Evaluation of groundwater quality in Kolhapur, Maharashtra, India with the insights of WQI and GIS, in the pandemic of Covid-19

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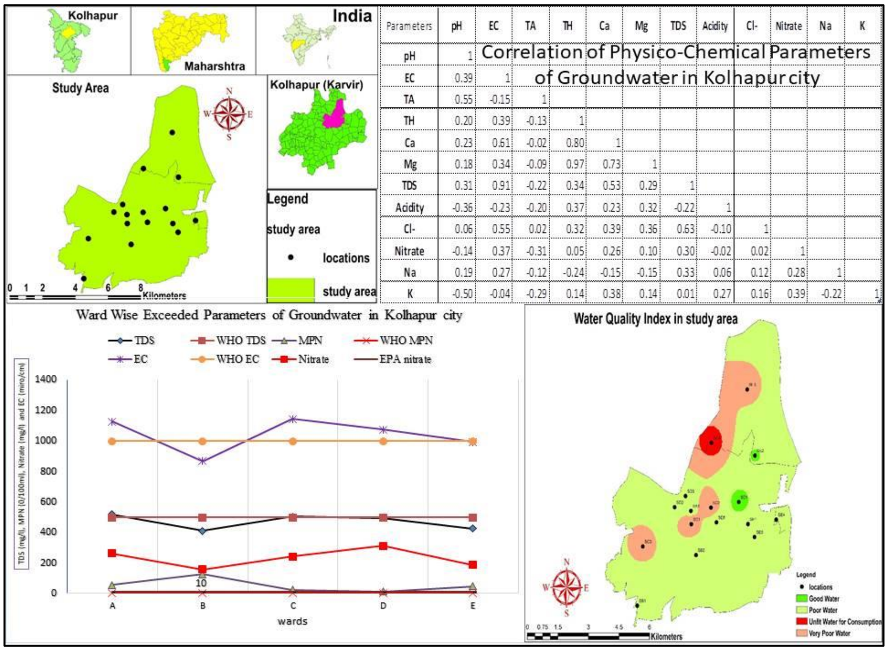
ABSTRACT

Since early 2020 the pandemic of Covid-19 forced the human to stop many of their activities especially those which have damaged the nature in particular polluted the water. The study was confined to the groundwater of Kolhapur city, Maharashtra, during the Covid-19 catastrophic to find out the number of certain contaminants especially those which have the same pathway of Coronavirus into the groundwater. Various parameters such as pH, EC, TDS, Total Hardness, Calcium, Magnesium, Sodium, Potassium, Alkalinity, Nitrate, MPN and Chloride were checked. The parameters were analyzed and compared with the WHO and EPA standards. Groundwater samples have been collected from 16 bore wells in the city. The sample analysis reveals that the groundwater is not entirely fit for drinking concerning bacteria which exceeded in all wards with the maximum 230/100 ml, EC with 1402.47 µS/cm, TDS with 601.5 mg/l, and Nitrate with the maximum of 434.7 mg/l. Presently, over 25 million people are infected by Covid-19 in India which can be the main path of this virus to the groundwater as humans are the source of bacteria such as Coliform in groundwater when all samples in the study showed positive results. GIS and WQI were used to interpret the collected data of groundwater. Water Quality Index that is represented with the help of GIS, illustrates that from 16 locations, only two of them, SE1 and SD2 come under the Good category, the site SC4 is Unfit for Consumption, while the rest are Poor or Very Poor water.

Graphical Abstract



KEYWORDS: Groundwater Evaluation, Suitability, WQI, GIS Interpolation, Covid-19, Kolhapur

1. Introduction

We should remember that life and water are inextricably linked. Water is found in a variety of natural and man-made bodies, including the ocean, sea, river, groundwater, lake, ponds, atmosphere, and certain biological bodies, in liquid, frozen, and vapor forms. Although water is abundant in nature, virtually all species are currently experiencing water shortages. Its abundance and scarcity have incredibly shaped peoples` lifestyles and the culture that inhabits a particular location. The drinking water which considers as freshwater, its global use has increased by a factor of six over the last century and continues to grow at a rate of nearly 1% per year since the 1980s (UN, 2021). Groundwater is a resource that, among the aforementioned water bodies, plays a fully vital and quiet function in providing the needed amount of water for human activities daily. Groundwater is generally defined as the water present in the saturation zone below the ground. This zone is technically called ''aquifer‟. Aquifers are permeable porous to supply water to wells and springs. Even though groundwater resource is replenishable, but limits resource. The availability of groundwater varies greatly across the country (Chatterjee, 2009).

Groundwater is a renewable natural resource; yet, due to various types of anthropogenic activity and skewed inventions and technologies, this critical life-sustaining resource replenishment has been severely reduced during the previous 4–5 decades (Fauzia *et al*., 2021). Over two billion people throughout the world rely on groundwater for their daily water source (Loni *et al.*, 2010). Furthermore, due to the unequal distribution of water resources in India, the majority of the population relies on groundwater, which is one of the most accessible, dependable, and naturally clean sources of water. Groundwater is a key resource for irrigation and drinking in non-perennial river basin environments across the world, particularly in the southern regions of India (Arunbose *et al.*, 2021). India's food security and drinking water supplies have become increasingly reliant on its groundwater resources. Groundwater now meets 64% of irrigation demand, 85% of rural drinking water demand, and more than 50% of urban water demand. Groundwater is believed to be directly responsible for 9% of India's Gross Domestic Product (GDP), (ICRIER, 2019). Because of its extensive usage by human-based activities, this valuable resource has already become polluted. As the world's reliance on groundwater grows, its quality becomes an increasingly pressing concern (Pye, 1983). Although the number of pollutants found in groundwater is continuously rising, they may be divided into three categories: chemical pollutants, biological pollutants, and radioactive pollutants. These pollutants can originate from both natural and man-made sources (Elumalai *et al.*, 2020). However, owing to the fast growth of the world population, urbanization, industrialization, agricultural output, and the economy, we are now confronted with the threat of anthropogenic pollutants (Li *et al.*, 2021). Groundwater quality and quantity concerns have become a key set of global challenges in this century (Luczaj, 2016).

Similarly, the exploding number of households settled in the city as well as in its periphery. The rapid urbanization of the city is changing this midtown to a bigger one day by day alongside the development of industries. Entirely, these have initiated a prospective threat to the resources, here in case, the groundwater. The multi-effects of population growth and huge utilization of groundwater have triggered broad exhaustion and corruption of groundwater assets (Amiri *et al.*, 2014). Inefficient monitoring of industrial and household waste has led to a decline in the quality of the water. Hence, assessment the groundwater quality is imperative (Asadi *et al.,* 2019). A conventional assessment of groundwater quality is straightforward but requires a step-by-step process with consideration of the individual parameters (Mohebbi *et al.,* 2013). Overuse of the groundwater sources, inappropriate maintenance of drainage systems has led to change in the basic properties of the groundwater. Additionally, the quality of groundwater is just as important as its quantity which depends on the consultation propose such as drinking, industries, and irrigation. In the past 50 years, exploded populations have required more food and water and the rate of spending has increased dramatically. The natural, physical, and complex state of water, as well as any adjustments that may have been caused by anthropogenic intervention, are defined as water quality (Asadi *et al.,* 2020). The quality of groundwater is established to investigate its physical, biological, and chemical properties e.g. an evaluation of chemical compounds and bacteriological microbes is necessary to ensure if the quality of the water is safe to the users or not.

Presently, over 25 million people have been infected by Covid-19 in India (mohfw.gov.in) which can be the main path of this virus to the groundwater as humans are the source of bacteria such as Coliform in groundwater. The pandemic can affect the water bodies namely groundwater positively and negatively. The positive impact is that the majority of effluents that were previously discharged into the surface water mainly rivers especially Panchganga in Kolhapur, which is one of the most important recharge sources of the city`s groundwater is stopped now and it will reduce the chemical pollution insignificant amount. Secondly, the adverse effect of the Covid is its spreading into the groundwater from the human as same as the Coliform and another microbe that contaminate the water (Huo, 2021). Water, sanitation, and hygiene have a key role in the transmission of Covid-19 via the fecal-oral route, especially in low-income countries (Ramady *et al.,* 2020). As humans are the source of coliform into water mainly groundwater due to seepage similarly infected people with Covid-19 can be the source of this virus to the groundwater. Covid-19 dissemination is currently based on respiratory and contact transmission; however, a faecal-oral route for SARS-CoV-2 transfer from the human gut to feces and wastewater has been proposed (Bhatt *et al.,* 2020; Gwenzi, 2021). This will be an alarming warning and threat for the cities and rural where their only water source is groundwater. Moreover, this condition will make it very difficult to avoid the Covid spreading to save lives. The sewages from hospitals where Covid-19 patients are kept, added a new environmental challenging issue worldwide.

In terms of analysis methods of groundwater evaluation, the GIS tool, and Water Quality Index have now become very useful tools not to collect the data, but to interpret them in the form of thematic presentation of a map or table of the study area. In recent years, groundwater quality has been assessed and monitored regularly utilizing a Geographic Information System (GIS) methodology combined with the Inverse Distance Weighted (IDW) interpolation method, which has shown to be a strong tool for assessing and analysing spatial data of water resources (Kamble *et al.,* 2020). The use of spatially distributed maps for parameters is considered to be represented for policymakers who can decide with regards to remediation and management Ahn and Chon (1999) two Koreans have attempted to establish the relationship between the constituents of groundwater investigated and the sources of pollution by constructing spatial data layers using GIS in the Asan and Gurogu areas of their country. From the GIS studies, it was concluded that the man activities such as industrial and agricultural, and weak management have led the groundwater sources in the study area to pollution. Spatial studies have also helped for effective groundwater quality management. Makki *et al.,* (2021) did a study on the assessment of groundwater quality for drinking, and irrigation purposes in central Iraq, based on an integrated analysis of Physico-chemical parameters and use of Geographic Information System (GIS). The Water Quality Index (WQI) is a valuable and unique evaluation that summarizes the overall status of water quality in a single phrase and assists in the selection of appropriate treatment solutions to solve the issues (Tyagi *et al.,* 2021). The WQI model has been used across the world to assess water quality surface and groundwater using local water quality standards. It has been a popular tool because of its generalized form and ease of use since its invention in the 1960s. Commonly, WQI models involve four consecutive stages; these are (1) selection of the water quality parameters, (2) for each parameter, the creation of sub-indices (3) the weighting values for the parameters, and (4) the aggregation of sub-indices to compute the overall water quality index (Uddin *et al.,* 2021). Vij (2021) studied to quantify the rate of declining water quality and to offer information about the main parameters impacting it by calculating WQI for 117 groundwater samples taken from five districts in Uttarakhand. The at hand, study is targeted, to evaluate Kolhapur`s city groundwater quality with the help of Geographical Information System and Water Quality Index, during the Covid-19 pandemic, to find out the certain amount of pollutants, and exceeded parameters compared to standards, especially the microbial contaminants for finding out relationship with Covid-19 pathway which is generally scrutinized as burdensome to detect and hard to resolve.

