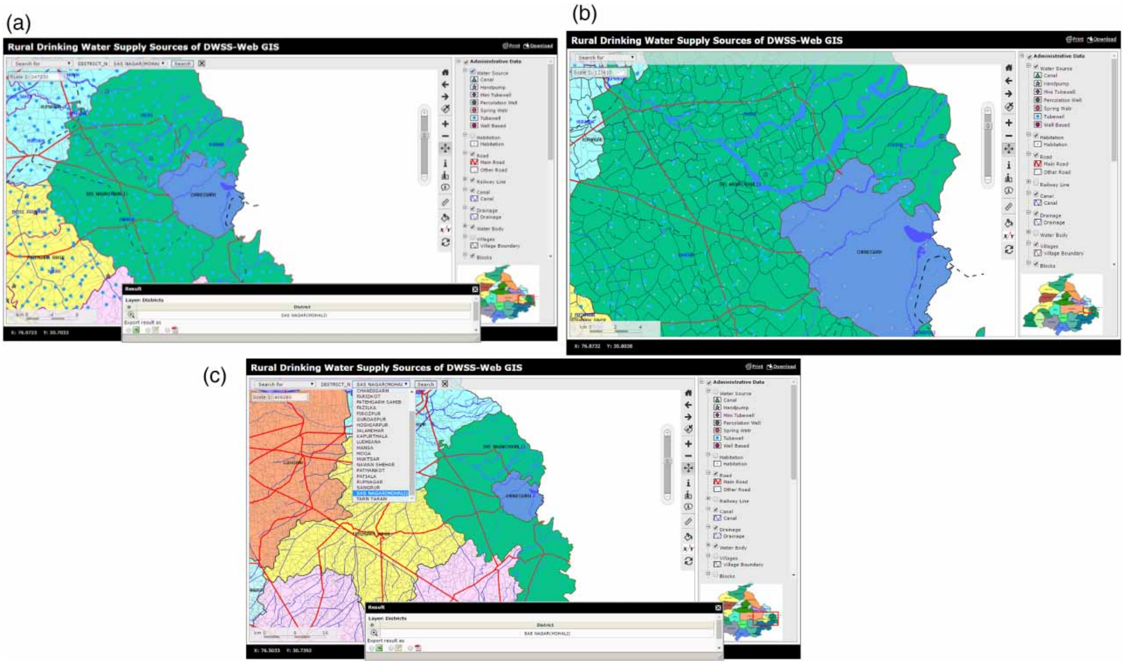

Figure 7 | (a) GUI of the Water Resource Information System of SAS Nagar and Patiala districts. (b) The reference map showing the extent of the main screen of SAS Nagar district. (c) Drop down list showing search on the basis of SAS Nagar and Patiala districts.

water resources needs to be collected from government agencies and accordingly the updating will be made on a regular basis. Similar to the present study, the Water Resources Information System (WRIS) developed by the Government of India (http://cwc.gov.in/water-resources-information-system-wris) has also been found to be very effectively useful for the reservoir module with daily level and storage data for reservoirs. India Water Tool version 2 (IWT 2.0), developed by Shiao *et al.* (2015), provides a high-resolution, user-friendly, and publicly available water platform to help companies, government agencies, and other users identify their water risks and prioritize their water management actions in India, which is also alike the present study. Furthermore, several other studies has been done by various researchers at different places around the world and these have found the developed web-GIS based information system to be more user-friendly, and to also provide the spatio-temporal information regarding water (Horne 2015; Evans *et al.* 2020; Gaffoor *et al.* 2020).

CONCLUSIONS

Groundwater is an important source of water supply throughout the world. The areas that are prone to excessive withdrawal result in the shortage of groundwater, which emphasizes the need for accurate estimates of the available subsurface resources and the importance of proper planning to ensure the continued availability of water. From the present study it was observed that in SAS Nagar, 9 villages had a high concentration of fluoride and iron. Whereas, Patiala district falls under the poor-quality water class, almost all villages of the district have a high concentration of fluoride, and some of 18 and 24 villages have iron and chloride problems. The present study has been accomplished using the open source tools, except the software Arc GIS 10. One of the best advantages of open source geo-spatial tools is that they are cost effective and provide functionality comparable to the proprietary software packages. Arc GIS 10 software has been used to delineate the spatial information and a web-based Water Resource Information System has been developed using the open source tools. Further, a web GIS-based Water Resource Information System has been developed for both districts. Web-based GIS has enhanced the quick retrieval and easy access to the information. In a web-based environment with basic GIS functionalities, the map becomes dynamic, interactive and accessible to a wide number of users and acts as a visual communication tool. The Water Resource Information System also provides search on the basis of districts, settlements, and water supply source and admin block. In addition, it also provides many other important tools such as measure distance/area, and identity of features based on the information supplied. Besides the information system can be used to map vulnerability of water resources based on spatial variability of parameters.

The distribution of a particular water quality parameter of the 'district' can be quickly viewed as maps. Complex analysis involving more than one parameter can also be carried out using this geo-database.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

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