



# Impact of lockdown due to COVID-19 pandemic on groundwater salinity in Punjab, India: some hydrogeoethics issues

G. Krishan<sup>1</sup> · N. Sudarsan<sup>1</sup> · B. S. Sidhu<sup>2</sup> · R. Vashisth<sup>3</sup>

Received: 23 September 2020 / Accepted: 1 April 2021 / Published online: 13 April 2021  
© The Author(s), under exclusive licence to Springer Nature Switzerland AG 2021

## Abstract

In the present study, a total of 48 groundwater samples (13 from shallow aquifers depth < 50 m and 35 samples from deep aquifers in the depth range 50–200 m) were collected from three industrial dominant districts (Ludhiana, Jalandhar and Moga) of Punjab after the lockdown period and before the start of southwest monsoon in the month of June, 2020 (pre-monsoon). The values for total dissolved solids (TDS) observed in Monsoon season (August, 2020) and November–December, 2019 (post-monsoon) were compared with the values taken in June, 2020 (pre-monsoon) to see the impact of lockdown due to COVID-19 pandemic on groundwater salinity. ~60% of samples were found to have TDS values more than acceptable limit (500 mg/l) before lockdown (post-monsoon season of 2019) period and after or during lockdown period (June, 2020) number of samples more than the acceptable limit (500 mg/l) reduced to 45%. Average TDS values reduced by 25% in shallow aquifers after lockdown and area under TDS values in acceptable limit (500 mg/l) increased by 23% of samples as compared to the TDS values found in monsoon season of year 2019. In deeper aquifers, increase of only 3% area under TDS values in acceptable limit of 500 mg/l was found. Reductions in TDS values in shallow aquifers clearly show that there is an urgent need for proper management of salinity causing elements and regulating these to check groundwater contaminations using the holistic and hydro-geoethical approach.

**Keywords** COVID-19 · Lockdown · Groundwater · Salinity · Punjab · Hydrogeoethics

## Introduction

Water plays an important role in human health, but has been adversely affected due to the contaminants added from minerals of geological origin and/or from industrial and agricultural activities (Nollet 2000). In most of the countries, higher incidences of diseases and mortality due to unsafe drinking water are the foremost concerns (WHO 2011). Demand for fresh water due to increasing population and developmental activities in various sectors such as agriculture, domestic and industrial is continuously increasing (Raju et al. 2011). Due to the inadequate supply of fresh surface water, people from semi-arid regions depend on groundwater for their needs

(Shankar and Sanjeev 2008; Gleeson et al. 2010) while in India, 85% of rural population exclusively depend on it (Kinzelbach et al. 2003).

Groundwater, the largest storage of fresh water is a vital constituent of hydrological cycle (Todd 1959). In India, groundwater quality has been deteriorating and constantly been questioned from health point of view (Garg et al. 2009; Alam 2014). The rivers carrying chemical effluents and toxic elements from various point and non-point sources degrade the quality of groundwater which is further degraded by the industrial wastes, unorganized use of pesticides and fertilizers, (Beg and Ali 2008). Many researchers have agreed that improper agricultural practices will lead to groundwater pollution (Mikayilov and Acar 1998; Ahmad and Khursheed 2019; Narsimha et al. 2013) including the groundwater salinity (Krishan 2019) which is primarily due to the high concentrations of salts and other elements including trace metals contributed from industrial and agricultural wastes.

Agriculture is widely recognized as an important source of water contamination (FAO and IWMI 2018). These include unsustainable cropping systems, waste from

✉ G. Krishan  
drgopal.krishan@gmail.com

<sup>1</sup> National Institute of Hydrology, Roorkee, Uttarakhand, India

<sup>2</sup> PSFC, Mohali, Punjab, India

<sup>3</sup> Department of Soil and Water Conservation, Chandigarh, Punjab, India

livestock and aquaculture as well as misuse of fertilizers (including manure applications), pesticides, bacteria, microorganisms and antimicrobial residues via leaching, surface and subsurface runoff from croplands and grazing systems pollute water resources (FAO 2020; Hallema et al. 2020).

Punjab, an agrarian state of the India is facing problems of groundwater depletion and contamination happening naturally and/or through agricultural inputs and industrial wastes (Lapworth et al. 2015, Lapworth et al. 2017; MacDonald et al. 2016). Groundwater salinity issues are on the rise in southwestern districts of Punjab (Krishan et al. 2020c, 2021) and there is an apprehension that it might extend to central Punjab.

There is a notable environmental recovery due to the direct and indirect impacts of COVID-19 pandemic. Satellite data are showing significant reductions of NO<sub>2</sub> (nitrogen dioxide) over major cities in China, Europe, USA, and India (NASA Earth Observatory 2020); in Venice, Italy, canal water appeared visibly clearer (Link 2020). Impact of COVID-19 on water resources has been reported by Krishan (2020) and its impact during and post-COVID-19 by Krishan and Kulshrestha (2020) where emphasis is laid on hydro-geoethical and holistic approaches to achieve sustainable governance working on the experiences of experts from different disciplinary domains (Marone and Bohle 2020).

COVID-19 is an unprecedented challenge for India; its large population and the economy's dependence on informal labor make lockdowns and other social distancing measures hugely disruptive. Even though the government has announced lockdown with the relaxations in farming, implementation was disrupted due to labor shortage.

The effects of reduced point source (Industrial sites) inputs on surface water quality might become evident within a matter of weeks while the effect of reduced non-point source (agriculture) inputs in groundwater could take much longer to measure. This encourages the need for this study which has been conducted in three main industrial districts of Punjab occupying the central position in the state to assess the impact of lockdown due to COVID-19 pandemic on groundwater salinity.

## Study area

The study is mainly focused on the three main industry dominant districts of Punjab: Ludhiana, Jalandhar and Moga have 12, 11 and 5 administrative blocks, respectively. The study area lies in the central region of Punjab state in India, comprising an area of about 8559 km<sup>2</sup>. The geographical co-ordinates are; 75° 15' to 76° 27' east Longitude and 30° 33' to 31° 37' north Latitude and the study area surrounded by Kapurthala, Hoshiarpur and SBS Nagar districts in the

north and bounded by Firozpur, Faridkot, Bathinda, Barnala, Sangrur, Fatehgarh sahib and Rupnagar districts in south.

Geologically, the study area forms a part of Indo-Gangetic alluvium of Quaternary period due to the deposits from Indus river system (Bonsor et al. 2017). The Sutlej River flows across the study area from east to west dividing the Bist-Doab in the north and Malwa region in the south. The map representing the study area is shown in the Fig. 1.