2. Study area:

Kolhapur, India is the research area in question. The city is located between the latitudes of 16.70 N and 74.220 E. It has a surface area of 8254.7 km^2. The temperature is usually constant between 10 and 35 degrees Celsius. Because of its proximity to the Western Ghats, the city receives a lot of rain from June to September. The average annual rainfall is 1025 mm, while the relative humidity in the environment is 55%. From November until February, Kolhapur experiences winter. As per 2011, the city population is 5, 49,283 (KMC ESR 2015-2016). Panchganga, Warna, Dudhganga, Bhogavati, Vedganga are the main rivers that flow towards the Western Ghats.

2.1. Climate:

Kolhapur has a moderate climate, though the western section of the city, near the Sahayadri, has a colder climate. Hot weather occurs from March to May, wet weather occurs from June to October, and cold weather occurs from November to February. The average temperature is around 27°C. Kolhapur's average rainfall is 1200 mm, however it varies greatly around the district, ranging from 600 mm to 6000 mm with 65 wet days. The relative humidity is at 55%. The majority of the district's locations are between 390 and 600 meters above sea level.

2.2. Geomorphology:

Kolhapur, also known as Karvir, is one of the oldest towns in India, with a history spanning over 2000 years. In terms of geology, it is the Deccan plateau, with black and red soil and basaltic rock. The city is currently becoming a hub for a variety of activities. Each year, the importance of the city is drawn from its political connection, commercial, religious, cultural, tourist, and educational centers to development. From a different point of view, Kolhapur is going on a rapid civilization. The district has 12 towns, 1203 villages spread over 12 Tahsils. Karvir Taluka has 128 villages situated in the tahsils. Kolhapur city has 5 administrative wards viz; A, B, C, D, and E (Fig. 1).

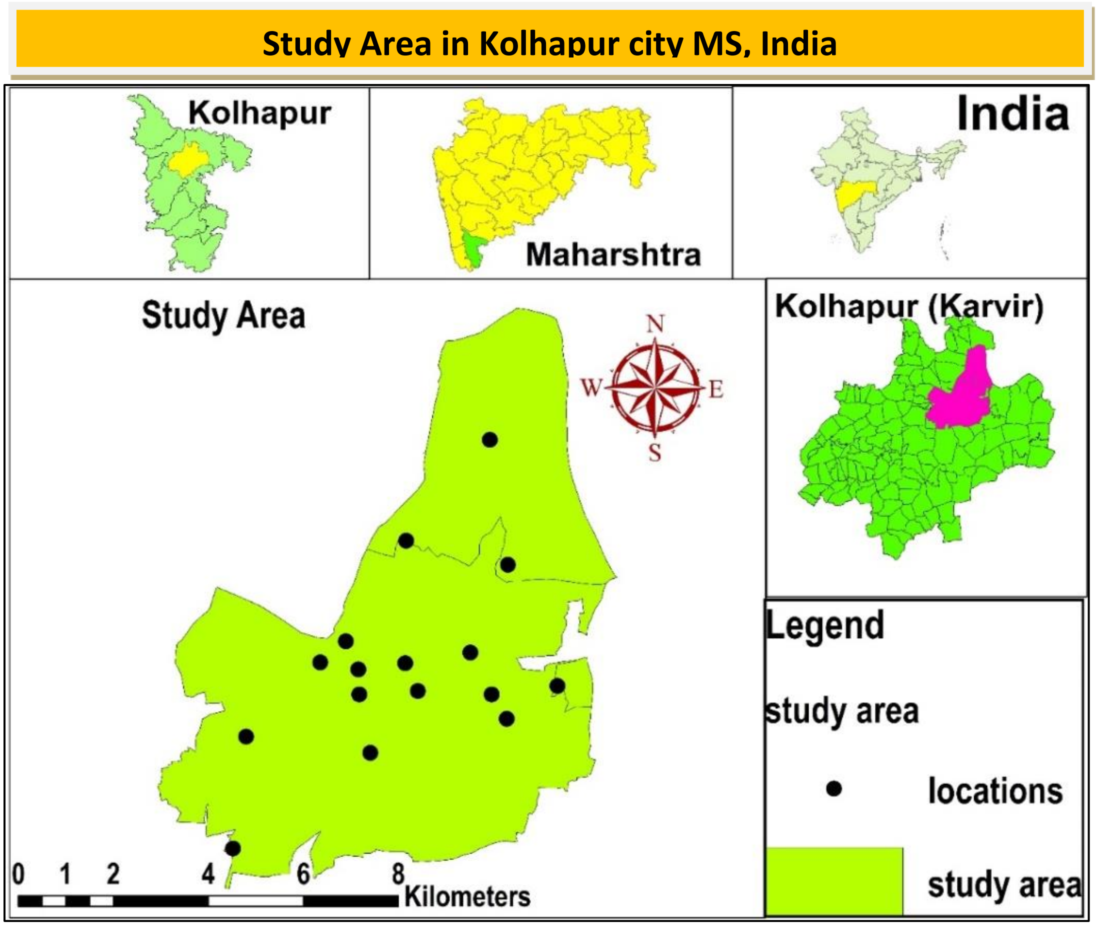
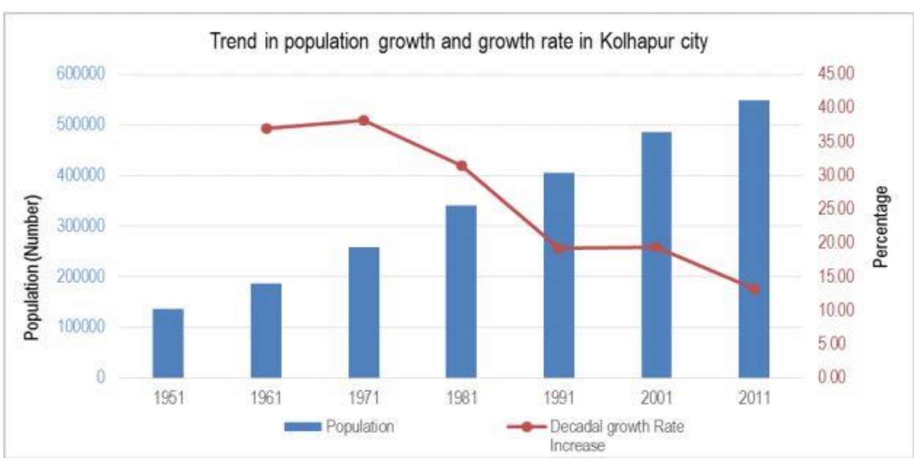


Figure 1. Map of the Study Area

As Environmental Status Report (ESR) by Kolhapur Municipal Corporation (KMC) in 2011-2012, the population growth is increasing. This growth runs all-natural resources towards a very huge pressure which one of the most important of them is groundwater. ESR represents the rate of population growth over 30 % from 1951 to 2011 (Graph 1). Apart from the water supply by Kolhapur Municipal Corporation (KMC), the residents of the city partially depend on groundwater as their alternative source.



Graph No. 1 Kolhapur city Population Growth (KMC, ESR 2011-2012)

3. METHODOLOGY

3.1. Sampling frequency

Groundwater sampling was done for an almost long period of 7 months i.e. once a month from. There were 16 sites under the study, which covered nearly all five wards.

3.2. Collection of groundwater samples

Groundwater samples were collected from bore wells and Government hand pumps as well as private or owned bore wells. Pre sterilized polythene bottles were used for the collection of samples each month. Samples were analyzed for elements like Calcium, Magnesium, Sodium, and Potassium as well as Physico-chemical parameters such as pH, Acidity, Alkalinity, Total Dissolved Solids (TDS), Hardness, Nitrate, Chlorides, and a Microbiological parameter i.e. Most Probable Number (MPN) for detection of coliform.

3.3 Instruments

Flame Photometer is used for determination of Sodium and Potassium, UV-Visible Spectrophotometer is used for Nitrate, calculation and titrimetric are also used for determination of another parameter (NEERI & NICD, 2009, APHA, 1998).

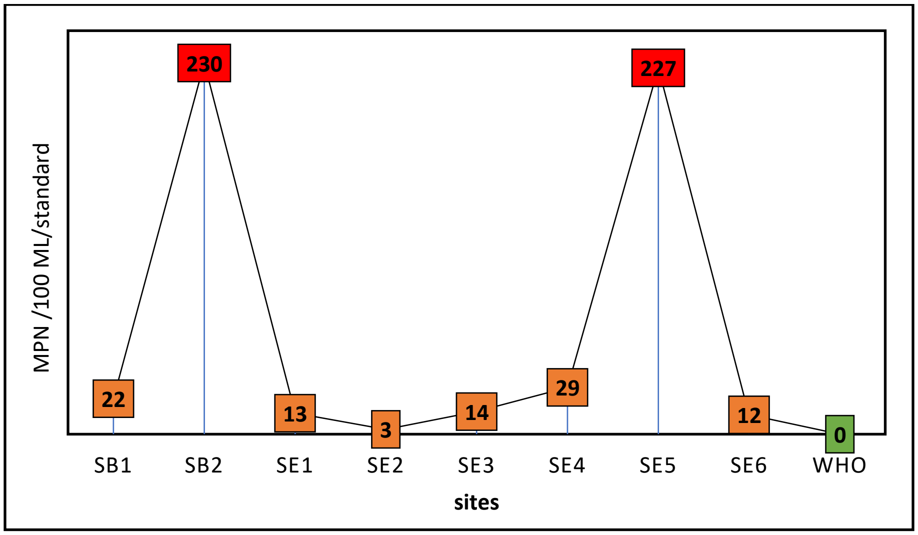
4. Results and Discussion

The obtained analyzed results from parameters of groundwater during Covid-19 in Kolhapur city represent that, certain parameters exceeded the standard limits for drinking as compare to standard limits (WHO, 2011). However, still some parameters do not exceed the limits of standards. In consideration of the overall average values of the parameters studied, certain conclusions or results can be discussed.

