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# Physico-chemical Analysis of Groundwater near Dumping Site of Gorakhpur City

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## ABSTRACT

Groundwater is the water present beneath Earth's surface in rock and soil pore spaces and in the fractures of rock formations. About 30 percent of all readily available freshwater in the world is groundwater.[1] A unit of rock or an unconsolidated deposit is called an aquifer when it can yield a usable quantity of water. The depth at which soil pore spaces or fractures and voids in rock become completely saturated with water is called the water table. Groundwater is recharged from the surface; it may discharge from the surface naturally at springs and seeps, and can form oases or wetlands. Groundwater is also often withdrawn for agricultural, municipal, and industrial use by constructing and operating extraction wells. The study of the distribution and movement of groundwater is hydrogeology, also called groundwater hydrology.

Typically, groundwater is thought of as water flowing through shallow aquifers, but, in the technical sense, it can also contain soil moisture, permafrost (frozen soil), immobile water in very low permeability bedrock, and deep geothermal or oil formation water. Groundwater is hypothesized to provide lubrication that can possibly influence the movement of faults. It is likely that much of Earth's subsurface contains some water, which may be mixed with other fluids in some instances.
Groundwater is often cheaper, more convenient and less vulnerable to pollution than surface water. Therefore, it is commonly used for public water supplies. For example, groundwater provides the largest source of usable water storage in the United States, and California annually withdraws the largest amount of groundwater of all the states. Underground reservoirs contain far more water than the capacity of all surface reservoirs and lakes ,, including the Lakes. Many municipal water supplies are derived solely from groundwater.]Over 2 billion people rely on it as their primary water source worldwide.

Use of groundwater has related environmental issues. For example, polluted groundwater is less visible and more difficult to clean up than pollution in rivers and lakes. Groundwater pollution most often results from improper disposal of wastes on land. Major sources include industrial and household chemicals and garbage landfills, excessive fertilizers and pesticides used in agriculture, industrial waste lagoons, tailings and process wastewater from mines, industrial fracking, oil field brine pits, leaking underground oil storage tanks and pipelines, sewage sludge and septic systems. Additionally, groundwater is susceptible to saltwater intrusion in coastal areas and can cause land subsidence when extracted unsustainably, leading to sinking cities and loss in elevation. These issues are made more complicated by sea level rise and other changes caused by climate changes which will affect the water cycle.

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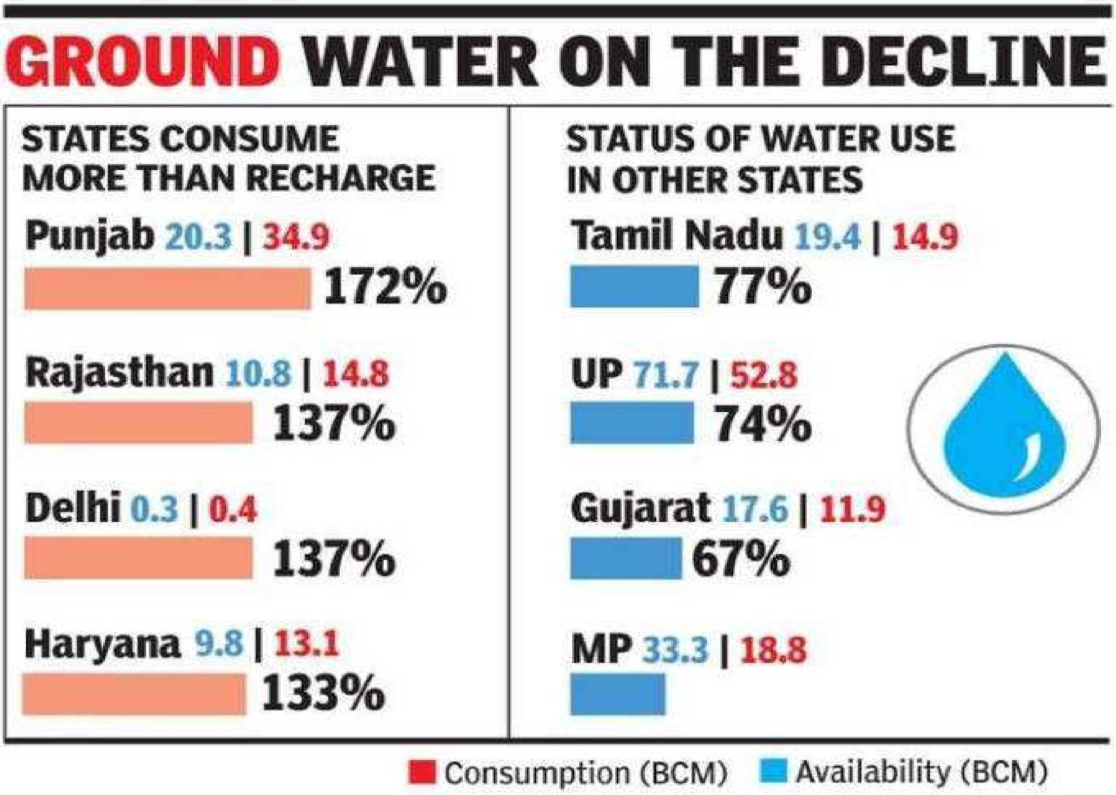
**KEYWORDS:** groundwater, Gorakhpur, dumping, site, physico-chemical, pollution, analysis, site

## INTRODUCTION

We analysed groundwater near dumping site in Gorakhpur, Uttar Pradesh, which was done methodically.

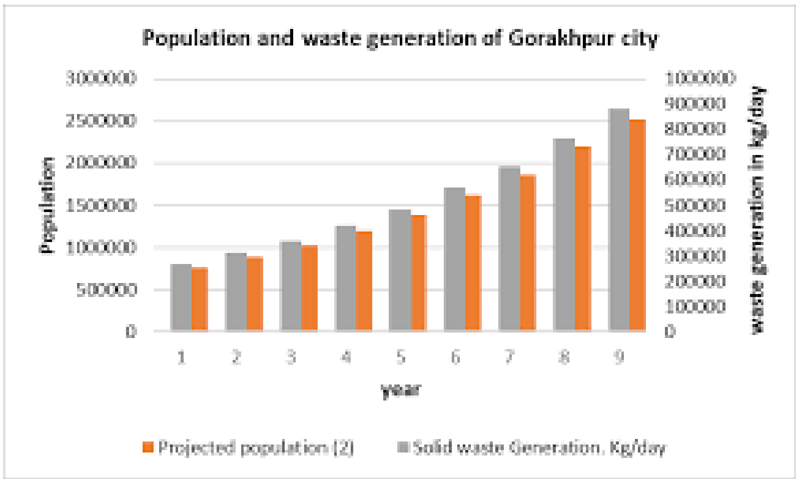
The process of water sampling introduces two significant problems:
The first problem is the extent to which the sample may be representative of the water source of interest. Water sources vary with time and with location. The

measurement of interest may vary seasonally or from day to night or in response to some activity of man or natural populations of aquatic plants and animals. [1,2]