## Topology

The slope of the surface influences the runoff conditions. The hilly regions are intrinsic of high slope terrain, which accounts in increased runoff rate thus reducing the infiltration. On the other hand, plain terrains are intrinsic of low slope and accounts in reduced runoff rate, significantly increasing the rate of infiltration. The steeper slope indicates the minimum groundwater recharge and the gentle slope offers maximum groundwater recharge (Duan et al. 2016; Rajaveni et al. 2015).

As the slope greatly depends on the elevation of the area, the topography should be known to determine this characteristic. The topology map was extracted from the Shuttle Radar Topography Mission (SRTM)—DEM of 1-arc second (Fig. 2). From the elevation map of the study area, it is clear that the variation of slope is gentle due to the non-occurrence of hilly terrain. Meanwhile, surface elevation varies along the flow of the river Sutlej, higher elevation in the east to lower elevation in the west of the study area.

## Geomorphology

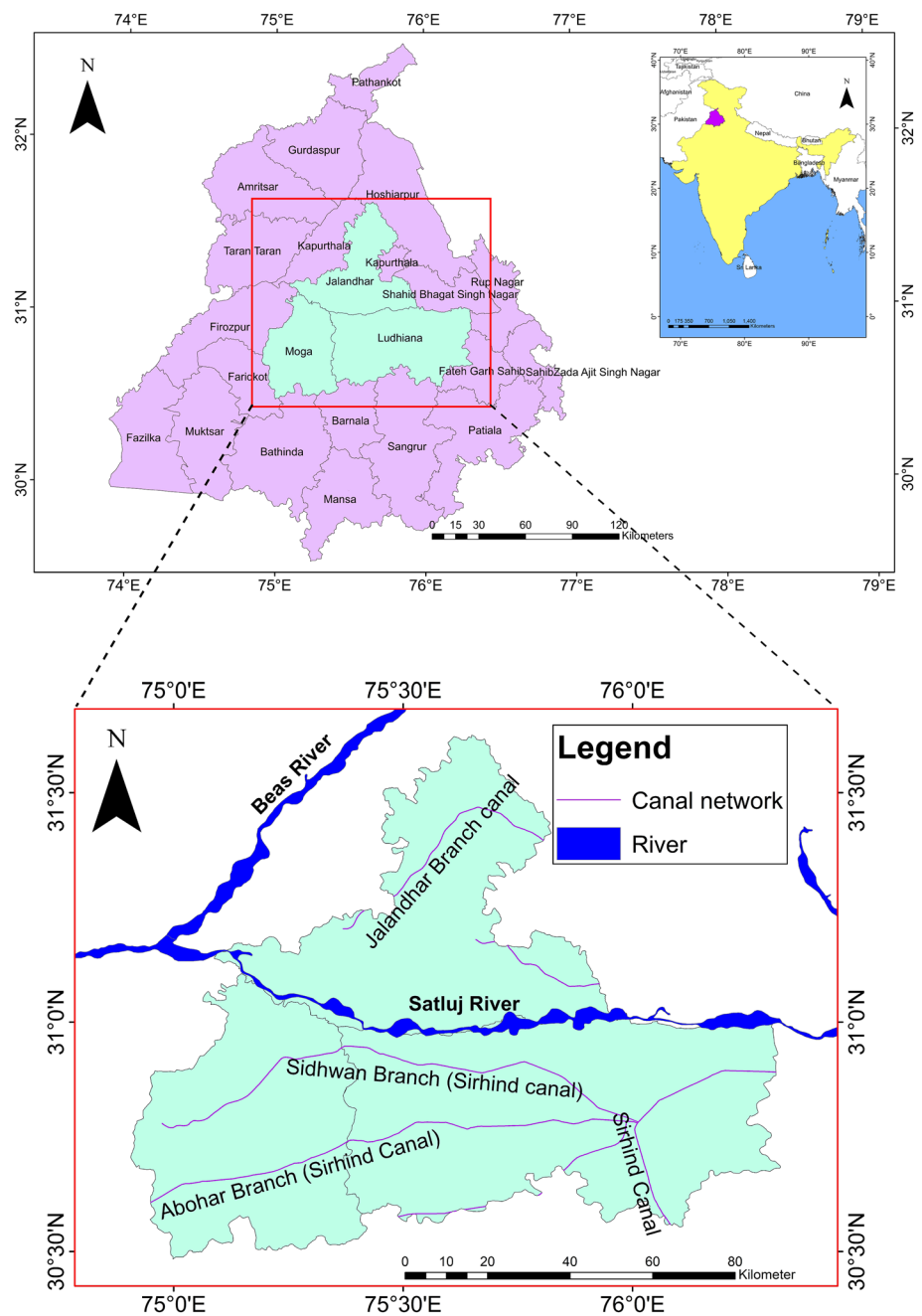
The external geological processes influence the geometry of the landform. The different geological processes such as chemical reactions, repeated freezing and thawing, seismic effects and weathering due to wind and water, dominates the shape of the surface (Rajaveni et al. 2015; Ganesh et al. 2017).

The geomorphology of the study area has been downloaded from the Geological Survey of India website (Bhukosh-GSI) and mapped with the help of ArcGIS 10.5. Four major landforms were mapped in the geomorphology map (Fig. 3). It is observed that the general landform of the study area is a alluvial plain and the flood plains were present in the sides of the Sutlej river. Additionally, Aeolian dunes were found only in the western part Jalandhar district.

## Hydrogeology

The study of groundwater conditions relies on the geological mapping and type of lithology present beneath. The different geological units which affect the groundwater flow and the quality should be paid attention (Ramaiah et al. 2012).

**Fig. 1** Study area showing river and canal network



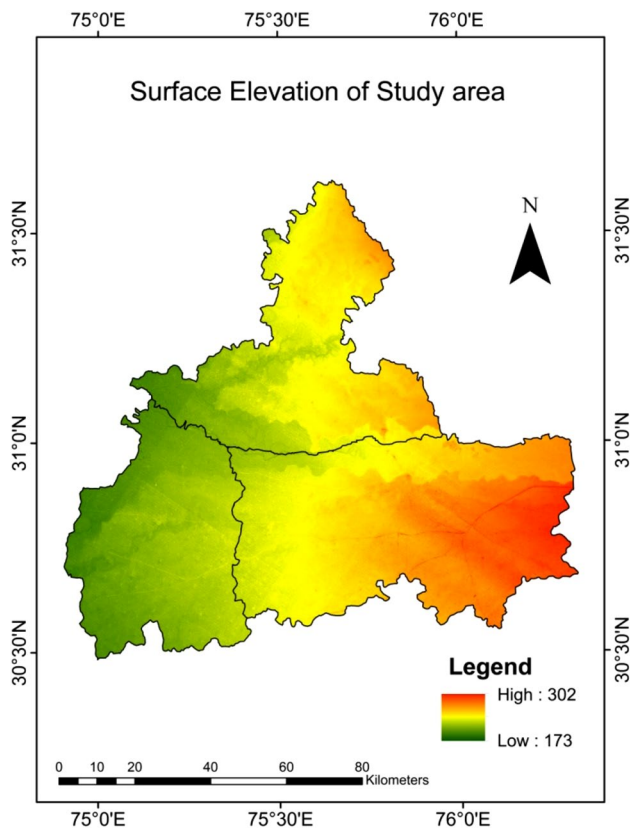
Study area forms Indus alluvial plains having multi aquifer systems upto depth of 300 m with alternate layers of sand and clay as shown in aquifer geometry map (Fig. 4) (CGWB 2017). The porosity of the rock decides the storage capacity of the rock and also the groundwater flow inside the aquifer depends upon the hydraulic conductivity or permeability of the rocks (Sedhuraman et al. 2014).