The pH of water is a key characteristic of its quality. The pH of water indicates its appropriateness for different uses, such as animal and plant toxicity, acidity, and alkalinity. The geology of the catchment region and the buffering capabilities of water both influence the pH of water. The pH of a solution is the intensity of its alkaline or acid condition. Due to the presence of carbonates and bicarbonates, the majority of the waters are alkaline (Baniya *et al.*, 2021). The overall pH of the sites in the A ward is 7.4 which indicates the groundwater is nearly neutral. As a point-to-point comparison in the city with standards, SE2 in the E ward which is a bore well has the maximum level of pH while another one SE1 in the same ward showed the minimum value of pH (Graph 2). Overall, there is a slight fluctuation in pH readings which is within the permissible limits (WHO, 2011).

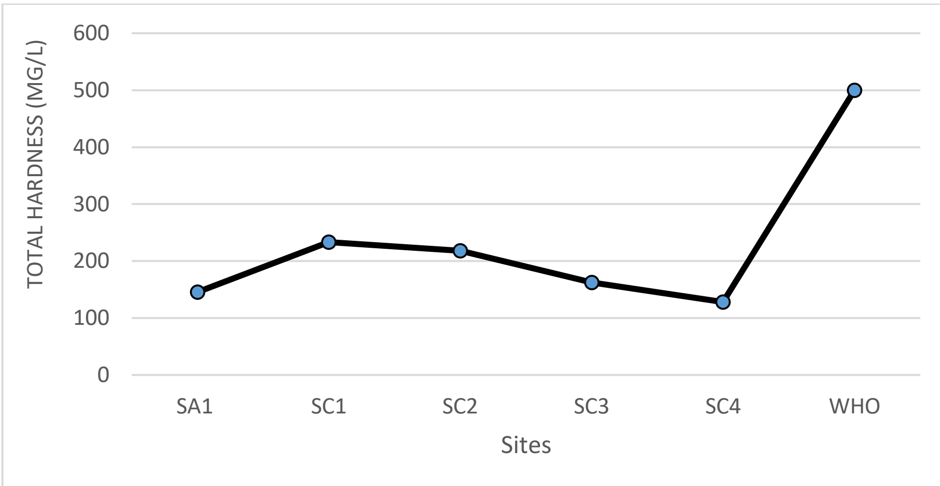
Graph No. 2 pH of Groundwater from A and E wards of Kolhapur city

The presence of Pathogenic Organisms is one of the most important aspects to consider when evaluating the water's appropriateness for various purposes, including drinking. In general, when considering water quality from the standpoint of public health, this criterion is always at the top of the list. If fecal pollution enters groundwater; likely, coliform bacteria will also be present as they are the source. Animals, including humans, are the primary hosts of coliforms in normal digestive systems, and they are present in their feces, as well as soil debris (Williams, 2014). From point-to-point comparison in the city with standards, the analyzed samples in B and E wards i.e. wells SB2 and SE5 respectively showed high values of MPN, (Graph 3). In both B and E wards, coliform bacteria passed the WHO limit which is 0 per 100ml of drinking water (WHO, 2006). The presence of the bacteria in water, a human-based source increases the spreading possibility of coronavirus from the same pathway (Huo, 2021).



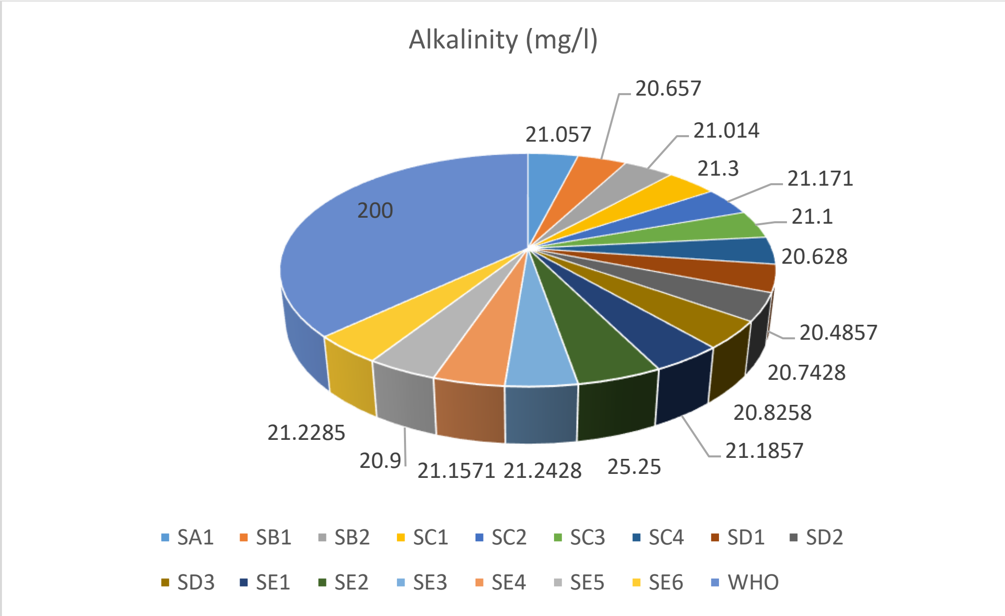
Graph No. 3 MPN of groundwater from B and E wards of Kolhapur city

Water containing Hardness concentration up to 60 mg/lit is called 'soft' water and those containing 120-180 mg/lit as 'hard' water. The presence of divalent metallic cations Ca^{2+} and Mg^{2+} in water causes water Hardness, which may be computed as the sum of Ca^{2+} and Mg^{2+} concentrations in mg/l corresponding to CaCO3 (Singh *et al.*, 2021). As a point-to-point comparison in the city with standards, the Hardness value at C ward SC1 makes the maximum reading as compared to A ward and other locations of C ward, while SC4 is far from SC1, but in the same ward makes the minimum value. As per (Graph 4) all samples are between 128.14-233.085 mg/l which consider as hard water. Meanwhile, all samples from A and C wards are within the limits as per the WHO guidelines WHO, (2011).



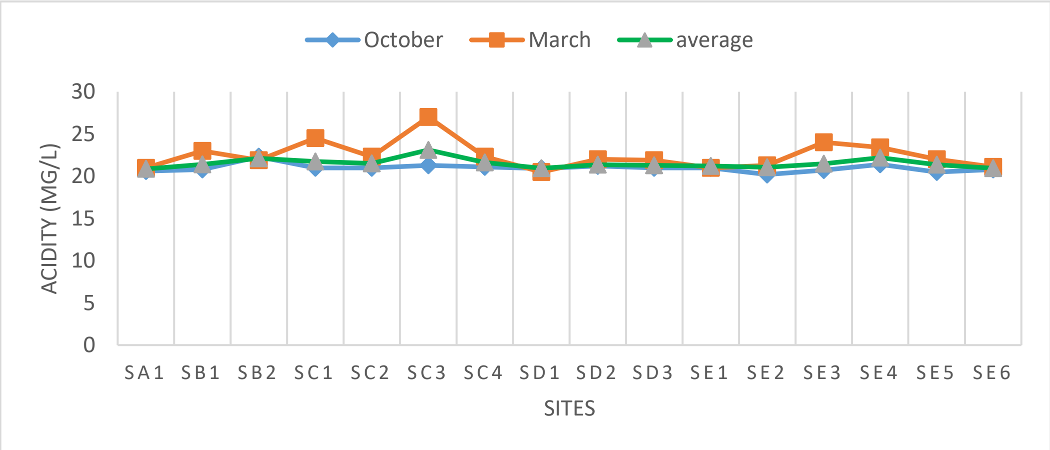
Graph No. 4 Hardness of Groundwater in A and C wards of Kolhapur city

Alkalinity is the capacity of neutralization of acidic water. The primary contributors to Alkalinity are carbonates and bicarbonates, phosphates, and nitrates. It illustrates the buffering capacities of water; high Alkalinity levels indicate the entropic nature of the water bodies, which also may be accompanied by objectionable taste, as well as unsafe potable use (EPA, 2006). Alkaline Electrolyzed Water (AEW) equipment has been authorized as a medicinal device in Japan. Drinking AEW has also been reported to be useful in easing gastrointestinal symptoms in people with gastrointestinal complaints. However, some AEW users do not have indefinite abdominal pain (Tanaka *et al.,* 2019). Normal Alkalinity of water is ranging from 20 to 200 mg/lit where all 16 selected sites were within the limits of WHO i.e. 200 mg/l. Maximum average Alkalinity was highest at E ward SE2, SE3, and SE4 orderly. The minimum values of Alkalinity were reported from the D ward SD3 and SD1. In unpolluted water, Alkalinity is firstly a measure of dissolved bicarbonate and carbonate; concentrations of them are much more than other acid-consuming solutes such as hydroxide, silicate, borate, and dissolved organic compounds (Graph 5).