The measurement of interest may vary with distances from the water boundary with overlying atmosphere and underlying or confining soil. The sampler must determine if a single time and location meets the needs of the investigation, or if the water use of interest can be satisfactorily assessed by averaged values of sampling over time and location, or if critical maxima and minima require individual measurements over a range of times, locations or events. The sample collection procedure must assure correct weighting of individual sampling times and locations where averaging is appropriate Where critical maximum or minimum values exist, statistical methods must be applied to observed variation to determine an adequate number of samples to assess the probability of exceeding those critical values. [3,4]

The second problem occurs as the sample is removed from the water source and begins to establish chemical equilibrium with its new surroundings – the sample container. Sample containers must be made of materials with minimal reactivity with substances to be measured; pre-cleaning of sample containers is important. The water sample may dissolve part of the sample container and any residue on that container, and chemicals dissolved in the water sample may sorb onto the sample container and remain there when the water is poured out for analysis. Similar physical and chemical interactions may take place with any pumps, piping, or intermediate devices used to transfer the water sample into the sample container. Water collected from depths below the surface will normally be held at the reduced pressure of the atmosphere; so gas dissolved in the water will collect at the top of the container. Atmospheric gas above the water may also dissolve into the water sample. Other chemical reaction equilibria may change if the water sample changes temperature. Finely divided solid particles formerly suspended by water turbulence may settle to the bottom of the sample container, or a solid phase may form from biological growth or chemical precipitation. Microorganisms within the water sample may biochemically alter concentrations of oxygen, carbon dioxide, and organic compounds. Changing carbon dioxide concentrations may alter pH and change solubility of chemicals of interest. These problems are of special concern during measurement of chemicals assumed to be significant at very low concentrations.[5,6]



**Graph: Municipal solid waste analysis in Gorakhpur**

The simplest methods of chemical analysis are those measuring chemical elements without respect to their form. Elemental analysis for oxygen, as an example, would indicate a concentration of 890 g/L (grams per litre) of water sample because oxygen (O) has 89% mass of the water molecule ($H_2O$). The method selected to measure dissolved oxygen should differentiate between diatomic oxygen and oxygen combined with other elements. The comparative simplicity of elemental analysis has produced a large amount of sample data and water quality criteria for elements sometimes identified as heavy metals. Water analysis for heavy metals must consider soil particles suspended in the water sample. These suspended soil particles may contain measurable amounts of metal. Although the particles are not dissolved in the water, they may be consumed by people drinking the water. Adding acid to a water sample to prevent loss of dissolved metals onto the sample container may dissolve more metals from suspended soil particles. Filtration of soil particles from the water sample before acid addition, however, may cause loss of dissolved metals onto the filter. The complexities of differentiating similar organic molecules are even more challenging.[7,8]

**Atomic fluorescence spectroscopy is used to measure mercury and other heavy metals**

Making these complex measurements can be expensive. Because direct measurements of water quality can be expensive, ongoing monitoring programs are typically conducted and results released by government agencies. However, there are local volunteer programs and resources available for some general assessment. Tools available to the general public include on-site test kits, commonly and biological assessment procedures.

Biosensors have the potential for "high sensitivity, selectivity, reliability, simplicity, low-cost and real-time response". For instance, bionanotechnologists reported the development of ROSALIND 2.0, that can detect levels of diverse water pollutants.[9,10]

**The following is a list of indicators often measured by situational category:**

- Alkalinity
- Color of water
- pH
- Taste and odor (geosmin, 2-Methylisoborneol (MIB), etc.)
- Dissolved metals and salts (sodium, chloride, potassium, calcium, manganese, magnesium)
- Microorganisms such as fecal coliform bacteria (Escherichia coli), Cryptosporidium, and Giardia lamblia; see Bacteriological water analysis

- Dissolved metals and metalloids (lead, mercury, arsenic, etc.)
- Dissolved organics: colored dissolved organic matter (CDOM), dissolved organic carbon (DOC)
- Radon
- Heavy metals
- Pharmaceuticals
- Hormone analogs

The district Gorakhpur occupies extreme North-Eastern part of Uttar Pradesh and lies between 260 15' and 270 06' N latitude and 830 06' and 830 45' E longitude, falling in survey of India Degree Toposheet 63 N. The total geographical area of the district is 3483.815 Km. There are 7 tehsils and 19 blocks. There are 191 Nyay Panchyat, 1224 Gram Sabha and 563 Panchyat Ghar. Gorakhpur is the head quarter of this district. The district is located in the part of Central Ganga Plain. [11,12]

The district Gorakhpur is underlain by quaternary alluvium brought by Ghaghra and Rapti river system. At comprises mainly sand of various grades, sandy clay, silt, clay with varying amount of kankar and gravels. The alluvial deposits are broadly classified under two categories (a) older (b) younger alluvium. The older alluvium deposits known as 'Bangar' or high land soils are due to denudation. The Bangar can be further sub divided into three sub categories on the basis of percentage of the sand content viz Balua containing more than 70% silica, Loam containing silica about 50% and Matiar containing less than 40% silica. The younger alluvium deposits known as 'Kachhar' occupy the marginal tract of Rapti and Ghaghra and other third order streams and consists of sandy clay and sand along the river tract and fine silt in the gentle sloping plains. Occurrence of ground water in the area is controlled by Ghaghra and Rapti and their main tributaries. Fine to coarse grained sand, mixed with gravel and kankar form the principal aquifer in the district. Ground water in the area occurs both under confined and water table conditions. It occurs in the zone of saturation within the granular zones encountered below land surface. South and East of Rapti the formation are sandy and suitable for construction of shallow and deep tubewells.[13,14]

Map: Geography of Gorakhpur district

## Discussion

Water testing is a broad description for various procedures used to analyze water quality. Millions of water quality tests are carried out daily to fulfill regulatory requirements and to maintain safety.[1]

Testing may be performed to evaluate:

- ambient or environmental water quality – the ability of a surface water body to support aquatic life as an ecosystem. [15,16]
- wastewater – characteristics of polluted water (domestic sewage or industrial waste) before treatment or after treatment. See Environmental chemistry and Wastewater quality indicators.
- "raw water" quality – characteristics of a water source prior to treatment for domestic consumption (drinking water). See Bacteriological water analysis and specific tests such as turbidity and hard water.
- "finished" water quality – water treated at a municipal water purification plant. See Bacteriological water analysis and Category: Water quality indicators.
- suitability of water for industrial uses such as laboratory, manufacturing or equipment cooling.