The lithology of the study area has been downloaded from the Geological Survey of India website (Bhukosh-GSI). Generally, the area is covered with the oxidized silt-clay with kankar. Moreover, the yellowish brown loose sands were found distributed all along the study area in small

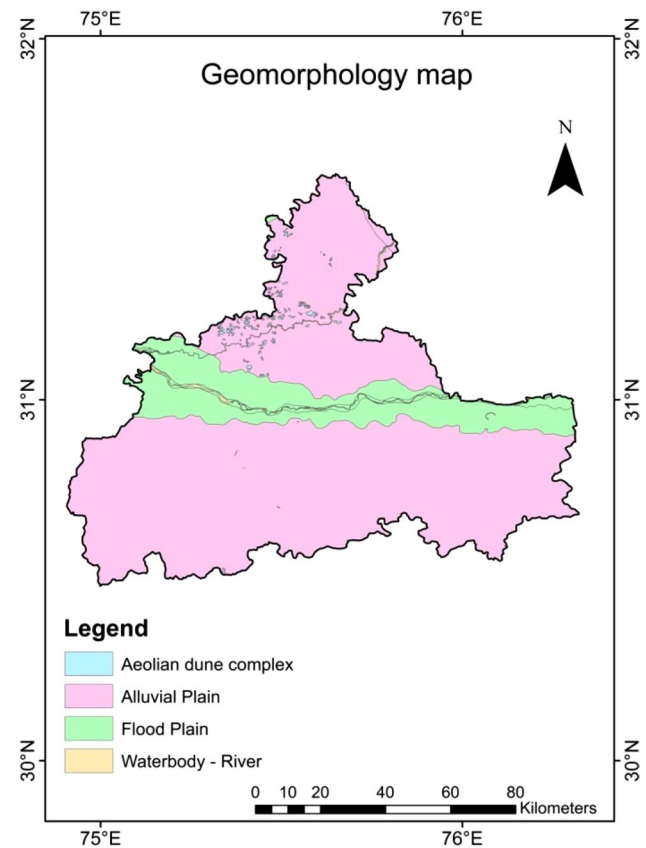
patches but mostly in the Jalandhar district. The Sutlej River was classified as Grey sand, slit and clay and the flood plains around the river were classified with the Grey Micaceous sand, silt and clay. The final maps were prepared in ArcGIS 10.5 software.

### Rainfall

Groundwater recharge of the shallow aquifer purely depends on the rainfall which infiltrates through the porous soil. The water table fluctuation highly correlates with the amount of precipitation (Halder et al. 2020). The amount of rainfall



**Fig. 2** Surface elevation map of study area



**Fig. 3** Geomorphology map of study area

recorded during the study period is necessary to correlate with the salinity changes in the shallow aquifer (Krishan et al. 2020a, 2020b). The data from Indian Meteorological Department (IMD) were downloaded from India-WRIS website.

## Materials and methods

Groundwater availability in an area depends on various factors such as topology of the land surface, geological formation, geomorphology, rainfall conditions, soil type, etc. while the quality of groundwater depends upon both the natural and anthropogenic sources. The causes of salinity fluctuation can be predicted only with the elevation, geology, geomorphology and rainfall data.

### Collection of water samples

The sampling was carried out in the study area with defined intervals between the sample points. Grids were prepared using GIS at the latitude interval of 5' N and longitude interval of 5'E, such as it makes 10 km × 10 km sampling. Totally 48 sampling locations were selected widely across

the study area and effective sampling was done August, 2019 for monsoon season and in November December, 2019 for post-monsoon season. These two samplings were carried out before lockdown period. After lockdown, sampling was carried out in the month of June, 2020 (pre-monsoon season). 13 groundwater samples from shallow depth upto 50 m and 35 samples from depth range 50–200 m were collected from the bore wells/ hand pump or open wells as per the availability. The sampled locations were shown in the gridded map (Fig. 5). Groundwater samples were collected after thoroughly flushing the water for at least 15 min or until temperature measurements indicated that all onsite storage was purged and water originated from the well bore or aquifer. The samples were collected in acid washed LDPE (low-density polyethylene) Tarson bottles.

### Analysis of pH and TDS

The pH of an aqueous solution is the measure acidic or basic capacity. The pH of a solution can be determined using the concentration of hydronium ion concentration in the solute. Initially the probe and glassware was rinsed with distilled or de ionized water and then probe (hand held portable Eutech pH meter) calibrated against pH buffer solution 4, 7 and 10