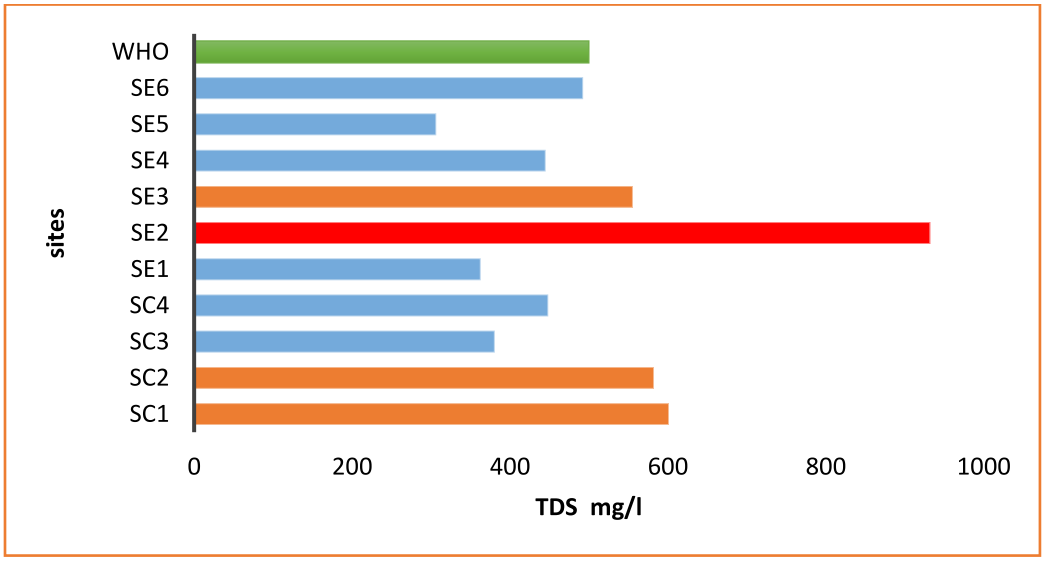
Graph No. 5 Alkalinity of groundwater in 16 sites of Kolhapur city

Acidity to the water is contributed by the strong mineral acids. But generally, non-polluted water has pH due to the presence of free carbon dioxide which is in the form of carbonic acid. The Acidity of water is the quantitative capacity for reacting to a strong alkaline with a designated pH. Acidity is caused by dissolved carbon dioxide, dissolved multivalent metal ions, strong mineral acids like sulfuric, nitric, and hydrochloric acids, and weak organic acids like acetic acid (EPA, 2006). The study discussed only two considerable months March which makes the maximum and October which makes the minimum reading is compared to an average of all 7 months in all sampling locations. Acidity values in selected points are ranging from 20.157 to 24.000 (mg/lit). Observations showed that Acidity values were maximum in SC3 of C ward of the city at 23.114 mg/l and minimum 20.157 mg/l in SA1 A ward according to average, and maximum in SC1 during March, minimum in SE4 during October (Graph 6).



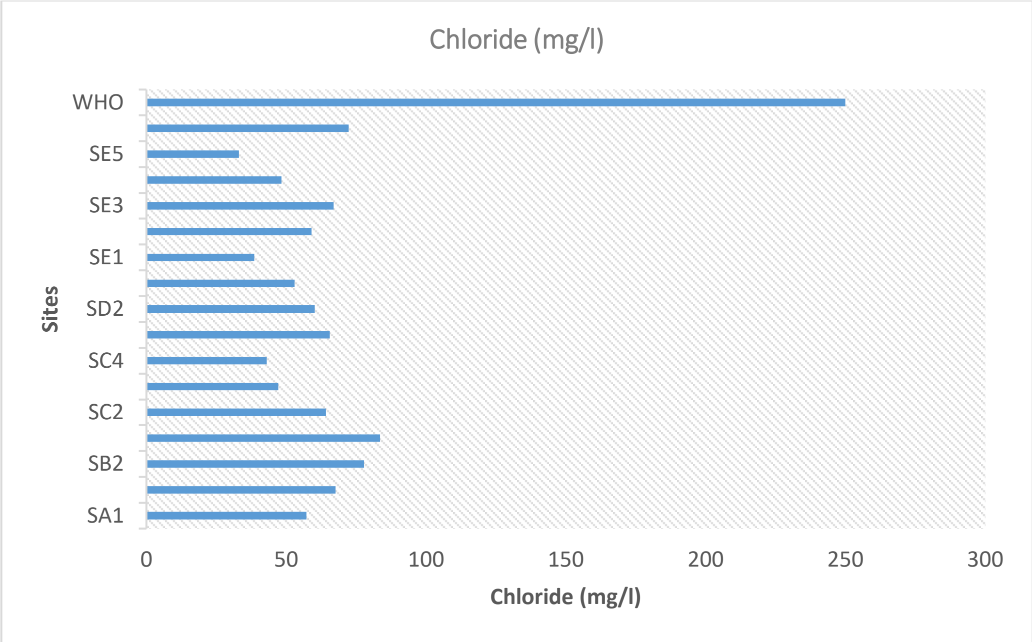
Graph No. 6 Average and monthly (minimum and maximum) Acidity of groundwater in 16 sites of Kolhapur city

The presence of Solids in water can be divided into three groups: major constituents, minor constituents, and trace elements. When groundwater travels via its flow routes in the saturated zone, TDS and most of the major ions are generally increased (Allan *et al.*, 1979). High TDS levels in groundwater can affect those with kidney and cardiac issues, while high-solid water might cause laxative or constipation effects (Senthilnathan *et al.*, 2011). More cations and anions in the water mean a higher TDS. From point-to-point comparison in the city with standards, (Graph 7) represented the wards where the limits of TDS values as compare to WHO standard limit 500 mg/l are exceeded. The study revealed that the amount of TDS is at an alarming rate at E ward in SE2 above 932 mg/l. furthermore, values passed the limits at the C ward too, which indicates the presence of contaminated groundwater.



Graph No. 7 TDS of Groundwater in E and C wards of Kolhapur City

Groundwater contains Chloride as a result of the weathering of the rocks through which it flows. It's one of the most common inorganic anions found in a lot of groundwater. Sodium Chloride (NaCl), potassium chloride (KCl), and calcium Chloride are all examples of Chloride (Mullaney *et al.*, 2009). Road salt is recognized to be a major source of Chloride in the environment; little study has been done on the environmental effects of Chloride emitted by water softeners, especially in locations where the water is hard (Overbo *et al.*, 2021). The salty taste of the water sometimes is due to the presence of Chlorides in large amounts in presence of Sodium cation. Chlorides observed during September to March 2020-2021 were in the range of 33.06 – 83.5 mg/l. Chlorides show maximum values in SC1 at C ward nearly to 84 mg/l, while SE5 with 33.06 mg/l makes the minimum values of Chloride among all the samples. In addition, the whole selected samples are within the limit of WHO 250 mg/l (Graph 8).



Graph No. 8 Chloride of groundwater in 16 sites of Kolhapur city

Electrical Conductivity is a test that determines a solution's capacity to conduct electricity. It is proportional to the ion concentration in the solution is a direct relationship (Foster, 1998). The EC value varies from 93 to 2022 µS/cm in January, and it varies from 82 to 2163 µS/cm during June in Muttom to Mandaikkadu coastal zone located within the Kanyakumari district in the southern part of Tamil Nadu (Stanly *et al.*, 2021). The results of EC which are observed from the related temperature of the samples revealed that SC2 and SC1 located in the C ward make the maximum values at 1402.477 and 1372.413 µS/cm respectively, as well as SA1, SD2, SD3, SE3, SE4, and SE6 make the higher values in different wards. In contrast, SC3, SE1, and SE5 showed the lowest values of Electrical Conductivity. As a result, the Electrical Conductivity exceeded the WHO limit in the A, C, D, and E wards of the city in eight points (Figure 2).

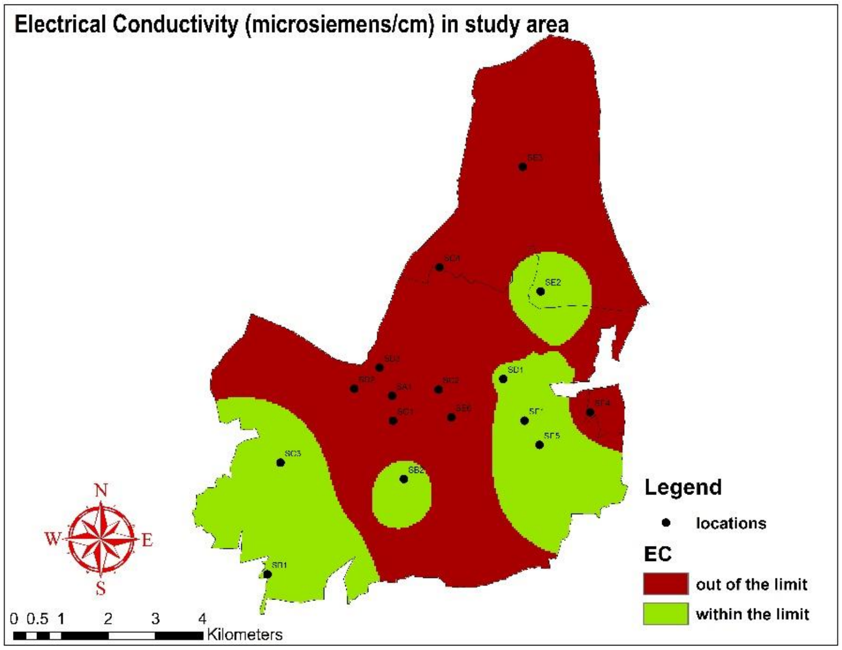
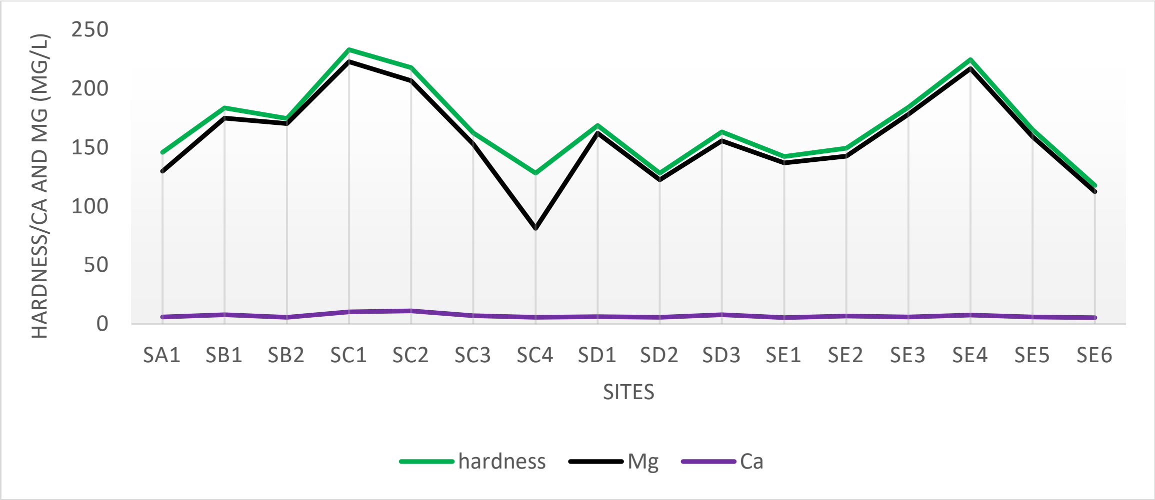