As per water level data 2012 C.G.W.B. during premonsoon the depth to water level in the dumping site ranges from 4.38 to 7.66 mbgl. Along the river water level varies from 7.00 to 8.00 mbgl show that river is effluent in nature. During the post monsoon water becomes shallower in the interfluve and ranges from 1.47 to 4.49 mbgl, 70% to 80% of the area during this period is under water level 2.00 to 4.00 mbgl indicating excellent recharge due to monsoon. During premonsoon N.H.S. wells at Urwa Bazar, [17,18] Jagdishpur, Khajani and Rambagh showing rising trend 0.0115 to 0.0800 m/year and N.H.S. wells at Kuriram, Urwa Bazar showing falling trend 0.0412 to 0.1409 m/year. During post monsoon N.H.S. wells at Rampur, Jagdishpur, Khajani and Ramgarh showing rising trend 0.0618 to 0.3373 m/year and N.H.S. wells at Kauriram and Urwa Bazar showing falling trend 0.0267 to 0.0291 m/year. The movement of ground water is towards the Rapti river which is flowing in N-S direction. The border area of the Bhathat, Sardar Nagar and Brahmpur block show entire behaviour of ground water which may be attributed to the running and closing of canals in proximity. Occurrences of ground water in the area is mainly controlled by three major rivers Ghaghra, Rapti and Kuwana.[19,20]

In Gorakhpur district five number of tubewells have been constructed by CGWB upto 200 mbgl depth and one tubewell at Sarpataha upto depth 450 mbgl. Tubewells upto 200 mbgl depth tapped aquifers zones ranging from 40.00 to 50.00mbgl, 80 mbgl - 100.00 mbgl and 180 mbgl – 195.00 mbgl indicating existence of three tier aquifer system. The discharge varies from 1100 to 2350 lpm and transmissivity range from 113 to 1032 m2 /day. First and second aquifers upto 100.00 metre and second and third aquifer below 200 metre depth. The deepest tubewell in the district is Sarpataha where tapping of zones start from 236.00 mbgl and zone tapped from 223 to 335.00 mbgl. The discharge of well was 2195 lpm. Except this in the entire district 70 to 180.00 m depth of tubewells were constructed and tapped first and second aquifer upto 100.00 metre and somewhere second and third aquifer below 180.00 mbgl. The discharge vary from 2733 to 3450 mbgl. The discharge vary from 2733 to 3450 lpm. Deeper tubewells are found in Khajani and Piprauli block area due to thick clay band between first aquifer and second aquifer which range from 85-95 m, 135-170 m of depth respectively. The discharge of tubewells ranges from 1500 to 2100 lpm. Except this area tubewells are down to depth of 100.00 m and discharge vary from 1200 to 1800 lpm, and along flood plains area the shallow aquifers constructed down to 60 to 70 m tubewells yield 1200 lpm using centrifugal pumps. The existing data show that 1.50 mm slot size with pea gravel has been used for construction of tubewells. The deeper aquifers have not been utilized as yet. However, the electrical and lithological logs indicate that they have good potential for future development.[21,22]

## Results

Environmental indicators are simple measures that tell us what is happening in the environment. Since the environment is very complex, indicators provide a more practical and economical way to track the state of the environment than if we attempted to record every possible variable in the environment. For example, concentrations of ozone depleting substances (ODS) in the atmosphere, tracked over time, is a good indicator with respect to the environmental issue of stratospheric ozone depletion.

Environmental indicators have been defined in different ways but common themes exist.

“An environmental indicator is a numerical value that helps provide insight into the state of the environment or human health. Indicators are developed based on quantitative measurements or statistics of environmental condition that are tracked over time. Environmental indicators can be developed and used at a wide variety of geographic scales, from local to regional to national levels.” [1]

“A parameter or a value derived from parameters that describe the state of the environment and its impact on human beings, ecosystems and materials, the pressures on the environment, the driving forces and the responses steering that system. An indicator has gone through a selection and/or aggregation process to enable it to steer action.[23,24]

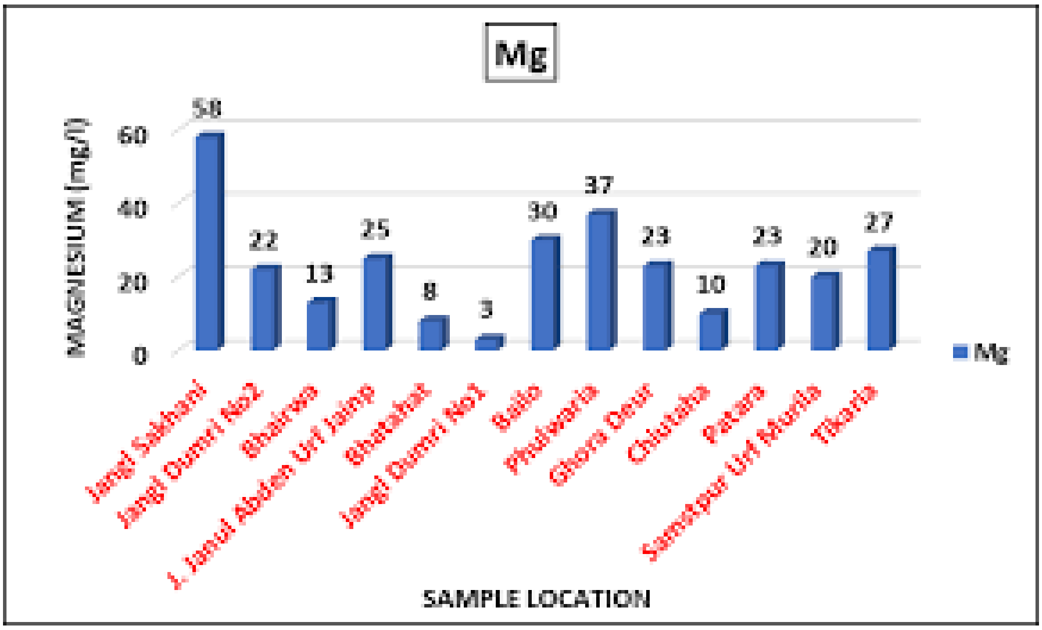
There are a wide range of sampling methods which depend on the type of environment, the material being sampled and the subsequent analysis of the sample. At its simplest a sample can be filling a clean bottle with river water and submitting it for conventional chemical analysis. At the more complex end, sample data may be produced by complex electronic sensing devices taking sub-samples over fixed or variable time periods.