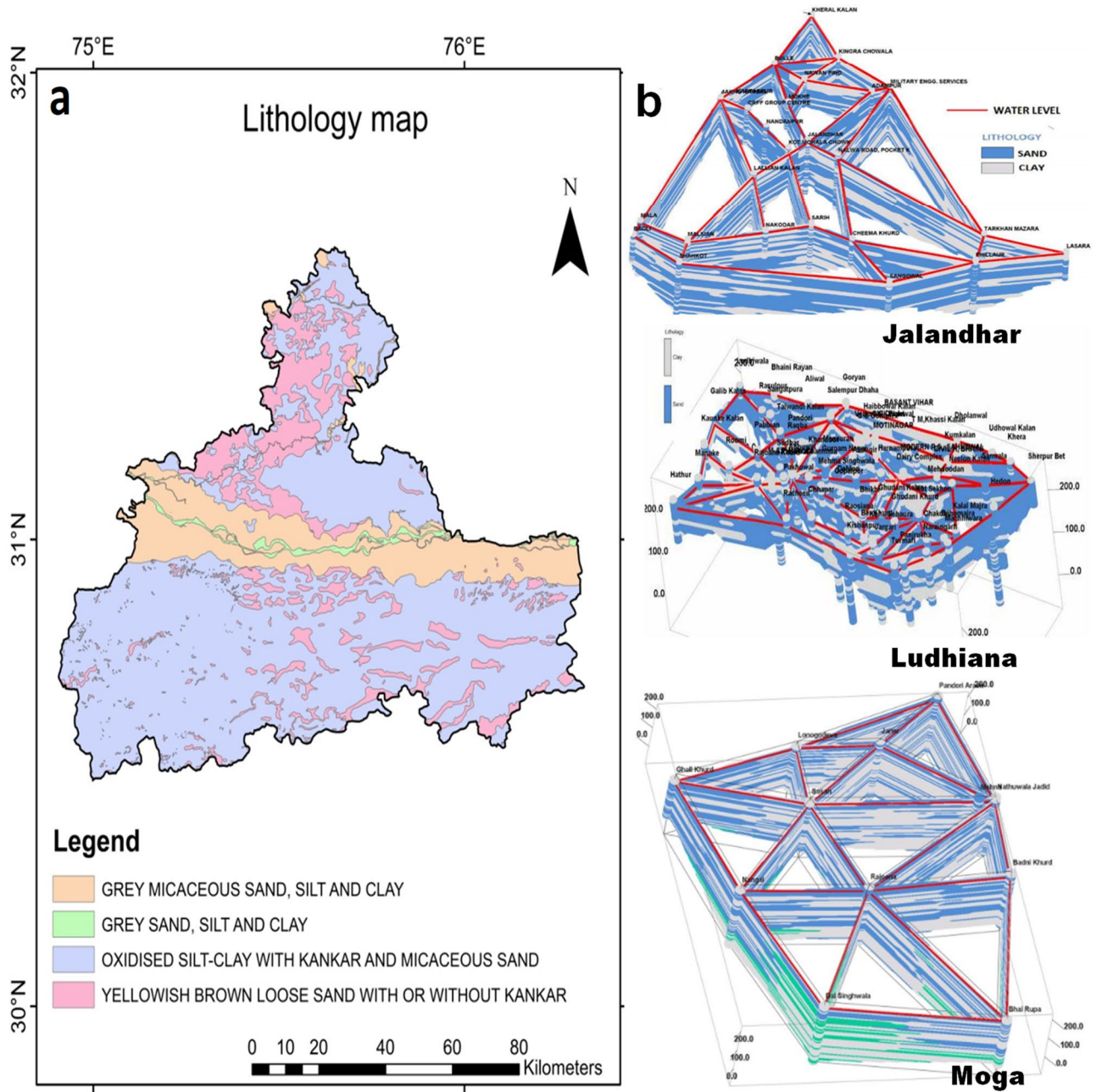


Fig. 4 Geology map (a) and aquifer geometry (b) of study area

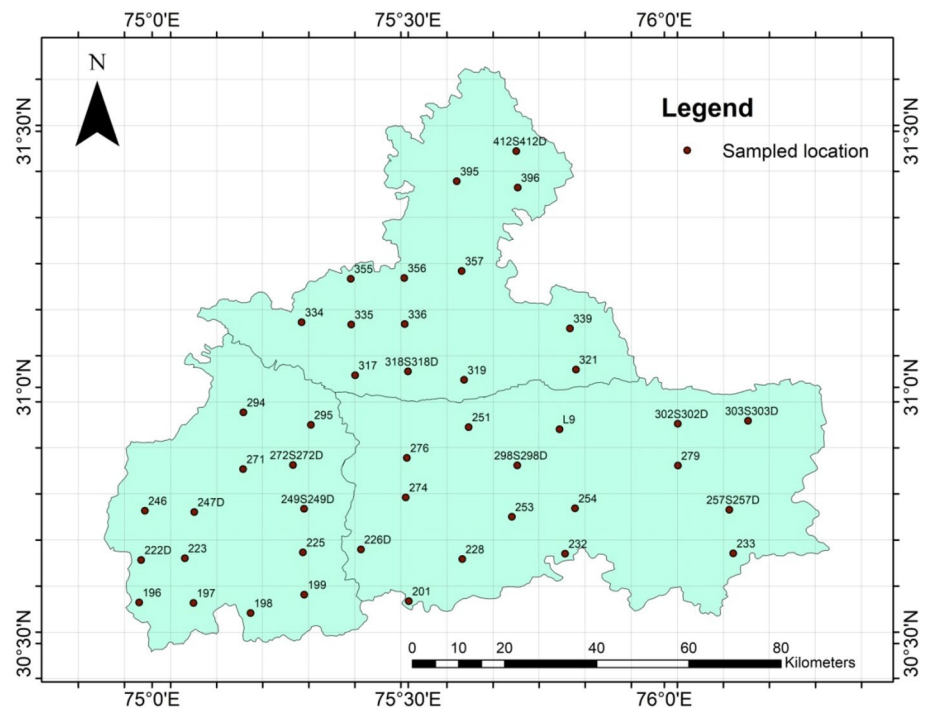
at 25 °C. pH measured insitu by immersing the probe in groundwater samples (Al-Qawati et al. 2018).

Conductivity is a measure of water’s capability to pass electrical flow. This ability is directly related to the concentration of ions in the water. Conductivity probe (multiparametric Eutech’s PCSTester 35, error ± 10 μS/cm i.e. ~ 1%) is rinsed with distilled water and cleaned with tissue paper and calibrated by standard solutions. After calibrating probe was once again rinsed with distilled water and cleaned with tissue paper. Then the probe was immersed in samples for EC

measurements. All measurements were made in situ. Later, Electrical Conductivity (EC) converted into Total dissolved solids (TDS) by an empirical formula (Eq. 1) (Rusydi 2018; Ali et al. 2012).

$$\text{Total dissolved solids} = 0.65 \times \text{electrical conductivity.} \quad (1)$$

**Fig. 5** Sampling locations with grid



**Mapping of groundwater salinity**

Geographical information system (GIS) is a most effective tool to analyse large amount of data from different sources with greater speed and accuracy (Ojo et al. 2014; Akin-torinwa and Okora 2019). Geographical information system (GIS) is considered as a significant and key tool to integrate the information with the location and temporal tags (Tiwari et al. 2017; Ferchichi et al. 2018). Interpolation is known as one of the geo-statistical technique which gives the values for unsampled locations. The mostly used interpolation techniques were inverse distance weighting (IDW) and kriging (Goyal et al. 2010; Jat et al. 2009; Shanmugasundharam et al. 2015; Elumalai et al. 2017).