Figure 2 Electrical Conductivity (EC) of groundwater in 16 sites of Kolhapur city

Hardness (Calcium and Magnesium) is a very stable property of water that stays relatively consistent throughout time. Ions such as Ca, Mg, and HCO3 are added to groundwater when it passes through subterranean deposits (Singh *et al.*, 2021). The development of froth when these ions mix with soap molecules affects whether the water is hard or soft. Many studies have mentioned a negative association between blood pressure and Calcium and Magnesium levels. Ca hardness is lower as compare to Mg for water hardness. Magnesium in groundwater also contributes majorly to the Hardness of the water. It is available in abundance as that of Calcium in groundwater too. Sometimes the undesirable taste of water is because of the presence of Mg. water Hardness is also happening by Magnesium. It was obtained by calculation method by using the following formula (APHA, 1998).

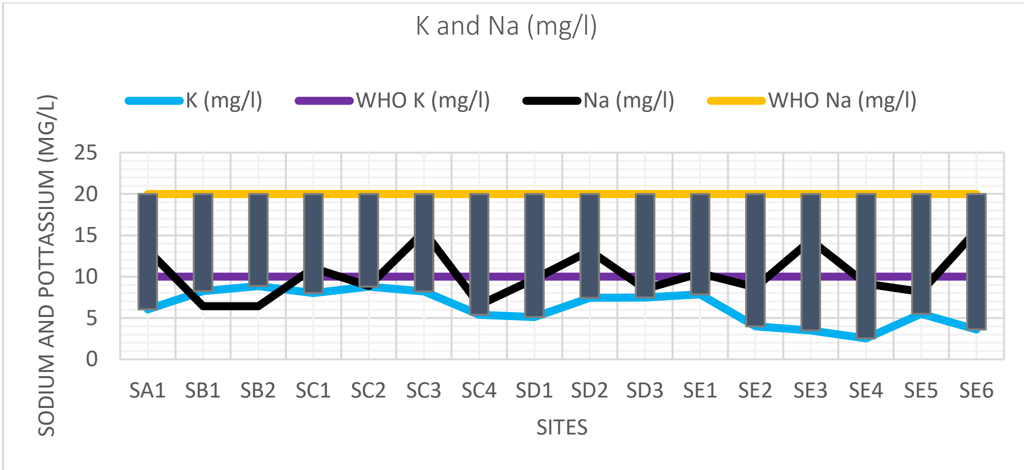
Mg hardness mg/l = Total Hardness as CaCO3 – Ca hardness as CaCO3

The maximum Calcium and Magnesium are recorded in SC2 and SE4 respectively in C and E wards, while the maximum hardness is shown in SC2 in the C ward related to a max of Calcium at the same location. In opposite, SE6 at E ward indicates the minimum amount of Calcium, and SD3, SC4 points in D and C wards illustrate a respective minimum amount for Magnesium and hardness (Graph 9).



Graph No. 9 A comparison of Total Hardness, Ca, and Mg of groundwater in 16 sites of Kolhapur city

Unlike, other parameters Potassium and Sodium presence are essential for drinking purposes. For this reason, nowadays in some drinking water plans a process which is called remineralization is done after Reverse Osmosis (RO) system to add these two important minerals (wqa.org/sitelogic.cfm) Potassium ions enter into the groundwater through Potassium-bearing minerals such as feldspar. Its content in most drinking water rarely exceeds 100 milligrams per liter. Potassium works as nutrition for both plants and humans and occurs in groundwater as a result of mineral dissolution. There is a negative relationship between deficiency of Na and K and muscle weakness and blood pressure (Institute of Medicine, 2005). The accepted limit by WHO is 10 mg/l for Potassium, while SB2 in B makes the maximum and SE4 makes in E ward makes the minimum values of Potassium. The presence of Sodium in total cations is essential in agriculture and human pathology. In the present study, the maximum values of Na are recorded SE6 at E ward while the minimum value is in SB1 and SB2 at B ward. All selected samples of both minerals are within the limits (Graph 10).



Graph No.10 Comparison of Na, and K of groundwater with their standards in 16 sites of Kolhapur city

Table No. 1 Ward wise average of groundwater parameters in the selected areas of Kolhapur city

parameters	Unite	wards					WHO
		A	B	C	D	E	
pH		7.48 ±0.520	6.99 ±0.331	7.21 ±0.329	7.08 ±0.259	7.29 ±0.424	6.5-6.8
Alkalinity	mg/l	21.057 ±0.820	20.835 ±0.709	21.05 ±0.771	20.685 ±0.479	25.528 ±28.845	200
Acidity	mg/l	20.857 ±0.475	21.75 ±1.060	22.001 ±1.634	21.2 ±0.4	21.373 ±0.933	No guidelines
Total Hardness	mg/l	145.8 ±3.196	179.1 ±4.180	185.4 ±3.394	153.4 ±2.028	163.9 ±2.930	500
TDS	mg/l	518 ±49.675	411.925 ±61.279	503.29 ±107.417	496.043 ±38.407	426.065 ±106.839	500
MPN	per 100 ml	55.85 ±119.047	125.69 ±395.67	24.034 ±54.169	12.35 ±9.211	49.35 ±230.319	0/100 ml
Chloride	mg/l	57.2 ±1.127	72.7 ±2.916	59.5 ±1.734	59.63 ±1.26	53.05 ±1.983	250
Calcium	mg/l	5.9 ±2.894	6.807 ±2.943	8.583 ±3.501	6.661 ±2.027	6.176 ±1.986	20
Magnesium	mg/l	1.7 ±2.045	2.242 ±2.2	2.369 ±2.585	1.121 ±1.454	2.172 ±2.439	10
EC (microsiemens/cm)	microsiemens /cm	1126.6 ± 51.077	869.4 ± 130.408	1144.1 ± 253.718	1076.03 ± 103.711	994.8 ±1 95.781	1000
Nitrate	mg/l	263.88 ± 0.268	157.1 ± 0.534	244.25 ±0.528	314.07 ±0.479	186.54 ±0.307	10
Sodium	mg/l	13.201 ±0.198	6.426 ±0.045	10.477 ±0.147	10.454 ±0.107	11.071 ±0.117	20
Potassium	mg/l	6.024 ±0.147	8.543 ±0.243	7.596 ±0.22	6.667 ±0.165	4.497 ±0.207	10

Taking the overall mean of the pH of all the groundwater samples into account, no locations exceeded the WHO guideline and were found to be within acceptable levels. Comparatively A and

E wards showed high pH than other wards (Fig. 3). Generally, the pH of the groundwater depends on the surrounding geological structure. Although there is no direct impact of the pH on consumers, still it is one of the most important operational water quality parameters (WHO, 2006). But groundwater with low pH can cause gastrointestinal disorder and this water cannot be used for drinking purposes.

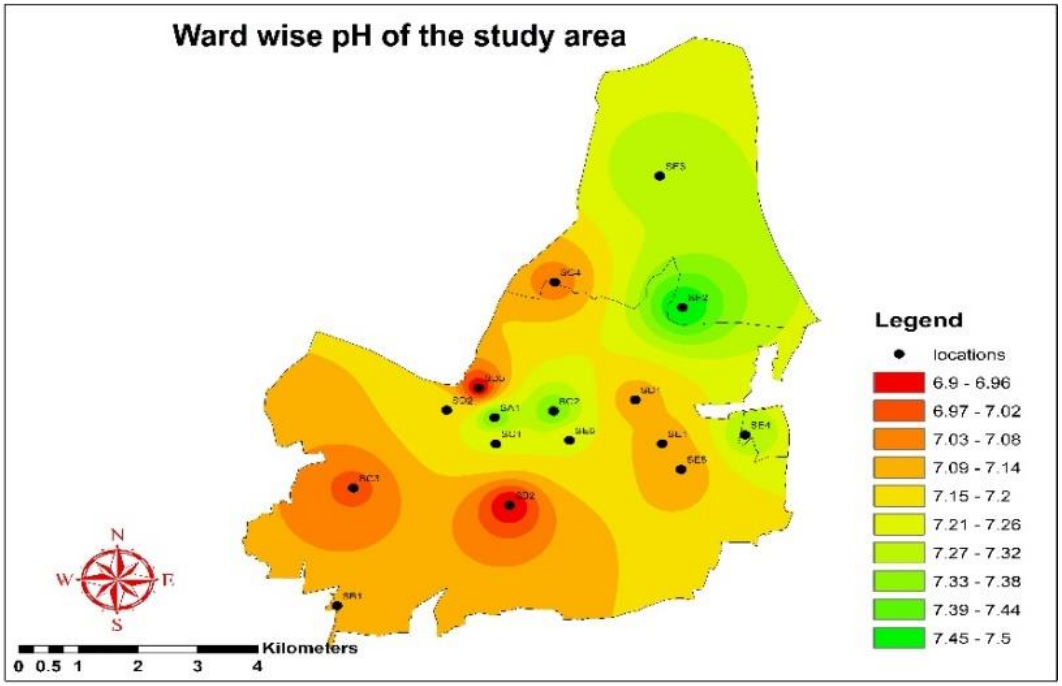
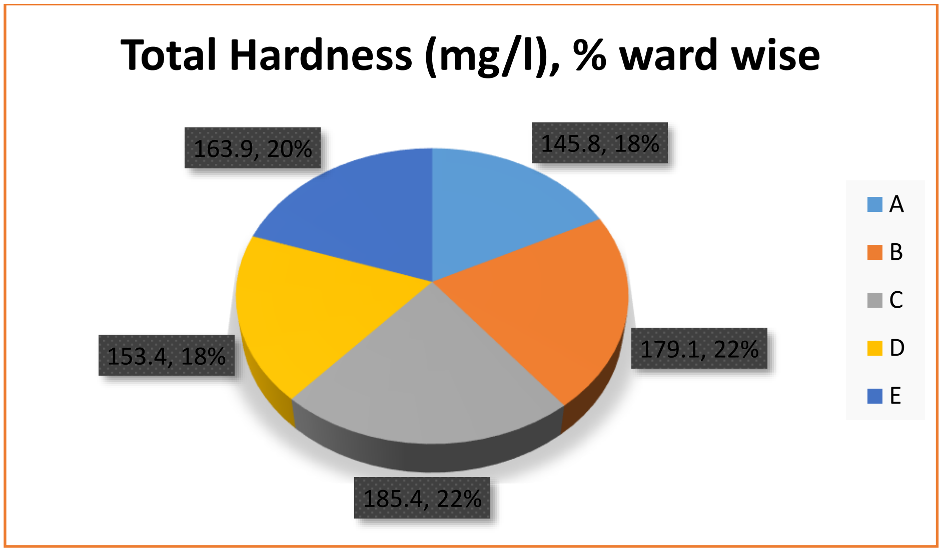