Sampling methods include judgmental sampling, simple random sampling, stratified sampling, systematic and grid sampling, adaptive cluster sampling, grab samples, semi-continuous monitoring and continuous, passive sampling, remote surveillance, remote sensing, biomonitoring and other sampling methods.[25,26]

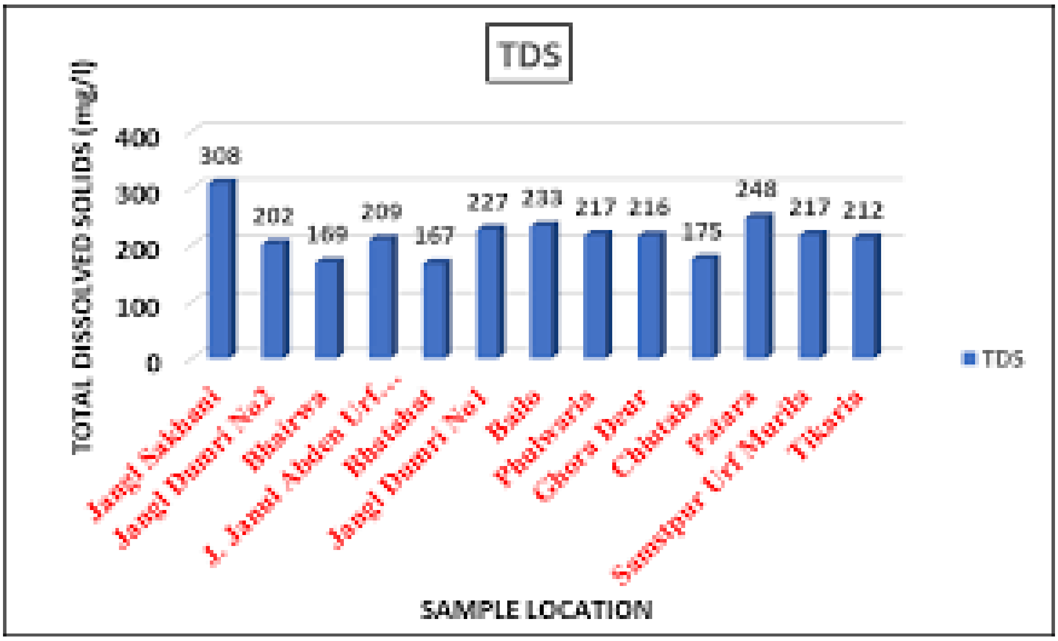
**The results of chemical analysis in the dumping site, Gorakhpur, showed the following range of various chemical constituents in the ground water:**
pH - 7.90 to 8.17
EC - 298 to 2010 mu/cm
Chloride - 12.00 to 265.00 mg/l
Carbonate - Nil
Bicarbonate - 110 to 600 mg/l

| OCPs | Mean | Median | Range |
|---|---|---|---|
| α-HCH | 0.19 | 0.13 | 0.09–0.46 |
| β-HCH | 0.18 | 0.12 | 0.07–0.39 |
| γ-HCH | 0.88 | 0.59 | 0.36–1.79 |
| δ-HCH | 0.31 | 0.20 | 0.09–0.82 |
| Aldrin | 0.24 | 0.10 | 0.12–0.37 |
| α-Endosulfan | 0.23 | 0.17 | 0.11–0.51 |
| β-Endosulfan | 0.05 | 0.02 | 0.01–0.10 |
| pp-DDE | 0.08 | 0.05 | 0.03–0.19 |
| pp-DDD | 0.06 | 0.04 | 0.02–0.14 |
| op-DDT | 0.04 | 0.02 | 0.01–0.11 |
| pp-DDT | 4.12 | 2.96 | 2.07–8.39 |
| Total | 6.38 | 4.04 | 2.98–13.27 |