Even though kriging was suggested by most of the researchers, IDW gives best results for the densely distributed sample points. Estimates of IDW (Eq. 2) interpolation are the weighted averaged values of surrounding

sample points. Weights are computed by the inverse of the distance from an observation to an estimate (Burrough and McDonnell 1998; Setianto and Triandini 2013; Honar-bakhsh et al. 2019; Selvam et al. 2014; Pande and Moharir 2018).

$$V_i = \frac{\sum_{j=1}^n \frac{V_j}{d_{ij}^p}}{\sum_{j=1}^n \frac{1}{d_{ij}^p}}, \tag{2}$$

where

$V_i$  =  $i$ th unknown value

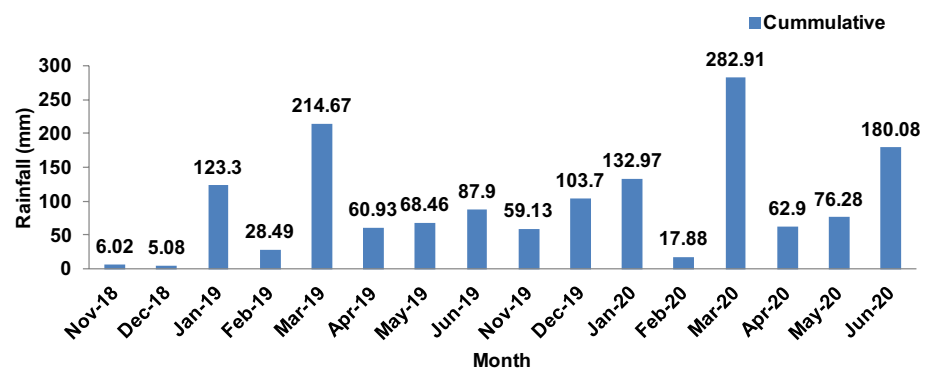
$n$  = number of points taken to obtain the unknown value

$V_j$  =  $j$ th known value

$d_{ij}$  = distance between the  $i$ th unknown value and the  $j$ th known value

$p$  = power

**Fig. 6** Monthly cumulative rainfall (Nov 2018–June 20)



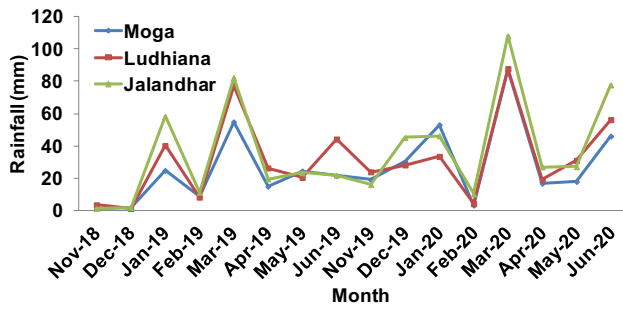


Fig. 7 District-wise monthly rainfall variations

## Results and discussion

Depending on the availability of data and resources, this study concentrates on the use of surface elevation, geomorphology, geology, rainfall and sample analysis results.

### Rainfall

The IMD rainfall data of the study period from November, 2018 to June, 2020 were analysed. The monthly average rainfall was found 94 mm/month for the study period where the average annual rainfall of the Punjab state is more than 640 mm. Monthly cumulative rainfall of the study area was plotted in a bar chart (Fig. 6). From the bar chart, it is also observed that, study area has a highest rainfall in the month on March, 2020 with 282.91 mm and lowest rainfall 5.08 mm was recorded in the month of Dec, 2018.

The rainfall behavior patterns of three states were plotted (Fig. 7), it is obvious that it follows a similar pattern in monthly fluctuations. But when comparing the cumulative rainfall between the districts, Jalandhar ranks first with 358 mm followed by Ludhiana with 284 mm and at last by Moga with 274 mm. The well-defined rainy period of the study area is during the southwest monsoon (July to September), 90% of the rainfall occurs during this period (CGWB 2017). There is not much rainfall during the study period.

### pH

According to Indian standards specifications (IS 10500: 2012), the pH value of drinking water should be in the range of 6.5–8.5. The pH value of the water samples for shallow aquifers varies from 6.9 to 8.1 with a mean of 7.6 in monsoon season; 7.2–8.2 with a mean of 7.7 in post-monsoon season and from 7.1 to 8.3 with the mean of 7.7 pre-monsoon season while for deep aquifers pH varies from 7.1 to 8.9 with a mean of 7.7 in monsoon season; 7.2–8.6 with a mean of 7.8 in post-monsoon season and from 7.1 to 8.9 with the mean of 7.7 pre-monsoon season (Table 1). In

Table 1 Statistical computation of pH, TDS in shallow and deep aquifers

Statistical Parameters	Shallow aquifer				Deep aquifer			
	pH		TDS		pH		TDS	
	Aug 2019*	Nov–Dec 2019**	June 2020***	Aug 2020***	Aug 2019*	Nov–Dec 2019**	June 2020***	Aug 2019*
Minimum	6.9	7.20	7.10	308	7.1	7.20	7.10	268
Maximum	8.1	8.20	8.30	1340	8.9	8.60	8.90	1340
Mean	7.6	7.69	7.60	557	7.69	7.78	7.68	522
Standard deviation	0.34	0.29	0.31	209	0.37	0.34	0.36	214
								Nov–Dec 2019**
								261
								1340
								558
								218
								187

\*Monsoon (2019)

\*\*Post-monsoon (2019)

\*\*\*Pre-monsoon (2020)

all three seasons, only 1% of the samples were found to be above the acceptable range of 6.5–8.5.

### Total dissolved solids (TDS)

The total dissolved solid (TDS) concentration is directly proportional to the salinity content of the water, assuming all the dissolved solids are of metal salts only. Many researchers have proved that TDS is an effective indicator of water quality.