Figure 3 Ward wise pH of groundwater in Kolhapur city

Ions such as Ca, Mg, and HCO3 are added to groundwater when it passes through subterranean deposits. The development of froth when these ions mix with soap molecules affects whether the water is hard or soft. The average Hardness of ward wise ranges from 7.6 to 9.685 mg/l. Groundwater samples from the C and B wards each with 22%, showed high Hardness (Graph 11). A high Hardness reading could result from high Magnesium concentrations with little or no Calcium present (Wurts, 1993). In the case of utilization of drinking water Hardness is a very influencing factor. Even water-storing utensils get affected by the appearance of white spots on them. However, 500 mg/l is a tolerance for consumers, but there is no mention of any health effects by WHO due to consuming hard water.



Graph No. 11 Ward wise Total Hardness of groundwater in Kolhapur city

A high value of TDS may result in the reduction of water utility for drinking purposes (WHO, 1996). In the present study, the TDS values range from 411.9 mg/l to 518 mg/l (Fig. 4). Ward A indicated exceeding the limit, while B ward makes the minimum value of TDS of the whole city. TDS levels are essential in influencing how water is used, and groundwater with high TDS levels is unsuitable for both irrigation and drinking (Davis *et al.*, 1996).

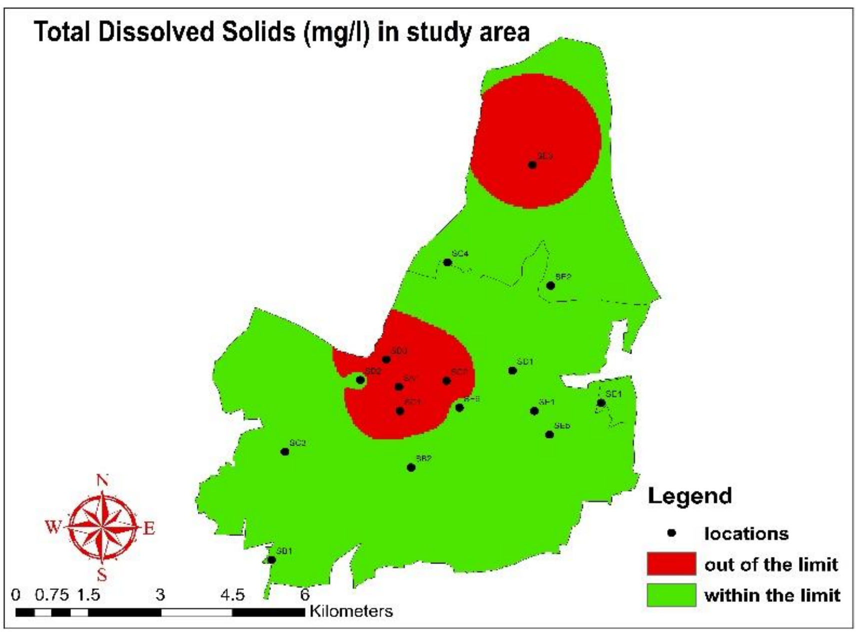


Figure 4 Ward Wise Total Dissolve Solid (TDS) of groundwater in Kolhapur city

Unfortunately, all of the samples showed significantly high values of MPN (Fig. 5) and crossed the WHO (0/100 ml) in a very alarming way. This is because septic tanks are commonly used in metropolitan areas to dispose of human waste and other types of wastewater (Krzysztof, 2008). While the geology subsurface operates as the finest filter of water and is always regarded safe from biological pollution, seepage from poor municipal sewage systems has caused its characteristics to alter (Joy *et al.*, 1994). Lack of canalization for human fecal matters is one of the main sources of groundwater pollution observed widely in the present study area. B ward showed very high values as compared to other wards.

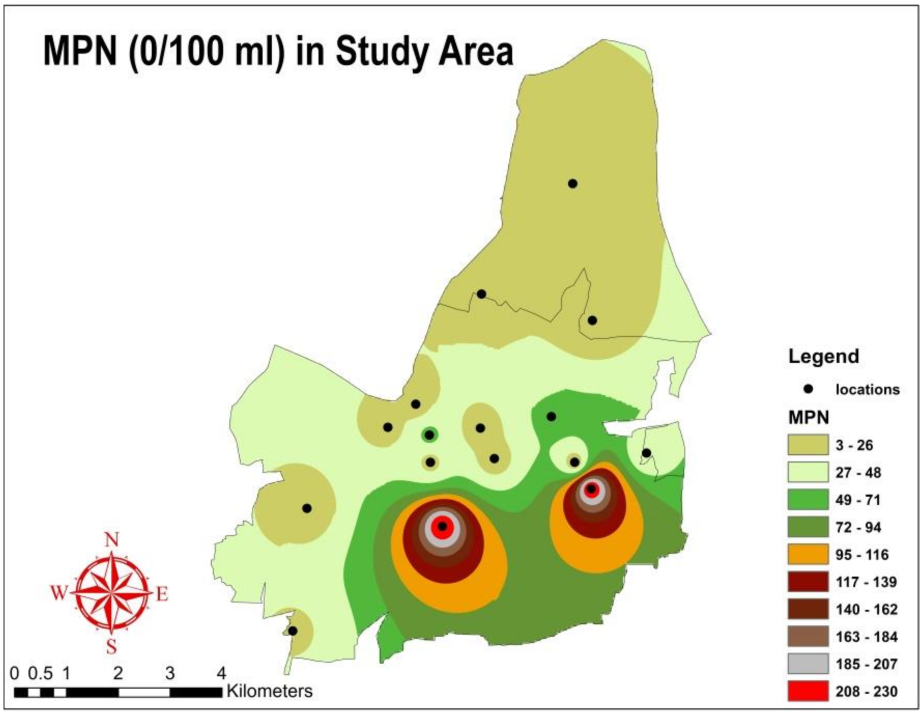


Figure 5 Ward wise MPN of groundwater in Kolhapur city

Nitrate is the significant oxidized form of nitrogen compounds generally present in natural waters. Long-term exposure to high Nitrate concentrations, on the other hand, can cause major health problems in children, such as methemoglobinemia (commonly known as blue baby syndrome) and stomach cancer in adults (Abdur Rahman *et al.,* 2021). One of the major reasons for excessive Nitrate in groundwater is the overuse of nitrogenous fertilizers in agriculture (Arora, 1980). As per the study result, all the samples highly crossed the limits of EPA especially SD3, SC2 in D and C wards for drinking purposes (Fig.6).