**Table-1: Statistical data of OCPs in dumping site of groundwater at Gorakhpur city (ng/L)**



**Graph 1: Physico-chemical analysis of Magnesium in dumping site of Gorakhpur city**



**Graph 2: Physico-chemical analysis of TDS in dumping site of Gorakhpur city**

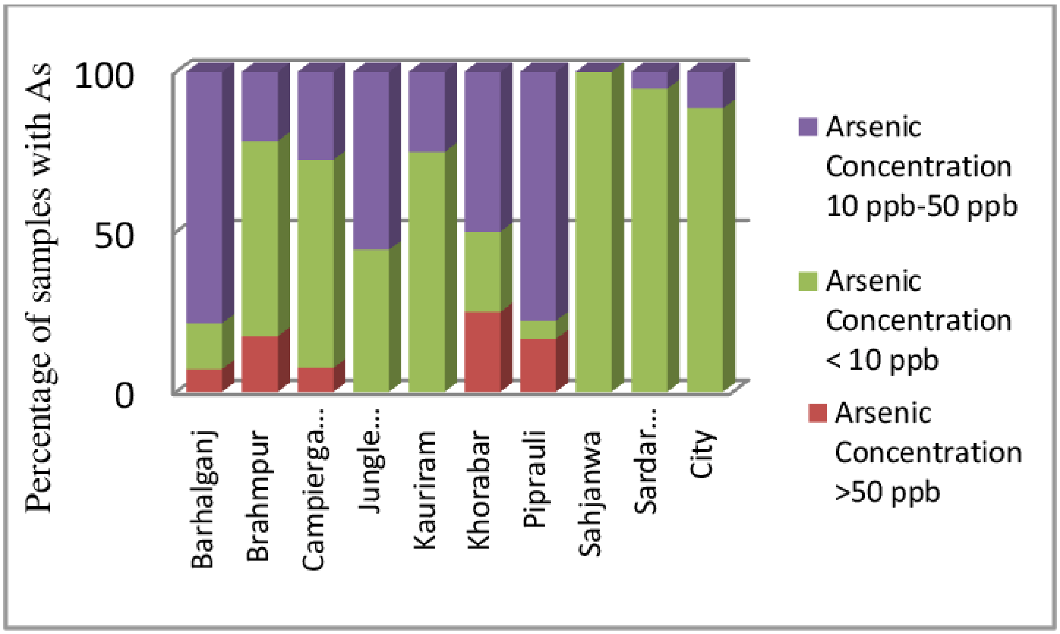
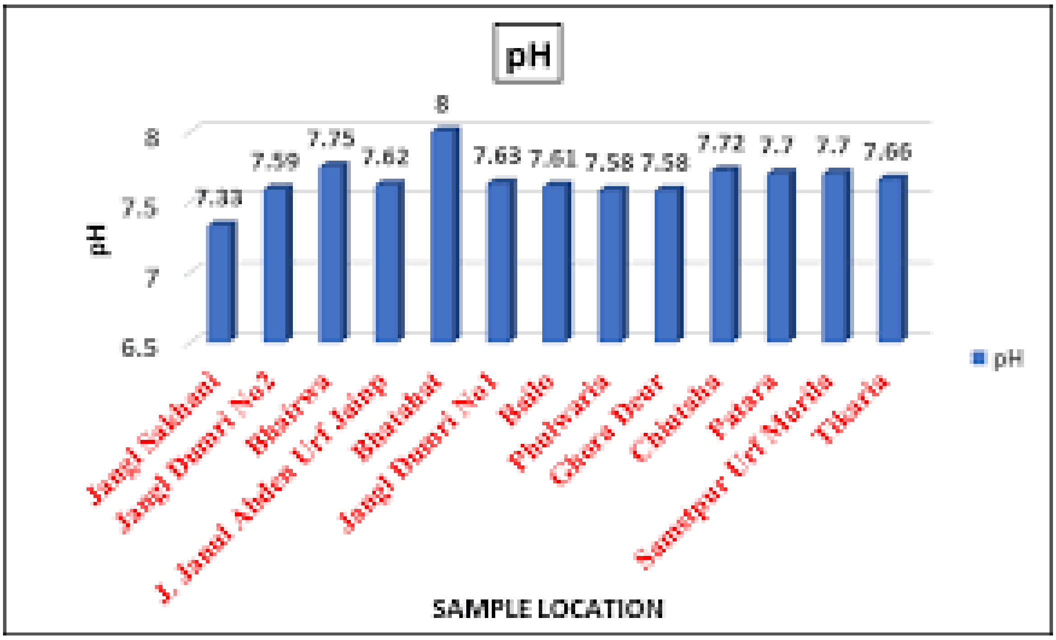
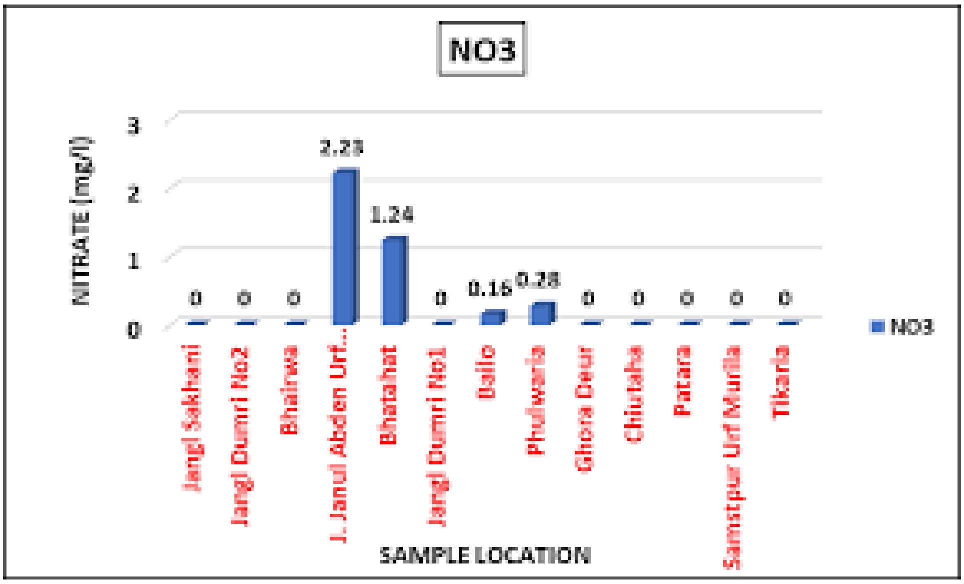


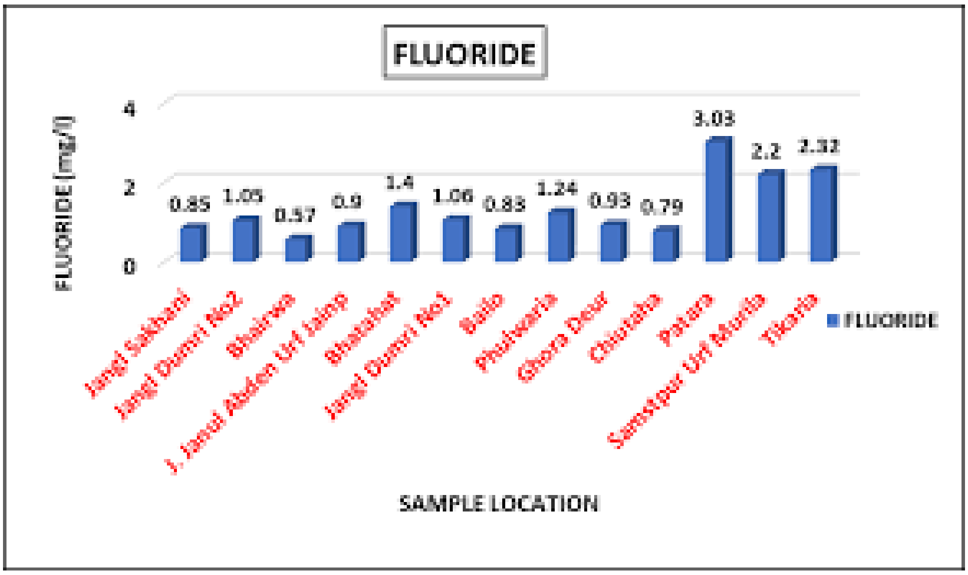
Fig. 3. Arsenic Concentration range



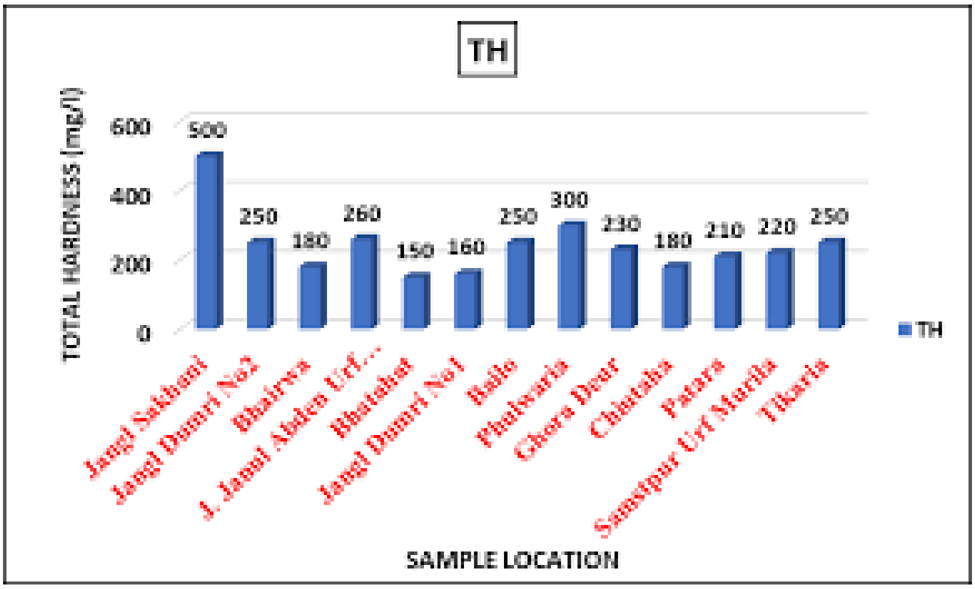
**Graph 4: Physico-chemical analysis of TDS in dumping site of Gorakhpur city**