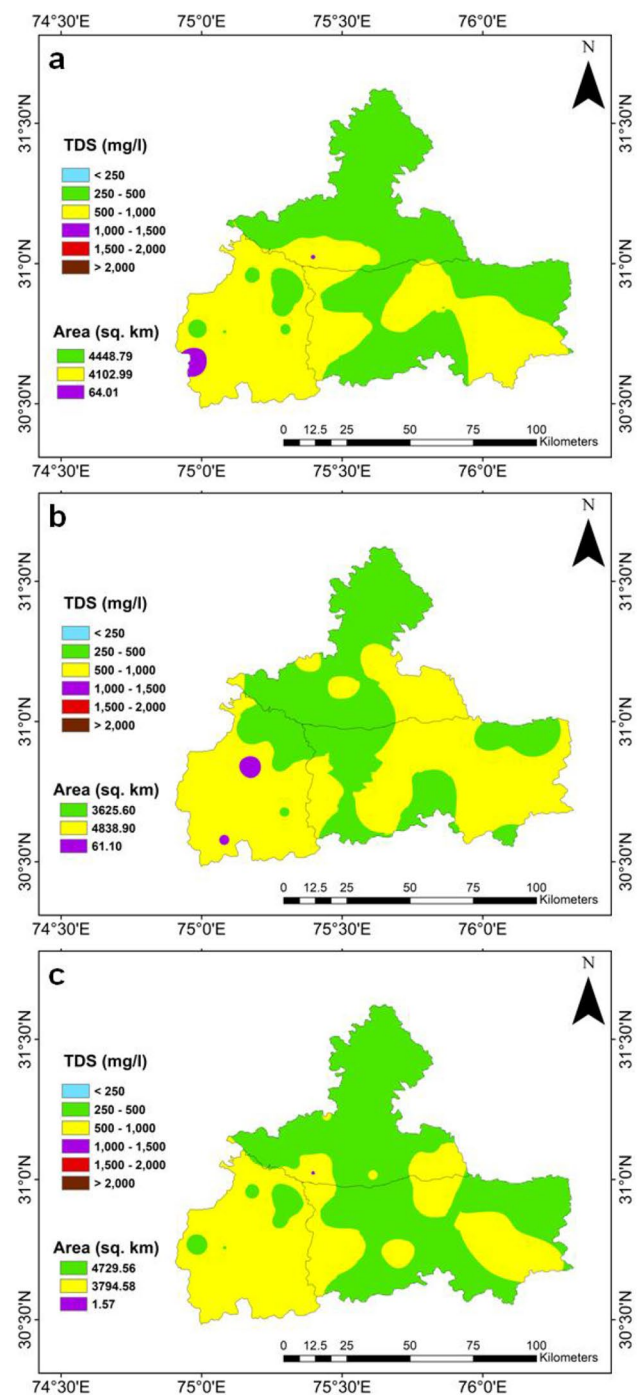
According to Bureau of Indian Standards (BIS) (IS 10500: 2012), the acceptable limit of TDS for drinking purpose is 500 mg/l. The statistical parameters of TDS from the sample analysis were tabulated in the Table 1. From the mean and maximum values, it is evident that the maximum salinity 743 mg/l was found in the monsoon season in the shallow aquifers. Out of 48 samples collected, ~60% of samples were found to have TDS values more than acceptable limit (500 mg/l) before lockdown (post-monsoon season of 2019) period and after or during lockdown period (June, 2020) number of samples more than the acceptable limit (500 mg/l) reduced to 45%. There was also slight reduction in percentage of samples (6%) with TDS values exceeding 1000 mg/l after lockdown as compared to the period before lockdown.

### Spatio-temporal distribution of salinity

The analysed samples were interpolated by the IDW technique and spatio-temporal variability maps were prepared using ArcGIS 10.5 software. The salinity distribution before and after lockdown for both shallow and deep aquifers were mapped separately and shown in Figs. 8 and 9 respectively (Li et al. 2015).

The TDS variation in maps have been shown by separating TDS values into 6 classes, as, < 250 mg/l, 250–500 mg/l, 500–1000 mg/l, 1000–1500 mg/l, 1500–2000 mg/l and > 2000 mg/l. The area occupied by each class was calculated. In deep aquifer only minor changes were found in TDS values due to the lockdown and TDS variation in deep aquifer were classified into three classes (Fig. 8) since there was no sample found with TDS value > 1500 mg/l. The area of classes was found to be equal in second and third classes. The TDS range of 1000–1500 mg/l (fourth class) was found to be spread around 61.10 km<sup>2</sup> before lockdown and after lockdown it reduced to 1.57 km<sup>2</sup>.

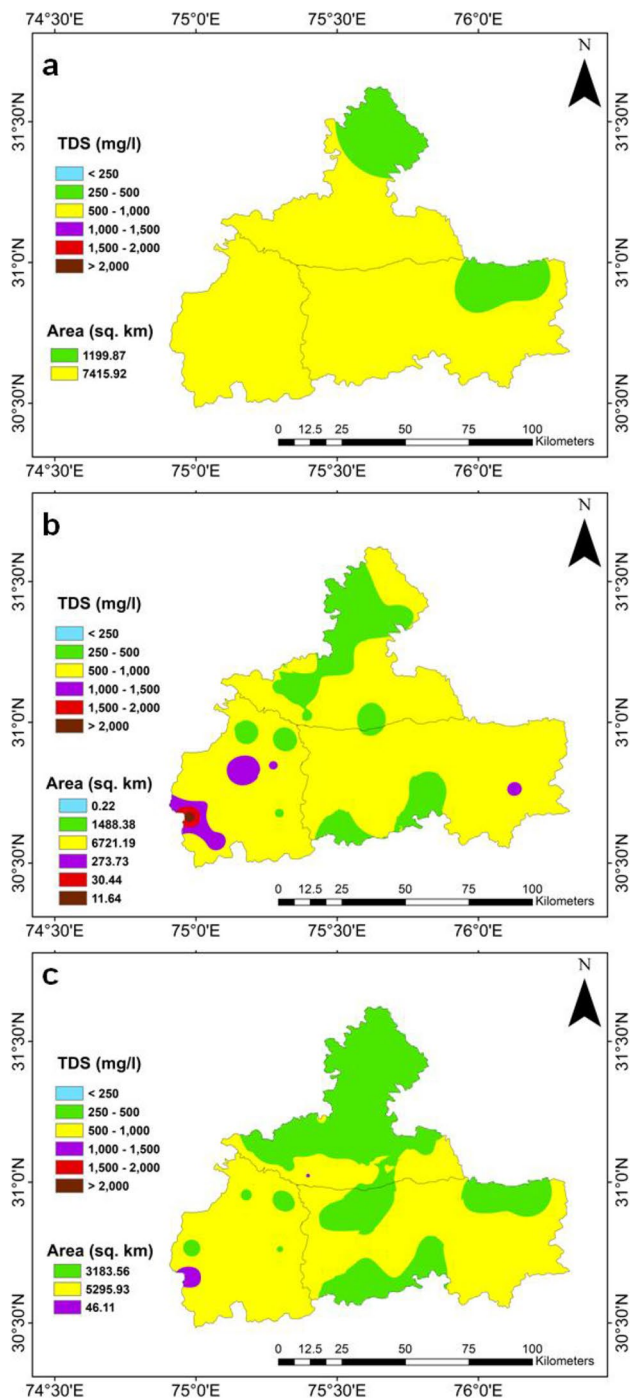
Shallow aquifers are influenced greatly by the external factors such as rainfall, pesticides, industrial wastes, etc. From the TDS values of the shallow aquifer (Fig. 9), it is found that salinity was high before lockdown and it reduced after lockdown period. Before lockdown, the TDS variation was



**Fig. 8** Salinity variation in deep aquifers **a** June, 2019 **b** November–December, 2019 and **c** June, 2020

higher as 11.64 km<sup>2</sup> of area was having TDS > 2000 mg/l, 30.44 km<sup>2</sup> of area was having TDS > 1500 mg/l and 273.73 km<sup>2</sup> of area was having TDS > 1000 mg/l. There is a drastic change after lockdown in shallow aquifers with no samples was found with TDS > 1500 mg/l TDS and only





**Fig. 9** Salinity variation in shallow aquifers **a** June, 2019 **b** November–December, 2019 and **c** June, 2020

46.11 km<sup>2</sup> of area was having TDS more than 1000 mg/l which was 315.81 km<sup>2</sup> before lockdown. The TDS values after lockdown reduced < 500 mg/l in 3183.56 km<sup>2</sup> area, with > 100% increase in area from 1488.38 km<sup>2</sup> before lockdown.