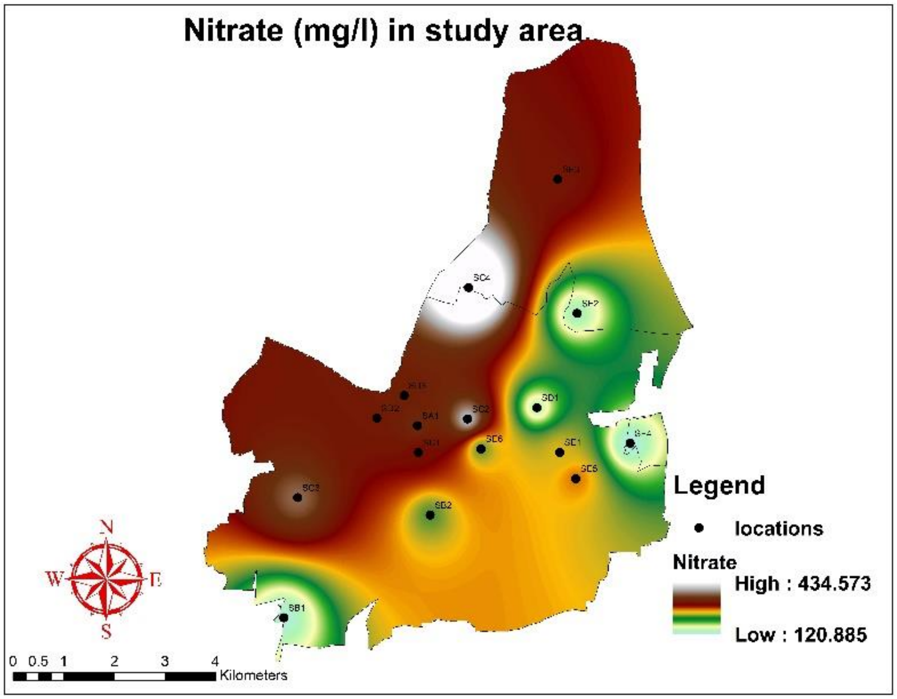


Figure 6 Ward wise Nitrate of groundwater in Kolhapur city

4.1. Physico-Chemical Correlation of groundwater parameters:

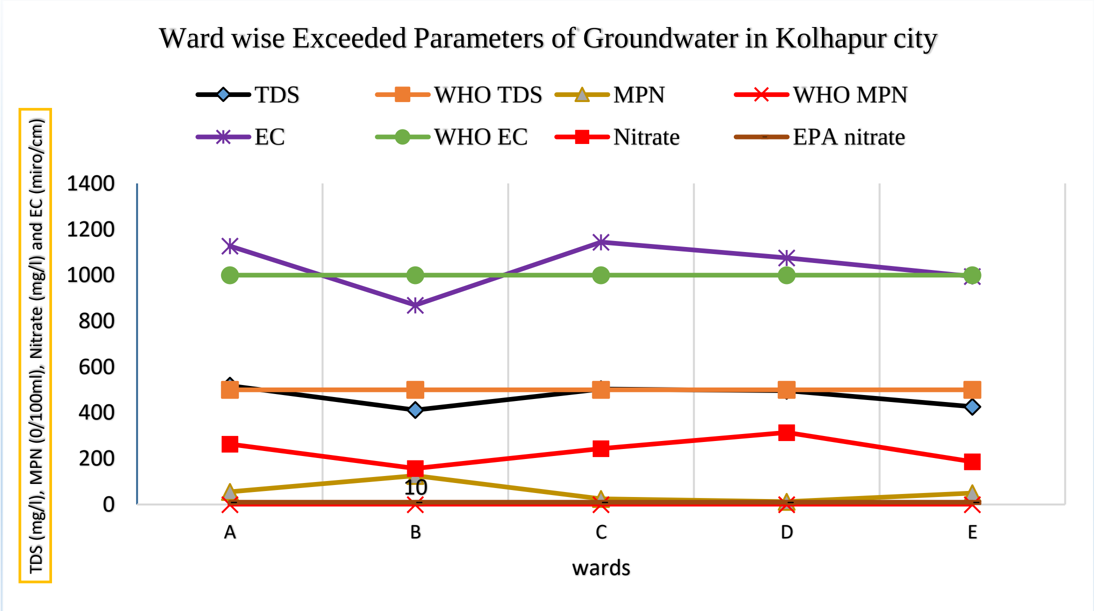
The Correlation Coefficient Matrix may be used to analyze the Correlation between the different variables based on the Physico-Chemical data. Correlation studies help forecast one parameter based on its connection with another. A strong correlation is defined as a correlation of greater than 0.5, whereas a weak or bad correlation is defined as a Correlation of less than 0.5. Table No. 2 demonstrates the overall matrices for the current investigation. The table shows both strong and weak correlations between several geochemical metrics. Total Hardness and Magnesium have been found to have a strong link to EC and TDS. Because increasing, hardness, alkalinity, and conductivity of the tested water sample are directly connected and impacted by increased TDS of water, it is regarded as the most essential characteristic to assess the quality of a water sample (Kothari *et al.*, 2021). Calcium ($r = 0.53$) and Magnesium ($r = 0.73$), respectively, were shown to have a significant association with Total Hardness. Ca^{2+} and Mg^{2+} both contribute a considerable amount to overall Hardness when coupled with other cations, showing that they come from the same source such as limestone and gypsum. Ca^{2+} ($r = 0.38$), Mg^{2+} ($r = 0.14$), and Cl- ($r = 0.16$) all have a positive association with potassium. The degree of hardness of a water sample is determined by measuring bicarbonates, carbonates, sulfates, and calcium and magnesium chlorides dissolved in water (Kothari *et al.*, 2021). The connection between Sodium and Nitrate ($r = 0.39$) suggests that both variables have a similar source of pollution, which is most likely connected to municipal, animal, or industrial waste.

Table No. 2 Physico-Chemical Correlation of groundwater parameters in the study area in Kolhapur city

Parameters	pH	EC	TA	TH	Ca	Mg	TDS	Acidity	Cl-	Nitrate	Na	K
pH	1											
EC	0.39	1										
TA	0.55	-0.15	1									
TH	0.20	0.39	-0.13	1								
Ca	0.23	0.61	-0.02	0.80	1							
Mg	0.18	0.34	-0.09	0.97	0.73	1						
TDS	0.31	0.91	-0.22	0.34	0.53	0.29	1					
Acidity	-0.36	-0.23	-0.20	0.37	0.23	0.32	-0.22	1				
Cl-	0.06	0.55	0.02	0.32	0.39	0.36	0.63	-0.10	1			
Nitrate	-0.14	0.37	-0.31	0.05	0.26	0.10	0.30	-0.02	0.02	1		
Na	0.19	0.27	-0.12	-0.24	-0.15	-0.15	0.33	0.06	0.12	0.28	1	
K	-0.50	-0.04	-0.29	0.14	0.38	0.14	0.01	0.27	0.16	0.39	-0.22	1

Considering the ward-wise average values, other parameters such as alkalinity, acidity chloride Ca, Na, K and Mg showed values that are within the limits.

The present study indicates some parameters of Kolhapur city groundwater considering ward wise were above the permissible limits of present standards (WHO, 2011; EPA, 2006) (Graph 12). In the below figure three parameters like TDS, MPN, and EC are compared to their standards (WHO, 2011). MPN in all wards, EC in A, C, and D wards, and TDS in A and C wards crossed the limits.



Graph No. 12 Ward wise exceeded parameters of groundwater in Kolhapur city

WQI is used in groundwater studies to classify water as acceptable or unfit for drinking. Because the threat of degrading water quality is rising as a result of urbanization and civilization, monitoring water quality is a great approach to assure its appropriateness for drinking. The Water Quality Index (WQI) is a useful and unique assessment that describes the entire state of water quality in a single phrase and aids in the selection of appropriate treatment options to address the concerns (Tyagi *et al.*, 2021). WQI models typically include four stages: (1) selection of water quality parameters, (2) development of sub-indices for each parameter, and (3) implementation. (3) The parameter weighting values, and (4) the sub-index aggregation to compute the overall water quality index (Uddin *et al.*, 2021). Water Quality Index (WQI) was performed on the obtained data from the study area. It can be concluded that the minority of the sites are good water such as SC4, and SE2. Site SD3 comes under the category "Unfit for Consumption" while the majority of the selected locations come in the poor and very poor categories. None of the sites represented an excellent quality which is the highest quality of WQI (Fig. 7)

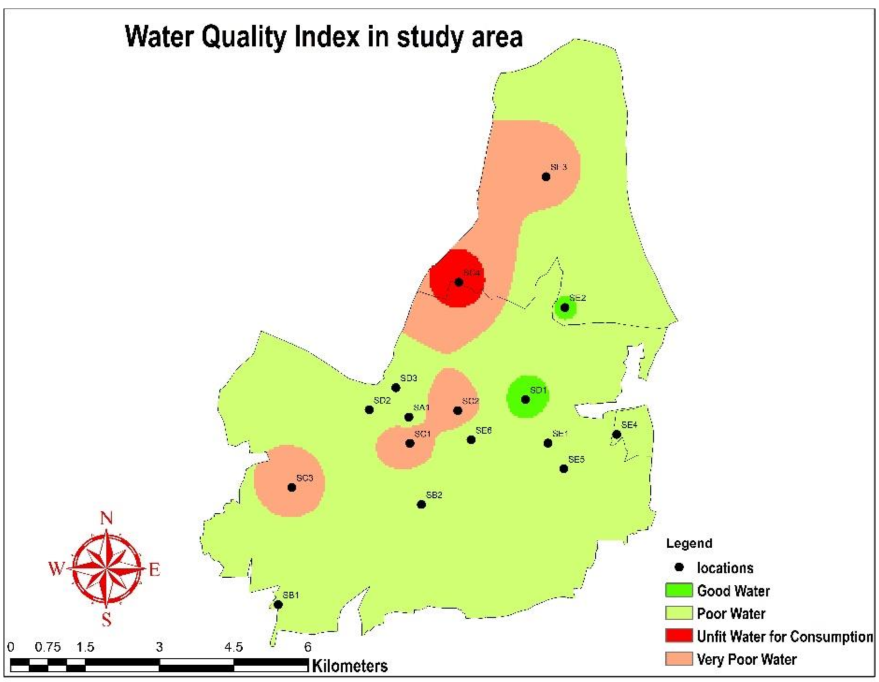


Figure 7 Water Quality Index (WQI) applied in Kolhapur city groundwater

5. CONCLUSION

From the present study, it can be concluded that the subjected groundwater samples` quality, the majority of Physico-chemical parameters were acceptable except a few of them. GIS interpolation (IDW), and WQI results, showed that four parameters included TDS, EC, MPN, and Nitrate exceeded the standards. C ward is heavily polluted due to exceeding of four above parameters and followed by E ward where Nitrate, TDS and MPN surpassed the standards. The coliform test showed positive results in all wards which direct use of water is not advisable in the whole city.

While coliform is observed in all sites, there is the chance of spreading Covid-19 into the groundwater. Similar to coliform Covid also can enter into the groundwater from its human chain. However, it needs more studies, but the initial step must be taken to avoid drinking this water before using RO or any other essential treatment. Also, it is time to make a very quick decision about the hospitals' sewage, especially where provide services for Covid-19 patients or keep them in beds. Luckily, only Reverse Osmosis installation on a community-based can reduce all the four exceeded parameters, so its installation is strongly suggested for drinking purposes.