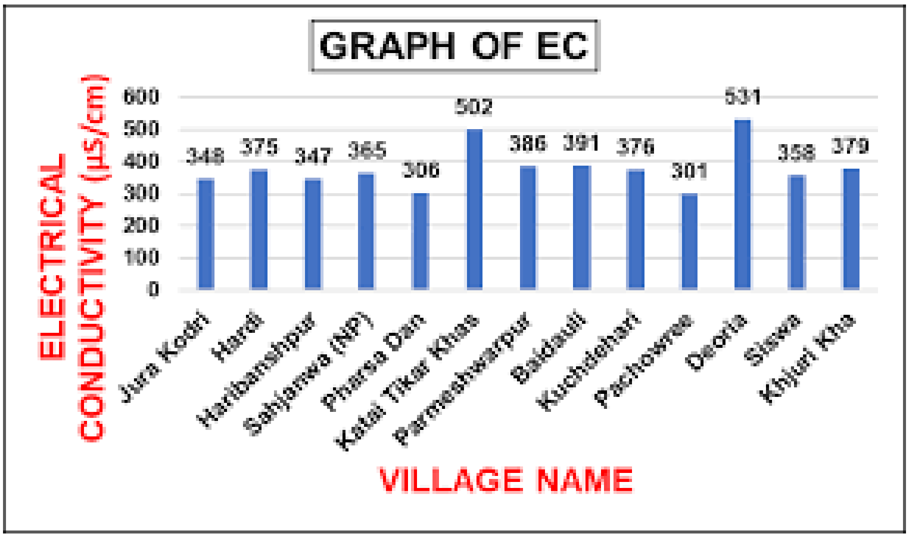
Graph 5: Physico-chemical analysis of NO3 in dumping site of Gorakhpur city



Graph 6: Physico-chemical analysis of Fluoride in dumping site of Gorakhpur city



Graph 7: Physico-chemical analysis of Fluoride in dumping site of Gorakhpur city



**Graph 8: Physico-chemical analysis of EC in dumping site of Gorakhpur city**

At present ground water development in this district is mainly through the shallow tubewells along with few deep tubewells. Which are pumped for drinking water supply and also for irrigation purposes. As per the Ground Water Estimation Committee 2009, the ground water availability calculated as 147151.44 ham. Gross draft for various uses is 97093.72 ham. Thus there is vast potential for future ground water development. The deeper aquifers also have a great potential & sustainability for development. Water samples in dumping sites around Gorakhpur city area, Kauriram, Barhalganj and Ramgarh area containing high bicarbonate, Sulphates and silicates which causes 14 incrustation and may result in failure of tubewells. Incrustation formed by precipitation of bicarbonates and may easily removed by action of acids or other chemicals. The sugar industries in Gola block, Sahjanawa block area whose untreated effluent may results in ground water pollution. The low cost Katcha latrines in the village area may lead to problem of ground water pollution high Nitrate in the district.[27,28]

The depth to water table condition in the district does not confirm any water logging conditions but prone to water logged area exists in canal commands in north eastern & southern part of district. The long term water level indicate a declining trend in Kauriram, Urwa Bazar and Jangal Kauri blocks Only one deep tubewell upto depth of 450.00 mbgl have been drilled so far, High capacity drilling rig is required to explore beyond 450 mbgl to know deeper aquifer geometry & characteristics. Natural erosion along the banks of the Ghaghra and Rapti river causing huge loss agricultural and residential land particularly in rainy season is a serious problem in the blocks along the river banks. No programme/activity has been organised in the district so far.[29,30]

Although water quality is usually sampled and analyzed at laboratories, since the late 20th century there has been increasing public interest in the quality of drinking water provided by municipal systems. Many water utilities have developed systems to collect real-time data about source water quality. In the early 21st century, a variety of sensors and remote monitoring systems have been deployed for measuring water pH, turbidity, dissolved oxygen and other parameters. Some remote sensing systems have also been developed for monitoring ambient water quality in riverine, estuarine and coastal water bodies.[31,32]

## Conclusions

Water quality modeling involves water quality based data using mathematical simulation techniques. Water quality modeling helps people understand the eminence of water quality issues and models provide evidence for policy makers to make decisions in order to properly mitigate water. Water quality modeling also helps determine correlations to constituent sources and water quality along with identifying information gaps.Due to the increase in freshwater usage among people, water quality modeling is especially relevant both in a local level and global level. In order to understand and predict the changes over time in water scarcity, climate change, and the economic factor of water resources, water quality models would need sufficient data by including water bodies from both local and global levels.

A typical water quality model consists of a collection of formulations representing physical mechanisms that determine position and momentum of pollutants in a water body. Models are available for individual components of the hydrological system such as surface runoff; there also exist basin wide models addressing hydrologic transport and for ocean and estuarine applications. Often finite difference methods are used to analyze these phenomena, and, almost always, large complex computer models are required. [33]

Water resource management is the activity of planning, developing, distributing and managing the optimum use of water resources. It is an aspect of water cycle management. The field of water resources management will have to continue to adapt to the current and future issues facing the allocation of water. With the growing uncertainties of global climate change and the long-term impacts of past management actions, this decision-making will be even more difficult. It is likely that ongoing climate change will lead to situations that have not been encountered. As a result, alternative management strategies, including participatory approaches and adaptive capacity are increasingly being used to strengthen water decision-making.[34,35]

**Drinking water ATM for public place, RO water supplier, Clean and Safe water**

Ideally, water resource management planning has regard to all the competing demands for water and seeks to allocate water on an equitable basis to satisfy all uses and demands. As with other resource management, this is rarely possible in practice so decision-makers must prioritise issues of sustainability, equity and factor optimisation (in that order!) to achieve acceptable outcomes. One of the biggest concerns for water-based resources in the future is the sustainability of the current and future water resource allocation.