In general, the change in the groundwater salinity in aquifers due to the external factors like geology or rainfall

can be ruled out as the lithology of the study area does not contribute to dilution of groundwater and it is also evident that the rainfall was not the cause for the dilution of salinity since the observations were recorded during pre-monsoon period of 2020. Ludhiana and Jalandhar districts are well known for industrial activities and it is found that due to the non-functioning of these industries and other related activities probably there may be minimum contamination from industrial effluents into groundwater.

## Conclusion

- It is concluded that there is less influence of geology, geomorphology and rainfall in the shallow aquifer of study area for the period studied.
- It is evident from that there was no industrial functioning during the lockdown.
- From the TDS maps, it is found that the salinity in the shallow aquifers reduced due to non-working of industrial activities.
- There is a need of efficient and proper handling of agricultural inputs like pesticides and fertilizers and by regulating the disposal of industrial wastes for saving groundwater from contaminations using the holistic and hydro-geothical approach.

**Acknowledgements** Funding received from Punjab state farmers and farm workers commission is duly acknowledged. Authors thanks Chairman PSFC and Director NIH for all support and encouragement.

## Declarations

**Conflict of interest** Authors declare there are no conflicts of interests.

## References

- Ahmad S, Khurshid S (2019) Hydrogeochemical assessment of groundwater quality in parts of the Hindon River basin, Ghaziabad, India: implications for domestic and irrigation purposes. *SN ApplSci* 1:151
- Akintorinwa O, Okoro O (2019) Combine electrical resistivity method and multi-criteria GIS-based modeling for landfill site selection in the Southwestern Nigeria. *Environ Earth Sci* 78:162
- Alam F (2014) Evaluation of hydrogeochemical parameters of groundwater for suitability of domestic and irrigation purposes a case study from central Ganga Plain India. *Arab J Geosci* 7(10):4121–4131
- Ali N, Mo K, Kim M (2012) A case study on the relationship between conductivity and dissolved solids to evaluate the potential for reuse of reclaimed industrial wastewater, KSCE. *J CivEng* 16(5):708–713

- Al-Qawati M, El-Qaysy M, Darwesh N et al (2018) Hydrogeochemical study of groundwater quality in the west of SidiAllalTazi, Gharb area Morocco. *J Mater Environ Sci* 9(1):293–304
- Beg KR, Ali S (2008) Chemical contaminants and toxicity of Ganga river sediment from up and down stream area at Kanpur. *Am J Environ Sci* 4(4):362
- BIS (Bureau of Indian Standards) (2012) Specification for drinking water IS 10500:2012 New Delhi India.
- Bonsor HC, MacDonald AM, Ahmed KM et al (2017) Hydrogeological typologies of the Indo-Gangetic basin alluvial aquifer South Asia. *Hydrogeol J* 25(5):1377–1406. <https://doi.org/10.1007/s10040-017-1550-z>
- Burrough PA, McDonnell RA (1998) Principles of geographical information systems. Oxford University Press, Oxford
- CGWB (2017) Aquifer mapping and management plan north western region. Central Groundwater Board, Ministry of Water Resources Government of India, Chandigarh
- Duan H, Deng Z, Deng F, Wang D (2016) Assessment of groundwater potential based on multicriteria decision making model and decision tree algorithms. *Math ProblEng*. <https://doi.org/10.1155/2016/2064575>
- Elumalai V, Brindha K, Sithole B, Lakshmanan E (2017) Spatial interpolation methods and geostatistics for mapping groundwater contamination in a coastal area. *Environ SciPollut Res*. <https://doi.org/10.1007/s11356-017-8681-6>
- FAO (2020) The state of World Fisheries and Aquaculture <http://www.fao.org/publications/sofia/2020/en/>. Accessed 20 Sept 2020
- FAO and IWMI (2018) More people, more food, worse water? a global review of water pollution from agriculture. Food and Agriculture Organization of the United Nations Rome, and International Water Management Institute on behalf of the Water Land and Ecosystems research program of the CGIAR Colombo, 2018
- Ferchichi H, Hamouda MF, Farhat B, Mammou A (2018) Assessment of groundwater salinity using GIS and multivariate statistics in a coastal Mediterranean aquifer. *Int J Environ SciTechnol*. <https://doi.org/10.1007/s13762-018-1767-y>
- Ganesh KM, Sankar J, Boyidi S, Murthy Y (2017) Integration of geology and geomorphology for groundwater occurrence in a hard rock region, Nakrekal basin, Nalgonda District, Telangana State, using remote sensing and GIS techniques. *Int J ApplInnoEng Manage* 6:10
- Garg VK, Suthar S, Singh S, Sheoran A, Garima M, Jai S (2009) Drinking water quality in villages of southwestern Haryana, India: assessing human health risks associated with hydrochemistry. *Environ Geol* 58:1329–1340
- Gleeson T, VanderSteen J, Sophocleous MA et al (2010) Groundwater sustainability strategies *Nat Geosci* 3(6):378
- Goyal SK, Chaudhary BS, Singh O, Sethi GK, Thakur PK (2010) GIS based spatial distribution mapping and suitability evaluation of groundwater quality for domestic and agricultural purpose in Kaithal district, Haryana state, India. *Environ Earth Sci* 61(8):1587–1597
- Halder S, Roy M, Roy M (2020) Analysis of groundwater level trend and groundwater drought using standard groundwater level Index: a case study of an eastern river basin of West Bengal, India. *SN ApplSci* 2:507
- Hallema D, Rabinne F, McNulty S (2020) Pandemic spotlight on urban water quality. *Ecol Process* 9:22
- Honarbaksh A, Azma A, Ostovari Y, Mousazadeh M, Eftekhari M (2019) Hydro-chemical assessment and GIS-mapping of groundwater quality parameters in semi-arid regions. *J Water Supply Res Technol Aqua* 68(7):509–522
- Jat MK, Khare D, Garg PK (2009) Urbanization and its impact on groundwater: a remote sensing and GIS-based assessment approach. *Environmentalist* 29:17–32
- Kinzelbach W, Bauer P, Siegfried T, Brunner P (2003) Sustainable groundwater management—problems and scientific tools. *Episodes* 26(4):279–284
- Krishan G (2019) Groundwater Salinity. *Curr World Environ* 14(2):186–188
- Krishan G (2020) Water sector scientific imperatives for COVID-19. *Curr World Environ* 15(1):05–07
- Krishan G, Kulshrestha U (2020) During and post COVID-19: Challenges in water sector and ethical issues. In: Geoethics and groundwater management congress organized by International Association of Hydro-geologists (IAH) and International Association for Promoting Geoethics (IAPG), during May 18–22, 2020 at Porto-Portugal
- Krishan G, Prasad G et al (2020a) Identifying the seasonal variability in source of groundwater salinization using deuterium excess—a case study from Mewat, Haryana, India. *J HydrolReg Stud* 31:100724. <https://doi.org/10.1016/j.ejrh.2020.100724>
- Krishan G, Ghosh NC et al (2020b) Understanding stable isotope systematics of salinity affected groundwater in Mewat, Haryana, India. *J Earth SystSci* 129:109. <https://doi.org/10.1007/s12040-020-1380-6>
- Krishan G, Bisht M, Ghosh NC, Prasad G (2020c) Groundwater salinity in north west of India a critical appraisal. In: Singh R, Shukla P, Singh P (eds) Environmental processes and management. Water Science and Technology Library, Springer, Cham
- Krishan G, Vashisht R, Sudarsan N et al (2021) Groundwater salinity and isotope characterization: a case study from South-West Punjab, India. *Environ Earth Sci* 80(4):169. <https://doi.org/10.1007/s12665-021-09419-7>
- Lapworth DJ, MacDonald AM, Krishan G, Rao MS, Goody DC, Darling WG (2015) Groundwater recharge and age-depth profiles of intensively exploited groundwater resources in northwest India. *Geophys Res Lett* 42(18):7554–7562. <https://doi.org/10.1002/2015GL065798>
- Lapworth DJ, Krishan G, MacDonald AM, Rao MS (2017) Groundwater quality in the alluvial aquifer system of northwest India: new evidence of the extent of anthropogenic and geogenic contamination. *Sci Total Environ* 599–600(2017):1433–1444
- Li W, Wang M, Liu L, Yan Y (2015) Assessment of long term evolution of groundwater hydrochemical characteristics using multiple approaches: a case study in Cangzhou, Northern China. *Water* 7:1109–1128. <https://doi.org/10.3390/w7031109>
- Link D (2020) Fact check: COVID-19 crisis has not created decreased long-term human environmental impact. *USA Today*. Mar 25. <https://www.usatoday.com/story/news/factcheck/2020/03/25/fact-check-coronavirus-crisisbenefiting-environment/2908300001/> Accessed 17 Apr 2020
- MacDonald A, Bonsor H et al (2016) Groundwater depletion and quality in the Indo-Gangetic Basin mapped from in situ observations. *Nat Geosci* 9:762–766
- Marone E, Bohle M (2020) Geoethics for nudging human practices in times of pandemics. *Sustainability* 12(18):7271. <https://doi.org/10.3390/su12187271>
- Mikayilov FD, Acar B (1998) Toprak ekosistemlerinde kirleticilerin tasınım mekanizmasının incelenmesi ve modellenmesi (Investigation and modelling of contaminant's movement processes within the soil ecosystems). *C<sub>u</sub> ev Kor* 28:20–23
- Narsimha A, Sudarshan V, Swathi P (2013) Groundwater and its assessment for irrigation purpose in Hanmakonda area, Warangal district, Andhra Pradesh, India. *Int J Res Chem Environ* 3(2):196–200
- NASA Earth Observatory (2020) Airborne nitrogen dioxide plumes over China. <https://www.earthobservatory.nasa.gov/>