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REFERENCES

1. Abdur Rahman, N. C. Mondal, K. K. Tiwari, 2021. Anthropogenic nitrate in groundwater and its health risks in the view of background concentration in a semi-arid area of Rajasthan, India, *Scientific Reports*, volume 11, Article number: 9279
2. Ahn Hong-I and Chon Hyo-Taek, 1999. Assessment of Groundwater Contamination Using Geographic Information Systems, *Environmental Geochemistry, and Health*, Vol. 21, pp. 273-289.
3. Allan, F.R., Cherry, J. A. 1979. *Groundwater*: Introduction. Englewood Cliffs, N.J: Prentice-Hall.
4. Amiri, V., Rezaei, M., Sohrabi, N., 2014. Groundwater quality assessment using entropy weighted Water Quality Index (EWQI) in Lenjanat, Iran. *Environ. Earth Sci*, 72, 3479–3490.
5. APHA, American Public Health Association, 1998. Standard Methods for Examination of Water and Wastewater. 20th Edition, American Public Health Association, Washington DC.
6. Arora, R.P., 1980. Fate of fertilizer-N in multiple cropping systems in Soil nitrogen a fertilizer or pollutant, IAEA, Vienna, 3-22,
7. Arunbose, S., Srinivas, Y., Rajkumar, S., Nithya, R., Nair, C., Kaliraj, S., 2021. Remote sensing, GIS, and AHP techniques based investigation of groundwater potential zones in the Karumeniyar river basin, Tamil Nadu, southern India, *Groundwater for Sustainable Development*, Volume 14,100586
8. Asadi, E., Isazadeh, M., Samadianfard, S., Ramli, M.F., Mosavi, A., Nabipour, N, Shamshirband S., Hajnal, E., Hajnal, Chau, K.W., 2019. Groundwater Quality Assessment for Sustainable Drinking and Irrigation. *Environ. Earth Sci*, 12 (177), 1–13.
9. Asadi, S., Isazadeh, M., Samadianfard, S., Ramli, M.F., Mosavi, A., Nabipour, N., Shamshirband, S., Hajnal, E., Chau, K.W., 2020. Groundwater Quality Assessment for Sustainable Drinking and Irrigation, *Sustainability*, 12, 17

10. Baniya, H.B., Guragain, R.P., Panta, G.P., Santosh, D. G., Chhetri, K., Joshi, U.M., Pandey, B. P., Subedi, D.P., 2021. Experimental Studies on Physicochemical Parameters of Water Samples before and after Treatment with a Cold Atmospheric Plasma Jet and its Optical Characterization, *Journal of Chemistry*, Volume, 6638939, pp 1-12
11. Bhatt A, Arora P, Prajapati SK, 2020. Occurrence, fates, and potential treatment approaches for removal of viruses from wastewater: A review with emphasis on SARS-CoV-2. *Journal of Environmental Chemical Engineering*, 8, 104429.
12. Chandrapati, M.G., Williams, 2014. TOTAL VIABLE COUNTS | Most Probable Number (MPN), Encyclopedia of Food Microbiology (Second Edition), Pp 621-624
13. Chatterjee, R. and Purohit, R.R., 2009. Introduction-estimation of replenishable groundwater resources of India and their status of utilization. *General article and current science*. VOL. 96, NO. 12, pp. 1581-1591.
14. Davis S. N., De Wiest R. J. 1966. Hydrogeology. New York: Wiley.
15. El-Ramady, H. R., Brevik, E. C., Eid, Y., (2020), New Pollution Challenges in Groundwater and Wastewater Due to COVID-19, *Journal of Sustainable Agricultural Science,* Vol. 46, No. 4. pp 61-73
16. Elumalai, V., Nethononda, V.G., Manivannan, V., Rajmohan, N., Li P., Elango, L., 2020. Groundwater quality assessment and application of multivariate statistical analysis in Luvuvhu catchment, Limpopo, South Africa. J Afr Earth Sci 171:103967.
17. Environmental Status Report (ESR), 2011-2012. by Kolhapur Municipal Corporation (KMC)
18. EPA, 2006. Parameters of water quality. In: Interpretation and standards, Published by the Environmental Protection Agency, Ireland, pp 25-30
19. EPA, 2006. Voluntary Estuary Monitoring Manual. In: pH and Alkalinity, 2nd. EPA, pp (11)1-10
20. Fauzia, F., Surinaidu, L., Abdur Rahman, Shakeel Ahmed, 2021. Distributed groundwater recharge potentials assessment based on GIS model and its dynamics in the crystalline rocks of South India, *Research Square*, v110.21203
21. Foster S, 1998. Groundwater assessing vulnerability and promotion protection of a threatened resource. In: Proceedings of the 8th Stockholm water symposium, Sweden, pp 79–90
22. Gwenzi W, 2021.Leaving no stone unturned in light of the COVID-19 fecal-oral hypothesis? A water, sanitation, and hygiene (WASH) perspective targeting low-income countries. *Science of the Total Environment*, 753, 141751.
23. How Reverse Osmosis Works. http://www.wqa.org/sitelogic.cfm?ID=872
24. https://www.mohfw.gov.in/
25. Huo, C., Dar, A.A., Nawaz, A., Hameed, J., Albashar, G., Pan, B., Wang, C., 2021. Groundwater contamination with the threat of COVID-19: Insights into CSR theory of Carroll's pyramid. *Journal of King Saud University – Science*. 33, 1–8.

26. Indian Council for Research on International Economic Relations, (ICRIER), 2019. Getting More from Less, Story of India's Shrinking, *Water Resources*
27. Institute of Medicine, 2005. Water Potassium Sodium Chloride Sulfate. The national academic press, Washington DC.
28. Joy, D. M., Shadford, B., Whiteley, H. R., Zelin S., Etches, C. and Lee, H., 1994. Use of Biotracers to Study Groundwater Contamination by Septic Tank Leaching Bed Systems. In: Transport and Reactive Processes in Aquifers, Dracos and Stauffer (eds.), Balkema, Rotterdam, 249-253.
29. Kothari, V. Vij, S., Sharma, Sharma, S.K., Gupta, N., 2021. Correlation of various water quality parameters and water quality index of districts of Uttarakhand, *Environmental and Sustainability Indicators*, Vol 9, 100093
30. Krzysztof D., 2008. the Influence of Anthropogenic Contamination on the Groundwater Chemistry of a Semi-confined Aquifer (The Wielkopolska Buried Valley Aquifer, Poland), Water Resour Manage, Springer Science + Business Media, 22, 343–355.
31. Li, P., Karunanidhi, D., Subramani, T., Srinivasamoorthy, K., 2021. Sources and Consequences of Groundwater Contamination, *Archives of Environmental Contamination and Toxicology*, Vol. 80:1–10
32. Loni, P. P., Patil A. K and Raut, P. D., 2010. Study of Groundwater Quality In Different Wards of Kolhapur City, *Journal of Advances in Science and Technology*, Vol. 13, No.1, June 2010, ISSN: 0971-9563.
33. Luczaj, J.A., Blaney, D., 2016. Groundwater Quantity and Quality, *MDPI*, Basel, Beijing, Wuhan, Barcelona, p.1.
34. Makki, Z.F., Zuhaira, A.A., Al-Jubouri, S.M., 2021. GIS-based assessment of groundwater quality for drinking and irrigation purposes in central Iraq. *Environ Monit Assess 193*, 107
35. Mohebbi, M.R.; Saeedi, R., Montazeri, A., Azam Vaghefi, K., Labbafi, S.; Oktaie, S., Abtahi, M., Mohagheghian, 2013. Assessment of water quality in groundwater resources of Iran using a modified drinking water quality index (DWQI). *Ecol. Indic*. 30, 28–34.
36. Mullaney, J. R.; Lorenz, D.L., Arntson, A. D., 2009. Introduction. *Chloride in Groundwater and Surface Water in Areas Underlain by the Glacial Aquifer System, Northern United States*. U.S. Geological Survey. pp. 9-20.
37. NEERI & NICD, 2009. *Guidance manual for drinking water quality monitoring and assessment: Analytical Methods.*
38. Overbo, A., Heger, S. Gulliver, J., 2021. Evaluation of chloride contributions from major point and nonpoint sources in a northern U.S. state, *Science of The Total Environment*, Volume 764, 144179.
39. Pye, V. and Ruth, P., 1983. Groundwater Contamination in the United States, Science, New Series, Published by: *American Association for the Advancement of Science*, 221(4612), 713-718.

40. Senthilnathan, T., Parvathavarthini, K. V., George, S. M., 2011. Assessment of Ground Water Quality of Maraimalai Nagar Town Near Chennai, India, *Journal of Environmental Research And Development*, Vol. 5(4), pp. 947.
41. Singh, S.K., Bharose, R., Jurec, J.N., Rawat, K.S., Singh, D., 2021. Irrigation water quality appraisal using statistical methods and WATEQ4F geochemical model, *Agricultural Water Management*, vol. 2021, Pp. 101-138.
42. Soujanya Kamble B, Saxena PR, Kurakalva RM, Shankar K., 2020. Evaluation of seasonal and temporal variations of groundwater quality around Jawaharnagar municipal solid waste dumpsite of Hyderabad city. *India SN* Appl Sci 2:498
43. Stanly, R., Yasala, S., D., Oliver, H., Nithya, C. Emperumal, K. Subash, A., 2021. Hydrochemical appraisal of groundwater quality for drinking, and irrigation: a case study in parts of the southwest coast of Tamil Nadu, India, *Applied Water Science*,
44. Tanaka, Y., Saihara, Y., Izumotani, K., Nakamura, H., 2019. Daily ingestion of alkaline electrolyzed water containing hydrogen influences human health, including gastrointestinal symptoms, *Med Gas Res*., 8(4): 160–166.
45. Tyagi S., Singh P., Sharma B., 2021. Water Quality Assessment in Terms of Water Quality Index, *American Journal of Water Resources*, Vol. 1, No. 3, 34-38
46. Uddin M.G., Nash S., Agnieszka I. Olbert, 2021. A review of water quality index models and their use for assessing surface water quality, *Ecological Indicators* 122 107218
47. United Nations, 2021. Valuing water: *Water demand and use*, UNESCO, pp 12–13
48. Vij S., 2021. Correlation of various water quality parameters and water quality index of Districts of Uttarakhand, *Environmental and Sustainability Indicators*. 9.100093
49. WHO, 2011. *Guidelines for Drinking Water Quality*. Geneva, Vol. 1, 4th.
50. WHO, 2011. Hardness in Drinking-Water Background Document for Development of WHO Guidelines for Drinking—Water Quality; World Health Organization: Geneva, Switzerland, 19p
51. World Health Organization WHO, 1996. Guidelines for drinking water quality 2nd edition Geneva, Switzerland, 444.
52. World Health Organization WHO, 2006. *Guidelines for drinking water quality* 3rd edition, Geneva, Switzerland, 382-426
53. Wurts W.A, 1993. Understanding water hardness, *World Aquaculture*, 24(1), 18.