Water treatment is any process that improves the quality of water to make it appropriate for a specific end-use. The end use may be drinking, industrial water supply, irrigation, river flow maintenance, water recreation or many other uses, including being safely returned to the environment. Water treatment removes contaminants and undesirable components, or reduces their concentration so that the water becomes fit for its desired end-use. This treatment is crucial to human health and allows humans to benefit from both drinking and irrigation use.[36,37]

Water is the most crucial compound for life on Earth, and having drinkable water is a key worldwide concern for the twenty-first century. All living things require clean, uncontaminated water as a basic requirement. Water covers more than 71 percent of the earth's surface, but only around 1% of it is drinkable according to international standards due to various contaminations. Waste water discharge from industries, agricultural pollution, municipal wastewater, environmental and global changes are the main sources of water contamination. Even trace levels of heavy metals, dyes, and microbes are hazardous to human health, aquatic systems, and the environment. According to a Food and Agriculture Organization assessment from 2007, absolute water scarcity will affect 1.8 billion people living in countries, and water stress might affect two-thirds of the global population.

To address water scarcity issues, it is required to recover water from current wastewater or develop alternate water sources for human consumption.

Domestic and industrial wastewater are the two types of wastewater. Domestic wastewater contains sewage, bacteria, viruses, hazardous and non-toxic organisms, sanitary outputs, rubbish, detergents, and other solid and liquid discharges from non-manufacturing processes.[38,39]

## Recommendations

A. Geomorphologically, area under flood plain, older meander and near oxbow lakes are suitable for construction of high discharge tubewells.

B. For balance of ground water of 46103.77 ham additional 1700 numbers of state tubewells and about 10000 private tubewells and pumping set is feasible in the district.

C. The level of development in Belghat, Campeerganj, Khajani, Pali and Piparaich is about 80% therefore it is recommended that the development of ground water in these blocks should be done judiciously with proper monitoring of water level in the area.

D. Canal commands areas covering Bhathat, Piparaich, Sardar Nagar, Kherabar blocks where depth to water level is shallow. To avoid future water logging in such area shallow tubewells may be constructed to develop the phreatic aquifer.[40,41]

E. For study the deeper aquifer geometry deep exploration in the district is recommended.

F. As indicated by the estimates of ground water resource potential, it is strongly recommended that stress on the use of ground water be given to boost economy of the district by bringing more agricultural area into irrigation.[42]

## References

[1] Dwivedi, S., A. K. Dwivedi (2013), River Pollution and Solution; New Central Book Agency Private Limited.

[2] Cordy, Gail E. (18 February 2014). ""A Primer on Water Quality"". USGS.

[3] Johnson, D. L.; Ambrose, S. H.; Bassett, T. J.; Bowen, M. L.; Crummey, D. E.; Isaacson, J. S.; Johnson, D. N.; Lamb, P.; Saul, M.; Winter-Nelson, A. E. (1997). "Meanings of Environmental Terms". Journal of Environmental Quality. 26 (3): 581–589. doi:10.2134/jeq1997.00472425002600030002x

[4] World Health Organisation (1997). "Guidelines for drinking-water quality". Surveillance and Control of Community Supplies. 3.

[5] "Water quality information - What are the key factors that influence water quality? | APEC Water". www.freedrinkingwater.com. Retrieved 25 March 2020.

[6] EPA. "National Primary Drinking Water Regulations." Code of Federal Regulations, 40 CFR 141.

[7] "Drinking Water Regulations". Drinking Water Requirements for States and Public Water Systems. EPA. 1 September 2017.

[8] "Secondary Drinking Water Standards: Guidance for Nuisance Chemicals". EPA. 8 March 2017.

[9] "FDA Regulates the Safety of Bottled Water Beverages Including Flavored Water and Nutrient-Added Water Beverages". Food Facts for Consumers. Silver Spring, Maryland: U.S. Food and Drug Administration. 22 September 2018.

[10] Katner, A. L., Brown, K., Pieper, K., Edwards, M., Lambrinidou, Y., & Subra, W.. (2018). America’s Path to Drinking Water Infrastructure Inequality and Environmental Injustice: The Case of Flint, Michigan (pp. 79–97). https://doi.org/10.1007/978-3-319-71389-2_5

[11] (2019, June 14). Drinking-water. World Health Organization. https://www.who.int/en/news-room/fact-sheets/detail/drinking-water.

[12] Babbitt, Harold E. & Doland, James J. Water Supply Engineering (1949) ASIN: B000OORYE2; McGraw-Hill p. 388

[13] Linsley, Ray K. & Franzini, Joseph B. Water-Resources Engineering (1972) McGraw-Hill ISBN 0-07-037959-9 pp. 454–456

[14] World Health Organization (2004). "Consensus of the Meeting: Nutrient minerals in drinking-water and the potential health consequences of long-term consumption of demineralized and remineralized and altered mineral content drinking-waters." Rolling Revision of the WHO Guidelines for Drinking-Water Quality (draft). From 11–13 November 2003 meeting in Rome, Italy at the WHO European Centre for Environment and Health.

[15] Guidelines for Drinking-water Quality: Fourth edition incorporating the first addendum (Report). Geneva: World Health Organization. 2017. pp. 99, 115, 377. hdl:10665/254637. ISBN 9789241549950.

[16] US EPA, OW (3 November 2014). "Supplemental Module: Human Health Ambient Water Quality Criteria". US EPA. Retrieved 25 March 2020.

[17] Zektser, S.; LoaIciga, H. A.; Wolf, J. T. (2004). "Environmental impacts of groundwater overdraft: selected case studies in the southwestern United States". Environmental Geology. 47 (3): 396–404. doi:10.1007/s00254-004-1164-3. S2CID 129514582.

[18] Sommer, Bea; Horwitz, Pierre; Sommer, Bea; Horwitz, Pierre (2001). "Water quality and macro invertebrate response to acidification following intensified summer droughts in a Western Australian wetland". Marine and

Freshwater Research. 52 (7): 1015. doi:10.1071/MF00021.

[19] Perrone, Debra; Jasechko, Scott (August 2019). "Deeper well drilling an unsustainable stopgap to groundwater depletion". Nature Sustainability. 2 (8): 773–782. doi:10.1038/s41893-019-0325-z. ISSN 2398-9629. S2CID 199503276.

[20] Upmanu Lall (28 July 2009). "Punjab: A tale of prosperity and decline". Columbia Water Center. Retrieved 2009-09-11.

[21] Bagheri, Rahim; Nosrati, Azad; Jafari, Hadi; Eggenkamp, Hermanus Gerardus M.; Mozafari, Morteza (5 May 2019). "Overexploitation hazards and salinization risks in crucial declining aquifers, chemo-isotopic approaches". Journal of Hazardous Materials. 369: 150–163. doi:10.1016/j.jhazmat.2019.02.024. ISSN 0304-3894. PMID 30776598. S2CID 73455611. Retrieved 2 March 2022.