- [images/146362/airborne-nitrogen-dioxide-plummet-over-china](https://doi.org/10.1007/s13201-018-0754-2)  
Accessed 17 Apr 2020.
- Nollet L (2000) Handbook of Water Analysis. Marcel Dekker, New York
- Ojo JS, Olorunfemi MO, Bayode S, Akintorinwa OJ, Omosuyi GO, Akinluyi FO (2014) Constraint map for landfill site selection in Akure Metropolis, Southwestern Nigeria. *Ife J Sci* 16:405–416
- Pande C, Moharir K (2018) Spatial analysis of groundwater quality mapping in hard rock area in the Akola and Buldhana districts of Maharashtra India. *Appl Water Sci*. <https://doi.org/10.1007/s13201-018-0754-2>
- Rajaveni SP, Brindha K, Elango L (2015) Geological and geomorphological controls on groundwater occurrence in a hard rock region. *Appl Water Sci*. <https://doi.org/10.1007/s13201-015-0327-6>
- Raju JN, Shukla UK, Prahlad R (2011) Hydrogeochemistry for the assessment of groundwater quality in Varanasi: a fast-urbanizing center in Uttar Pradesh, India. *Environ Monit Assess* 173:279–300
- Ramaiah SN, Gopalakrishna GS, Vittala SS, Najeeb KMd (2012) Geomorphological mapping for identification of ground water potential zones in hard rock areas using geo-spatial information— a case study in Malur Taluk, Kolar District, Karnataka, India. *Nat Environ Pollut Technol* 11(3):369–376
- Rusydi A (2018) Correlation between conductivity and total dissolved solid in various type of water: a review, IOP conference series: Earth and environmental science, vol 118, Global Colloquium on GeoSciences and Engineering 2017, 18–19 October 2017, Bandung, Indonesia
- Sedhuraman M, Revathy SS, Suresh BS (2014) Integration of geology and geomorphology for groundwater assessment using Remote Sensing and GIS techniques. *Int J Innovative Res Sci Eng Technol* 3(3):10203–10211
- Selvam S, Manimaran G, Sivasubramanaian P, Balasubramanaian N, Seshunarayana T (2014) GIS-based evaluation of water quality index of groundwater resources around Tuticorin in coastal city, South India. *Environ Earth Sci* 71:2847–2867
- Setianto A, Triandini T (2013) Comparison of kriging and Inverse Distance Weighted (IDW) interpolation methods in lineament extraction and analysis. *J Southeast Asian Appl Geol* 5(1):21–29
- Shankar BS, Sanjeev L (2008) Assessment of water quality index for the groundwater of an industrial area in Bangalore India. *Environ Eng Sci* 25(6):911–916
- Shanmugasundharam A, Kalpana G, Mahapatra SR, Sudharson ER, Jayaprakash M (2015) Assessment of groundwater quality in Krishnagiri and Vellore districts in Tamil Nadu India. *Appl Water Sci*. <https://doi.org/10.1007/s13201-015-0361-4>
- Tiwari K, Goyal R, Sarkar A (2017) GIS-based spatial distribution of groundwater quality and regional suitability evaluation for drinking water. *Environ Process* 4:645–662
- Todd DK (1959) Groundwater hydrology. Wiley, New York
- World Health Organization WHO (2011) Guidelines for drinking-water quality, 4th edn. WHO Press, Geneva

**Publisher's Note** Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.