[22] Famiglietti, James S.; Ferguson, Grant (23 April 2021). "The hidden crisis beneath our feet". Science. 372 (6540): 344–345. Bibcode:2021Sci...372..344F. doi:10.1126/science.abh2867. PMID 33888627. S2CID 233353241. Retrieved 10 May 2021.

[23] "The largest assessment of global groundwater wells finds many are at risk of drying up". ScienceDaily. Retrieved 10 May 2021.

[24] Jasechko, Scott; Perrone, Debra (23 April 2021). "Global groundwater wells at risk of running dry". Science. 372 (6540): 418–421. Bibcode:2021Sci...372..418J. doi:10.1126/science.abc2755. ISSN 0036-8075. PMID 33888642. S2CID 233353207. Retrieved 10 May 2021.

[25] Galloway, Devin L.; Burbey, Thomas J. (December 2011). "Review: Regional land subsidence accompanying groundwater extraction". Hydrogeology Journal (in English, French, Spanish, Chinese, and Portuguese). 19 (8): 1459–1486. Bibcode:2011HydJ...19.1459G. doi:10.1007/s10040-011-0775-5. S2CID 127084866. Retrieved 2 March 2022.

[26] Dokka, Roy K. (2011). "The role of deep processes in late 20th century subsidence of New Orleans and coastal areas of southern Louisiana and Mississippi". Journal of Geophysical Research. 116 (B6): B06403. Bibcode:2011JGRB..116.6403D. doi:10.1029/2010JB008008. ISSN 0148-0227. S2CID 53395648.

[27] Sneed, M; Brandt, J; Solt, M (2013). "Land Subsidence along the Delta-Mendota Canal in the Northern Part of the San Joaquin Valley, California, 2003–10" (PDF). USGS Scientific Investigations Report 2013-5142. Retrieved 22 June 2015.

[28] Tosi, Luigi; Teatini, Pietro; Strozzi, Tazio; Da Lio, Cristina (2014). "Relative Land Subsidence of the Venice Coastland, Italy". Engineering Geology for Society and Territory – Volume 4. pp. 171–73. doi:10.1007/978-3-319-08660-6_32. ISBN 978-3-319-08659-0.

[29] Aobpaet, Anuphao; Cuenca, Miguel Caro; Hooper, Andrew; Trisirisatayawong, Itthi (2013). "InSAR time-series analysis of land subsidence in Bangkok, Thailand". International Journal of Remote Sensing. 34 (8): 2969–82. Bibcode:2013IJRS...34.2969A. doi:10.1080/01431161.2012.756596. ISSN 0143-1161. S2CID 129140583.

[30] Arroyo, Danny; Ordaz, Mario; Ovando-Shelley, Efrain; Guasch, Juan C.; Lermo, Javier; Perez, Citlali; Alcantara, Leonardo; Ramírez-Centeno, Mario S. (2013). "Evaluation of the change in dominant periods in the lake-bed zone of Mexico City produced by ground subsidence through the use of site amplification factors". Soil Dynamics and Earthquake Engineering. 44: 54–66. doi:10.1016/j.soildyn.2012.08.009. ISSN 0267-7261.

[31] Nicholls, R. J.; Hanson, S.; Herweijer, C.; Patmore, N.; Hallegatte, S.; CorfeeMorlot, J.; Chateau, Jean; Muir-Wood, Robert (2008). "Ranking Port Cities with High Exposure and Vulnerability to Climate Extremes: Exposure Estimates" (PDF). OECD Environment Working Papers (1). doi:10.1787/011766488208. Retrieved 22 May 2014.

[32] "Free articles and software on drainage of waterlogged land and soil salinity control". Retrieved 2010-07-28.

[33] Ludwig, D.; Hilborn, R.; Walters, C. (1993). "Uncertainty, Resource Exploitation, and Conservation: Lessons from History" (PDF). Science. 260 (5104): 17–36. Bibcode:1993Sci...260...17L. doi:10.1126/science.260.5104.17. JSTOR 1942074. PMID 17793516. Archived from the

original (PDF) on 2013-08-26. Retrieved 2011-06-09.

[34] ILRI (1989), Effectiveness and Social/Environmental Impacts of Irrigation Projects: a Review (PDF), In: Annual Report 1988 of the International Institute for Land Reclamation and Improvement (ILRI), Wageningen, The Netherlands, pp. 18–34

[35] ILRI (2003), Drainage for Agriculture: Drainage and hydrology/salinity - water and salt balances. Lecture notes International Course on Land Drainage, International Institute for Land Reclamation and Improvement (ILRI), Wageningen, The Netherlands. Download from: [1], or directly as PDF: [2]

[36] Befus, K. M.; Barnard, P. L.; Hoover, D. J.; Finzi Hart, J. A.; Voss, C. I. (October 2020). "Increasing threat of coastal groundwater hazards from sea-level rise in California". Nature Climate Change. 10 (10): 946–952. Bibcode:2020NatCC..10..946B. doi:10.1038/s41558-020-0874-1. ISSN 1758-6798. S2CID 221146885.

[37] Polemio, M.; Dragone, V.; Limoni, P.P. (2009). "Monitoring and methods to analyse the groundwater quality degradation risk in coastal karstic aquifers (Apulia, Southern Italy)". Environmental Geology. 58 (2): 299–312. Bibcode:2009EnGeo..58..299P. doi:10.1007/s00254-008-1582-8. S2CID 54203532.

[38] Fleury, P.; Bakalowicz, M.; De Marsily, G. (2007). "Submarine springs and coastal karst aquifers: a review". Journal of Hydrology. 339 (1–2): 79–92. Bibcode:2007JHyd..339...79F. doi:10.1016/j.jhydrol.2007.03.009.

[39] Eawag (2015) Geogenic Contamination Handbook – Addressing Arsenic and Fluoride in Drinking Water. C.A. Johnson, A. Bretzler (Eds.), Swiss Federal Institute of Aquatic Science and Technology (Eawag), Duebendorf, Switzerland. (download: www.eawag.ch/en/research/humanwelfare/drinkingwater/wrq/geogenic-contamination-handbook/)

[40] Sophocleous, Marios (2002). "Interactions between groundwater and surface water: the state of the science". Hydrogeology Journal. 10 (1): 52–67. Bibcode:2002HydJ...10...52S. doi:10.1007/s10040-001-0170-8. S2CID 2891081.

[41] U.S. Environmental Protection Agency (EPA). 2006-11-08. "National Primary Drinking Water Regulations: Ground Water Rule; Final Rule." Federal Register, 71 FR 65574

[42] “Ground Water Rule". Drinking Water Requirements for States and Public Water Systems. EPA. 2018-12-18.